International Conference on Engineering, Management and Interdisciplinary Research (ICEMIR 2025)

2–3 December 2025 | Muscat, Sultanate of Oman

CONFERENCE PROCEEDINGS

THEME: Innovative Interdisciplinary Research for Sustainable Development and Societal Impact

EDITED BY:

Assoc. Prof. Dr. Majed A. A. Aldahdooh
Editor-in-Chief & Chair, ICEMIR 2025
International College of Engineering and Management (ICEM), Oman

HOSTED BY:

International College of Engineering and Management (ICEM), Muscat, Oman

IN COLLABORATION WITH:

Karabük Üniversitesi, Türkiye
University of Engineering & Technology (UET) Peshawar, Pakistan

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INNOVATIVE INTERDISCIPLINARY RESEARCH FOR SUSTAINABLE DEVELOPMENT AND SOCIETAL IMPACT

PROCEEDINGS OF THE

1st INTERNATIONAL CONFERENCE ON ENGINEERING, MANAGEMENT & INTERDISCIPLINARY RESEARCH
(ICEMIR 2025) | Online

2–3 DECEMBER 2025 | SULTANATE OF OMAN

JOINTLY ORGANIZED BY

International College of Engineering and Management, Muscat, Sultanate of Oman
University of Engineering and Technology, Peshawar, Pakistan
Karabük University, Karabük, Türkiye

EDITED BY

Associate Prof. Dr. Majed A. A. Aldahdooh

Proceedings of the
1st International Conference on Engineering, Management & Interdisciplinary Research (ICEMIR 2025) | *Electronic Conference Proceedings*

Publisher
International College of Engineering and Management (ICEM)
Muscat, Sultanate of Oman

In collaboration with:
University of Engineering and Technology (UET), Peshawar, Pakistan
Karabük University, Türkiye

Edited by
Associate Prof. Dr. Majed A. A. Aldahdooh
Editor-in-Chief and Conference Chair, ICEMIR 2025

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Year of publication: 2025
Official publication website: https://www.icem.edu.om/copy-of-conference-overview
Produced in Sultanate of Oman

Foreword

The International Conference on Engineering, Management, and Interdisciplinary Research (ICEMIR 2025) was established to advance interdisciplinary scholarship and to promote the exchange of knowledge addressing contemporary scientific, technological, and societal challenges. This volume presents the electronic proceedings of the inaugural ICEMIR, held virtually on 2–3 December 2025.

ICEMIR 2025 received 27 abstract submissions across four thematic tracks, reflecting balanced participation from faculty members, undergraduate and postgraduate students, research scholars, and industry professionals. The conference was led by a strong institutional presence from the International College of Engineering and Management (ICEM), with additional national and international contributions from Pakistan, Türkiye, the United Arab Emirates, and the United Kingdom, demonstrating both a solid local foundation and growing global engagement. The submitted research covered a broad interdisciplinary spectrum, with a strong emphasis on engineering, technology, and innovation, complemented by studies in sustainability, health and safety, management, digital transformation, and applied computing. This thematic distribution reinforces the conference's engineering focus while highlighting its interdisciplinary character.

Of the 27 abstract presenters, 18 contributors were invited to proceed to the full-paper submission stage. These manuscripts underwent editorial screening and peer review, with feedback focused on scholarly rigor, clarity, and quality enhancement. Following this process, 11 authors successfully submitted finalized full-paper manuscripts, which were accepted for inclusion in Book 2: Full Papers Proceedings. The review and revision stages reflected strong author engagement and a clear commitment to maintaining academic standards. In addition to the conference proceedings, two papers were selected for journal publication. One was accepted in a Scopus-indexed (Q3) journal, while the other was selected for publication in a newly established, non-indexed open-access journal, supporting both established and emerging research outlets.

Special appreciation is extended to the Dean of the College for his unwavering encouragement and institutional support, and to the Assistant Dean for Academic Affairs for his invaluable guidance. Sincere thanks are also due to our co-organizing institutions for their collaborative commitment to the successful delivery of the conference. I am deeply grateful to our keynote speakers, conference co-chairs, session chairs, moderators, reviewers, observers, and the Chair and members of the Research and Ethics Committee for their dedication in ensuring the smooth and effective conduct of the conference. Appreciation is further extended to the organizing, administrative, and technical teams, whose efforts were instrumental in coordinating the virtual proceedings.

A special acknowledgement is due to all authors, presenters, attendees, and participants for sharing their scholarly work and engaging in meaningful discussions. Through their contributions, ICEMIR 2025 has highlighted the important role of undergraduate and early-career research in fostering innovation, collaboration, and academic excellence. It is hoped that the research presented in this volume will support future inquiry, encourage interdisciplinary collaboration, and contribute meaningfully to ongoing academic and professional discourse.

Associate Prof. Dr. Majed A. A. Aldahdooh
Editor-in-Chief and Conference Chai,
ICEMIR 2025

Conference Overview

International Conference on Engineering, Management, and Interdisciplinary Research (ICEMIR 2025)

Innovative *Interdisciplinary Research for Sustainable Development and Societal Impact*
2–3 December 2024

***ICEMIR 2025** aimed to provide an inclusive international platform for sharing original research, fostering interdisciplinary collaboration, and promoting student-led and early-career innovation in engineering, management, and related fields.*

Sub-Themes

Engineering, Technology, and Innovation
Artificial Intelligence, Computing, and Digital Transformation
Health, Medicine, Safety, and Environment
Business, Management, and Entrepreneurship
Education, Language, and Science Teaching
Tourism, Hospitality, Agriculture, and Sustainability

Hosted By:

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In Collaboration With:

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University of Engineering & Technology
Peshawar, Pakistan

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Prof. Dr. Sakine Ugurlu Karaağaç
Full Professor
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Dr. Songül Kaskun Ergani
Associate Professor
Karabük Üniversitesi, Türkiye

Dr. Aamir Hussain Bhat
Senior Lecturer
University of Technology and Applied Sciences, Oman.

Dr. Muhammad Mubashir
Membrane Technology Specialist
Saline Water Conversion Corporation (SWCC), Saudi Arabia

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Assistant Professor
University of Wyoming, USA

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Participation Ways

Abstract Submission with Full Paper Option: Authors submit an abstract and, upon acceptance, may choose to submit a full paper for inclusion in the conference proceedings and consideration for potential recommendation to indexed journals, subject to journal policies and review outcomes.
Abstract-Only Submission: Authors submit an abstract for presentation and inclusion in the ICEMIR 2025 electronic proceedings without submitting a full paper.

Total Number of Submissions and Participation Summary:

A total of 27 abstract submissions were received from contributors, including faculty members, students, research scholars, and industry professionals. Institutional participation was led by the International College of Engineering and Management (ICEM), with additional contributions from Pakistan, Türkiye, the United Arab Emirates, and the United Kingdom. Of the 27 abstract presenters, 18 contributors elected to proceed with the full-paper submission pathway. Following the peer-review process and the circulation of reviewer comments, 13 authors successfully submitted revised full-paper manuscripts, which were subsequently included in Book 2: Full Papers Proceedings. The conference welcomed more than 150 attendees, fostering international academic collaboration, scholarly exchange, and research excellence.

Review & Evaluation Process

All submissions to ICEMIR 2025 were subject to an initial editorial screening to confirm originality, relevance, and compliance with the conference scope and ethical standards. Accepted abstracts were reviewed by subject experts, and authors were optionally invited to submit full papers. Full papers underwent a peer-review process conducted by qualified internal and external reviewers, with decisions based on academic quality, technical soundness, and clarity. Authors were required to address reviewers' comments prior to final acceptance. Presentations were further evaluated during the conference based on content quality, clarity, visual presentation, and adherence to timing, ensuring a rigorous, transparent, and fair evaluation process.

Certificates and Awards:

Certificates were awarded to recognize valuable contributions to ICEMIR 2025, including participation, presentation, publication, reviewing, session chairing, moderation, and appreciation.

Best Awards

Best Presenter Awards were conferred in recognition of excellence in research quality, presentation clarity, and academic contribution and were awarded to:

1. Ms. Elif Nurber Borucu
2. Dr. Dhanalakshmi C. P.
3. Prof. Dr. Nageswara Rao Lakkimsetty
4. Ms. Nur Kabave Kutlu

Best Student Presenter Award was presented to:

1. Ms. Zuwaina Masoud Rashid Al Yaarubi

ICEMIR 2025 Tentative Program Overview

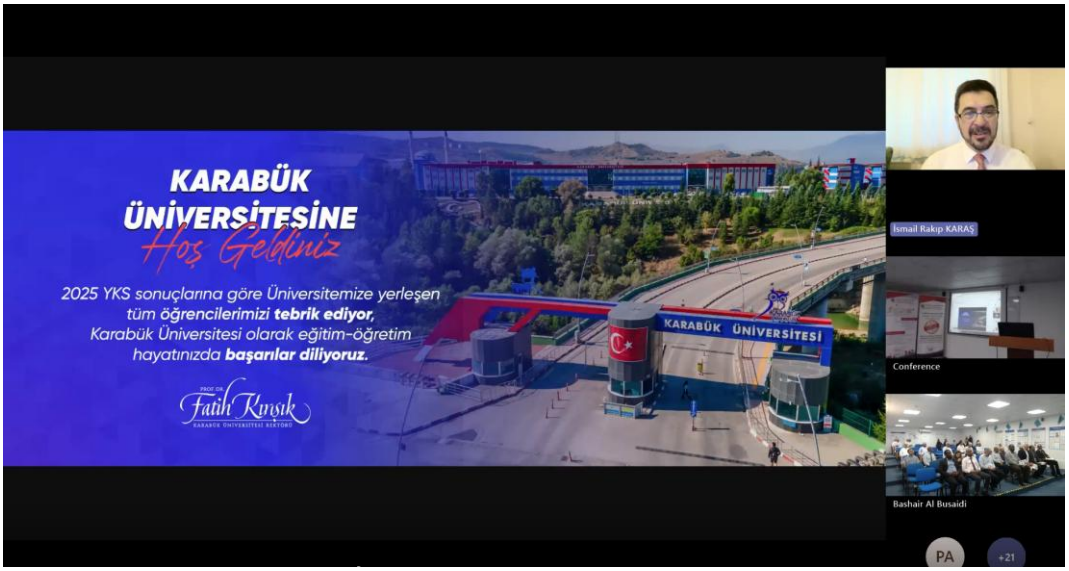
Day 1 – Tuesday, 2 December 2025

The first day of ICEMIR 2025 was dedicated to the opening ceremony and keynote sessions, conducted fully online via MS Teams. The program commenced with formal opening proceedings, including welcome addresses by ICEM leadership and international co-organizers. This was followed by a structured keynote session featuring distinguished speakers from academia and industry, covering topics in sustainable materials, hydrogen technologies, nanotechnology, desalination, and advanced energy systems. The day concluded with collective discussions and a formal closing session.

Day 2 – Wednesday, 3 December 2025

The second day comprised parallel technical presentation sessions, delivered entirely online via MS Teams, across four thematic tracks. Each presentation was allocated 15 minutes followed by a 5-minute Q&A, moderated by assigned session chairs. The conference concluded with closing sessions in each track, ensuring orderly discussion, feedback, and participation closure.

Organizer's Welcome Address
Dr. Yingkui Zhao,
Dean, International College of Engineering and Management, Oman.



Co-Organizer's Remarks
Prof. Dr. İsmail Rakıp KARAŞ
Vice Rector, Karabük Üniversitesi, Türkiye.

Co-Organizer's Remarks
Prof. Dr. Saeed Gul
University of Engineering & Technology Peshawar, Pakistan

Conference
(ICEMIR 2025)

Day One

Conference Program

Tuesday, 2 December 2025

We are delighted to have you join us; click the MS Teams logo to join.

Meeting ID: 320 872 824 560 14,
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Opening Ceremony

8:30 – 9:00 9:00 – 9:02 9:02 – 9:05	**Registration** **Oman National Anthem** **ICEM Anthem**		**Organizing Team**
9:05 – 9:15	**Holy Quran**	**Mr. Ahmed AL Sumri,** *WE-Student, ICEM*	
9:15 – 9:30	**Organizer's Welcome Address** International College of Engineering and Management, Oman.	**Dr. Yingkui Zhao,** *Dean*	**Dr. Don Anton Balida** *Moderator*
9:30 – 9:45	**Co-Organizer's Remarks** Karabük Üniversitesi, Türkiye.	**Prof. Dr. İsmail Rakıp KARAŞ,** *Vice Rector*	
9:45 – 10:00	**Co-Organizer's Remarks** University of Engineering and Technology, Pakistan.	**Dr. Saeed Gul** *Professor*	

Keynote Session

10:00 – 10:30	Natural coagulants and their use in wastewater treatments	**Prof. Dr. Sakine Ugurlu Karaağaç** *Karabük Üniversitesi, Türkiye*	**Dr. Don Anton Balida** *Moderator*
10:35 – 11:05	Blue Hydrogen Production Using the Steam Methane Reforming Process	**Dr. Asadullah** *University of Wyoming, USA*	
11:10 – 11:30	**Break (20 minutes)**		
11:35 – 12:05	Electrically conductive anti bio fouling ceramic membranes for desalination	**Dr. Muhammad Mubashir** *Membrane Technology Specialist Saline Water Conversion Corporation (SWCC), Saudi Arabia.*	**Dr. Nasir Khan** *Moderator*
12:10 – 12:40	Nanotech-Driven Waste Valorization: Smart Solutions from Scrap.	**Dr. Aamir Hussain Bhat** *University of Technology and Applied Sciences, Oman.*	
12:45 – 13:15	Gel-Based Materials for Thermo-Electrochemical Cells (TECs)	**Dr. Muhammad Siyar** *National University of Science and Technology, Pakistan.*	
13:20 – 13:50	Enhanced Hydrogen Production from Sodium Borohydride ($NaBH_4$) Hydrolysis via Functionalized Multi-Walled Carbon Nanotubes (MWCNTs)	**Assoc. Prof. Dr. Songül Kaskun Ergani** *Karabük Üniversitesi, Türkiye.*	
13:50 – 14:15	**Discussions and Closing Session**		

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Day Two

Wednesday, 3 December 2025

Conference Program

Parallel Presentation Sessions

Welcome to Day 2 of ICEMIR 2025, featuring four parallel MS Teams rooms with 15-minute presentations followed by 5-minute Q&A sessions.

Room	Track (*Parallel Presentation Sessions*)	Join Link	Meeting ID	Passcode
Room A	Built Environment, Safety & Facilities Management		327 830 171 953 85	Kz7bX33q
Room B	Energy, Industrial Processes & Environmental Engineering		348 711 497 091 3	qc97Sw3b
Room C	Engineering Innovation, Computing & Intelligent Systems		325 258 442 556 71	2rw7JG9A
Room D	Health, Environment & Human Performance Studies		325 883 472 468 78	Gm7Jd7vF

Conference
(ICEMIR 2025)

Room C – Engineering Innovation, Computing & Intelligent Systems |

09:00–09:20	Evaluation of Processed Sandstone Drilled Cuttings as Sustainable Additive Materials	**Mr. Asif Zamir**	**Dr. Muhammad Yassir** *Moderator* **Dr. Sivi Varghese** *Moderator* **Mr. Ali Al Bahri** *Moderator*
09:20–09:40	Development of ML Models for 3-Phase Horizontal Separator Optimization: A Study from Oman Oilfield	**Ms. Hanan Taia Mahammad Al Gharibi**	
09:40–10:00	The Perceptions of Mechanical Engineers on The Use of Artificial Intelligence in Aircraft Maintenance	**Mr. Kinan S. S. Abu Amro**	
10:00–10:20	Development of Machine Learning to Predict Fracture Progression in Oil Shale Reservoirs while Hydraulic Fracture Operation	**Engr. Rawina Mohammed Al Jabri**	**Dr. Riyad Mahfud** *Moderator* **Dr Hashim Elbadri** *Moderator* **Dr. Victor Otitolaiye** *Moderator*
10:20–10:40	Investigation of Graphite-Based Drilling Fluids for Enhanced Cutting Transportation	**Mr. Alwaqqas Almawali**	
10:40–11:00	Harnessing Artificial Intelligence and Machine Learning for Innovative Marine Water Desalination and Sustainable Resource Use	**Prof. Dr. Nageswara Rao Lakkimsetty**	
11:00–11:20	Impact of Principal Component Analysis on Clustering Algorithms: A Comparative Study of K-Means, DBSCAN, and HDBSCAN on High-Dimensional Music Data	**Ms. Nur Kabave Kutlu**	
11:20-11:30	**Closing Session**		

Conference
(ICEMIR 2025)

Room B – Energy, Industrial Processes & Environmental Engineering |

09:00–09:20	Effective Removal of Fe^{+2} and Acidity (H^+) from Wastewater Using Optimized Guar Gum-HPTMGG Treatment	**Engr. Muhammad Riaz**	**AP. Dr. Girma Chala** *Moderator* **Mr. Al Haitham Al Kalbani** *Moderator* **Dr. Don Anton Balida** *Moderator*
09:20–09:40	Effect of Persulfate for Petroleum Wastewater Treatment	**Mr. Eldar Abdullayev**	
09:40–10:00	Feasible Solution for Sulfur Removal from Bituminous Coal	**Dr. Muhammad Irfan**	
10:00–10:20	Electrocoagulation and Natural Coagulation for Effective Removal of Heavy Metals and Organic Pollutants	**Mr. Ahmad Mohamed Ramdan Abudaia**	
10:20–10:40	Development of Amphoteric Guar Gum Derivative for Hydraulic Fracturing and Oil Well Drilling	**Engr. Saad Ur Rehman**	**Dr. Nasir Khan** *Moderator* **Mr. Ali Imran** *Moderator* **Mr. Asif Zamir** *Moderator*
10:40–11:00	Green Synthesis of CuO Nanoparticles and CuO-Pd Nanocomposite by Using Olive Leaves Extract and Its Coating Application	**Dr. Dhanalakshmi C. P**	
11:00–11:20	A Comparative Analysis of Machine Learning Algorithms for Sentinel-2 Image Classification in Çorum, Turkey	**Ms. Elif Nurber Borucu**	
11:20-11:30	**Closing Session**		

Conference
(ICEMIR 2025)

Room A – Built Environment, Safety & Facilities Management |

09:00–09:20	Assessing Viability of Proactive Maintenance in Omani Facilities through Digital Twin Integration: A Facilities Management Perspective	**Ms. Zain Hilal Aamir Alhajri**	**Dr. Abubakar Mahmoud** *Moderator* **Mr. Eldar Abdullayev** *Moderator* **Mr. Meet Panchal** *Moderator*
09:20–09:40	A Comprehensive Strategy for Enhancing Real Estate Asset Management: Integrating Risk Control, Value Optimization, and Efficiency Improvement	**Ms. Rawan Abdullah Mohamed Al Hinai**	
09:40–10:00	Sustainable HVAC Systems in Commercial Buildings in Oman	**Ms. Bashayer Ali Said Al Fazari**	
10:00–10:20	Study of Fire Characteristics and Flame Propagation in Palm Grove	**Ms. Zuwaina Masoud Rashid Al Yaarubi**	**Dr. Ajaya Kumar** *Moderator* **Ms. Shajira Seema** *Moderator* **Ms. Azza Al Saaidi** *Moderator*
10:20–10:40	Design and Fabrication of an In-Pipe Inspection Robot	**Ms. Arwa Aamir Mubarak Al Hadhrami**	
10:40–11:00	Innovative Approaches to Fire Safety Management: Integrating Technology and Occupant Behavior	**Ms. Muna Salim Saayid Al Riyami**	
11:00–11:20	The Impact of Solar Energy on the Efficiency of Building Services in Facilities Management	**Ms. Maryam Murad Al Balushi**	
11:20-11:30	**Closing Session**		

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Room D – Health, Environment & Human Performance Studies |

09:00–09:20	In Situ Synthesis of ZnO Nanoparticles and ZnO-Pd Nanocomposite by Using Almond Leaves Extract and Its Biomedical Application	**Dr. Dhanalakshmi C. P.**	**Dr. Eiman Ibrahim** *Moderator* **Dr. Sreejaya K V** *Moderator* **Ms. Rasha Abdelrahim** *Moderator*
09:20–09:40	Sustainable UV-Enhanced Photocatalytic Approach to Legionella Elimination in Hospital Water	**Ms. Wajd Said Salim Al Omrani**	
09:40–10:00	Emergence of Integrated Smart Healthcare System: A Comprehensive Review of Internet of Health Things for Medical Diagnostics and Treatment	**Dr. Yasser Khan**	
10:00–10:20	Determinants of Green Behaviour in Pakistan's Healthcare Sector	**Dr. Sadia Akhtar**	**Dr. Faris Mahammed** *Moderator* **Ms. Lekha K** *Moderator* **Ms. Abeer Jaradat** *Moderator*
10:20–10:40	Hiking Tourism in Oman: Knowledge and Awareness of Health and Safety Practices among Hikers	**Ms. Doaa Ahmed Mohammed Al-Sharif**	
10:40–11:00	Impact of Body Mass Index (BMI) on Mental Health of Firefighters	**Mr. Mohammed Ahmed Al Shehhi**	
11:00-11:30	**Closing Session**		

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Book 1: Abstracts Proceedings

*In **Book 1: Abstracts Proceedings**, each abstract is assigned a unique paper code (for example, A01, B03, C07). These codes are used consistently across the ICEMIR 2025 proceedings to enable clear identification and cross-referencing.*

*Where applicable, the paper code corresponds directly to a full paper published in **Book 2: Full Papers Proceedings**. The page number displayed in this volume indicates the starting page of the abstract within Book 1. For papers that proceeded to full manuscript publication, the complete paper can be found in Book 2 under the same paper code.*

*If a paper code appears **without a corresponding full paper in Book 2**, this indicates that only the abstract was submitted and presented at the conference, and no full manuscript was included in the Full Papers Proceedings.*

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*All abstracts in this volume are organized according to their designated **conference tracks and presentation rooms**, ensuring consistency with the official ICEMIR 2025 scientific program.*

Book 1 provides a concise overview of the research themes, methodologies, and findings presented during the conference, while Book 2 serves as the primary source for detailed technical and scholarly reference through full-length peer-reviewed papers.

Published by:
International College of Engineering and Management (ICEM)
Muscat, Sultanate of Oman

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Track A – Built Environment, Safety & Facilities Management

Paper Cod in Book 2: --

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Assessing Viability of Proactive Maintenance in Omani Facilities through Digital Twin Integration: A Facilities Management Perspective

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Abstract

As Omani buildings turn more complex, facilities management becomes increasingly challenging even in smaller scale buildings, as the traditional reactive maintenance approaches applied start to fall short. This dissertation examines the viability of integrating Digital Twin Technology into facilities management applications in Sultanate of Oman, aiming to enable a transition toward proactive maintenance approaches. Digital Twin Technology is a module that facilitates virtual mirror and real-time monitoring of building assets, thus supporting predictive fault detection, while optimizing scheduling and resource allocation. The mixed methods research deign was applied for this dissertation, including a survey that targeted professionals in this facilities management field in Oman, alongside an interview conducted with a maintenance manager. All of which was supported by literary analysis for the technological feasibility and practical challenges of adoption. Findings showcased how Digital Twin Technology may advance asset life cycle, reducing downtime, and fault detection, and maintenance scheduling, alongside cutting costs and waste. Supporting technologies, namely virtual and augmented reality integration, internet of things, or building information management systems were found to be synergistic with Digital Twins, improving monitoring, spatial visualization, and immersive training. However their adoption is constrained by technical complexity, limited expertise, resistance to change, high initial investment, and integration challenges with legacy systems despite the potential for scalability and long-term cost savings. This dissertation can contribute to the body of literature by providing region-specific insight to an area with limited scholarly research.

Keywords: *Digital Twin Technology (DTT), Proactive Maintenance; Facilities Management (FM), Predictive Maintenance, Preventive Maintenance, Sultanate of Oman*

Track A – Built Environment, Safety & Facilities Management

Paper Cod in Book 2: *A02*
Paper Page Range in Book 2*:* *33–36*

A Comprehensive Strategy for Enhancing Real Estate Asset Management: Integrating Risk Control, Value Optimization, and Efficiency Improvement

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Abstract

Real estate asset management is essential for ensuring long-term asset value, operational performance, and risk mitigation. In Oman, organizations increasingly recognize the importance of structured asset management, yet face persistent challenges related to inconsistent planning, limited technological adoption, and inadequate risk control. This study develops an integrated framework for enhancing asset management practices by examining current strategies, risk management approaches, and value optimization methods. A mixed-methods design was used, combining survey responses from 101 professionals and semi-structured interviews with three industry experts. Quantitative results indicate that although 81.8% of organizations apply structured asset management practices, gaps remain in systematic performance evaluation, standardised risk assessment, and the use of digital tools such as Building Information Modelling (BIM). Qualitative findings further highlight barriers including financial constraints, insufficient training, and limited integration of sustainability principles. The proposed framework emphasises performance monitoring, proactive risk mitigation, capacity building, and BIM-enabled decision-making. This research provides practical insights for improving asset performance in Oman and contributes to the broader understanding of strategic real estate asset management in emerging markets.

Keywords: *Asset management, Real estate, BIM, Risk control, Value optimization, Oman.*

Track A – Built Environment, Safety & Facilities Management

Paper Cod in Book 2: --
Paper Page Range in Book 2: --

Sustainable HVAC system in commercial buildings in Oman

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Abstract

This study investigates the role of sustainable Heating, Ventilation, and Air Conditioning (HVAC) systems in enhancing energy efficiency and environmental performance in commercial buildings in Oman. Given the country's hot and dry climate, cooling demand is exceptionally high, making HVAC systems one of the largest energy consumers in buildings. The research aims to identify the types of sustainable HVAC systems, evaluate their benefits, examine the current systems used in Oman, highlight barriers to adoption, and propose practical methods for improving sustainability in existing systems. A structured survey approach was employed, targeting engineers, building owners, facility managers, and other stakeholders. A total of 30 questionnaires were distributed, and 18 valid responses were received, yielding a 60% response rate. The data collected was analyzed to assess awareness, adoption rates, perceived benefits, and challenges related to sustainable HVAC systems. The findings revealed that most commercial buildings in Oman continue to rely on traditional central air conditioning and VRF systems, with limited adoption of sustainable technologies. Participants identified key benefits of sustainable HVAC systems, including reduced energy consumption, lower operating costs, improved indoor air quality, and decreased carbon emissions. However, barriers such as high initial costs, lack of government incentives, limited technical expertise, and low awareness remain significant obstacles. The study concludes that sustainable HVAC systems hold great potential to support Oman's Vision 2040 goals of energy efficiency and environmental sustainability. To increase adoption, financial incentives, professional training programs, and awareness campaigns are recommended, along with gradual retrofitting of existing systems.

Keywords: *Sustainable HVAC, Energy Efficiency, Environmental Performance, Oman, Vision 2040*

Track A – Built Environment, Safety & Facilities Management

Paper Cod in Book 2: *A04*
Paper Page Range in Book 2*:* *38–57*

Study of Fire Characteristics and Flame Propagation in Palm Grove

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Abstract

This study focuses on palm groves and the importance of their role in GCC society in particular and the Arab society in general. The research covers the various ways in which fire can spread within the palm grove and their components. Accordingly, 12 different experiments were conducted horizontally and vertically to monitor the movements and patterns of fire and their effect on all samples. One of the most important objectives that were focused on was the behavior of palm tree samples when exposed to burning, and analyzing the characteristics and behavior of the resulting fire, along with its directions and extent of spread, while calculating the speed/rate of spread and the temperature. It also includes factors that affect the spread of flame in palm groves horizontally and vertically with caucuses. The combustion process and the spread of fire in open spaces are affected by the wind factor. Accordingly, the extent of the effect of fire and its spread on samples while exposed to wind was tested. The extent to which certain factors affect the flame propagation process was determined after listing the results of the experiments during the research. The rate of flame propagation increased in several cases, including the presence of wind and other conditions during the experiments which were examined and analyzed thoroughly in this study.

Keywords: *Fire, Speed, Flame spread, vertical and horizontal.*

Track A – Built Environment, Safety & Facilities Management

Paper Cod in Book 2: --
Paper Page Range in Book 2: --

Design and Fabrication of an In-Pipe Inspection Robot

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Abstract

In-pipe inspection robots are essential to the upkeep and surveillance of pipeline systems in sectors including sewage management, water supply, and oil and gas. In order to find flaws, corrosion, obstructions, and structural irregularities that could cause failures or safety risks, these robotic systems are made to manoeuvre in tight pipeline spaces. This project describes the design and development of an in-pipe inspection robot that can move through pipes of different diameters and orientations while carrying sensors for imaging and data collecting in real time. The robot maximises mobility and durability by integrating lightweight structural components, such as alloy steel for the main frame and ABS plastic for the wheels. Important design factors that have a big impact on the robot's stability, traction, and operational dependability are temperature, flow velocity, internal pressure, and pipe surface conditions. The suggested approach provides a more economical option to manual or external inspection techniques while increasing inspection efficiency and decreasing downtime. By improving the safety and integrity of subterranean infrastructure systems, this effort advances pipeline maintenance technology.

Keywords: *Robot, mobility, sewage management, water supply*

Track A – Built Environment, Safety & Facilities Management

Paper Cod in Book 2: *A06*
Paper Page Range in Book 2*:* *57– 64*

Innovative Approaches to Fire Safety Management: Integrating Technology and Occupant Behavior

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Abstract

Fire safety remains a critical challenge in building facilities, where outdated detection systems, insufficient training, and behavioral gaps continue to threaten life and property. This study investigates fire safety management practices in Oman with a focus on integrating innovative technologies and occupant behavior to enhance emergency preparedness. A mixed-method design was adopted, combining expert interviews with a questionnaire survey administered to 30 respondents, including facility managers, government staff, and students across Muscat and Musandam. Results showed that 53% of participants were unfamiliar with their building's detection systems and 50% had not received fire safety training in the past year, while awareness of modern solutions such as IoT-enabled detection (23%), VR/AR training (43%), and BIM-based applications remained limited. Interviews further revealed complacency during drills, weak enforcement of safety protocols, and concerns about the reliability and privacy of video-assisted systems. Although evacuation plans were generally trusted, behavioral gaps persisted, with 23% of respondents relying on others' decisions during emergencies. These findings highlight that technology alone cannot ensure safety without corresponding improvements in human behavior and awareness. The study concludes that a dual approach is essential: upgrading to advanced detection and guidance systems while mandating regular occupant training and awareness programs. Future directions include extending research across different building types, integrating AI-driven early detection, and implementing smart evacuation guidance with audio-visual alerts to support inclusive and effective evacuation strategies.

Keywords: *Fire Safety Management, Occupant Behavior, Fire Detection Systems, Innovative Technologies, Emergency Preparedness.*

Track A – Built Environment, Safety & Facilities Management

Paper Cod in Book 2: --
Paper Page Range in Book 2: --

The Impact of Solar Energy on the Efficiency of Building Services in Facilities Management

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Abstract

This study evaluates the impact of solar energy integration on the efficiency and performance of building services, specifically HVAC and lighting, within facilities management. Traditionally, non-renewable energy sources such as coal, oil, and natural gas have powered building systems, supporting essential functions in residential and commercial buildings. Solar-powered lighting systems, which use electricity generated from photovoltaic panels to operate LED fixtures, offer a significantly more energy-efficient alternative that reduces overall consumption. Survey results indicated that solar energy integration positively influences energy efficiency, cost savings, and occupant comfort; however, several challenges were identified, including legal permit requirements, worker availability, building size constraints, traditional mindsets, cost factors, technology availability, and maintainability issues.

Keywords: *Solar Energy; Building Services; Facilities Management; Energy Efficiency; HVAC Systems; Lighting Systems; Renewable Energy Integration; Cost Savings; Occupant Comfort; Sustainable Buildings*

Track B – Energy, Industrial Processes & Environmental Engineering

Paper Cod in Book 2: *B01*
Paper Page Range in Book 2*:* *65–68*

Effective Removal of Fe^{+2} and Acidity (H^{+}) from Wastewater Using Optimized Guar Gum-HPTMGG Treatment

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Abstract

Metal surface finishing industries also release acidic effluents that usually contain heavy metal ions and suspended solids in high concentrations, and their source discharge can lead to hazards to the water and aquatic life. Such wastes are either disposed of via various means, thus creating by-product pollution and expensive sludge disposal. This paper compares the performance of a natural coagulant, hydroxypropyl trimethyl ammonium guar gum (HPTMGG), with a modified version to assess the suitability of the modified natural coagulant where acidic wastewater is concerned. The dose of the coagulant (0-200 g/200mL) was assessed based on its coverage of Fe+2, H+, pH adjustment, turbidity, total dissolved solids (TDS), and conductivity. At low concentrations (15-50 g/200 mL), there was a low level of Fe+2 and H+ elimination (approximately 10-23% and 25-30% respectively), with minimal change in pH. Optimal Fe+2 removal (approximately 52) was noted with the doses of 120-150 g/200 mL with concomitant H+ neutralization (approximately 60) and a slight increase in pH (approximately 0.7 units) at higher doses (170-190 g/200 mL). Turbidity decreased drastically to less than 5 NTU at 20 g/200 mL before it rose once more at higher doses. The reduction of TDS was whereas a nonlinear (R2 = 0.83) curve, and the conductivity reduced in a linear way (R2 = 0.77). Although there was a great increase in the quality of water, the end pH was still low enough to warrant the additional alkalization. The results indicate that HPTMGG has the potential to eliminate metal ions, acidity, and particulates efficiently and thus is a potential substitute for the chemical coagulants in treating acidic wastewater.

Keywords: *Acidic wastewater treatment, Natural coagulants, Environmental remediation, Eco-friendly coagulant, Dose optimization.*

Track B – Energy, Industrial Processes & Environmental Engineering

Paper Cod in Book 2: --

Paper Page Range in Book 2: --

Effect of Persulfate for Petroleum Wastewater Treatment

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Abstract

Petroleum wastewater is a major environmental concern due to its high levels of toxic organics, hydrocarbons, and color-causing compounds that resist conventional treatment. Advanced Oxidation Processes (AOPs) have emerged as effective alternatives owing to their ability to generate powerful radicals for degrading persistent pollutants. This study investigates the use of persulfate (Ps) in a shaker-assisted system for petroleum wastewater treatment, with Ps dosages ranging from 0 to 1.0 g. Treatment efficiency was evaluated by measuring pH, chemical oxygen demand (COD), and color removal. Results showed that COD removal was dosage-dependent but inconsistent, reaching a maximum of 36% at 0.2 g Ps and 26% at 0.8 g Ps, while minimal or no removal was observed at other doses. In contrast, color removal remained consistently high across all treatments, exceeding 94% and reaching up to 97.6%. These findings indicate that persulfate is highly effective for decolorization of petroleum wastewater but less stable in reducing COD under the tested conditions. The study highlights the potential of Ps-based AOPs as a promising treatment approach, while emphasizing the need for further optimization of dosage and process conditions to enhance pollutant degradation.

Keywords: *Petroleum wastewater, Advanced Oxidation Processes, Persulfate, COD removal, Color removal, Shaker-assisted treatment.*

Track B – Energy, Industrial Processes & Environmental Engineering

Paper Cod in Book 2: *B03*
Paper Page Range in Book 2*:* *69–72*

Feasible Solution for Sulfur Removal from Bituminous Coal

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Abstract

Reducing the sulfur content of coal should help reduce environmental pollution and sulfur dioxide emissions during bituminous coal combustion, as well as increase the efficiency of coal use. The emission of sulfur dioxide leads to acid rain, which is very harmful to the environment and agriculture. Desulfurization is regarded as a sustainable and environmentally friendly solution to the severe issue. This paper discusses a feasible way of desulfurizing bituminous coal using a new process. The process includes comminution, leaching, purification, filtration, and drying to get cleaner coal suitable for industrial use. In the extraction, the ratio of HCl and KOH was manipulated to determine the impacts of acidic and alkaline substances on coal purification. The findings showed that the KOH effect on the removal of sulfur is larger than that of HCl. Sulfur content was determined by X-ray fluorescence (XRF) and X-ray diffraction (XRD). The given strategy helps to decrease not only the possible emissions of sulfur dioxide but also promotes the calorific value and combustion efficiency of coal. The given work proves that chemical desulfurization with an acid-alkali leaching optimization is an effective and scalable approach to reducing the adverse impact of coal burning on the environment and contributing to a cleaner energy output.

Keywords: *Bituminous coal, Desulfurization, Acidic-alkaline leaching, Sulfur reduction, Clean coal technology*

Track B – Energy, Industrial Processes & Environmental Engineering

Paper Cod in Book 2: --

Paper Page Range in Book 2: --

Electrocoagulation and Natural Coagulation for Effective Removal of Heavy Metals and Organic Pollutants from Industrial Effluents

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Abstract

This study examined wastewater treatment options that utilize natural coagulation with peach seed powder and electrocoagulation (EC). The system was examined for its effectiveness in eliminating color, turbidity, total suspended solids (TSS), chemical oxygen demand (COD), ammoniacal nitrogen (NH_3-N), and selected heavy metals (Al, Pb, Zn, Cr, Fe). Experimental conditions, i.e, coagulant dosage, current density, and pH, were systematically varied. Using iron and aluminum electrodes coupled to a DC power source, electrocoagulation tests were conducted in 1-liter beakers. At concentrations of 0.05–0.1 g/L, the natural coagulant performed optimally, removing up to 95.43% of COD and 93.24% of NH_3-N. At 0.5–0.6 A and pH levels of 9 –11, electrocoagulation produced the highest efficiencies, removing up to 90.78% of COD and up to 55.25% of NH_3-N. Iron and zinc, two heavy metals, were successfully eliminated (> 92% and > 96 %, respectively), but lead and chromium were barely or not removed at all. Interestingly, aluminum showed negative removal at higher pH and current levels, suggesting the possibility of secondary contamination and electrode dissolution. These approaches proved to work differently: natural coagulants efficiently removed particulates, while EC targeted dissolved and persistent contaminants. However, system performance was susceptible to operational conditions such as current intensity and pH. These findings highlighted the potential of the used methods as a sustainable, low-chemical-input solution for wastewater treatment, especially suitable for decentralized or resource-constrained environments.

Keywords: *Wastewater Treatment, Natural Coagulants, Electrocoagulation, Heavy Metals Removal, Peach Seed Powder.*

Track B – Energy, Industrial Processes & Environmental Engineering

Paper Cod in Book 2: --

Paper Page Range in Book 2*:* --

Development of Amphoteric Guar Gum Derivative for Hydraulic Fracturing and Oil Well Drilling

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Abstract

Polysaccharides, especially guar gum with cationic, anionic, and nonionic functional groups substitution are commonly used in hydraulic fracturing and oil well drilling, each providing specific benefits over others. Nonionic-anionic and nonionic-cationic based polysaccharide double derivatives are also well investigated due to the better performance of the two functional groups in comparison to the singly substituted but zwitterionic polysaccharide derivatives of guar gum, particularly as the guar gum is not well explored. In this study, an amphoteric guar gum derivative containing carboxymethyl (as an anionic group) and hydroxypropyl trimethyl ammonium chloride (as a cationic group) is prepared in the slurry method in the presence of sodium hydroxide. The outcome of the different reaction parameters was tested under varying levels of substitution of functional groups. Various material analysis procedures were used to describe the newly developed amphoteric guar gum. The structure of the product was studied using FTIR spectroscopy to verify the presence of zwitterionic modification. The XRD showed a decrease in crystallinity of the guar gum, and zeta potential results were stable at various pH levels. It was also found that the viscoelastic and cross-linking properties of the amphoteric guar gum were assessed in relation to different temperatures and shear rates. Besides, the stability of gum-diesel suspension was also tested and was found to be 97% stable after 24 hours. The findings indicate that the amphoteric gum can be applied in hydraulic fracturing and oil well drilling, with possibilities of oxidation and enzymatic decay once the gum is successfully applied.

Keywords: *Amphoteric guar gum, Zetapotential, Polysaccharide Derivatives, Hydraulic Fracturing, Oil-well Simulation*

Track B – Energy, Industrial Processes & Environmental Engineering

Paper Cod in Book 2: --

Paper Page Range in Book 2: --

Green Synthesis of CuO Nanoparticles and CuO–Pd Nanocomposite Using Olive Leaves Extract and Its Coating Application

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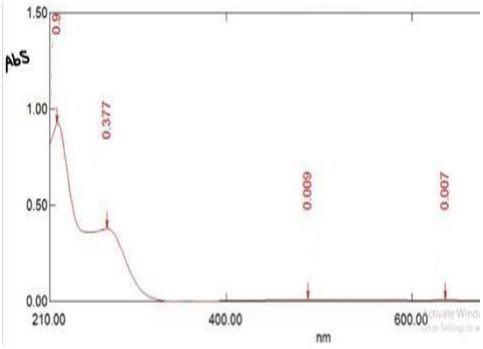
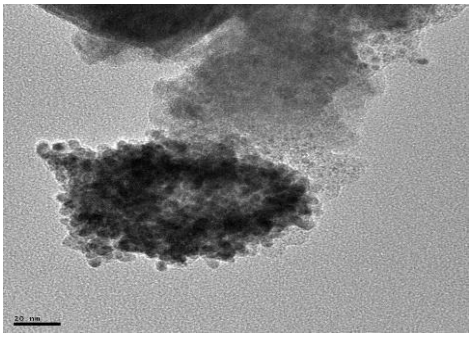
Abstract

Nanotechnology has emerged as among the most exciting areas of study, offering significant advancements across various scientific disciplines. Copper oxide nanoparticles have drawn a lot of attention lately because of its unique physicochemical characteristics, which can be further enhanced through nanometer-scale synthesis. Synthesis process leveraged the bioactive compounds in olive leaf extract, providing an eco-friendly and sustainable approach. In this study, olive leaves (Olea europaea) were utilized for producing CuO nanoparticles from copper nitrate in an environmentally friendly manner. From these CuO nanoparticles, CuO- Pd nanocomposite was prepared by using PdCl2 as a raw material. The synthesized CuO NPs and CuO-Pd nanocomposite were characterized using Ultraviolet-Visible (UV-Vis) spectrophotometry and Fourier Transform Infrared Spectroscopy (FTIR) and TEM studies. UV- Vis spectrophotometric Analysis showed the CuO NPs exhibited absorption peaks within the range of 234–275 nm with an absorbance value of 0.294, confirming the formation of CuO NPs. FTIR Spectroscopy analysis spectrum provided insights into the functional groups involved in nanoparticle stabilization, particularly identifying the CuO stretching vibrations, which are indicative of CuO nanoparticle formation. This study highlights the potential value of CuO-Pd nanocomposite in green nanotechnology, contributing to sustainable material synthesis for electrical, medical, environmental, and industrial applications.

Keyword: *CuO nanoparticles (CuONPs), TEM (Transmission electron microscopy) studies, Olive leaves extract, UV- Vis spectrophotometric analysis, FTIR spectroscopy analysis.*



UV spectrum of CuO-Pd nano composite



TEM image of CuO- Pd nanocomposite

Track B – Energy, Industrial Processes & Environmental Engineering

Paper Cod in Book 2: *B07*
Paper Page Range in Book 2*:* *73–80*

A Comparative Analysis of Machine Learning Algorithms for Sentinel-2 Image Classification in Çorum, Türkiye

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Abstract

Accurate and timely Land Use/Land Cover (LULC) information is crucial for sustainable development and environmental management. The advent of high-resolution satellite imagery like Sentinel-2, coupled with advanced machine learning (ML) algorithms, has significantly enhanced our capacity for large-scale LULC mapping. However, the performance of these ML models is highly dependent on their hyperparameter configuration, and a comprehensive comparison of their effectiveness for Sentinel-2 data remains a key research focus. This study conducts an evaluation of five ML algorithms: Random Forest (RF), XGBoost, AdaBoost, LightGBM, and CatBoost for LULC classification of Çorum province, Türkiye. A Sentinel-2 image was processed to create a dataset with five LULC classes. Each algorithm was optimized using three techniques: Grid Search, Random Search, and Bayesian Optimization. The models were evaluated based on Overall Accuracy (OA), Kappa coefficient, precision, recall, F1-score, and confusion matrix analysis. The results indicated that ensemble methods, particularly gradient boosting algorithms, delivered superior performance. CatBoost achieved the highest accuracy (OA=0.79) with default parameters, demonstrating robust out-of-the-box performance. However, after hyperparameter optimization, XGBoost, tuned with Grid Search, yielded the highest overall accuracy of 0.80. Hyperparameter optimization was found to be critically important for some algorithms, dramatically improving AdaBoost's accuracy from 0.57 to 0.77. The primary source of confusion across all models was between spectrally similar Urban and Bare Soil classes. This study concludes that XGBoost, when properly optimized, is a highly effective classifier for generating accurate LULC maps from Sentinel-2 imagery, providing a valuable benchmark for remote sensing practitioners and land management applications.

Keywords: *Land Use/Land Cover, Sentinel-2, Machine Learning, XGBoost, Hyperparameter Optimization, Remote Sensing.*

Track C – Engineering Innovation, Computing & Intelligent Systems

Paper Cod in Book 2: --

Paper Page Range in Book 2: --

Evaluation of Processed Sandstone Drilled Cuttings as Sustainable Additive Materials

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Abstract

The effective sealing of wellbores through cementing is critical for long-term well integrity and environmental protection. This study investigates the feasibility of using processed drilled cuttings as a partial substitute for conventional cement in oil and gas well cementing applications. The main objective was to assess the performance of cement slurries containing varying percentages (0%, 5%, 10%, and 15%) of drilled cuttings in terms of their fresh and hardened properties. Processed cuttings were subjected to drying and grinding before being incorporated into the cement blends. Laboratory tests were conducted to evaluate parameters such as thickening time, rheological behavior, compressive strength, and gel strength. The results indicated that increasing the cuttings content led to a moderate decrease in compressive strength and thickening time, while enhancing certain rheological characteristics such as yield point and gel stability. Notably, mixes containing up to 10% cuttings maintained performance within acceptable field limits, suggesting their potential as sustainable alternatives in cement formulations. Overall, the study demonstrates that utilizing drilled cuttings not only provides an environmentally responsible method for waste reuse but also contributes to cost reduction in cementing operations. The findings support the viability of incorporating up to 10% of processed cuttings without significantly compromising the structural and operational integrity of the cement system.

Keywords: *Sandstone, drilling cutting, cementing material, wellbore integrity, Oil and Gas Drilling.*

Track C – Engineering Innovation, Computing & Intelligent Systems

Paper Cod in Book 2: *C02*
Paper Page Range in Book 2*:* *81– 88*

Development of ML Models for 3-Phase Horizontal Separator Optimization: A Study from Oman Oilfield

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Abstract

A silent challenge exists in Oman's oil fields, where fluctuating temperatures reduce the efficiency of three-phase separators, affecting oil, water, and gas separation and increasing energy consumption. This study applies machine learning to enhance separator performance by analyzing key parameters, including pressure, temperature, and flow rates. Among several regression models, linear regression performed best ($R^2 = 1$, zero errors). Box plot analyses confirmed well-distributed data. These results indicate that ML, particularly linear regression, can improve separator adaptability, energy efficiency, and overall performance in Omani oil fields.

Keywords: *Machine-learning, Separator, Regression models, Data analysis, Oilfield.*

Track C – Engineering Innovation, Computing & Intelligent Systems

Paper Cod in Book 2: *C03*
Paper Page Range in Book 2*:* *89 –96*

The Perceptions Mechanical Engineers on The Use of Artificial Intelligence in Aircraft Maintenance

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Abstract

The objective of this study is to examine the perceptions of mechanical engineers on the use of artificial intelligence in aircraft maintenance, including its benefits and detriments, providing further insights on artificial intelligence's use in the aviation industry from the perspective of experienced professionals. Qualitative data were collected using a semi-structured written interview that was mailed to the mechanical engineers working in aircraft maintenance, resulting in seven respondents. The findings were obtained through thorough thematic data analysis, and they show that AI greatly improves the speed, accuracy, and safety of aircraft inspections and repairs through tools like real-time diagnostics, predictive maintenance, and automated scheduling. While participants noted that AI can streamline maintenance and lower costs, they also pointed out challenges such as cybersecurity risks, high implementation costs, and the danger of excessive reliance on AI. The study concludes that addressing these issues is crucial for AI to be successfully integrated into aviation. These findings offer useful guidance for airline executives, AI developers, and maintenance teams, helping them adapt to the growing role of AI in aircraft maintenance.

Keywords: *Artificial Intelligence, Mechanical Engineer, Aircraft Maintenance, Cybersecurity, Aviation.*

Track C – Engineering Innovation, Computing & Intelligent Systems

Paper Cod in Book 2: *C04*
Paper Page Range in Book 2*:* *97–100*

Development of Machine Learning to Predict Fracture Progression in Oil Shale Reservoirs while Hydraulic Fracture Operation

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Abstract

Hydraulic fracturing is a widely applied technique to increase oil and gas recovery, but predicting fracture progression in shale reservoirs remains difficult due to the complexity of subsurface formations and their nonlinear behavior. Inaccurate predictions can reduce efficiency, increase costs, and create environmental risks such as aquifer contamination or unwanted fracture growth into adjacent zones. This research develops a machine learning based predictive framework, implemented in Python using AI codes and libraries, to monitor fracture progression and improve hydraulic fracturing design in Oman's oil shale reservoirs. Simulation data were generated to study the effect of three operational parameters operation time, injection fluid rate, and fluid viscosity on fracture geometry. Four machine learning algorithms were tested: Linear Regression, Decision Tree, Random Forest, and Support Vector Regression. Model performance was evaluated using statistical indicators, including R^2 and RMSE, to measure accuracy and reliability. Results showed that the Decision Tree model consistently outperformed the others by effectively capturing nonlinear relationships and providing accurate predictions for two of the three studied parameters, while Random Forest delivered strong performance for one parameter. In contrast, Linear Regression and Support Vector Regression struggled with complex data. The findings demonstrate that Python-based machine learning can be a powerful tool for predicting and monitoring fracture progression, enabling better treatment design, reducing risks to sensitive zones, and minimizing environmental impacts. This work highlights how artificial intelligence can drive smarter, data driven, and more sustainable energy solutions in oil and gas operations.

Keywords: *Hydraulic Fracturing, Oil Shale Reservoirs, Machine Learning Prediction, Artificial Intelligence, Fracture Progression, Sustainable Engineering.*

Track C – Engineering Innovation, Computing & Intelligent Systems

Paper Cod in Book 2: --

Paper Page Range in Book 2: --

Investigation of Graphite-Based Drilling Fluids for Enhanced Cutting Transportation

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Abstract

Drilling fluids are one of the most important factors affecting any ongoing drilling procedures. Where it provides lubrication and cooling of down hole equipment (drill stem) as well as the well bores stability also helps on the management of lost circulation and hole cleaning by cuttings transportation. Therefore, an approach to further study the graphite type of nanoparticles is pursued to investigate the ability to enhance the cutting transportation by investigating the rheological properties by conducting several tests and evaluating the results. Adequate or proper hole cleaning is one of the most important aspects to achieve a successful drilling operation. Ther are numerous issues that are encountered due to improper hole cleaning or improper cuttings removal such as excessive wear in drilling bits, stuck pipe situations, increase in drag and torque and formation damage as well. Therefore, the cutting transportation efficiency of the drilling fluid used should be high enough to avoid all the mentioned problems and issues to be encountered while drilling. The results and analysis of the experiments conducted, highlights the influential impact of adding graphite Gr into Water-Based Mud. Were these experiments conducted, shows that increasing the Gr content % has enhanced the essential rheological properties like yield point and plastic viscosity. These enhancements made by graphite presents a more durable internal structure in fluids, leading to enhanced cutting transport efficiency by better flow resistance and cutting suspension

Keywords: *Graphite, Drilling Mud, Drilling Fluid, Water based Mud, Cuttings, Cutting Transportation*

Track C – Engineering Innovation, Computing & Intelligent Systems

Paper Cod in Book 2: --

Paper Page Range in Book 2: --

Harnessing Artificial Intelligence and Machine Learning for Innovative Marine Water Desalination & Sustainable Resource Use

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Abstract

Desalination of marine water is a vital technology for addressing the global freshwater deficit, particularly in arid and semi-arid regions where natural water resources are scarce. This process removes dissolved salts, minerals, and other impurities from seawater, rendering it suitable for industrial, agricultural, and domestic applications. This review explores key desalination technologies including Reverse Osmosis (RO), Multi-Stage Flash (MSF) Distillation, Multi-Effect Distillation (MED), and Electrodialysis (ED)with emphasis on their underlying mechanisms, operational efficiency, and associated environmental impacts. The integration of renewable energy sources such as solar, wind, and geothermal energy is also discussed to enhance the sustainability and cost-effectiveness of desalination processes. To address critical challenges such as high energy demand, brine disposal, and ecological degradation, the report proposes innovative solutions including energy recovery systems, hybrid desalination technologies, and advanced membrane materials, particularly those based on nanofiltration. The role of desalination in promoting environmental sustainability is further underscored through its diverse applications in municipal water supply, industrial cooling, and agricultural irrigation. Achieving long-term water security through advanced marine desalination requires a multidisciplinary approach involving technological innovation, policy support, and sustainable resource management. Moreover, the integration of Artificial Intelligence (AI) and Machine Learning (ML) offers significant potential to enhance desalination operations. These technologies enable predictive maintenance, energy optimization, and real-time water quality monitoring, thereby improving system performance, adaptability to changing marine conditions, and decision-making based on data analytics.

Keywords: *Marine Water Desalination, Renewable Energy Integration, Sustainable Water Management, And Advanced Desalination Technologies, Machine Learning*

Track C – Engineering Innovation, Computing & Intelligent Systems

Paper Cod in Book 2: *C07*
Paper Page Range in Book 2*:* *101 –104*

Impact of Principal Component Analysis on Clustering Algorithms: A Comparative Study of K-Means, DBSCAN, and HDBSCAN on High-Dimensional Music Data

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Abstract

High-dimensional music datasets encompassing features such as danceability, energy, tempo, and acousticness present valuable opportunities for clustering and analysis. This study evaluates the effectiveness of three unsupervised clustering techniques, K-Means, DBSCAN, and HDBSCAN, on a dataset of 170,653 songs. We applied Principal Component Analysis (PCA) to reduce the dataset's dimensionality and assessed its impact on clustering performance using metrics such as the Davies-Bouldin Index (DBI) and the Calinski-Harabasz Index (CHI). The results showed that PCA significantly improved the performance of the K-Means algorithm, lowering the DBI from 188.58 to 16.38 and raising the CHI from 7,579.25 to 26,987.73 for a cluster count of 27. Similar enhancements were observed for 29 clusters, highlighting the adaptability of the K-Means algorithm to PCA-driven dimensionality reduction. PCA had a substantial impact on DBSCAN but a subtle effect on HDBSCAN among density-based methods. It reduced the DBI to 6.60 and increased the CHI to 1,440.92 for DBSCAN across 27 clusters, while for HDBSCAN across 29 clusters, it reduced the DBI to 5.30 but slightly decreased the CHI to 1,328.86. Although PCA's effect varies across density-based algorithms, it enhances K-Means clustering by improving separation and compactness and substantially improves DBSCAN while having a mixed impact on HDBSCAN. These results underscore the importance of nonlinear dimensionality reduction techniques and hyperparameter optimization.

Keywords: *Principal Component Analysis (PCA), K-Means, DBSCAN, HDBSCAN, Clustering.*

Track D – Health, Environment & Human Performance Studies

Paper Cod in Book 2: --

Paper Page Range in Book 2: --

In Situ Synthesis of ZnO Nanoparticles and ZnO–Pd Nanocomposite Using Almond Leaves Extract and Its Biomedical Application

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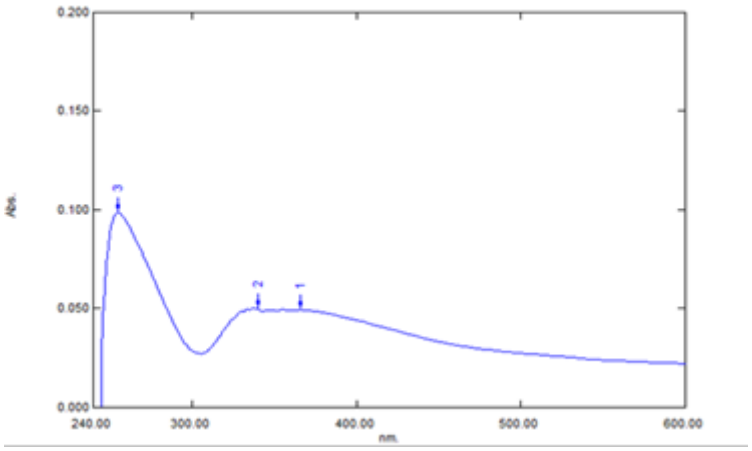
Abstract

This study investigated the green synthesis of Zinc-based nanomaterials using almond (Prunus dulcis) leaf extract, highlighting an environmentally friendly and sustainable approach to nanoparticle production Zinc oxide (ZnO) and Zinc oxide palladium (ZnO-Pd) nanocomposite, The almond leaf extract, rich in phytochemicals such as flavonoids, phenolics, tannins, and saponins, functioned effectively as both reducing and stabilizing agents in the nanoparticle synthesis process. Characterization studies were carried out from nanomaterials and nanocomposite by using FTIR and UV-VIS spectrophotometer. FTIR confirmed the presence of functional groups and Zn–O bonding essential for nanoparticle formation, while UV-Vis analysis showed significant absorption peaks appeared at 240–400 nm, indicated good optical properties. Antimicrobial activity was assessed against Escherichia coli and Staphylococcus aureus. Results showed that ZnO-Pd nanocomposite had superior inhibitory effects, especially in solid form, when compared to other synthesized materials. The presence of palladium improved bioactivity, suggesting the potential for ZnO-Pd in medical and environmental applications. This research supports the growing trend of green nanotechnology by demonstrating that natural plant extracts can be effectively used in nanoparticle synthesis. The successful development and application of green synthesis Zinc oxide nanomaterials and Zinc oxide-Pd nanocomposite could lead to sustainable alternatives for industrial, biomedical, and environmental uses.

Keywords: *Zinc oxide nanoparticles, Zinc oxide-Pd nanocomposite, almond leaf extract, green synthesis, antimicrobial activity, nanotechnology, FTIR, UV-Vis.*



UV-Vis spectrum of ZnO-Pd nanocomposite

Track D – Health, Environment & Human Performance Studies

Paper Cod in Book 2: --

Paper Page Range in Book 2*:* --

Evaluating Water Disinfection Practices with Emphasis on UV-Based Alternatives for Legionella Control in Al Rustaq Hospital Water System

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Abstract

Eliminating Legionella bacteria from hospital water systems remains a critical challenge, as the pathogen poses serious risks to respiratory health. In Oman, chlorine is the most commonly used disinfection method; however, it often only suppresses bacterial activity, can damage water infrastructure, and presents environmental concerns. This study explores a more sustainable and effective alternative by using ultraviolet (UV) light enhanced with photocatalysis and oxidizing agents to ensure the complete inactivation of Legionella from the earliest stages of water treatment. The methodology involved laboratory experiments combining UV light, biochar, and hydrogen peroxide to assess the effectiveness of photocatalytic disinfection. A survey was also conducted with water treatment companies, including OWTACO, the company responsible for disinfection at RUSTAQ Hospital, to evaluate current disinfection practices and their impacts. In addition, interviews with medical staff at RUSTAQ Hospital, supported by a patient case study, were conducted to confirm the health risks associated with Legionella exposure. Results show that photocatalysis effectively generates reactive species, particularly hydroxyl radicals, which penetrate bacterial cells and destroy their DNA, leading to complete bacterial elimination. Unlike chlorine, which mainly suppresses bacterial growth, photocatalytic treatment ensures full and lasting disinfection. Importantly, the enhancement of UV radiation through hydrogen peroxide and the biochar photocatalyst significantly strengthened the efficiency of UV disinfection in the early stages of treatment by producing reactive radicals and free molecules capable of penetrating bacterial DNA and completely eliminating the pathogen from the onset of disinfection. The study recommends the integration of photocatalytic disinfection into hospital water systems as a safer, more sustainable, and environmentally friendly solution to enhance patient safety and public health.

Keywords: *Healthcare System; Internet of Health Things; Medical Diagnostics*

Track D – Health, Environment & Human Performance Studies

Paper Cod in Book 2: *D03*
Paper Page Range in Book 2*:* *105 – 109*

Emergence of Integrated Smart Healthcare System: A Comprehensive Review of Internet of Health Things for Medical Diagnostics and Treatment

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Abstract

The Internet of health things (IoHT) is the new avenue of technology to connect smart gadgets to the human body for the collection of physiological variables and assist healthcare professionals in making informed decisions. In a traditional medical care facility, the record of the patient is routinely updated on a standalone digital system, making it difficult for medical staff to assemble and analyze the electronic health record of the patients. To overcome this problem, the existing healthcare system is transformed into a highly connected system to gather data on a centralized ecosystem. The required record is accessed for an expert medical opinion to diagnose and take anticipatory actions. This research article aims to conduct a comprehensive survey on the wireless body area sensory network, communication system, and protocols incorporated in the layered architecture hence, cause efficient delivery of information. The complex operation of the health care system is elaborated into explicit illustrations for easy understanding of medical and technology managers. The applications of diverse segments of the smart medical-care system and associated challenges of the internet-connected health system are thoroughly deliberated. With the implementation of IoHT, the efficiency for diagnosis of disease, cost optimization, and provisioning of medical care at home are substantially upgraded.

Keywords: *Biosensors, wearables, Smart Health, Healthcare protocols, Smart hospitals*

Track D – Health, Environment & Human Performance Studies

Paper Cod in Book 2: --

Paper Page Range in Book 2*:* --

Determinants of Green Behaviour in Pakistan's Healthcare Sector

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Abstract

Compared to the other developing nations, Pakistan is beset by various challenges and problems in terms of the healthcare sector, with regard to sustainability. Mismanagement of hospital waste may lead to many serious illnesses, including infection, human immunodeficiency virus, hepatitis B virus, and other patients and hospital employees. The performance of the hospitals is being affected by these issues because they are threatening the local community and environment in Pakistan. Thus, healthcare organizations can facilitate environmental sustainability by encouraging green behavior among employees. This research paper seeks to investigate how the policies of institutional sustainability, organizational climate, green inclusive leadership, and the employees' knowledge of the environment affect the green practices among employees of the health sector in Pakistan. The quantitative approach was employed, and the data were gathered randomly among full-time employees (doctors, nurses, and technicians). The survey was done online, and 271 responses were obtained. The data have been analyzed with the help of the SPSS software, which made it possible to confirm reliability and validity. Green inclusive leadership, institutional sustainability policies, organizational climate, and environmental knowledge of the employees were found to have significant effects. The findings highlight the significance of good sustainability policies, dedicated leadership, exchange of knowledge and a positive organizational culture, as well as powerful mechanisms that ensure environmentally responsible behaviors among the healthcare personnel. The research provides useful information to policymakers and hospital administrators on how to achieve successful incorporation of sustainability practices in medical institutions. The healthcare sector in Pakistan can be crucial in the struggle against environmental issues and the promotion of sustainability issues within the country.

Keywords: *Environmental knowledge, Green behavior, Green inclusive leadership, Healthcare organizations, Institutional sustainability policies, Organizational climate*

Publication note: *This paper was presented at ICEMIR 2025 and included in Book 1: Abstracts Proceedings only. The full manuscript was published independently in an external academic journal and is not included in the ICEMIR 2025 Full Papers Proceedings (Book 2). Abstract inclusion does not constitute prior or duplicate publication.*

Track D – Health, Environment & Human Performance Studies

Paper Cod in Book 2: --

Paper Page Range in Book 2*:* --

Hiking Tourism in Oman: Knowledge and Awareness of Health and Safety Practices among Hikers

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Abstract

Although, hiking in Oman became popular in recent years, several health and safety (HS) concerns have been raised. This study explores the knowledge and awareness of HS practices among hikers who are guided by certified operators registered by the Ministry of Tourism and Heritage in Oman. Through a mixed methodology using questionnaires, aspects such as hikers' understanding of essential safety measures, first aid techniques, navigation skills, and awareness of local hazards were investigated. The sample included 192 participants, predominantly males (161) with a significant portion holding bachelor's degrees. Key findings revealed high levels of safety preparedness, with most hikers carrying first aid kits (73.9%), checking the weather forecast (78.1%), and being familiar with potential hazards (75.5%). However, gaps exist, as some hikers never carry a first aid kit (9.9%) and lack emergency handling knowledge (7.8%). Demographic factors, including hiking experience, were found to influence awareness levels. For instance, the study identified a positive correlation between hiking frequency and carrying first aid kits, but a negative correlation with familiarity with hazards. Furthermore, the majority of participants support mandatory safety training (47.4%) and express interest in additional resources (88%). Additional findings include high awareness of responsible environmental hiking practices, and proactive emergency response behaviours. The findings explain how hikers perceive HS practices and highlight the need for targeted initiatives to enhance safety awareness and responsible practices. Future research should evaluate the effectiveness of these interventions and their impact on hiking safety outcomes.

Keywords: *Hiking, Knowledge, Awareness, Health and Safety, Preparedness.*

Track D – Health, Environment & Human Performance Studies

Paper Cod in Book 2: --

Paper Page Range in Book 2*:* --

Impact of Body Mass Index (BMI) on Mental Health of Firefighters

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Abstract

Firefighting is a profession marked by extreme physical demands and frequent psychological stressors. This study investigates the relationship between Body Mass Index (BMI) and mental health among firefighters, focusing on how body composition may influence psychological well-being and job performance. A total of 37 firefighters with having average of 9 years of experience participated and answered a questionnaire which addresses the relationship between BMI and workplace mental health. The study shows that 65% of participants were overweight or obese, 27% of firefighters reported mental or emotional challenges, and 19% experienced symptoms of anxiety or depression over the past year. Sleep disruption was common, with 38% reporting insufficient or poor-quality rest, alongside frequent emotional exhaustion and mood swings. While most participants demonstrated calmness in emergencies, hidden stress and unhealthy coping strategies, such as smoking, were evident. Such approaches can strengthen resilience, improve overall well-being, and enhance operational readiness, ultimately ensuring a healthier and more effective firefighting workforce.

Keywords: *Firefighters, Body Mass Index (BMI), Mental Health, Psychological Well-being, Occupational Health.*

Book 2: Full Papers Proceedings

*This **Book 2**: Full Papers Proceedings presents the complete manuscripts submitted for ICEMIR 2025. These papers represent the technical and scholarly contributions of researchers, academics, and practitioners from diverse fields, including engineering, energy, computing, sustainability, and human performance.*

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Each paper in this volume is linked to its corresponding abstract in Book 1:

- *The paper code (e.g., A01, B03, C06) is identical in both books.*
- *Page numbers in this book represent the full manuscript location.*
- *Abstract-only submissions appear in Book 1 but do not appear in this volume.*

We extend our appreciation to all authors, reviewers, conference chairs, and organizing partners for their contributions to this publication.

Published by:
International College of Engineering and Management (ICEM)
Muscat, Sultanate of Oman

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Track A – Built Environment, Safety & Facilities Management

Paper Cod in Book 2: *A02*
Paper Page Range in Book 2*:* *33–36*

A Comprehensive Strategy for Enhancing Real Estate Asset Management: Integrating Risk Control, Value Optimization, and Efficiency Improvement

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Abstract

Real estate asset management is essential for ensuring long-term asset value, operational performance, and risk mitigation. In Oman, organizations increasingly recognize the importance of structured asset management, yet face persistent challenges related to inconsistent planning, limited technological adoption, and inadequate risk control. This study develops an integrated framework for enhancing asset management practices by examining current strategies, risk management approaches, and value optimization methods. A mixed-methods design was used, combining survey responses from 101 professionals and semi-structured interviews with three industry experts. Quantitative results indicate that although 81.8% of organizations apply structured asset management practices, gaps remain in systematic performance evaluation, standardised risk assessment, and the use of digital tools such as Building Information Modelling (BIM). Qualitative findings further highlight barriers including financial constraints, insufficient training, and limited integration of sustainability principles. The proposed framework emphasises performance monitoring, proactive risk mitigation, capacity building, and BIM-enabled decision-making. This research provides practical insights for improving asset performance in Oman and contributes to the broader understanding of strategic real estate asset management in emerging markets.

Keywords: Asset management, Real estate, BIM, Risk control, Value optimization, Oman.

Introduction

Real estate asset management plays a central role in sustaining the long-term performance, value, and financial viability of property portfolios. As global real estate markets become increasingly competitive, organizations are expected to adopt structured strategies that combine risk control, technological innovation, and systematic performance monitoring to ensure efficient asset operation. International standards such as ISO 55000 emphasise the need for measurable indicators, lifecycle thinking, and continuous improvement; however, translating these principles into practice remains a challenge in many regions.

In Oman, the real estate sector is an important driver of national economic diversification and urban development, yet asset management practices are still evolving. Existing studies highlight persistent issues such as inconsistent asset planning, inadequate risk evaluation, and slow adoption of digital tools, particularly Building Information Modelling (BIM). Although global research demonstrates the benefits of integrating data analytics, sustainability principles, and value-based optimization into asset management, these approaches are not yet fully embedded in Omani practice. Instead, organizations often rely on reactive methods, fragmented strategies, and short-term operational responses, limiting their ability to enhance asset value or ensure long-term resilience.

The literature further suggests gaps in standardized risk control frameworks, weak alignment between planning and performance monitoring, and limited integration of technology in facility operations. While each of these components has been examined independently, little research has explored how they interact within a unified asset management framework tailored to the Omani context. This gap underscores the need for a holistic approach that brings together risk mitigation, value optimization, and operational efficiency.

In response to these challenges, this study develops an integrated framework designed to strengthen real estate asset management practices in Oman. The research evaluates current organizational approaches, identifies key risks affecting asset performance, and examines the extent to which value optimization and technologies such as BIM are incorporated into asset strategies. By combining quantitative survey data with qualitative expert insights, the study offers a critical assessment of existing practices and proposes a model to support more consistent, efficient, and value-driven asset management across the sector.

The aim of this study is to develop an integrated framework that strengthens real estate asset management practices in Oman by addressing the key gaps identified in current organisational approaches. Specifically, the research seeks to assess how asset management strategies are currently implemented, evaluate the effectiveness of performance monitoring processes, and examine the weaknesses that persist in existing risk control mechanisms. It further aims to analyse the extent to which value optimisation practices and technological tools—particularly Building Information Modelling (BIM)—are incorporated into asset management activities. By combining these insights, the study proposes a unified framework that brings together risk control, value optimisation, and operational efficiency to support more consistent, proactive, and sustainable asset management across the sector.

Literature Review

Effective real estate asset management requires the integration of strategic planning, risk control, value optimization, and technological innovation. Prior research consistently argues that aligning operational decisions with long-term organizational objectives is essential for maintaining asset performance and value (Warren, 2006). International frameworks such as ISO 55000 reinforce this view by highlighting lifecycle management, measurable performance indicators, and continuous monitoring. However, evidence from both global and regional studies shows that many organizations, particularly in developing markets, struggle to implement these principles in a systematic manner.

A central challenge relates to risk management. Although organizations often develop risk plans, these frameworks are frequently fragmented, inconsistently applied, or updated only in response to incidents rather than through routine assessment. Studies such as KPMG (2021) and Pagani et al. (2020) emphasize that financial and market risks receive the most attention, while operational, environmental, and technological risks are undervalued. This reactive approach restricts organizations' ability to maintain asset reliability and anticipate disruptions.

Value optimization is another key element of modern asset management. The literature highlights the importance of lifecycle costing, energy-efficiency measures, tenant engagement, and data-driven performance analysis in sustaining asset value (CGI, 2020). Yet, many organizations apply these strategies in isolation, focusing on short-term improvements rather than embedded, long-term planning. As a result, asset value is influenced more by immediate priorities than by structured, cumulative interventions.

Technological integration—particularly through Building Information Modelling (BIM)—is widely recognized as a transformative tool for facility and asset management. BIM enhances data accuracy, supports preventive maintenance, improves documentation, and contributes to sustainability performance (Manola, 2008; Wong & Zhou, 2015). However, Eastman et al. (2018) note significant barriers to adoption, including high implementation costs, lack of training, and limited compatibility with existing systems. These challenges are especially evident in developing markets, where BIM is more commonly used during design and construction than during operational management.

Across the literature, three recurring gaps are evident: fragmented adoption of asset management practices, weak risk control mechanisms, and limited technological integration. Importantly, few studies examine how these issues converge within the context of Oman's rapidly developing real estate sector. Existing research does not provide a unified framework that addresses operational, technological, and strategic components together. This gap highlights the need for an integrated model tailored to the realities and maturity level of asset management practices in Oman—a need that the present study aims to address.

Materials and Methods

This study adopted a mixed-methods research design to provide a comprehensive understanding of real estate asset management practices in Oman. The mixed-methods approach was selected because quantitative data can reveal broad patterns in organizational behaviour, while qualitative insights help explain underlying issues and provide contextual depth. An explanatory sequential design was used: a quantitative survey was first administered to identify prevailing practices, followed by qualitative interviews to validate and expand upon the survey findings. This design is especially suited to exploratory research in sectors where asset management practices remain unevenly developed or insufficiently documented.

The study targeted professionals engaged in asset and facility management within both public and private organizations, including asset managers, engineers, property managers, and senior decision-makers. Purposive sampling ensured that participants possessed direct experience with asset management activities. In total, 150 questionnaires were distributed electronically, and 101 valid responses were obtained, yielding a response rate of 67%. The sample represented a wide range of organization sizes and asset portfolios, contributing to the generalizability of the results within the Omani context. To enrich the quantitative findings, three experts with more than ten years of experience in asset and facilities management were selected for semi-structured interviews based on their professional expertise, sector involvement, and familiarity with risk management and technological implementation.

Data were collected using a structured questionnaire comprising four thematic areas: organizational characteristics, asset management planning, risk control practices, and technological adoption, particularly the use of BIM. Most survey items employed a five-point Likert scale ranging from "strongly disagree" to "strongly agree," enabling respondents to indicate the level of implementation and perceived effectiveness of their asset management practices. The qualitative component consisted of semi-structured interviews designed to explore barriers to effective risk control, challenges in adopting technologies such as BIM, approaches to performance monitoring, and perceptions of asset management maturity in Oman. Interviews were conducted in person or online between November 2024 and May 2025.

Quantitative data were analysed using descriptive statistical techniques, including frequencies, percentages, mean scores, and cross-tabulations to compare practices across different organization types. This facilitated an overview of the maturity and variability of asset management practices in the sector. The qualitative data were transcribed and examined using thematic analysis. Initial coding was used to identify recurring patterns related to risk management gaps, value optimization strategies, and technological constraints. These codes were then organised into broader themes that aligned with principles from ISO 55000, strengthening the interpretive validity of the findings. Triangulation of survey and interview data enhanced reliability by allowing quantitative patterns and qualitative explanations to inform one another.

Several measures ensured the reliability and validity of the research. A pilot test conducted with five asset management professionals resulted in minor refinements to the questionnaire, and Cronbach's alpha values exceeded 0.8 for all constructs, indicating strong internal consistency. Content validity was strengthened through expert review of both the survey instrument and interview protocol. Ethical approval was obtained from the relevant academic institution, and participation was voluntary. All respondents provided informed consent, and confidentiality and anonymity were maintained throughout the study, with data stored securely and used exclusively for research purposes.

Results and Discussion

The analysis of the survey responses from 101 participants and interviews with three industry experts reveals both progress and persistent gaps in real estate asset management practices in Oman. Although most organizations claim to apply structured asset management strategies, the findings indicate inconsistencies in how these strategies are implemented and monitored. A total of 81.8% of respondents reported that their organizations follow formal asset management procedures, yet a notable proportion still lacks systematic processes. Performance monitoring illustrates this inconsistency: while some organizations conduct evaluations monthly or annually, a quarter of respondents reported that performance assessments are rarely carried out. Expert insights confirmed that evaluations are often reactive, prompted by operational problems rather than embedded within a preventive framework. This suggests that asset management practices remain only partially aligned with international principles such as ISO 55000, which emphasize continuous monitoring and the use of measurable indicators.

Risk management presents a similar pattern. Although 77% of respondents indicated the presence of a risk management plan, these frameworks often lack standardization, regular updates, and scenario-based assessments. Financial risks and market fluctuations emerged as the most frequently cited threats. According to experts, risk registers are typically updated only after incidents occur, highlighting a predominantly reactive culture rather than a predictive one. This is consistent with global studies showing that organizations tend to prioritize financial risks while overlooking operational and environmental ones. The findings therefore suggest that risk control mechanisms in many Omani organizations remain underdeveloped and insufficiently integrated into strategic planning.

Value optimization practices appear to be moderately adopted but similarly fragmented. Nearly half of the respondents noted using methods such as renovations, energy-efficiency improvements, and data-driven planning, and many organizations reported some engagement with sustainability initiatives. However, interview data revealed that these efforts are usually undertaken on a project-by-project basis, rather than as part of a coherent lifecycle strategy. Sustainability practices, in particular, were described as emerging but not yet institutionalized, largely due to financial limitations and limited understanding of lifecycle methodologies. This fragmented approach aligns with previous research showing that organizations often struggle to embed value optimization into long-term asset strategies.

Technology adoption—especially BIM—further illustrates the gap between awareness and practice. While 52.1% of respondents reported being familiar with BIM, only 42% indicated that it is actually used in preventive maintenance or operational planning. Interviews revealed several barriers contributing to low adoption levels, including high implementation costs, insufficient staff training, incompatibility with existing systems, and a general lack of organizational readiness. Experts noted that BIM is typically applied during design and construction stages, with limited integration into facilities management. This reflects broader global trends in which BIM's operational potential remains underutilized, particularly in developing markets.

Taken together, the results highlight the uneven maturity of asset management practices across Omani organizations. They show a sector that recognizes the importance of structured management, risk control, value optimization, and technological innovation, yet struggles to integrate these elements into a unified, long-term strategy. The findings are consistent with literature indicating that asset management in emerging markets often remains reactive, fragmented, and insufficiently

aligned with global standards. By revealing how gaps in evaluation, risk management, value enhancement, and technology adoption intersect, the study contributes new insights into the systemic challenges facing asset management in Oman. These insights reinforce the need for an integrated framework that supports proactive planning, lifecycle-based decision-making, and digital integration objectives that align with the framework proposed in this research.

Conclusion

This study investigated the current state of real estate asset management in Oman and identified the key gaps that limit the sector's ability to achieve long-term performance, value creation, and operational resilience. Although many organizations have begun adopting structured asset management practices, the findings reveal that implementation remains inconsistent, particularly in areas related to performance monitoring, risk management, and digital integration. The mix of quantitative and qualitative data highlights a sector in transition aware of best practices yet constrained by financial, technical, and organizational barriers. Collectively, these results demonstrate the need for a more unified and systematic approach to asset management, forming the basis for the integrated framework proposed in this research.

- Significant variation exists in how organizations conduct performance monitoring, with many relying on reactive rather than preventive assessments.
- Risk management plans are present in most organizations but are often outdated, non-standardised, and weakly linked to strategic planning.
- Value optimisation activities, such as renovations and sustainability initiatives, are implemented but typically in isolation rather than through a lifecycle-based strategy.
- Awareness of BIM is relatively high, yet practical adoption remains limited due to cost constraints, insufficient training, and poor system compatibility.
- Both datasets indicate a fragmented approach to asset management, with limited integration across planning, risk control, value creation, and technological systems.

To address these issues, the study proposes an integrated framework that prioritises:

- the use of measurable performance indicators and consistent evaluation cycles,
- proactive and predictive risk management tools,
- enhanced training and organisational capacity-building,
- broader adoption of BIM and digital technologies to support data-driven decision-making, and
- embedding sustainability and lifecycle optimisation into asset strategies.

By adopting these measures collectively, organizations in Oman can strengthen asset reliability, increase long-term value, and improve operational efficiency. Future research may extend this model to different asset categories or evaluate its implementation over time to measure its practical effectiveness.

Acknowledgments

The authors extend sincere appreciation to the International College of Engineering and Management (ICEM) and the University of Central Lancashire (UCLan) for their academic support and guidance. Gratitude is also expressed to the professionals, survey participants, and industry experts who contributed their valuable time and insights to this research. The authors also acknowledge the use of AI-assisted tools, employed solely for proofreading, grammar refinement, and linguistic clarity; all analysis, interpretation, and research findings remain the authors' own work.

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Track A – Built Environment, Safety & Facilities Management
Paper Cod in Book 2: *A04*
Paper Page Range in Book 2*:* *38–57*

Study of Fire Characteristics and Flame Propagation in Palm Grove

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Abstract

This study focuses on palm groves and the importance of their role in GCC society in particular and the Arab society in general. The research covers the various ways in which fire can spread within the palm grove and their components. Accordingly, 12 different experiments were conducted horizontally and vertically to monitor the movements and patterns of fire and their effect on all samples. One of the most important objectives that were focused on was the behavior of palm tree samples when exposed to burning, and analyzing the characteristics and behavior of the resulting fire, along with its directions and extent of spread, while calculating the speed/rate of spread and the temperature. It also includes factors that affect the spread of flame in palm groves horizontally and vertically with caucuses. The combustion process and the spread of fire in open spaces are affected by the wind factor. Accordingly, the extent of the effect of fire and its spread on samples while exposed to wind was tested. The extent to which certain factors affect the flame propagation process was determined after listing the results of the experiments during the research. The rate of flame propagation increased in several cases, including the presence of wind and other conditions during the experiments which were examined and analyzed thoroughly in this study.

Keywords: *Fire, Speed, Flame spread, vertical and horizontal.*

Introduction

Palm groves constitute a fundamental component of socio-economic, cultural, and agricultural life across the Gulf Cooperation Council (GCC) region and the wider Arab world. In the Sultanate of Oman, date palms (*Phoenix dactylifera*) are among the most widespread and historically significant tree species, forming a central pillar of food security and rural livelihoods [2]. Their strategic importance has been emphasized at the national level, where date palms are regarded as essential to long-term agricultural sustainability and food resilience [3]. Beyond their economic value, palm groves represent a deeply rooted cultural heritage, sustained over generations through traditional farming systems adapted to arid environments [1], [12], [13].

Oman is characterized by a semi-arid climate with high temperatures, limited precipitation, and extended dry seasons, conditions that significantly influence vegetation stress and fire susceptibility [4]. The country's geographical position along the Tropic of Cancer results in intense solar radiation during summer months, leading to elevated surface temperatures and increased thermal loading on exposed vegetation [5]. Under such climatic conditions, the accumulation of dry biomass, combined with high ambient temperatures and sufficient oxygen availability, creates favorable circumstances for fire ignition and propagation [6]. Palm groves are particularly vulnerable in this regard, as they contain combustible components such as dry fronds, fibrous trunks, and residual agricultural waste that can intensify fire behavior when exposed to heat sources [7], [26].

Fire is a complex physicochemical process governed by the interaction of fuel, heat, and oxygen, resulting in combustion, flame formation, and the release of thermal energy and gaseous by-products [16], [18]. In vegetated environments, fires commonly initiate as surface fires fueled by grasses, fallen leaves, and organic debris before potentially developing into more destructive forms depending on fuel continuity, moisture content, and environmental conditions [19], [20]. Of particular concern is the transition from surface fires to vertically spreading fires, as this transition significantly increases energy release and accelerates flame propagation, making suppression more difficult and hazardous [22], [23].

Flame spread within vegetative fuels is primarily controlled by heat transfer mechanisms, namely convection, conduction, and radiation [27], [28], [29]. Among these mechanisms, convection plays a dominant role in facilitating vertical flame propagation by transporting heat and combustible gases upward, thereby igniting higher fuel layers [18]. Experimental investigations have demonstrated that vertical flame spread occurs at substantially higher rates than horizontal spread, particularly in lightweight and vertically continuous fuels such as trees and suspended plant materials [30], [31].

Consequently, the spatial arrangement and continuity of fuel critically determine the direction, intensity, and extent of fire spread within vegetated systems [32].

Wind is widely recognized as one of the most influential external factors affecting fire behavior in open environments. It enhances oxygen supply, bends flames toward unburned fuel, transports embers, and accelerates fuel drying, collectively increasing flame spread velocity and fire intensity [36], [37]. Empirical studies have shown that the forward rate of fire spread can be approximated as a fraction of the prevailing wind speed, underscoring the importance of wind–fire interaction in predicting fire dynamics and risk [38]. These effects are further amplified in open agricultural landscapes and sloped terrain, where wind exposure is less obstructed and heat transfer processes are intensified [35], [39].

Despite the widespread distribution of palm groves across Oman and the broader GCC region, most existing fire research has focused on forested ecosystems, with limited attention given to palm-based agricultural systems. The unique structural characteristics of palm trees, including vertically aligned fibrous trunks and dense canopies, suggest that fire behavior within palm groves may differ substantially from that observed in conventional forest settings. However, controlled experimental studies examining horizontal and vertical flame spread in palm tree components, particularly under wind influence, remain scarce.

Accordingly, this study aims to experimentally investigate fire spread mechanisms within palm groves by analyzing horizontal and vertical flame propagation in palm tree samples under controlled conditions. Twelve experimental tests were conducted to evaluate flame movement, temperature development, and spread direction, with specific emphasis on the influence of wind on combustion behavior. By addressing this knowledge gap, the study seeks to provide a scientific basis for improved fire risk assessment and mitigation strategies tailored to palm-dominated agricultural landscapes in arid and semi-arid regions.

Materials and Methodology

Test Zone with Experimental setups

A tray (basin) of soil was used to place/install samples on/on top of it, similar to the palm plantation in fact. Thermocouples have also been used to measure ignition temperature and the highest temperature over time. Finally, two steel holders were used to hold and stabilize the eyes, whether horizontally or vertically.

Figure 1. Test Setup.

Weighing machine

Scale/weighing machine, specially designed to measure the weights of tools and equipment with only a small weight up to 310 grams.

Figure 2. Weighing machine.

Leaf sheath

It is one of the parts of the palm tree and wraps around it in a circular (axial) shape from the upper region, which is a fibrous fabric that intersects horizontally and vertically, forming a mesh-like shape and its dimensions were 35×9 square centimeters.

Figure 3. Leaf Sheath of palm tree.

Leaves

They are branched leaves from the branches of the palm tree, numbering more than 30 leaves according to the age and size of the palm, affected by its nature in color over time. Its length was between 30-35 cm.

Figure 4. Palm tree leaves.

Trunk

It is part of the trunk of the palm and is almost the roughest, and it looks like protruding squares, extending to the upper part of the leaf sheath and from which branches are also formed, where its beginning is thick and its end is slender and leafy. It was between 14-15 cm long and 1.5-2 cm thick. There is also a second specimen with a length of 15 cm, which is a mini palm tree consisting of a stick of trunk, leaves and sheath fixed by superglue and metal wire.

Figure 5. Palm tree trunk, 3 different samples.

Fan

Fan with 360° free motion, chargeable , with a installation able clasp, it has different speeds like 0.72 ±0.02 meters per second. They were used with a distance of about 15 cm between them and the samples and were actually representative of the wind.

Figure 6. Fan that represents wind.

Anemometer

The AN100 anemometer is a device dedicated to measuring air/wind speed in meters per second, every second. It was used to measure the speed and intensity of the fan as mentioned above.

Figure 7. Anemometer device.

Candle

The candle was used as a source of fire similar to reality in the event of a fire in the palm plantation.

Figure 8. Candle for diffusion flame.

Schematic diagrams

Wildfire, along straight line

In the first wildfire experiment, in basin of soil a 10 specimens were mini palm trees lined up with a distance of 5 cm between them, and the palm was about 15 cm long. This experiment was created to test the spread of flame and the ability of the samples to hold them until the end of the fire.

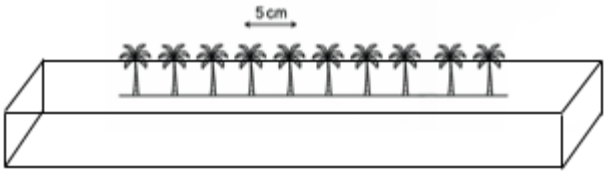

Figure 9. Palm tree in along straight line.

Wildfire, along straight line schematic diagram-(2, 3)

In the second and third wildfire experiment, in basin of soil a 10 specimens were mini palm trees lined up with a distance of 5 cm between them, and the palm was about 15 cm long. This experiment was created to test the flame spread with wind effect by providing a fan with 2 different speed, the space between samples and the fan was 50 cm.

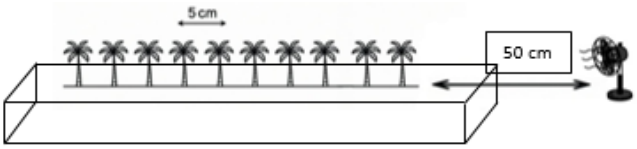

Figure 10. Palm tree in along straight line schematic diagram-(2, 3).

Wild fire, Zig Zag Pattern schematic diagram-4

In the fourth wildfire experiment, in the soil basin, 10 specimens were mini palm trees lined up randomly in zigzag shape (1,2,1,2,1,2,1), and the palm was about 15 cm long. This experiment was created to test the spread of flame if the palm is lined up zigzag.

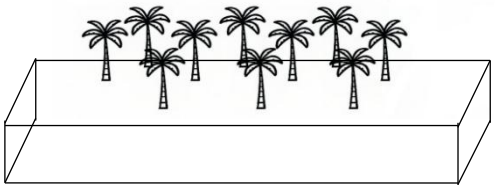

Figure 11. Palm tree in zigzag Pattern.

Wild fire, Mini Grove schematic diagram-5

In the fifth wildfire experiment, in basin of soil 15 specimens were mini palm trees lined up in 3 rows with a distance of 5 cm between them, and the palm was about 15 cm long. This experiment was created to test flame spread way and pattern.

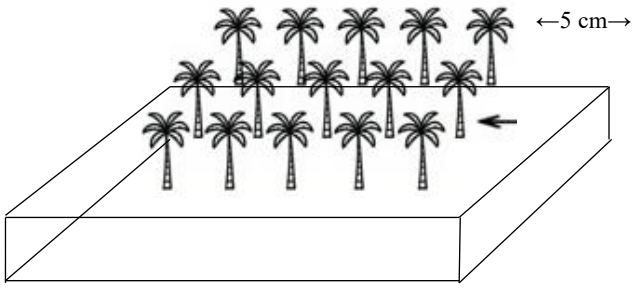

Figure 12. Mini Grove of Palm trees.

Wild fire, Mini Grove-Wind schematic diagram-6.

In the sixth experiment of forest fires, in the soil basin, 15 specimens were mini palm trees lined up in 3 rows with a distance of 5 cm between them, and the length of the palms was about 15 cm. This experiment was created to test the method and pattern of flame propagation. A fan has also been installed at 50 cm distance to test flame spread in case of wind.

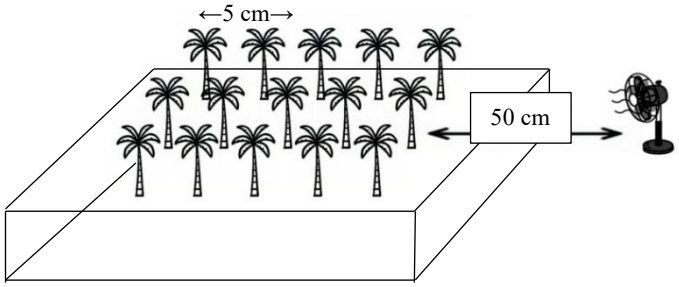

Figure 13. Mini Grove of Palm trees.

Result and Discussion

Experiment 1 – Leaf Sheath in Horizontal Position

The leaf sheath is fixed horizontally on the stand and 2 thermocouples are placed, one on the ignition point and the other in the middle of the sample. 2 and 3 experiments with wind.

Figure 14. Leaf sheath in Horizontal with fire.

Table 1. Leaf sheath in Horizontal with fire.

Sample/No.	**Mass (g)**	**Length (cm)**	**Time (s)**	**Temperatue (C°)**	**Flame spread distance (cm)**	**Flame Spread Rate (cm/s)**	**Wind Speed (m/s)**
Leaf sheath 1/Horizontal	13	35.5	86	179	35.5	0.41	-
Leaf sheath 2/Horizontal	18.3	35	17	142	35	2.05	0.72± 0.02
Leaf sheath 3/Horizontal	6.2	35.2	65	451	7	0.107	0.72± 0.02

In the first sample, after being set on fire by the candle, the flame spread along it horizontlly in just 86 seconds at a spread rate of 0.41 cm per second and reached a maximum temperature of 179 ° C. There was no residue from the first sample except ashes. For second sample the flame spread along it horizontlly in 17 seconds at a spread rate of 2.05 cm per second, because of wind effect it got better result. Leaf Sheath 2 reached a maximum temperature of 142 ° C with no residues except ashes. In the last one flame spread rate and distance were not high despite the high temperature and wind effect because of hard portion of leaf Sheath which non flameable.

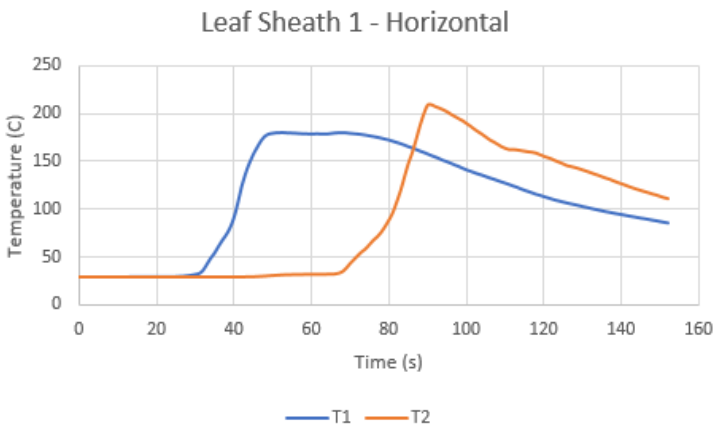

Figure 15. Time vs temperature grapg for Leaf Sheath 1.

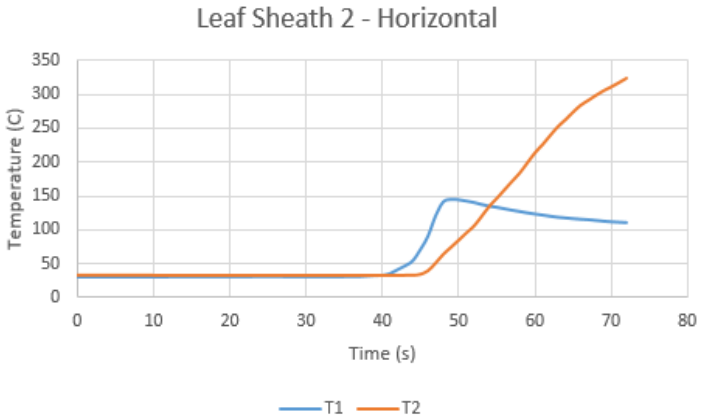

Figure 16. Time vs temperature grapg for Leaf Sheath 2.

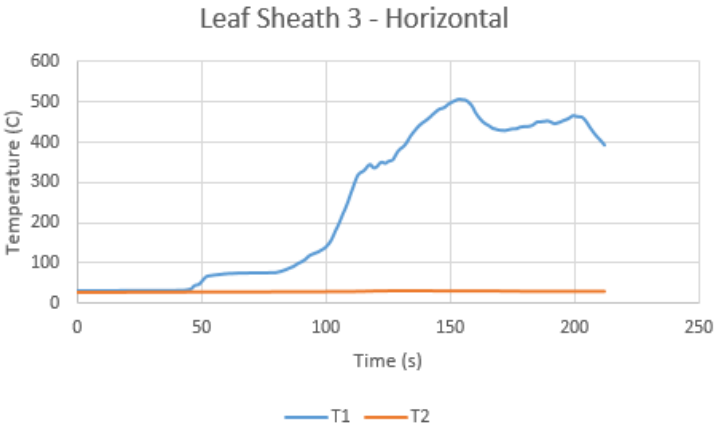

Figure 17. Time vs temperature grapg for Leaf Sheath 3.

Experiment 2 – Leaf Sheath in Vertical Position

The leaf sheath is fixed vertically on the stand using steel wire and 2 thermocouples are placed, one on the ignition point and the other in the middle of the sample.

Figure 18. Leaf sheath in vertical with fire.

Table 2. Leaf sheath in vertical with fire.

Sample/No.	**Mass (g)**	**Length (cm)**	**Time (s)**	**Temperatue (C°)**	**Flame spread distance (cm)**	**Flame Spread Rate (cm/s)**
Leaf sheath 4/Vertical	4.8	35.4	12	98	35.4	2.95
Leaf sheath 5/Vertical	14.5	35.5	23	199	35.5	1.5
Leaf sheath 6/Vertical	18.8	35	16	258	35	2.18

In the fourth sample, after being set on fire by the candle, the flame spread along it vertically in just 12 seconds at a spread rate of 2.95 cm per second and reached a maximum temperature of 98 ° C. There was residue of ashes and pyrolysis parts. For fifth sample the flame spread along it vertically in 23 seconds at a spread rate of 1.5 cm per second. Leaf Sheath 5 reached a maximum temperature of 199 ° C with no residues except ashes. In the last one the flame spread along it vertically in just 16 seconds at a spread rate of 2.18 cm per second and reached a maximum temperature of 258 ° C. There was residue of ashes only.

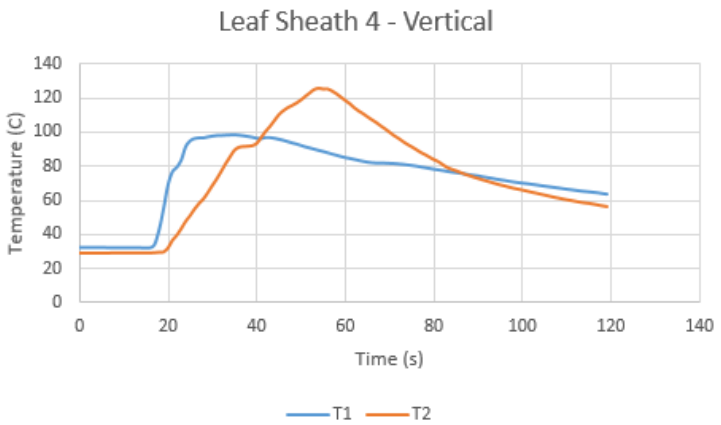

Figure 19. Time vs temperature grapg for Leaf Sheath 4.

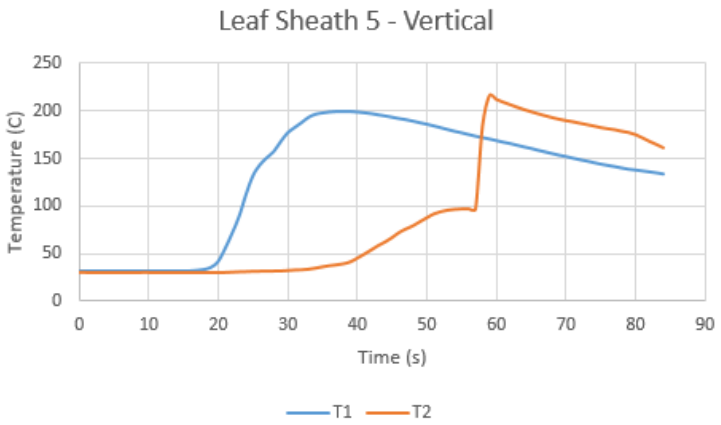

Figure 20. Time vs temperature grapg for Leaf Sheath 5.

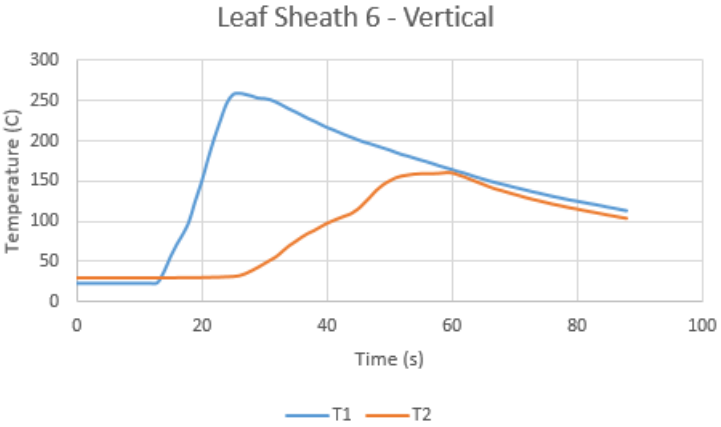

Figure 21. Time vs temperature grapg for Leaf Sheath 6.

Experiment 3 – Trunk in Vertical Position

The trunk is fixed vertically on the stand and 2 thermocouples are placed, one on the ignition point and the other in the middle of the sample.

Figure 22. Trunk in vertical with fire.

Table 3. Trunk in vertical with fire.

Sample/No.	**Mass (g)**	**Length (cm)**	**Time (s)**	**Temperatue (C°)**	**Flame spread distance (cm)**	**Flame Spread Rate (cm/s)**
Trunk 1/Vertical	31.9	14.5	33 s	182	5 cm	1.6
Trunk 2/Vertical	28.2	15	-	149	-	-
Trunk 3/Vertical	39.6	14.5	-	114	-	-

In the first sample, after being set on fire by the candle, the flame spread vertically till 5 cm only during 33 s. Spread rate reach 1.6 cm per second and reached a maximum temperature of 182 ° C. Sample 1 did not affected fully, little pet sooty with burnt edge. For second and third samples, the flame did not spread and it did not catch fire due to the trunk material that cannot catch fire.

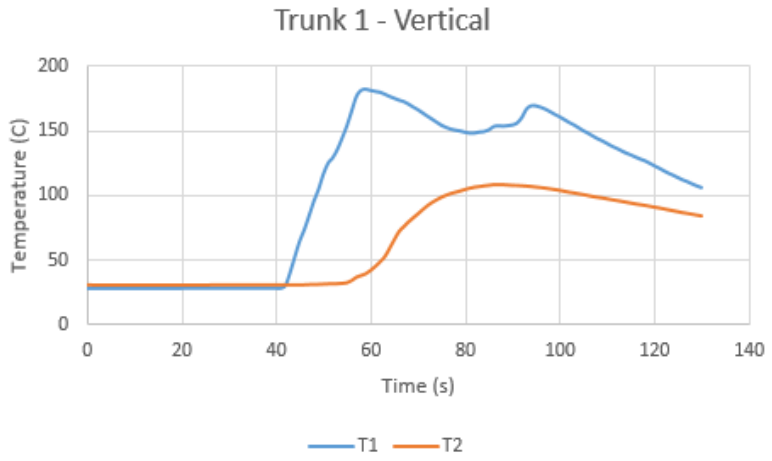

Figure 23. Time vs temperature grapg for Trunk 1.

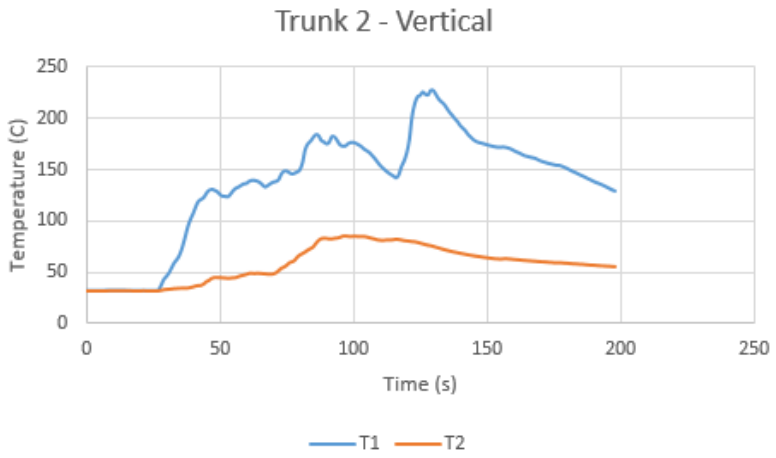

Figure 24. Time vs temperature grapg for Trunk 2.

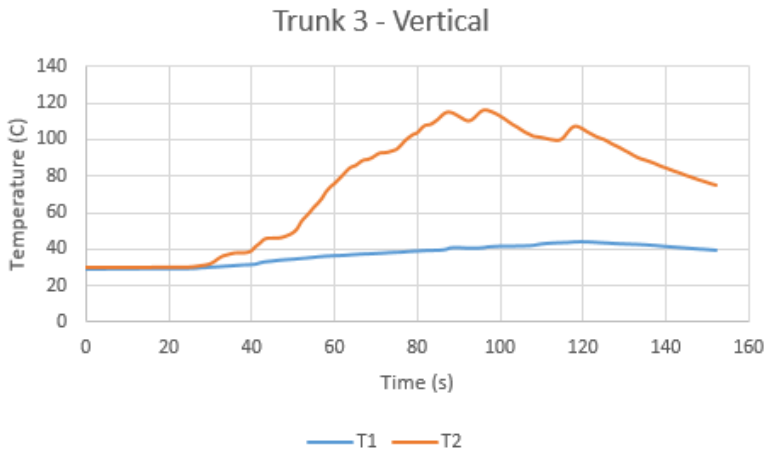

Figure 25. Time vs temperature grapg for Trunk 3.

Experiment 4 – Trunk in Horizontal Position

The Trunk is fixed horizontally on the stand and 2 thermocouples are placed, one on the ignition point and the other in the middle of the sample. 2 and 3 experiments with wind.

Figure 26. Trunk in horizontal with fire.

Table 4. Trunk in horizontal with fire.

Sample/No.	**Mass (g)**	**Length (cm)**	**Time (s)**	**Temperatue (C°)**	**Flame spread distance (cm)**	**Flame Spread Rate (cm/s)**	**Wind Speed (m/s)**
Trunk 4/ Horizontal	30.6	15	9	450	-	-	-
Trunk 5/ Horizontal	34.3	14.5	7	276	-	-	0.72± 0.02
Trunk 6/Horizontal	43	15	12	45	-	-	0.72± 0.02

In the 4,5 and 6 samples, after being set on fire by the candle, the flame did not spread and the 3 samples catch a small fire. The 3 samples did not affected fully, little pet sooty with burnt edge.

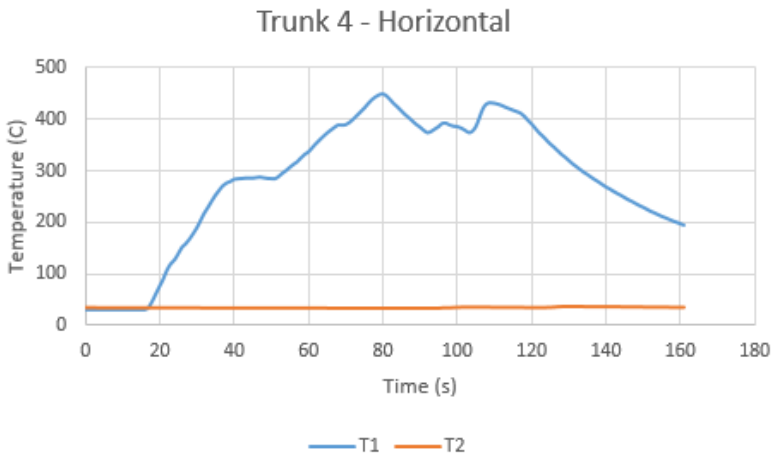

Figure 27. Time vs temperature grapg for Trunk 4.

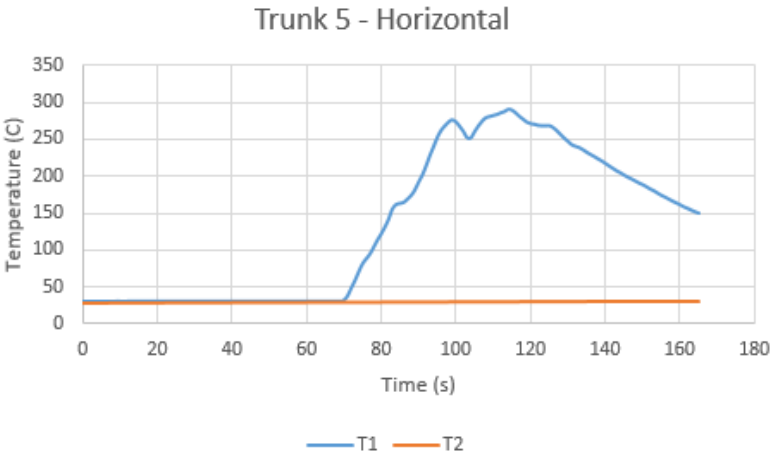

Figure 28. Time vs temperature grapg for Trunk 5.

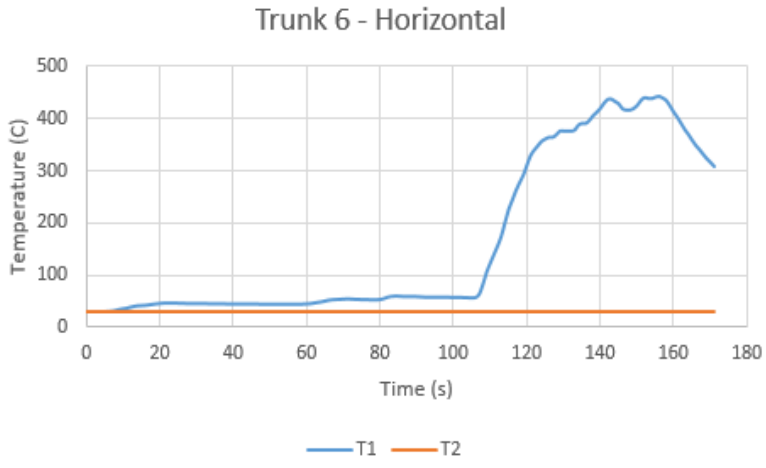

Figure 29. Time vs temperature grapg for Trunk 6.

Experiment 5 – Leaves in Horizontal Position

The leaves are fixed horizontally on the stand and 2 thermocouples are placed, one on the ignition point and the other in the middle of the sample. 2 and 3 experiments with wind.

Figure 30. Leaves in Horizontal with fire.

Table 5. Leaves in Horizontal with fire.

Sample/No.	**Mass (g)**	**Length (cm)**	**Time (s)**	**Temperatue (C°)**	**Flame spread distance (cm)**	**Flame Spread Rate (cm/s)**	**Wind Speed (m/s)**
Leaves 1/Horizontal	62.7	33	138	162	9	0.065	-
Leaves 2/Horizontal	59.6	30	21.1	345	1.5	0.072	0.72± 0.02
Leaves 3/Horizontal	71.3	34	60	354	6	0.1	0.72± 0.02

In the first sample, after being set on fire by the candle, the flame spread on it horizontlly till 9 cm in 138 seconds at a spread rate of 0.065 cm per second and reached a maximum temperature of 162° C. Sample 1 did not affected fully, there is some ashes and soot. In the second sample, flame spread on it horizontlly till 1.5 cm in 21.1 seconds at a spread rate of 0.072 cm per second, because of wind effect it got little more better result. Leaves 2 reached a maximum temperature of 345° C with some burnt and sooty parts. In the last one, after being set on fire by the candle, the flame spread on it horizontlly till 6 cm in 60 seconds at a spread rate of 0.1 cm per second and reached a maximum temperature of 354° C. Sample 3 did not affected fully, there is some ashes and soot.

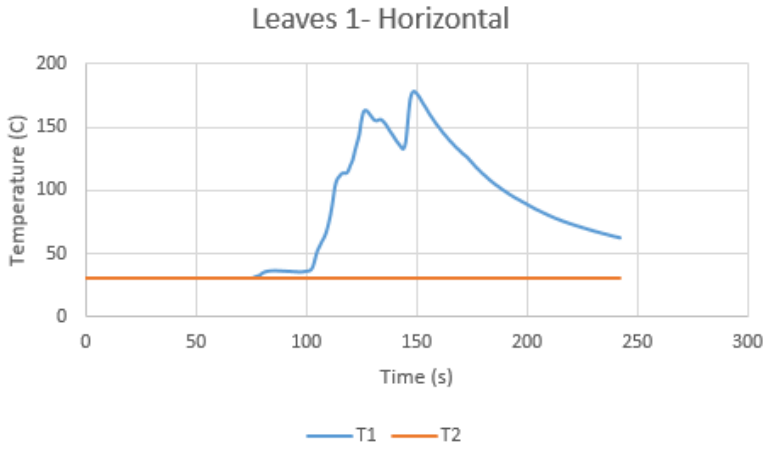

Figure 31. Time vs temperature grapg for Leaves 1.

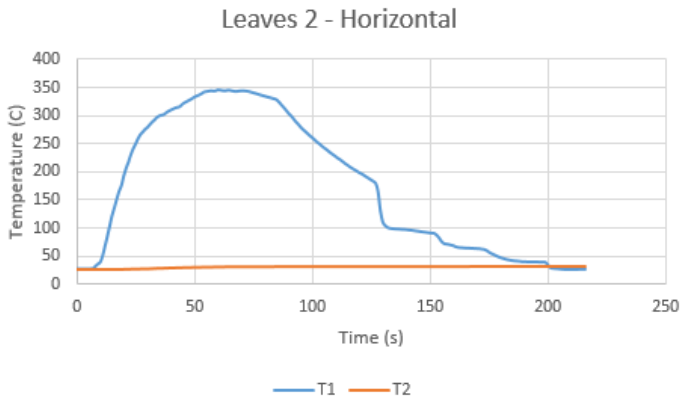

Figure 32. Time vs temperature grapg for Leaves 2.

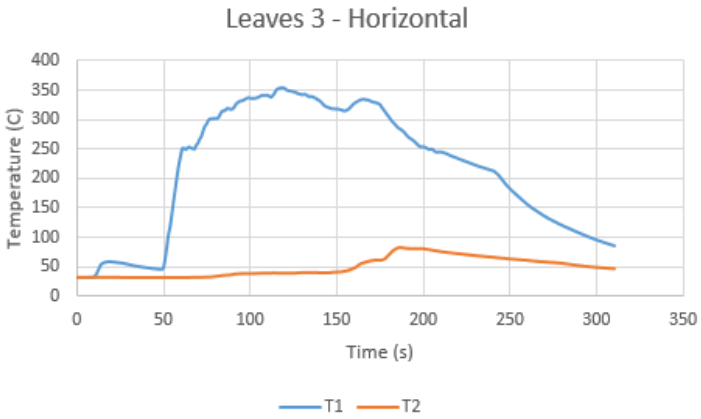

Figure 33. Time vs temperature grapg for Leaves 3.

Experiment 6 – Leaves in Vertical Position

The leaves is fixed vertically on the stand and 2 thermocouples are placed, one on the ignition point and the other in the middle of the sample.

Figure 34. Leaves in vertical with fire.

Table 6. Leaves in vertical with fire.

Sample/No.	Mass (g)	Length (cm)	Time (s)	Temperatue (C°)	Flame spread distance (cm)	Flame Spread Rate (cm/s)
Leaf 4/Vertical	93.6	35	90	197	10	0.11
Leaf 5/Vertical	94.2	34	64	262	9	0.14
Leaf 6/Vertical	73.1	35	63	299	5	0.08

In the first sample, after being set on fire by the candle, the flame spread on it vertically till 10 cm in 90 seconds at a spread rate of 0.11 cm per second and reached a maximum temperature of 197 ° C. There was small part left from the first sample with sooty and some ashes. For second sample the flame spread on it horizontlly till 9 cm in 64 seconds at a spread rate of 0.14 cm per second, because of wind effect it got better result. Leaves 2 reached a maximum temperature of 262 ° C with small part left from the it, sooty and some ashes. In the last one flame spread rate reach 0.08 highet one of them also in temperature that reach 299 ° C in 63 s .

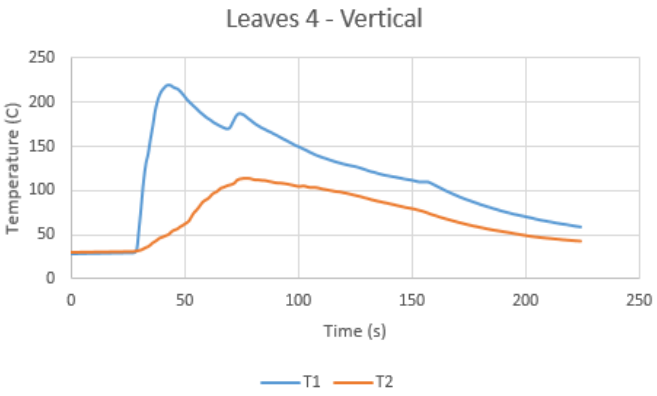

Figure 35. Time vs temperature grapg for Leaves 4.

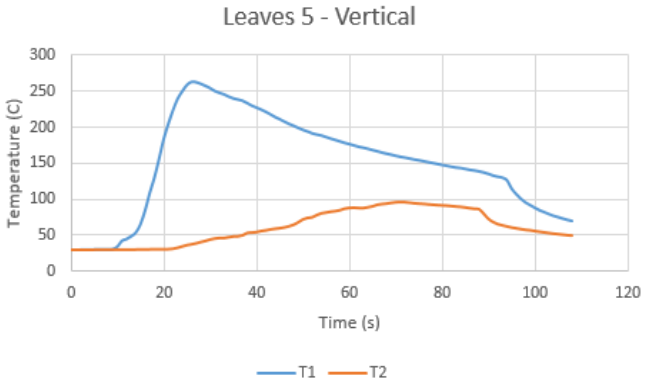

Figure 36. Time vs temperature grapg for Leaves 5.

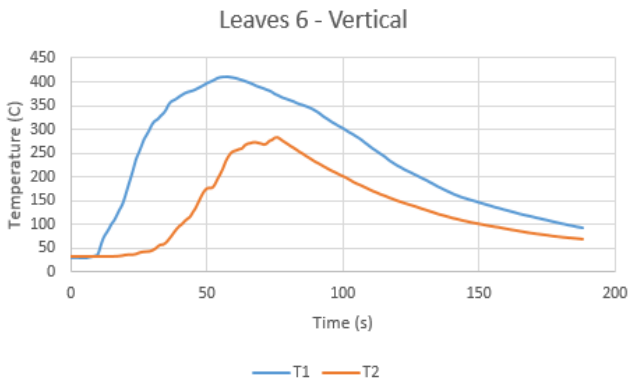

Figure 37. Time vs temperature grapg for Leaves 6.

Palm Tree Wild Fire Experiment

Experiment 7 – Along Straight Line

Figure 38. Palm tree along straight line.

Table 7. Palm tree along straight line with fire.

Sample	Time (s)	Flame spread distance (cm)	Flame spread rate (cm/s)	Wind Speed (m/s)
1	77.17	25	0.32	-
2	41.87	25	0.59	0.72± 0.02
3	62.5	50	0.8	0.72± 0.02

After the candle lit the fire, the first sample caught fire that began to move from one sample to another where the fire traveled a distance of 25 cm, until the fifth sample exactly within 77.17 seconds and 41.78 seconds in the first experiment and the second experiment despite the use of the fan as a wind effect, and the flame spread rate was 0.32 and 0.59 cm per second respectively.In the third experiment, a fan was used at a higher speed and as a result the fire traveled a distance of 50 cm, meaning that all 10 samples burned out within 62.5 seconds. A thermocouple was also placed to periodically measure temperatures as flames spread between samples at the ignition point.

Experiment 8 – Zig Zag Pattern

Figure 39. Palm tree in Zig Zag Pattern.

Table 8. Palm tree in Zig Zag Pattern.

Sample	Time (s)	Flame spread distance (cm)	Wind Speed (m/s)
1	96.55	Till 7th sample	-

In the zigzag pattern experiment after the first sample caught fire, it moved towards the next two samples, and so on until it reached the seventh sample, the fire stopped spreading and subsided, and this process took 96.55 seconds.

Experiment 9 – Mini Grove (15 samples)

Figure 40. Palm tree Mini Grove.

Table 9 Palm tree in Mini Grove.

Sample	Time (s)	Flame spread distance (cm)	Wind Speed (m/s)
1	44.1	First 3 columns except one	-
2	54	All except 2 samples in left down	0.72± 0.02

In the first experiment of mini grove, after the candle lit the fire, the first line (3 samples) caught fire then it move to another line where the fire traveled a distance of 15 cm in first and second line (3 samples) and 10 cm from the third line , within 44.1 seconds. In the second experiment of mini grove, after the candle lit the fire, the first line (3 samples) caught fire then it move to another line where the fire traveled a distance of 15 cm in all lines except last 3 samples in dowen left. All that took 54 s.

Conclusion

One of the most important reasons that contribute to making a fire huge is the spread of flame from one area to another due to several factors. In the palm grove, there are many factors that contribute to the growth and inflation of fire in the event of a fire, such as combustible materials (paper sheath, leaves, fallen palm residues and even small or dry shrubs).

In the above lines it was explained that it is possible for the flame to spread between palm trees through the leaves and leaf sheath only because the trunk is made up of solid layers that are difficult to burn or catch fire easily. The results of previous experiments also showed the ability of the flame to spread within a short period of time (seconds - minutes). By changing the factors affecting the spread of the flame, the flame will be affected and its spread will be affected, as we saw previously when placing the fan as an effect of the wind, the rate of spread increased and the time taken for the fire to spread decreased in some experiments, and in some of them the fire was extinguished due to exposure to air/wind. This indicates that the wind may be able to extinguish the fire just as it has the ability to expand its spread among the palm trees.

Hence I recommend continuous pruning of palm groves to minimize damage as much as possible. It is also certainly more likely to keep the trees relatively moist with good moisture that is not exaggerated that causes mold and not dry that increases their combustibility in order to protect them from flames in the event of a fire, as was explained earlier, the fact that the trees are wet hinders the spread of fire.

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Track A – Built Environment, Safety & Facilities Management

Paper Cod in Book 2: *A06*
Paper Page Range in Book 2*:* *57– 64*

Innovative Approaches to Fire Safety Management: Integrating Technology and Occupant Behavior

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Abstract

Fire safety remains a critical challenge in building facilities, where outdated detection systems, insufficient training, and behavioral gaps continue to threaten life and property. This study investigates fire safety management practices in Oman with a focus on integrating innovative technologies and occupant behavior to enhance emergency preparedness. A mixed-method design was adopted, combining expert interviews with a questionnaire survey administered to 30 respondents, including facility managers, government staff, and students across Muscat and Musandam. Results showed that 53% of participants were unfamiliar with their building's detection systems and 50% had not received fire safety training in the past year, while awareness of modern solutions such as IoT-enabled detection (23%), VR/AR training (43%), and BIM-based applications remained limited. Interviews further revealed complacency during drills, weak enforcement of safety protocols, and concerns about the reliability and privacy of video-assisted systems. Although evacuation plans were generally trusted, behavioral gaps persisted, with 23% of respondents relying on others' decisions during emergencies. These findings highlight that technology alone cannot ensure safety without corresponding improvements in human behavior and awareness. The study concludes that a dual approach is essential: upgrading to advanced detection and guidance systems while mandating regular occupant training and awareness programs. Future directions include extending research across different building types, integrating AI-driven early detection, and implementing smart evacuation guidance with audio-visual alerts to support inclusive and effective evacuation strategies.

Keywords: *Fire Safety Management, Occupant Behavior, Fire Detection Systems, Innovative Technologies, Emergency Preparedness.*

Introduction

Fires remain one of the most devastating hazards, causing severe loss of life, injuries, and property damage across industrial, commercial, and healthcare sectors. Effective fire safety management is therefore critical for minimizing risks and safeguarding occupants. Fire safety has been defined as an integrated framework of procedures and systems designed to reduce fire risks and protect both people and property [1]. According to Jones [2], fire safety systems are intended to detect and address fire threats before escalation. Despite widespread use, conventional systems such as smoke, flame, and heat detectors are constrained by slow response times, frequent false alarms, high maintenance requirements, and outdated technology [3]. These limitations reduce confidence in system reliability and highlight the need for improvement.

Technological advancements have introduced new opportunities to enhance fire safety management. The integration of the Internet of Things (IoT), Building Information Modelling (BIM), and immersive learning through virtual and augmented reality (VR/AR) offers faster detection, predictive monitoring, and more realistic evacuation training [4]. However, research indicates that their practical application is hindered by low awareness, privacy concerns, cost barriers, and challenges related to interoperability with existing systems [5,6]. Furthermore, while the technological dimension has advanced, human behavior during emergencies remains highly variable, with evacuation compliance, decision-making, and perception of alarms directly influencing survival outcomes [4]. This underscores the importance of coupling technology with behavioral preparedness.

A clear gap in knowledge emerges from the imbalance between studies focusing on technical systems and the limited attention given to occupant behavior, awareness, and training. In the Omani context, where many buildings still rely on outdated detection systems and fire safety training is inconsistent, few studies have systematically explored how technology and human factors interact in shaping emergency outcomes. Addressing this gap, the present study aims to (i) evaluate occupant awareness and training levels, (ii) examine perceptions of detection system reliability, (iii) assess knowledge and adoption of innovative fire safety technologies, and (iv) analyze behavioral responses during emergencies. By employing

a mixed-method design that combines questionnaires and expert interviews, this research contributes evidence-based insights into integrating advanced detection technologies with behavioral strategies to improve fire safety management.

Methods

Research Design

A mixed-method design was employed to address the study aims: (i) assess occupant awareness and training, (ii) evaluate perceptions of detection system reliability, (iii) measure awareness of innovative fire safety technologies, and (iv) analyze behavioral responses during emergencies. Quantitative data were collected through a structured questionnaire, while qualitative insights were obtained via semi-structured interviews. This approach follows established methodological frameworks for mixed-methods research [7–9].

Data Collection

The questionnaire comprised 12 closed-ended questions grouped into four themes reflecting the study aims. It was distributed through social media platforms and government departments, targeting participants with direct exposure to fire safety systems. A total of 30 valid responses were collected from facility managers, employees, and students in Muscat and Musandam.

Six open-ended interview questions were conducted with facility managers and staff to explore the impact of training, system reliability, adoption barriers to IoT/BIM/VR tools, and decision-making during emergencies.

Sampling

A purposive sampling strategy was applied to ensure participants had prior exposure to fire safety practices, including evacuation drills and interaction with detection systems [9].

Data Analysis

Survey data were analyzed in Microsoft Excel using descriptive statistics. Percentages were calculated as:

$$P_i = \frac{n_i}{N} \times 100$$

where P_i= percentage in category i, n_i= number of responses in that category, and $N = 30$.

Interview responses were analyzed thematically to identify patterns and recurring themes related to training, reliability, technology adoption, and occupant behavior.

Ethics and Limitations

All participants provided informed consent, and anonymity and confidentiality were maintained in line with International College of Engineering and Management ethical policies. The main limitations were the modest sample size, language barriers for some participants, and organizational reluctance to disclose sensitive information.

Results and Discussion

Awareness and Training

Occupant awareness and training are fundamental components of effective fire safety management, yet the results indicate considerable gaps in both areas, as shown in Figures 1 and 2. Half of the respondents (50%) reported not receiving any fire safety training within the last 12 months, while only 30% confirmed participation and 20% were unsure, as shown in Figure 1. Similarly, with regard to familiarity with fire safety systems, only 23% of respondents described themselves as very familiar, compared with 53% who were somewhat familiar and 23% who were not familiar at all, as shown in Figure 2.

These findings highlight that a substantial proportion of occupants either lack recent training or have only partial understanding of the systems intended to protect them. Such limitations directly undermine the efficiency of installed fire safety measures, since awareness and correct behavioral responses are critical to minimizing risk during emergencies. Previous studies have shown that insufficient training and low system familiarity significantly delay evacuation and reduce confidence in alarm systems [1,4].

Qualitative interview responses further emphasized these shortcomings. Facility managers reported that training sessions are often perceived as formalities rather than essential preparedness activities, leading to low engagement and weak retention of knowledge. This aligns with literature suggesting that without active and continuous reinforcement, training exercises fail to instill the urgency required for real-life emergencies.

To strengthen fire safety management, training programs should be mandatory, recurring, and designed to engage participants effectively. The integration of immersive methods, such as VR-based fire drills, could address training fatigue

and enhance both retention and realism. Improving awareness through regular campaigns and transparent communication about fire safety systems is also necessary to increase confidence and encourage proactive responses during emergencies.

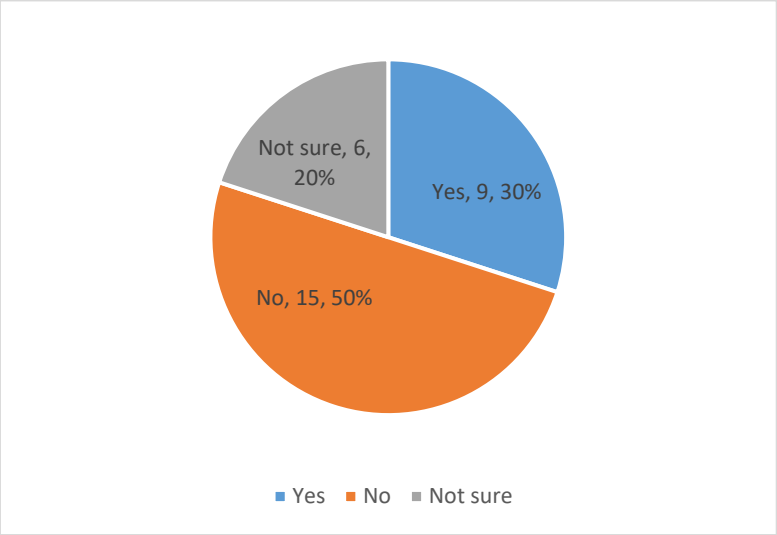

Figure 1. Participation in fire safety training during the past 12 months.

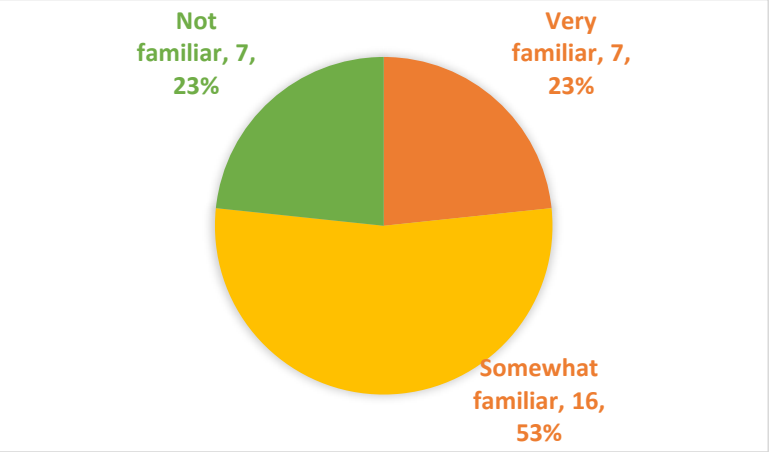

Figure 2. Familiarity with fire safety detection systems.

Reliability of Systems and False Alarms

Perceptions of fire detection system reliability were mixed among respondents, as shown in Figure 3. While 40% believed their systems respond quickly and reliably, 37% indicated they work but may not always be reliable. As shown in Figure 3, only 3% judged them as ineffective in real fire situations, while 20% admitted unfamiliarity with how the systems operate. These findings reveal a twofold problem: inconsistent confidence in system performance and limited occupant knowledge.

This lack of trust has significant behavioral implications. Previous research has shown that false alarms or uncertainty about detection accuracy often lead to alarm fatigue, where occupants delay or dismiss evacuation signals [2,4]. Such hesitation increases vulnerability during emergencies. Jones [2] emphasized that conventional detectors, although widespread, remain constrained by slow response and susceptibility to false activations, reducing user confidence. Similarly, as noted by recent studies [3], outdated systems and insufficient maintenance contribute to skepticism regarding alarm effectiveness.

The interviews confirmed this trend, with several facility managers reporting occupant reluctance to treat alarms seriously, particularly in buildings with frequent false activations. This aligns with findings that reliability is not solely a technical matter but also a matter of occupant perception and trust [4].When building occupants doubt system performance, even well-functioning alarms may fail to achieve their intended purpose.

Addressing this issue requires a dual strategy. First, technical reliability must be reinforced through routine maintenance and modernization of systems to reduce false alarms and improve response times. Second, awareness and engagement are essential, ensuring that occupants understand how detection systems operate and why immediate evacuation is critical. As

emerging technologies such as IoT and BIM offer predictive monitoring and real-time feedback [4,5], their integration could further enhance both reliability and occupant trust. However, without addressing underlying behavioral skepticism, even advanced systems risk underutilization.

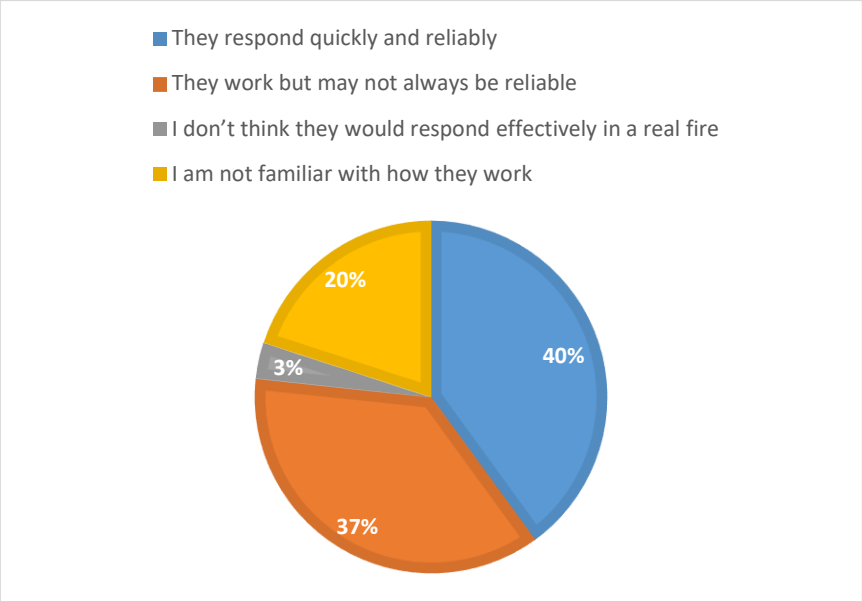

Figure 3. Reliability of Fire Detection Systems.

Modern Technologies and Integration

The survey results in Figure 4 highlight a considerable knowledge gap regarding modern safety technologies. As shown in Figure 4, almost half of the respondents (47%) reported having no awareness of smart IoT-enabled fire detection systems, while 30% had only a superficial awareness without certainty of their application. Only 23% confirmed that they had seen such systems in action. This distribution indicates that while IoT-based fire safety solutions are emerging globally, their integration into local contexts remains limited.

These findings reinforce earlier studies emphasizing the slow adoption of digital and smart building technologies in developing regions. For instance, IoT-enabled fire detection systems have demonstrated superior performance in early hazard identification and real-time monitoring compared to conventional smoke detectors, offering benefits such as remote alerts, predictive analytics, and integration with building management systems [10–12]. However, as noted in recent literature, challenges such as cost barriers, lack of skilled operators, and limited stakeholder awareness continue to hinder widespread implementation [13–15].

The gap between awareness and practical implementation reflects a broader issue of technology diffusion in the construction and facilities management sectors. According to recent studies, successful integration of smart safety technologies requires not only technical readiness but also institutional frameworks, regulatory support, and capacity-building initiatives [16,17]. This aligns with the current survey results, which suggest that awareness campaigns, training programs, and demonstration projects are urgently needed to bridge this knowledge gap.

Furthermore, the relatively low awareness of IoT-enabled fire detection contrasts with the increasing emphasis on Industry 4.0 and smart city frameworks, which rely on digitalization for enhancing resilience and safety in built environments [18,19]. Without adequate dissemination and training, there is a risk that facilities will continue relying on outdated systems, leaving them vulnerable to delayed response times and higher fire-related risks.

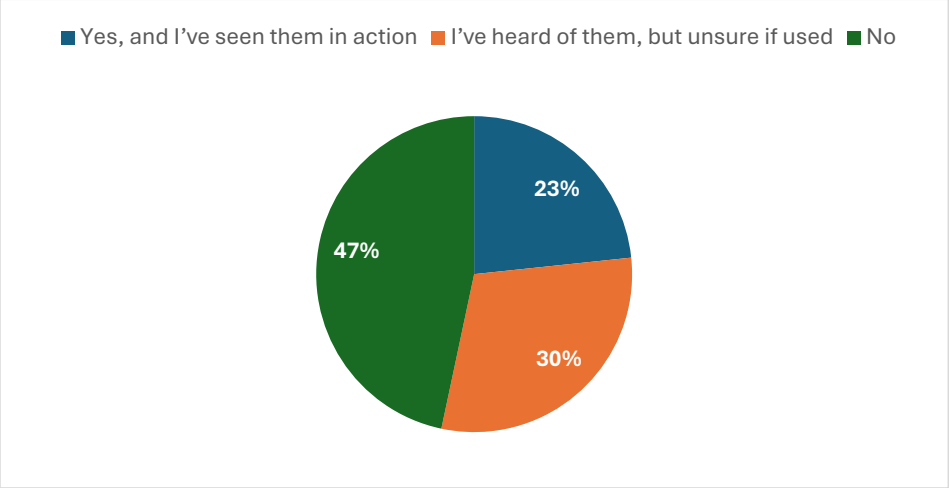

Figure 4. Awareness of Modern IoT/VR/BIM Technology.

Behavioral Aspects

The results in Figure 5 provide important insights into how individuals are likely to respond in the event of a fire. A strong majority (70%) indicated they would follow emergency signs or trained procedures, suggesting that training and clear signage remain the most effective tools in guiding safe evacuation behavior. However, nearly a quarter (23%) stated they would follow others' actions, while 7% admitted they would decide spontaneously based on the situation, as shown in Figure 5.

This distribution highlights both strengths and vulnerabilities in emergency preparedness. The high reliance on signs and procedures underscores the effectiveness of awareness campaigns, drills, and standardized evacuation protocols, which are consistently shown in the literature to improve response times and reduce fatalities [20–22]. However, the 30% of respondents who rely on social influence or situational judgment represent a significant concern. Research indicates that in high-stress situations, untrained individuals often follow the crowd, which can lead to bottlenecks, delayed evacuation, or unsafe decisions [23,25].

The findings align with prior studies that emphasize the importance of periodic fire drills, scenario-based training, and behavioral simulations to reinforce appropriate responses during emergencies [27]. Furthermore, the reliance on "following others" is consistent with social psychology research on herd behavior during crises, suggesting that without sufficient preparedness, occupants may defer decision-making, increasing risks [26].

Overall, the results imply that while training has had a positive impact on a majority of respondents, further measures are needed to address the remaining behavioral gaps. Targeted interventions, such as more frequent drills, visual signage upgrades, and integration of IoT-based real-time guidance systems, could further strengthen preparedness and ensure faster, more coordinated evacuation responses.

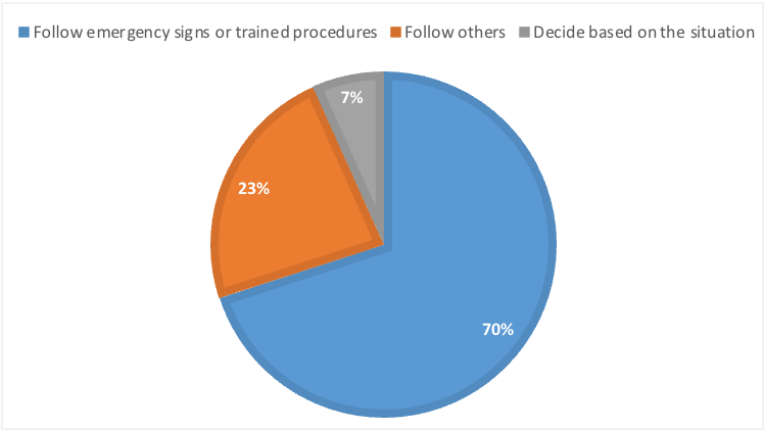

Figure 5. Behavioral Responses During Fire Emergencies.

Conclusions

This study assessed awareness, training, and behavioral responses related to fire safety and the integration of modern technologies. The following key conclusions can be drawn:

- A substantial proportion of respondents demonstrated awareness of fire safety practices and training. However, gaps were observed, with some participants lacking exposure to structured training sessions, highlighting the need for continuous reinforcement.
- The survey revealed limited familiarity with IoT-enabled fire detection systems, with nearly half of the respondents reporting no awareness. This indicates that while advanced technologies exist, their adoption and visibility remain low within the studied context.
- Most respondents (70%) indicated they would follow emergency signs or trained procedures during a fire, demonstrating the positive effect of training and signage on safe evacuation. Nonetheless, a notable portion (30%) reported reliance on others or situational decisions, pointing to behavioral vulnerabilities in emergency response.

The findings confirm that awareness, structured training, and visible emergency guidance are critical in shaping effective fire response behaviors. At the same time, the limited awareness of smart fire detection technologies underscores the importance of integrating modern solutions into existing safety management frameworks.

Acknowledgments

The author sincerely thanks Associate Prof. Dr. Majed Aldahdooh for his valuable supervision and guidance throughout this study. Gratitude is also extended to all participants, family members, and friends for their continuous support. The author acknowledges the use of ChatGPT and Grammarly as a tool for language refinement, grammar correction, and idea organization during the preparation of this manuscript.

Author Contributions

Muna S. S. Al Riyami: Conceptualization, Methodology, Data Collection, Formal Analysis, Writing – Original Draft. Majed A. A. Aldahdooh: Supervision

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgments

The authors would like to thank the survey participants for their valuable time and input, which contributed significantly to the success of this study.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethical Approval

The study was conducted in accordance with institutional guidelines, and participation was voluntary and anonymous. No personal or sensitive information was collected.

AI Use Disclosure

The authors used generative AI tools to assist in language polishing and formatting. All ideas, analyses, and conclusions are the authors' own, and the final manuscript was carefully reviewed and approved by them.

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Track B – Energy, Industrial Processes & Environmental Engineering

Paper Cod in Book 2: *B01*
Paper Page Range in Book 2*:* *65–68*

Effective Removal of Fe^{+2} and Acidity (H^{+}) from Wastewater Using Optimized Guar Gum-HPTMGG Treatment

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Abstract

Metal surface finishing industries also release acidic effluents that usually contain heavy metal ions and suspended solids in high concentrations, and their source discharge can lead to hazards to the water and aquatic life. Such wastes are either disposed of via various means, thus creating by-product pollution and expensive sludge disposal. This paper compares the performance of a natural coagulant, hydroxypropyl trimethyl ammonium guar gum (HPTMGG), with a modified version to assess the suitability of the modified natural coagulant where acidic wastewater is concerned. The dose of the coagulant (0-200 g/200mL) was assessed based on its coverage of Fe+2, H+, pH adjustment, turbidity, total dissolved solids (TDS), and conductivity. At low concentrations (15-50 g/200 mL), there was a low level of Fe+2 and H+ elimination (approximately 10-23% and 25-30% respectively), with minimal change in pH. Optimal Fe+2 removal (approximately 52) was noted with the doses of 120-150 g/200 mL with concomitant H+ neutralization (approximately 60) and a slight increase in pH (approximately 0.7 units) at higher doses (170-190 g/200 mL). Turbidity decreased drastically to less than 5 NTU at 20 g/200 mL before it rose once more at higher doses. The reduction of TDS was whereas a nonlinear (R2 = 0.83) curve, and the conductivity reduced in a linear way (R2 = 0.77). Although there was a great increase in the quality of water, the end pH was still low enough to warrant the additional alkalization. The results indicate that HPTMGG has the potential to eliminate metal ions, acidity, and particulates efficiently and thus is a potential substitute for the chemical coagulants in treating acidic wastewater.

Keywords: *Acidic wastewater treatment, Natural coagulants, Environmental remediation, Eco-friendly coagulant, Dose optimization.*

Introduction

Industrial wastewater management has become a significant issue worldwide due to the rapid growth in the manufacturing and surface finishing industries. Large quantities of acidic effluents, containing heavy metals such as iron, nickel, chromium, and zinc, as well as suspended and dissolved solids, are produced in metal surface finishing units [1]. These wastes pollute water systems, contaminate the soil and groundwater by accumulating metals, and cause disruption in the pH balance. Such effluents are directly discharged, leading to bioaccumulation of toxic metals and loss of biodiversity, and require efficient, long-term, cost-effective treatment solutions [2]. The traditional treatment techniques, such as chemical precipitation, ion exchange, and membrane filtration, are effective but have limitations in that they are expensive, create sludge, and cause secondary pollution. Inorganic coagulants such as alum and ferric chloride raise salinity and cause non-biodegradable sludge [3],[4]. This has caused a need to use green and sustainable coagulants, whereby natural biopolymers are being sought for their biodegradability, environmental friendliness, and ability to eliminate contaminants.

A galactomannan polysaccharide called guar gum from the seeds of Cyamopsis tetragonoloba is famous for its flocculation ability, but it does not work well in acidic conditions because of charge neutrality. It becomes more cationic through chemical modification, and this improves solubility, stability, and adsorption [5]. A single such derivative, Hydroxypropyl trimethyl ammonium guar gum (HPTMGG), contains quaternary ammonium groups that enable strong electrostatic interaction between the derivative and negatively charged particles in acidic wastewater, thus increasing its coagulation flocculation efficiency [6], [7]. This paper aims at optimizing HPTMGG dosage (0 200g/200mL) to treat acidic wastewater in metal surface finishing sectors by assessing the removal of Fe^{+2} and H^{+}, pH change, turbidity, TDS, and conductivity. It

aims at determining the ideal dose that allows the maximum number of pollutants to be removed in a sustainable and cost-effective way.

The study helps in the sustainable management of wastewater by using natural, biodegradable coagulants, which helps to avoid the use of synthetic chemicals and lessen secondary pollution. It also gives important information on how modified guar gum behaves at acidic conditions, which is a basis to extend the application of modified guar gum in the treatment of industrial effluent.

Materials and Methods

Materials
Hydroxypropyl trimethyl ammonium guar gum (HP-TMA-GG, 2300 cps viscosity, 0.27 degree of substitution) was purchased at Viscolloids Industries Pvt. Ltd., Hattar, Pakistan. Potassium permanganate ($KMnO_4$) of analytical grade was bought in Shanghai-Sinopharm Chemical Reagent Co., Ltd., China, whereas ferrous chloride ($FeCl_2$), sodium hydroxide (NaOH), and phenolphthalein were obtained in Duksan.

2.2 Preparation of the Synthetic Acidic Wastewater and Guar Gum Solutions.
The 0.005 g/mL guar gum solution was made by adding 1.0 g guar gum powder to 200 mL. A magnetic stirring was done to prepare the solutions to a uniform dispersion, and the solutions were allowed to hydrate after 1 hour at 25 °C, while the synthetic acidic wastewater was prepared using 1.0 M HCl and 0.25 M $FeCl_2$ in distilled water having a strength comparable to the wastewater produced by metal surface finishing industries.

Jar Test Procedure

Standard jar tests were done to test the coagulation efficiency. The 200 mL samples of the wastewater were subjected to different dosages of guar gum solution, after which it was well mixed at 200 rpm and slowly mixed at 50 rpm for 1 hour, after which they were left to settle for 45 minutes.

Analytical and Filtration Methods

Following the process of sedimentation, the samples were vacuum-filtered, and their turbidity (NTU), pH, and TDS were measured. The concentration of Fe^{+2} was measured through redox titration with 0.02 M $KMnO_4$, and the concentration of H^+ was determined through titration with 0.1 M NaOH in the presence of phenolphthalein as the indicator.

Results and Discussion

Change of Turbidity, Total Dissolved Solids (TDS), and Conductivity with Guar Gum–HPTMGG Dose

Figure 1 presents the change in turbidity, TDS, and conductivity along with the increase in dose of the Guar gum-HPTMGG (0-200 g/200 mL). Turbidity declined drastically with low doses associated with successful destabilization of particles but rose slightly at elevated doses, which could be explained by the reversal of the charges, saturation of the polymers, or restabilization of colloidal particles. The progressive decline and later increase in TDS and conductivity are attributable to the initial binding and incorporation of the ions in the polymeric flocs and then the release of ionic groups of the excess guar gum at higher dosage. TDS and conductivity reduced gradually (R^2 = 0.79 and 0.60, respectively), indicating the gradual removal of dissolved impurities and homogenous ion reduction, respectively. These moderate and strong correlations were confirmed using the regression of a polytree, which confirmed the trends.

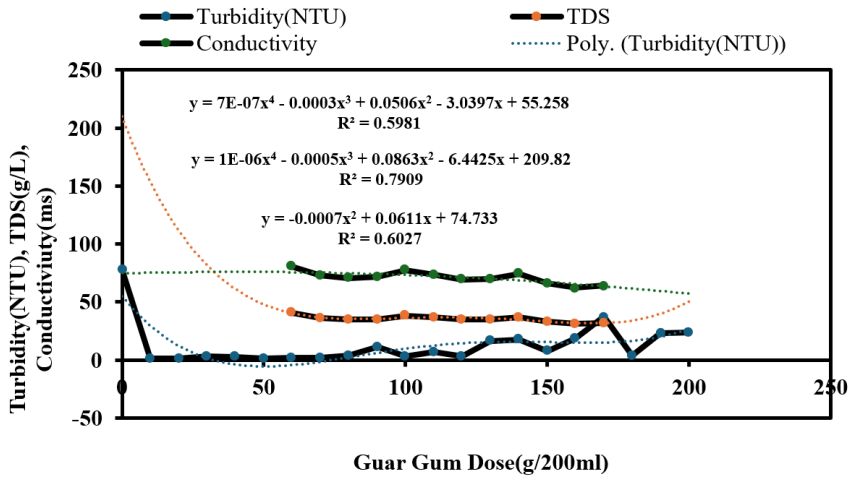

Figure 1 Change of Turbidity, Total Dissolved Solids (TDS), and Conductivity with Guar Gum–HPTMGG Dose.

Fe^{2+} and H^{+} Removal Efficiency and pH Variation with Guar Gum–HPTMGG Dose

Figure 2 shows how the efficiency of Fe^{+2} and H^{+} removal and pH depend on the dose of Guar gum-HPTMGG (0-200 g/200 mL). Removal of both Fe^{+2} and H^{+} was also dependent on dosage, with limited efficiency (10-30%) when concentrations were low (<50 g/200 mL), since charge neutralization was not very efficient. At 100-150 g/200 mL, efficiency increased significantly to approximately 50-55 and which signifies increased adsorption and complexation by the modified biopolymer. The maximum removal was experienced around 170 g/200 mL, and then there was a slight oscillation due to the destabilization of particles.

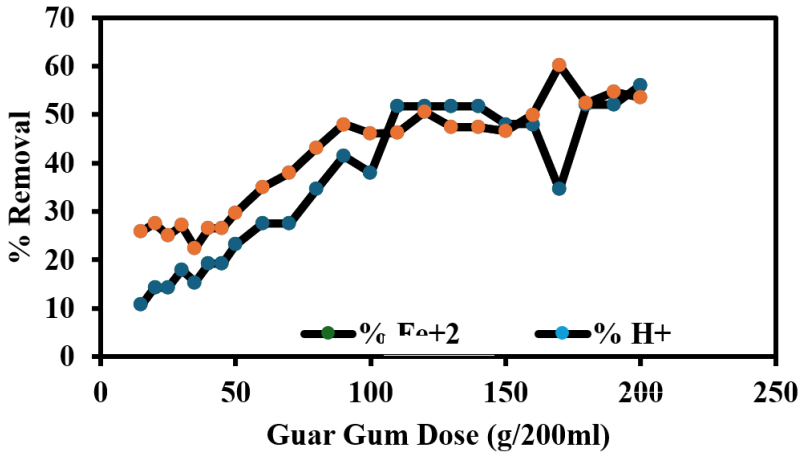

Figure 2. Percent Removal of Fe^{+2} and H^{+} with Guar Gum Dose.

A slow increase in pH (0.1-0.7 units) was a sign of successful neutralization of acidity, and it showed a close relationship ($R^2 = 0.9229$) (Figure 3). The increase in pH, though moderate, indicates the proton adsorption and buffering capacity of HPTMGG, and thus, the wastewater is less acidic and can undergo further treatment.

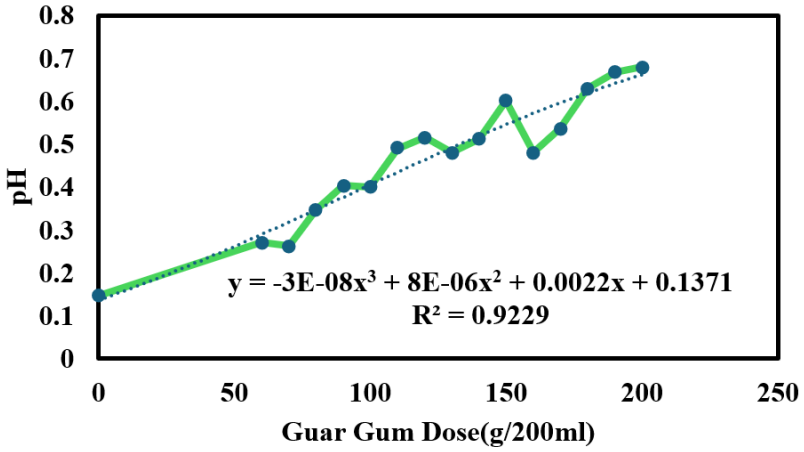

Figure 3. Change in pH with Guar Gum Dose.

Conclusion

The paper established that HPTMGG is an efficient and eco-friendly coagulant in acidic wastewater, with a removal percentage of up to around 52 percent Fe^{+2} and 60 percent H^{+} with significant turbidity and conductivity reduction observed at 120-150 g/200 ml. HPTMGG is a safe replacement of traditional coagulants to treat industrial wastewater, although a slight pH adjustment is necessary. The observations suggest that HPTMGG could successfully eliminate metal ions, acidity, and particulates simultaneously, hence delivering a promising candidate to treat acidic wastewater via chemical coagulants.

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Track B – Energy, Industrial Processes & Environmental Engineering

Paper Cod in Book 2: *B03*
Paper Page Range in Book 2*:* *69–72*

Feasible Solution for Sulfur Removal from Bituminous Coal

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Abstract

Reducing the sulfur content of coal should help reduce environmental pollution and sulfur dioxide emissions during bituminous coal combustion, as well as increase the efficiency of coal use. The emission of sulfur dioxide leads to acid rain, which is very harmful to the environment and agriculture. Desulfurization is regarded as a sustainable and environmentally friendly solution to the severe issue. This paper discusses a feasible way of desulfurizing bituminous coal using a new process. The process includes comminution, leaching, purification, filtration, and drying to get cleaner coal suitable for industrial use. In the extraction, the ratio of HCl and KOH was manipulated to determine the impacts of acidic and alkaline substances on coal purification. The findings showed that the KOH effect on the removal of sulfur is larger than that of HCl. Sulfur content was determined by X-ray fluorescence (XRF) and X-ray diffraction (XRD). The given strategy helps to decrease not only the possible emissions of sulfur dioxide but also promotes the calorific value and combustion efficiency of coal. The given work proves that chemical desulfurization with an acid-alkali leaching optimization is an effective and scalable approach to reducing the adverse impact of coal burning on the environment and contributing to a cleaner energy output.

Keywords: *Bituminous coal, Desulfurization, Acidic-alkaline leaching, Sulfur reduction, Clean coal technology*

Introduction

Coal is considered the most popular fossil fuel, particularly used in the production of electricity and in industries because of its energy density and availability throughout the world. Nevertheless, its high level of sulfur poses significant environmental and operational issues. When it burns, the sulfur is emitted as sulfur dioxide (SO_2), which is a serious air pollutant contributing to acid rain, corrosion of equipment, and respiratory illnesses [1-3]. The emissions also hasten the material wear in boilers and reactors, leading to increased maintenance expenditure and lower efficiency [4-6]. The most popular type of coal, which is used in energy production, is the bituminous coal that includes sulfur in three main forms: pyritic, sulfate, and organically bonded sulfur [7]. Traditional methods of desulfurization, including physical coal washing, are useful in the removal of pyritic and sulfate sulfur and ineffective in the removal of organic sulfur species [8,9]. Thus, sulfur desulfurizing processes based on acid or alkali leaching have been achieved to get a deeper removal of sulfur without breaking the coal structure.

Past studies have investigated acid leaching using either HCl or nitric acid to dissolve sulfuric compounds that are inorganic and alkali leaching using sodium or potassium hydroxide to dissolve organic sulfur bonds [10]. Most of these studies, however, consider the two processes independently and do not necessarily optimize parameters to be used as a combined and sequential application. Moreover, there is insufficient information on laboratory-scale application of bituminous coal, which has been quantitatively treated by using the sulfur reduction proved by the use of sophisticated elemental analysis like X-ray fluorescence (XRF).

The proposed research closes these gaps by coming up with a viable acid-alkali sequential leaching process for sulfur reduction of one ton of bituminous coal. The inorganic sulfur was targeted using HCl, and the organic sulfur fractions were removed using KOH. This research paper comes up with an optimized HCl-KOH sequential leaching of sulfur reduction in bituminous coal, through which the efficiency of the desulfurization process is verified by XRF. The innovation process improves coal quality, which allows combustion that is cleaner combustion and the sustainable production of energy.

Materials and Methods

Materials

In this study, bituminous coal was taken as the raw material, and it was gathered from a local source in Pakistan. Analytical grade hydrochloric acid (HCl, Sigma-Aldrich, USA) and potassium hydroxide (KOH, Duksan Pure Chemicals, South Korea) were used as leaching agents. Washing processes were used using distilled water. To perform sulfur analysis, coal samples in the mixture with limestone (Sigma-Aldrich, USA) and binder tablets were pressed to form pellets before X-ray fluorescence (XRF) analysis.

Size Reduction and Screening

The preparation of coal samples was first done to a particle size of less than 2.5 mm in a hammer mill. The screen analysis was done in the analytical sieve shaker to get the required size of the particles. The fractions that were oversized went to the hammer mill, where they were recycled; the necessary fractions were passed to the leaching units.

Acid Leaching (HCl)

The initial stage of leaching involved the treatment of coal samples with 1%, 3% and 5 % percent of hydrochloric acid solutions. About 5 g of coal was combined with 100 mL of HCl solution and stirred at 90°C for 1.5 hours with a mechanical agitator (Biobase, China). The mixture was filtered and then rinsed with a lot of distilled water, and then dried in an oven at 107°C.

Alkali Leaching (KOH)

In the second phase, leaching of pretreated coal with potassium hydroxide was carried out. 0.02 M, 0.04 M, 0.06 M, 0.08 M, and 0.1 M solutions were prepared, and 3g of coal was put in 100 ml of each solution. A mechanical agitator (Biobase, China) was used to stir the samples at 90 °C for 1 hour, after which they were filtered, washed, and dried. The most effective solution was found to be the 0.02 M KOH solution, which is effective in removing sulfur.

Sulfur Analysis by XRF

Before and after leaching, the content of sulfur was determined with the help of the X-ray fluorescence (XRF) spectrometer (Bruker TITAN, Germany). Limestone (Sigma-Aldrich, USA) (8 g of mass) was mixed with one gram of treated coal and pressed in the form of pellets using a force of 70 kN. XRF has been chosen because it is the most effective in elemental composition analysis. It can be seen that the general workflow of the experiment is presented in Figure 1, where the steps of the purification process are outlined sequentially: size reduction, screening, acid leaching, alkali leaching, washing, filtration, and drying.

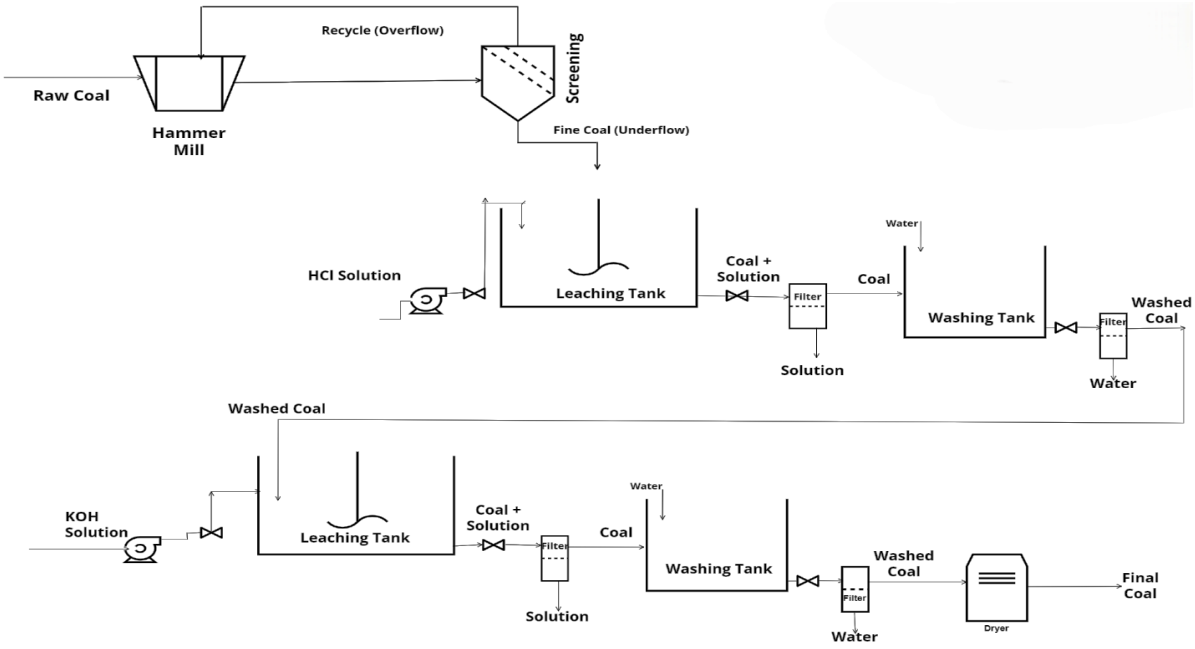

Figure 1. Process flow diagram for sulfur reduction from bituminous coal.

Results and Discussion

Acid Leaching (HCl)

Treatment with hydrochloric acid had minimal sulfur removal. The efficiencies of the sulfur removal at 1% and 3% amounts were 3.2% and 6.5, respectively, and the highest percentage of sulfur removal was 9.8% at 5% HCl (Table 1). This establishes that HCl is selective for inorganic sulfur fractions, but very weak with organic sulfur.

These findings are in agreement with the findings of Behera et al., who discovered that bituminous coal leached with 5% HCl lost approximately 8 to 10 percent of total sulfur oxide [2]. In like ways, Demirbas and Balatn [8] noted that acid leaching is capable of eliminating inorganic sulfur, especially iron pyrites, because they are more soluble in acidic conditions. Therefore, the current paper reaffirms that the ability of acid treatment to bring about deep desulfurization alone cannot be successful since it lacks the ability to break the resistant C-S and S-S bonds of organic sulfur.

Alkali Leaching (KOH)

Potassium hydroxide leaching demonstrated better desulfurization activity than the treatment of HCl, especially in low concentrations. The sulfur removal was 35% at 0.02 M KOH (Table 1), which indicated a good chemical reaction between hydroxide ions and sulfur-bearing functional groups. This reaction probably includes C-S and S-S bond cleavage and the formation of soluble sulfide compounds. In addition to the optimal concentration, the removal rate decreased because the surface became saturated and there was potential secondary precipitation of sulfur species.

Similar results were obtained by Çağlayan and İpek [1], who obtained about a 28% reduction in sulfur with a basic extraction liquid of oak ash, and by Xia and Xie [9], who reported the ability of alkali leaching in the breakdown of organosulfur bonds. The increased efficiency achieved in this work (35%) may be explained by the optimized concentration of KOH and pre-acid treatment, which increases the pore accessibility and the reactivity of the pore when exposed to alkali.

Table 1. Sulfur removal efficiency using HCl and KOH leaching

Treatment	Concentration	Sulfur Removal (%)
HCl	1%	3.2
HCl	3%	6.5
HCl	5%	9.8
KOH	0.02 M	35.0
KOH	0.04 M	28.6
KOH	0.06 M	24.1
KOH	0.08 M	21.4
KOH	0.10 M	19.5

Comparative Analysis

The experiment results have indicated clearly that KOH leaching is superior to HCl in causing a decrease in the amount of sulfur. Although HCl mainly dissolves the inorganic sulfur (pyritic and sulfate ions), KOH attacks organic sulfur through hydrolytic cleavage. Sequential acid-alkali treatment is better because it increases the total desulfurization since the acid pretreatment increases the coal pores accessible to the alkali, hence to the organic sulfur sites. It has been highlighted by Behera et al. [2] and Demirbaş and Balat [8] that the combined leaching technique provides a better outcome compared to single-step treatment. The overall sulfur reduction (up to 35) is higher in this study than that efficiency in the majority of previous literature, which is usually around 2030. These findings were supported by XRF analysis (Figure 2) that showed a significant decrease in the number of sulfur peaks following each treatment. The sudden decrease at 0.02 M KOH is associated with the maximum removal efficiency. The slight increases at elevated concentrations indicate re-adsorption or insufficient washing. These findings affirm that sequential leaching of HCl and KOH is a good way of altering the inorganic structure and the organic structures of sulfur.

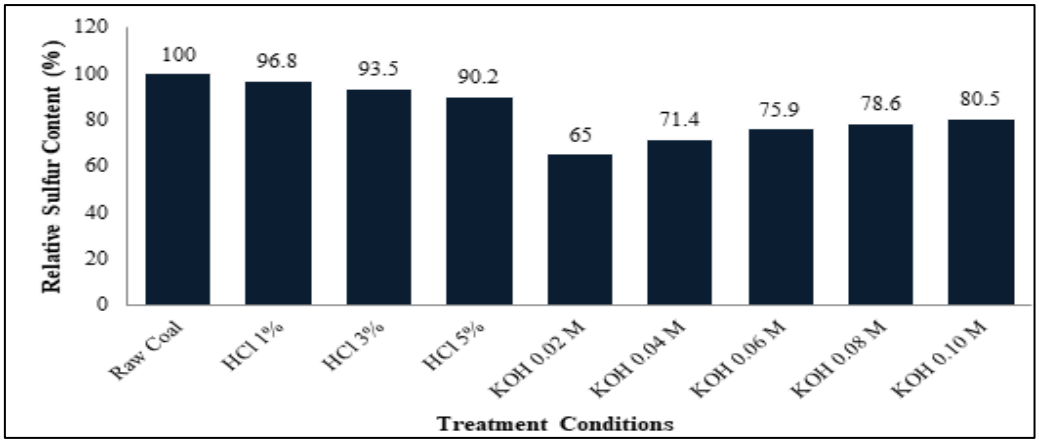

Figure 2. XRF analysis for the comparison of sulfur content in raw and treated coal samples.

Implications

The results reveal that sequential acid-alkali leaching is a potential chemical desulfurization plan for bituminous coal. This process will greatly cut down the amount of sulfur and, as a result, decrease SO_3 and enhance the efficiency of the combustion processes. Additional optimization of the concentration of reagents, reaction temperature, and time would result in increased desulfurization efficiency, reduced chemical waste, and industrial-scale use.

Conclusion

This study has proven that bituminous coal can be desulfurized using sequential acid-alkali leaching as a viable process. To achieve cleaner coal to be used in the industries, the coal was crushed, grinded, leached, filtered, and dried. HCl washed away to 9.8% of sulfur that was predominantly inorganic, and KOH washed away to 35% sulfur by breaking organic sulfur bonds. The analysis showed that there was a significant decrease in the level of sulfur following the treatment by the use of XRF and XRD. The HCl and KOH sequence showed significant optimization in reducing the possibility of sulfur dioxide emissions and enhancing the calorific value and combustion characteristics of the coal that was treated. On the whole, the process introduced is a scalable and sustainable method of using cleaner coal.

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Track B – Energy, Industrial Processes & Environmental Engineering

Paper Cod in Book 2: *B07*
Paper Page Range in Book 2*:* *73–80*

A Comparative Analysis of Machine Learning Algorithms for Sentinel-2 Image Classification in Çorum, Türkiye

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Abstract

Accurate and timely Land Use/Land Cover (LULC) information is crucial for sustainable development and environmental management. The advent of high-resolution satellite imagery like Sentinel-2, coupled with advanced machine learning (ML) algorithms, has significantly enhanced our capacity for large-scale LULC mapping. However, the performance of these ML models is highly dependent on their hyperparameter configuration, and a comprehensive comparison of their effectiveness for Sentinel-2 data remains a key research focus. This study conducts an evaluation of five ML algorithms: Random Forest (RF), XGBoost, AdaBoost, LightGBM, and CatBoost for LULC classification of Çorum province, Türkiye. A Sentinel-2 image was processed to create a dataset with five LULC classes. Each algorithm was optimized using three techniques: Grid Search, Random Search, and Bayesian Optimization. The models were evaluated based on Overall Accuracy (OA), Kappa coefficient, precision, recall, F1-score, and confusion matrix analysis. The results indicated that ensemble methods, particularly gradient boosting algorithms, delivered superior performance. CatBoost achieved the highest accuracy (OA=0.79) with default parameters, demonstrating robust out-of-the-box performance. However, after hyperparameter optimization, XGBoost, tuned with Grid Search, yielded the highest overall accuracy of 0.80. Hyperparameter optimization was found to be critically important for some algorithms, dramatically improving AdaBoost's accuracy from 0.57 to 0.77. The primary source of confusion across all models was between spectrally similar Urban and Bare Soil classes. This study concludes that XGBoost, when properly optimized, is a highly effective classifier for generating accurate LULC maps from Sentinel-2 imagery, providing a valuable benchmark for remote sensing practitioners and land management applications.

Keywords: *Land Use/Land Cover, Sentinel-2, Machine Learning, XGBoost, Hyperparameter Optimization, Remote Sensing.*

Introduction

Land Use/Land Cover (LULC) information is a fundamental geospatial data product critical for informed decision-making in a wide array of environmental and socio-economic domains, including sustainable resource management, urban planning, agricultural monitoring, and climate change impact assessment [1, 2]. The rapid pace of global change, driven by both anthropogenic activities and natural processes, necessitates efficient and accurate methods for mapping and monitoring the Earth's surface over large areas and at regular intervals [3].

Remote sensing technology has emerged as the primary tool for fulfilling this need, providing synoptic, repetitive, and cost-effective observations of the planet. Among the various satellite missions, the European Space Agency's (ESA) Sentinel-2 constellation, part of the Copernicus Programme, has marked a significant advancement. With its high spatial resolution (up to 10 meters), systematic global coverage, and frequent revisit time, Sentinel-2 provides an unprecedented data source for detailed LULC mapping and change detection [4]. The rich spectral information across 13 bands allows for robust discrimination between different land cover types, from built-up areas and agricultural fields to forests and water bodies [5].

The proliferation of high-resolution satellite imagery like Sentinel-2 has been paralleled by advancements in data analysis techniques. While traditional pixel-based classification methods have been widely used, Machine Learning (ML) algorithms have demonstrated superior performance in handling the high dimensionality and complex, non-linear relationships inherent in multispectral data [6, 7]. In particular, ensemble learning methods, which combine multiple base models to create a single, powerful predictor, have become the state-of-the-art in remote sensing classification. Algorithms such as Random Forest (RF) and Gradient Boosting variants (e.g., XGBoost, LightGBM, CatBoost) are frequently lauded for their high accuracy, robustness to overfitting, and ability to model complex feature interactions [8, 9].

However, the performance of these ML models is highly contingent upon the configuration of their hyperparameters. Selecting optimal hyperparameters is a non-trivial task that significantly impacts model generalizability and predictive accuracy [10]. While several optimization strategies ranging from exhaustive methods like Grid Search to more efficient ones like Random Search and Bayesian Optimization are available, a comprehensive comparison of their effectiveness in tuning ensemble classifiers for LULC mapping with Sentinel-2 data remains an area of active research.

This study aims to address this gap by conducting a rigorous comparative analysis of five prominent ML algorithms Random Forest, XGBoost, AdaBoost, LightGBM, and CatBoost for LULC classification using Sentinel-2 imagery. The research is conducted over the province of Çorum, Türkiye, a region characterized by a diverse landscape of agricultural lands, forests, and urban areas, providing a robust testbed for the classifiers. The specific objectives of this paper are:

- To evaluate and compare the performance of the five selected ensemble algorithms in classifying key LULC classes.
- To investigate the impact of three hyperparameter optimization techniques (Grid Search, Random Search, and Bayesian Optimization) on the classification accuracy of each model.
- To identify the most effective model-optimization combination for generating an accurate LULC map of the study area.

The findings of this research are expected to provide valuable insights for the remote sensing community, offering practical guidance on algorithm selection and tuning for generating reliable LULC products from Sentinel-2 data, thereby supporting environmental monitoring and land management initiatives.

Methods

The methodological framework for this study was designed to systematically evaluate and compare the performance of multiple machine learning algorithms for LULC classification. The process, illustrated in Figure 1, encompassed four main stages: (1) Study Area and Data Acquisition, (2) Data Preprocessing, (3) Machine Learning Classification and Hyperparameter Optimization, and (4) Model Evaluation (See Figure 1).

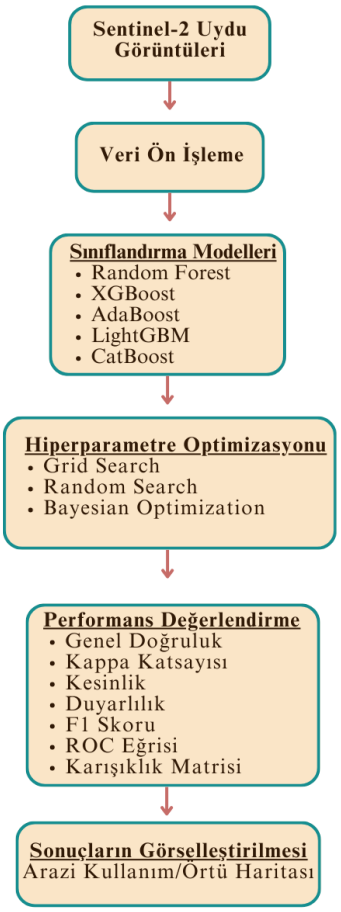

Figure 1. Overall workflow of the research methodology.

Study Area and Data Acquisition

The study was conducted over the Çorum province of Türkiye, located between 39°54'–41°20' N and 34°04'–35°28' E (See Figure 2). This region represents a transitional zone between the Central Anatolian plateaus and the Black Sea region, featuring a diverse topography of mountains, plateaus, and plains, with elevations ranging from 350 m to 2,097 m [11]. The land cover is a heterogeneous mix of agricultural areas (approximately 43% of the land), forested zones (concentrated in the north), urban settlements, and bare soil. This diversity makes Çorum an ideal and challenging case study for evaluating LULC classification algorithms.

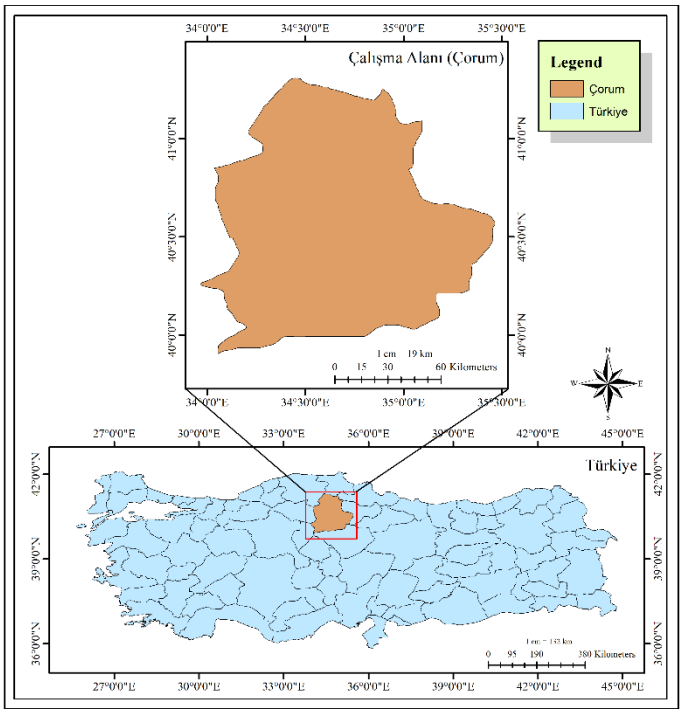

Figure 2. Location of the study area.

A cloud-free Sentinel-2A Level-2A (Bottom-of-Atmosphere) image from August 6, 2021 (See Figure 3), was acquired free of charge via the Sentinel Hub EO Browser. The summer acquisition period was selected to capture the peak phonological stage of vegetation, maximizing spectral separability between land cover classes. The dataset included all 12 spectral bands (B1-B9, B11, B12) at their native spatial resolutions (10m, 20m, 60m).

Figure 3. Sentinel-2 satellite image of the study area.

Data Preprocessing

Preprocessing and dataset generation were performed using ArcGIS 10.5. The 12 spectral bands were composited into a single multiband image using the "Composite Bands" tool. Subsequently, a supervised classification approach was

employed to create a reference dataset. Training samples (polygons) were manually digitized for five distinct LULC classes: Water (0), Bare Soil (1), Forest (2), Agricultural Field (3), and Urban (4). A total of 3,000 random points were generated within the study area. Using the "Extract Multi Values to Points" tool, the spectral values from all 12 Sentinel-2 bands and the corresponding class label from the reference map were extracted for each point.

The resulting dataset was cleaned by removing any points with null or zero values. It was then split into two parts: the spectral band values (B1-B12) as features (input.txt) and the class labels as the target variable (target.txt). The final dataset was randomly divided into a 80% training set (for model building and hyperparameter tuning) and a 20% independent test set (for final model evaluation).

Machine Learning Classification and Hyperparameter Optimization

All machine learning modeling and analysis were implemented in Python using the Google Colab environment. Five tree-based ensemble algorithms were selected for comparison:

A. Random Forest (RF): A bagging-based ensemble method that constructs multiple decorrelated decision trees [12].
B. eXtreme Gradient Boosting (XGBoost): A scalable gradient boosting system known for its computational efficiency and regularization techniques to control overfitting [13].
C. Adaptive Boosting (AdaBoost): A boosting algorithm that iteratively focuses on misclassified samples by adjusting their weights [14].
D. Light Gradient Boosting Machine (LightGBM): A high-performance gradient boosting framework that uses a leaf-wise tree growth strategy and histogram-based algorithms for faster training [15].
E. Categorical Boosting (CatBoost): A gradient boosting algorithm designed to handle categorical features effectively and reduce overfitting through ordered boosting [16].

To ensure a fair comparison and maximize each model's potential, a comprehensive hyperparameter optimization was conducted. For each algorithm, three optimization techniques were applied using 3-fold or 5-fold cross-validation on the training set: First, Grid Search: An exhaustive search over a predefined set of hyperparameter values. Second, Random Search: A random sampling of hyperparameter combinations from a defined search space. Lastly, Bayesian Optimization: A probabilistic model-based approach that efficiently explores the hyperparameter space to find the optimal combination.

The key hyperparameters tuned for each algorithm included the number of estimators (n_estimators), maximum tree depth (max_depth), and learning rate (for boosting algorithms). The model with the highest cross-validation accuracy for each optimization method was retained and retrained on the entire training set.

Model Evaluation Metrics

The performance of the final, optimized models was assessed on the held-out 20% test dataset using a suite of standard classification metrics [17, 19]. The following metrics were calculated based on the confusion matrix: Overall Accuracy (OA): The proportion of correctly classified pixels among the total pixels. Kappa Coefficient (K): A measure of agreement that accounts for chance, providing a more robust assessment than overall accuracy alone [20]. Precision: The proportion of correctly predicted positive observations for a given class. Recall (Sensitivity): The proportion of actual positives that were correctly identified for a given class. F1-Score: The harmonic mean of precision and recall, providing a single balanced metric. ROC-AUC: The Area Under the Receiver Operating Characteristic curve, which evaluates the model's ability to distinguish between classes across all classification thresholds.

Results and Discussion

This section presents the experimental results of the LULC classification for Çorum province using the five machine learning algorithms. The performance of both the default and optimized models is reported, followed by a comparative analysis and visualization of the final classification maps.

Overall Model Performance and Comparison

The overall performance metrics for all five classifiers with their default parameters, evaluated on the independent test set, are summarized in Table 1. Among the models, CatBoost achieved the highest performance, with an Overall Accuracy (OA) of 0.79 and a Kappa coefficient (K) of 0.71. It was closely followed by XGBoost and LightGBM (both with OA = 0.78, K = 0.70), and then Random Forest (OA = 0.77, K = 0.69). In contrast, AdaBoost exhibited significantly lower performance with default parameters, achieving an OA of only 0.57 and a Kappa of 0.41.

Table 1. Performance comparison of machine learning models with default parameters.

Model	Overall Accuracy	Kappa Coefficient	Precision	Recall	F1-Score
Random Forest	0.77	0.69	0.77	0.77	0.76
XGBoost	0.78	0.70	0.78	0.78	0.77
AdaBoost	0.57	0.41	0.57	0.57	0.56

LightGBM	0.78	0.70	0.78	0.78	0.77
CatBoost	0.79	0.71	0.79	0.79	0.78

Impact of Hyperparameter Optimization

Hyperparameter optimization was applied to enhance model performance. The results, detailed in Table 2, reveal its varying impact across different algorithms. The Random Forest optimization techniques (Grid Search, Random Search, Bayesian Optimization) yielded only marginal changes, with the best OA remaining at 0.77. This suggests that the default parameters of RF were already near-optimal for this dataset. The XGBoost Grid Search provided the most significant improvement, increasing the OA to 0.80 and the Kappa to 0.72. This demonstrates the sensitivity of XGBoost to its parameter configuration. The AdaBoost Hyperparameter tuning had a dramatic positive effect on AdaBoost. Its performance was elevated from an OA of 0.57 to a maximum of 0.77 with Bayesian Optimization, indicating that the default setup was highly suboptimal. The LightGBM: While Grid Search surprisingly led to a performance drop (OA=0.68), both Random Search and Bayesian Optimization successfully achieved an OA of 0.79. The CatBoost algorithm showed robust performance, maintaining its high OA of 0.79 across all optimization methods, with Bayesian Optimization yielding a slightly superior Kappa of 0.72.

Table 2. Best performance achieved by each model after hyperparameter optimization.

Model	Optimization Method	Overall Accuracy	Kappa Coefficient
Random Forest	Grid Search	0.77	0.68
XGBoost	Grid Search	0.80	0.72
AdaBoost	Bayesian Optimization	0.77	0.68
LightGBM	Bayesian Optimization	0.79	0.71
CatBoost	Bayesian Optimization	0.79	0.72

Class-Wise Analysis and Confusion Matrices

A analysis of the confusion matrices provided insights into class-specific performance. For the top-performing models (XGBoost, CatBoost, LightGBM), the Forest class was consistently the most accurately classified, with precision and recall values often exceeding 90%. This is attributed to its distinct spectral signature in the Near-Infrared and SWIR bands.

The Urban and Bare Soil classes presented the greatest challenge, frequently exhibiting mutual confusion. This is likely due to spectral similarity between built-up areas (e.g., asphalt, concrete) and dry, barren land. Similarly, some confusion was observed between certain Agricultural areas and Bare Soil, particularly for fallow or recently harvested fields.

The normalized confusion matrix for the optimized XGBoost model (Figure 4) exemplifies these patterns, showing high diagonal values (correct classifications) and concentrated off-diagonal errors primarily between Urban (Class 4) and Bare Soil (Class 1).

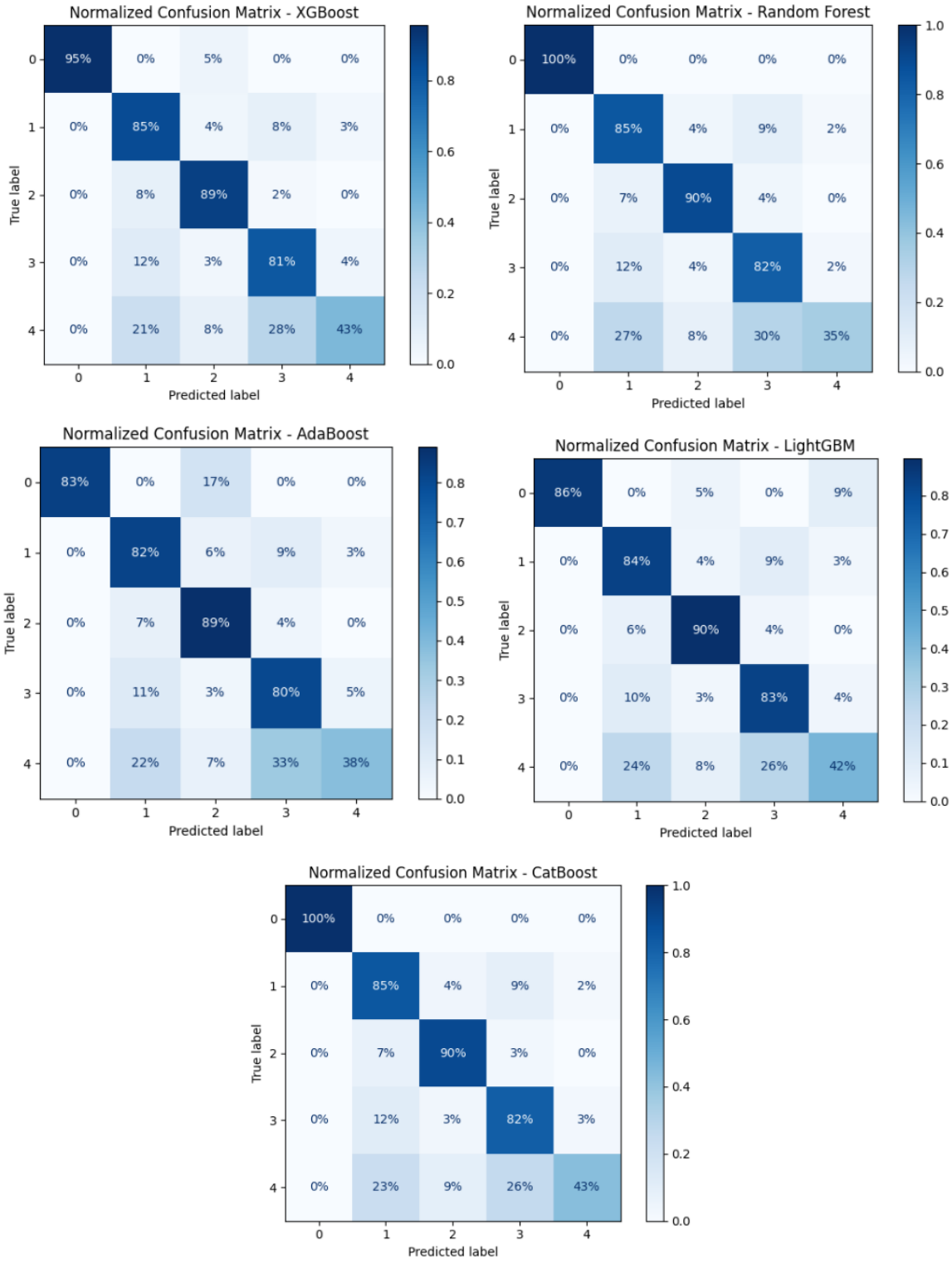

Figure 4. Normalized confusion matrix for the optimized models.

Final Land Use/Land Cover Maps

The classification results were used to generate LULC maps for the study area. Figure 5 presents a visual comparison of the output from all five machine learning models, alongside the original Sentinel-2 RGB image and the ground truth training data for context. Visually, all three maps effectively capture the broad spatial patterns of the region: the forested areas in the north, the agricultural plains, and the urban center of Çorum city. However, upon closer inspection, the map generated by the optimized XGBoost model shows slightly more coherent and less "salt-and-pepper" noise in the transitional zones between agriculture and bare soil, corroborating its superior quantitative metrics.

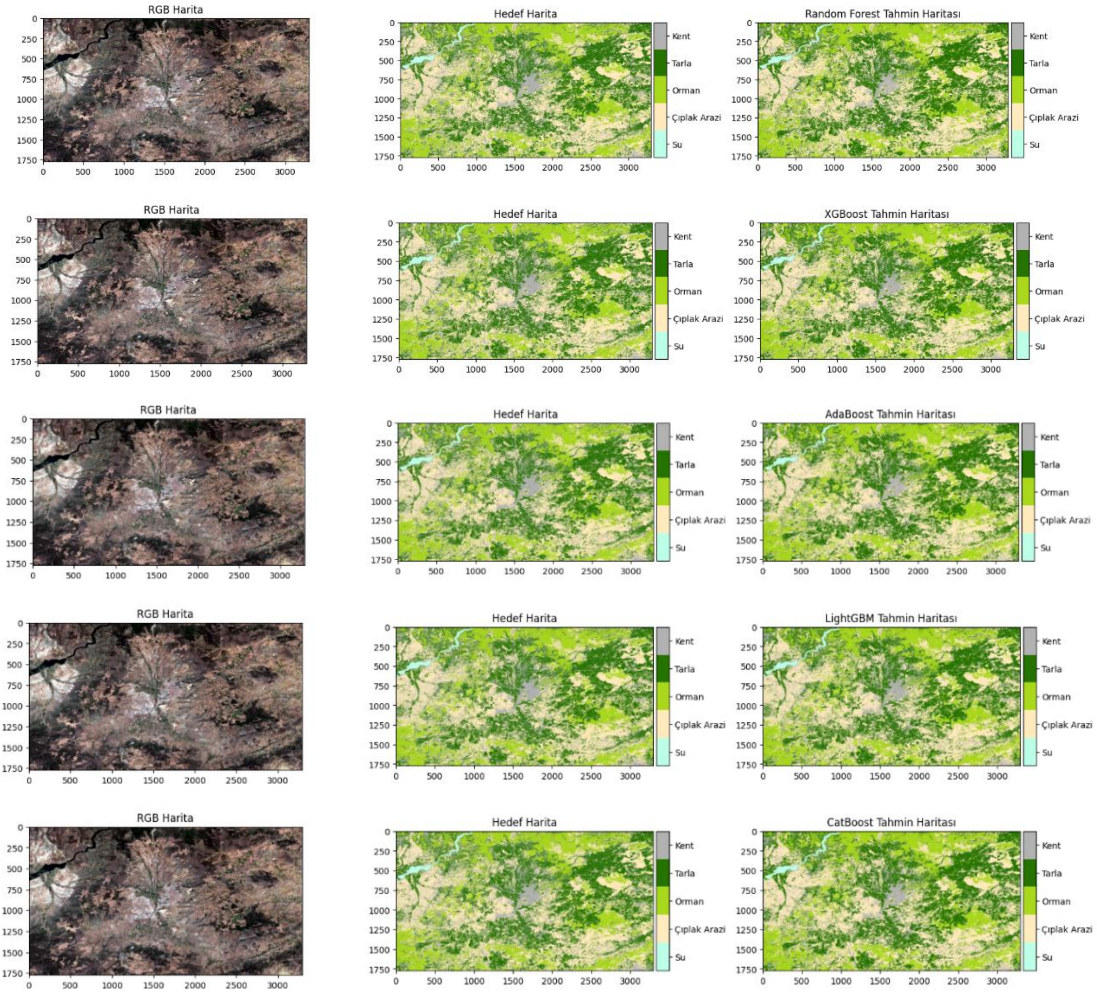

Figure 5. Visual comparison of final LULC maps: (a) Original Sentinel-2 RGB image (August 6, 2021), (b) Ground Truth Training Samples, (c) classification models.

Conclusion

This study conducted a comprehensive comparative analysis of five advanced machine learning algorithms Random Forest, XGBoost, AdaBoost, LightGBM, and CatBoost for Land Use/Land Cover classification using Sentinel-2 satellite imagery over the diverse landscape of Çorum, Türkiye. The research evaluated not only the baseline performance of these models but also the impact of three hyperparameter optimization techniques: Grid Search, Random Search, and Bayesian Optimization.

The experimental results lead to several key conclusions. First, tree-based ensemble methods, particularly the gradient boosting variants, are highly effective for processing the complex, high-dimensional spectral data provided by Sentinel-2. The superior performance of these algorithms underscores their capability to model the non-linear relationships inherent in multispectral remote sensing imagery. Second, the role of hyperparameter optimization was found to be critical yet variable across different algorithms. Its impact was most pronounced for AdaBoost, where optimization dramatically improved the Overall Accuracy from 0.57 to 0.77, and for XGBoost, where Grid Search boosted its accuracy to the highest value of 0.80. In contrast, algorithms like Random Forest and CatBoost demonstrated robust performance with less sensitivity to parameter tuning, suggesting greater out-of-the-box reliability for this specific task. Third, a detailed analysis of confusion matrices and the resulting LULC maps revealed consistent class-specific challenges, primarily the spectral confusion between Urban and Bare Soil areas. Despite this, the optimized XGBoost model proved most adept at minimizing these misclassifications, resulting in the most spatially coherent and cartographically refined output map with the highest quantitative accuracy.

Based on these findings, the XGBoost algorithm, optimized via Grid Search, is recommended as the most effective model for generating accurate LULC maps from Sentinel-2 data in regions with similar landscape characteristics to the Çorum province.

For future work, several avenues are suggested to build upon this research. Incorporating multi-temporal Sentinel-2 data could help resolve spectral ambiguities and improve classification robustness. Furthermore, integrating additional data

sources, such as Sentinel-1 SAR data for better structural information, or employing Deep Learning models like Convolutional Neural Networks (CNNs) to leverage spatial context, presents a promising direction for achieving even higher accuracy. Finally, testing the transferability of these optimized models to other geographical regions would be a valuable contribution to the field.

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Track C – Engineering Innovation, Computing & Intelligent Systems

Paper Cod in Book 2: *C02*
Paper Page Range in Book 2*:* *81– 88*

Development of ML Models for 3-Phase Horizontal Separator Optimization: A Study from Oman Oilfield

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Abstract

A silent challenge exists in Oman's oil fields, where fluctuating temperatures reduce the efficiency of three-phase separators, affecting oil, water, and gas separation and increasing energy consumption. This study applies machine learning to enhance separator performance by analyzing key parameters, including pressure, temperature, and flow rates. Among several regression models, linear regression performed best ($R^2 = 1$, zero errors). Box plot analyses confirmed well-distributed data. These results indicate that ML, particularly linear regression, can improve separator adaptability, energy efficiency, and overall performance in Omani oil fields.

Keywords: *Machine-learning, Separator, Regression models, Data analysis, Oilfield.*

Introduction

Efficient oil production in Oman relies heavily on the performance of three-phase separators, which are responsible for separating oil, water, and gas streams under varying operational conditions. However, separator efficiency is often reduced due to fluctuations in operating temperature, pressure, and flow conditions, which directly affect separation behavior and phase stability [3], [6]. Conventional separator designs are typically based on fixed operating assumptions and therefore lack adaptive capability to respond to dynamic field conditions, resulting in performance degradation and increased operational losses [10].

Recent studies have highlighted the influence of separator geometry, inlet conditions, fluid properties, and operating parameters on separation efficiency in horizontal three-phase separators [6], [9]. In particular, variations in temperature and flow rates can alter fluid rheology, droplet size distribution, and residence time, thereby reducing separation effectiveness [3], [4]. Despite extensive research on separator design and optimization, most existing approaches rely on deterministic or empirical models, which may not adequately capture complex nonlinear relationships between operational variables [2], [5].

To address these limitations, data-driven approaches such as machine learning have gained increasing attention for process optimization and performance prediction in multiphase systems [2], [7]. Machine learning models can identify hidden patterns within operational data and provide adaptive predictive capabilities that enhance system reliability and decision-making. Therefore, this study applies machine learning techniques to identify key operational and design parameters affecting three-phase separator performance and to improve separation efficiency, productivity, and operational reliability in an Omani oilfield.

Materials and Methods

Data Exploratory

Data summary

Operational data obtained from an actual Omani oilfield were analyzed to determine the parameters most influential on three-phase separator performance. The dataset was categorized into operational and design variables, as summarized in Table 1. The separator configuration, including major geometric dimensions such as vessel diameter, fluid heights, and weir location, is illustrated in Figure 1, representing a conventional horizontal three-phase separator with a weir, commonly used in oil production facilities [10].

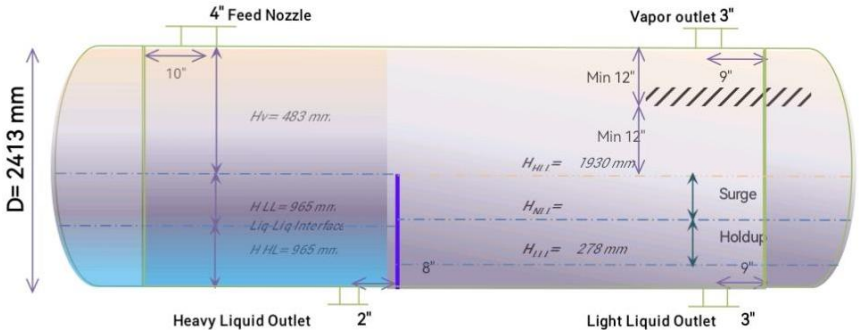


Figure 1. Horizontal Three- Phase Separator with Weir.

Table 1. Operational and design Data.

Operational Data	Values	Design Data	Values
Operating Pressure	1440 Psig	Vessel diameter	2413 mm
Design Pressure	1612 Psig	Height of oil	965 mm
Operating Temperature	194 °F	Height of water	965 mm
Design Temperature	250 °F	Weir	1930 mm
Vapor Flow Rate	415,179 kg/hr	High level of oil	1930 mm
Vapor Density	0.1 Ib/ft^3	High level of water	278 mm
Water Flow Rate	39,720 kg/hr	Inlet	101.6 mm
Water Density	1100 kg/m^3	Oil outlet	76.2 mm
Water Viscosity	0.89 cP	Vapor Outlet	76.2 mm
Oil Flow Rate	132,400 kg/hr	Water Outlet	50.8 mm
Oil Viscosity	31.29 cP		
Oil Density	49.9 Ib/ft^3		

Data analysis

A box plot analysis was conducted on the key variables to evaluate data distribution and identify potential outliers that may influence separator performance. Box plots represent the interquartile range (Q1–Q3), whiskers indicating non-outlier limits, and individual points representing outliers. The analysis revealed that oil height, water height, and the liquid–liquid interface exhibited notable outliers (Figure 2), suggesting irregular fluid level behavior within the separator.

Such anomalies may arise from operational disturbances, including fluctuations in inlet flow rates, transient operating conditions, or incomplete phase separation, all of which can contribute to phase mixing and reduced separation efficiency [3], [6]. In contrast, pressure and temperature variables displayed relatively normal distributions, indicating stable operating conditions over the observed period.

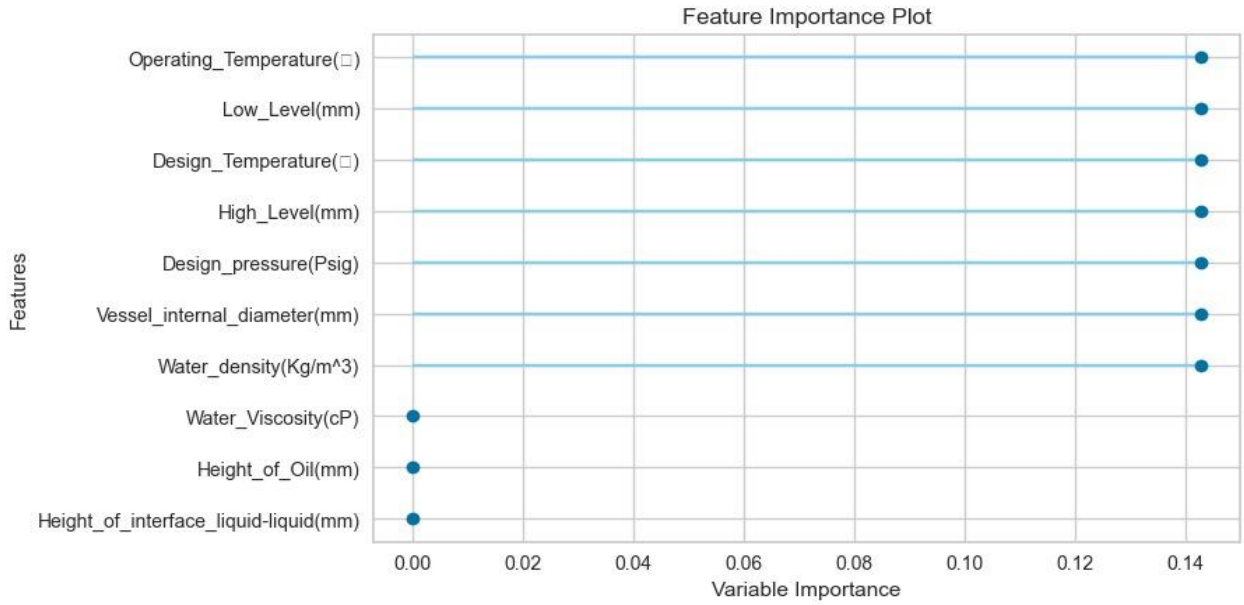


Figure 2. Feature importance plot.

Based on the predictive variables of the 3-phase separator, a correlation heat map (Figure 3) was used to assess linear relationships.

This analysis highlights closely related variables that may collectively influence performance, identifies independent factors, guides feature selection for predictive modeling, and focuses on the parameters that most significantly impact separation efficiency.

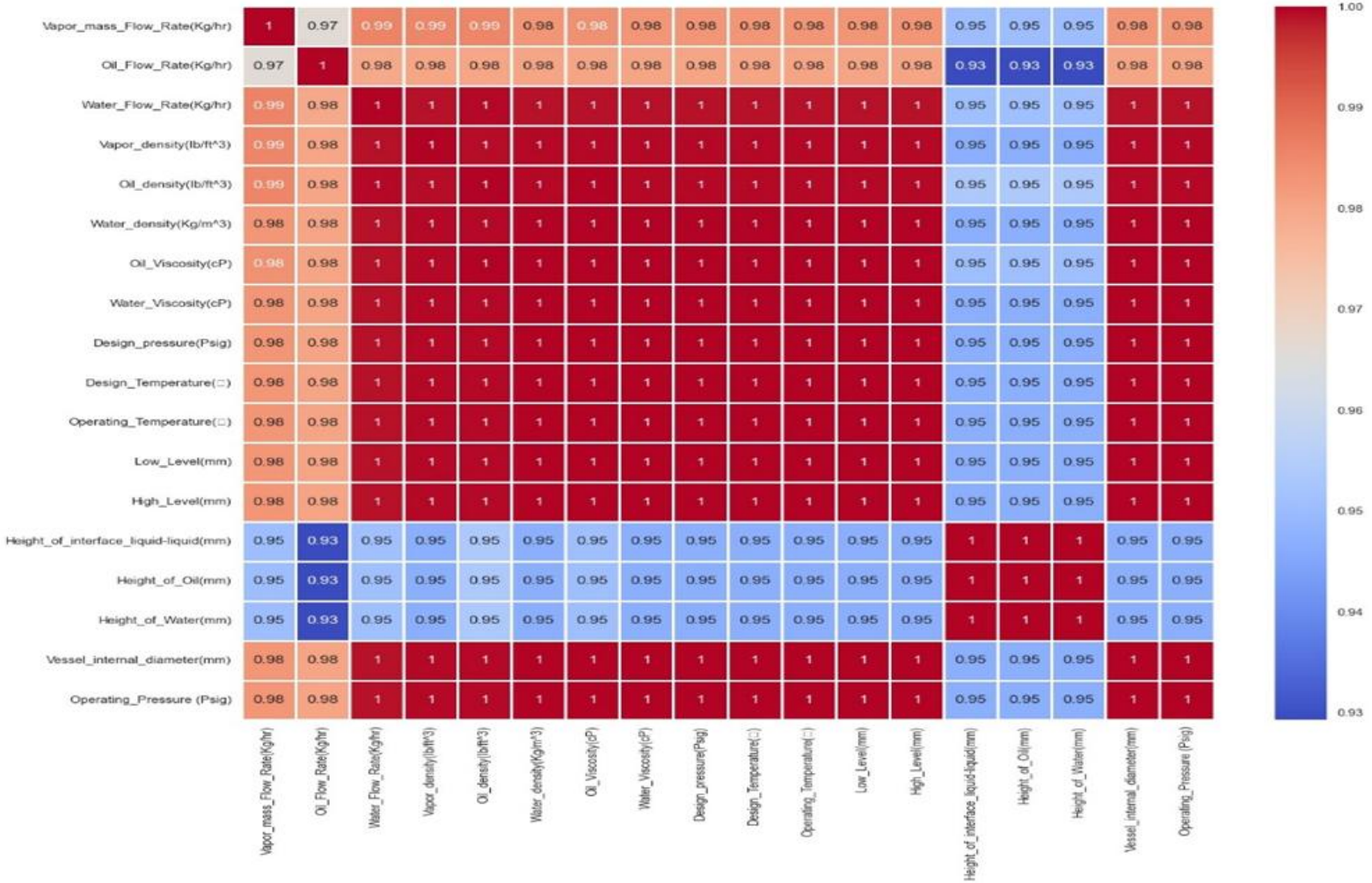


Figure 3. Correlation heat map matrix.

Key variables affecting performance

A feature selection analysis was performed to determine the most influential variables affecting the separator's internal performance. As shown in Figure 4, several parameters exhibited the highest relative contribution (approximately 14% each), including operating temperature, low oil level, design temperature, high oil level, design pressure, vessel internal diameter, and water density. These findings are consistent with previous studies indicating that separator geometry, fluid properties, and operating conditions collectively govern separation behavior in horizontal three-phase separators [6], [7].

Figure 4. Methodology flow chart.

Results and Discussion

Machine-learning models

Several machine learning models were tested to evaluate separator performance (Table 2). Linear regression achieved the best results, with an R^2 of 1.000 and zero errors across all statistical tools, indicating highly accurate predictions and reliable performance assessment under the studied operating conditions.

Table 2. Machine-learning models and statistical tools.

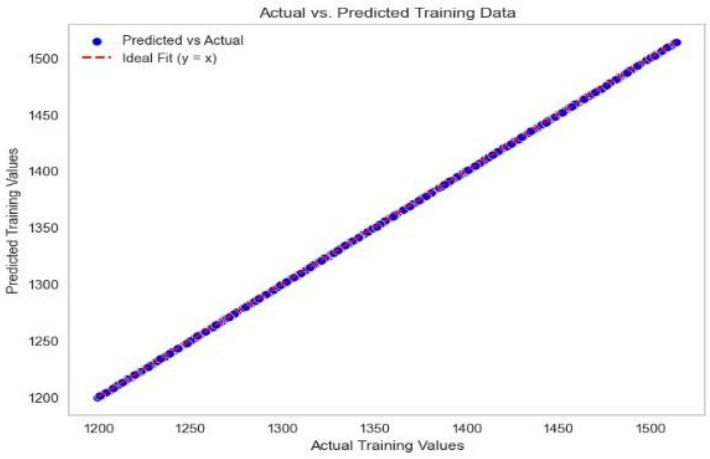
Models	MAE	MSE	RMSE	R^2	RMSLE	MAPE	TT
Linear regression	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.6720
Ridge regression	0.0418	0.2926	0.1730	1.0000	0.0001	0.0000	0.0190
Extra Trees Regressor	0.2371	0.9776	0.5129	0.9999	0.0004	0.0002	0.1080

The strong performance of linear regression suggests that the dominant relationships between the selected input variables and separator performance are largely linear within the analyzed operating range. This observation aligns with previous separator performance studies where linear dependencies between flow parameters, fluid properties, and separation efficiency were reported under steady operating conditions [3], [9].

Linear regression performance

Scatter plots comparing actual and predicted values illustrate the effectiveness of the linear regression model. During the training phase (70% of the dataset), the model achieved near-perfect agreement between predicted and observed values. The validation phase (15%) was used to fine-tune model performance, while the testing phase (15%) confirmed strong generalization capability, with minimal deviation between predicted and actual outcomes (Figure 5).

These results demonstrate that linear regression can reliably predict three-phase separator performance when key operational and design variables are appropriately selected. The application of machine learning-based predictive modeling offers a practical tool for optimizing separator operation, improving production efficiency, reducing phase losses, and minimizing unnecessary energy consumption in oilfield operations [2], [6].



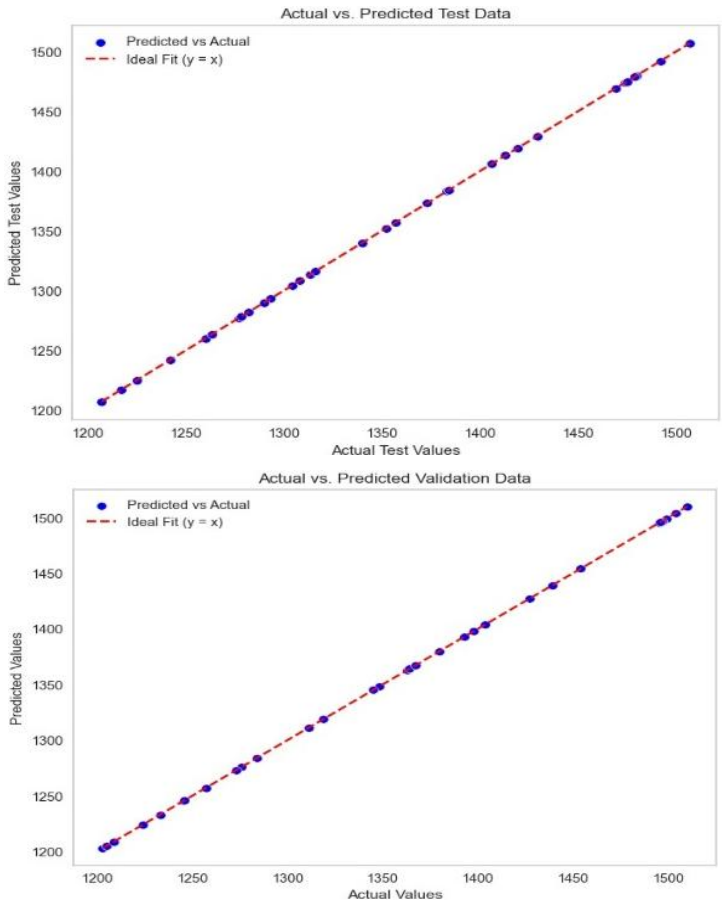


Figure 5. Actual vs Predicted Data.

Conclusion

The machine learning model accurately predicts three-phase separator performance, improving separation efficiency, reducing energy consumption and losses, and ensuring reliable operation. This approach offers scalability, commercial potential, and practical applicability for optimizing oil production in Oman's oil and gas sector.

Redesign the three-phase separator and apply the linear regression model for accurate prediction of interval performance under Omani conditions.

Regularly monitor operational data and extend the approach to other sites, using advanced models (e.g., Random Forest, Gradient Boosting) if variability requires improved predictions.

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Track C – Engineering Innovation, Computing & Intelligent Systems
Paper Cod in Book 2: *C03*
Paper Page Range in Book 2*:* *89 –96*

The Perceptions Mechanical Engineers on The Use of Artificial Intelligence in Aircraft Maintenance

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Abstract

The objective of this study is to examine the perceptions of mechanical engineers on the use of artificial intelligence in aircraft maintenance, including its benefits and detriments, providing further insights on artificial intelligence's use in the aviation industry from the perspective of experienced professionals. Qualitative data were collected using a semi-structured written interview that was mailed to the mechanical engineers working in aircraft maintenance, resulting in seven respondents. The findings were obtained through thorough thematic data analysis, and they show that AI greatly improves the speed, accuracy, and safety of aircraft inspections and repairs through tools like real-time diagnostics, predictive maintenance, and automated scheduling. While participants noted that AI can streamline maintenance and lower costs, they also pointed out challenges such as cybersecurity risks, high implementation costs, and the danger of excessive reliance on AI. The study concludes that addressing these issues is crucial for AI to be successfully integrated into aviation. These findings offer useful guidance for airline executives, AI developers, and maintenance teams, helping them adapt to the growing role of AI in aircraft maintenance.

Keywords: *Artificial Intelligence, Mechanical Engineer, Aircraft Maintenance, Cybersecurity, Aviation.*

Introduction

Artificial intelligence (AI) has rapidly transformed industries worldwide, influencing strategic decision-making and operational practices across sectors. In the aviation industry, senior executives increasingly recognize AI as a key enabler for waste reduction, customer service enhancement, operational quality, and efficiency improvement [14]. Airline leadership has emphasized that AI can be integrated across operations, strategy, and planning, highlighting its broad applicability within airline businesses [14].

In aircraft maintenance, mechanical engineers play a critical role, as they are responsible for dismantling, testing, inspecting, repairing, and reassembling aircraft engines, accessories, and ancillary systems. Their responsibilities also include working on electrical systems, aircraft frame sub-assemblies, oxygen systems, and conducting pre-flight inspections of critical components [9]. The integration of AI into these activities has the potential to significantly reduce manual workload and improve maintenance outcomes.

AI-enabled visual inspection systems allow maintenance tasks to be completed with reduced time and effort by analyzing large datasets, recognizing patterns, and responding intelligently to detected anomalies [5]. Such systems replace time-consuming and error-prone manual inspections, improving both speed and accuracy. Moreover, AI is widely acknowledged to possess vast untapped potential, with applications that continue to expand beyond current utilization levels [14]. AI-driven solutions further support key maintenance processes such as diagnostics, repair documentation, and quality assurance, while also contributing to optimized fleet operations and reduced operational costs [10], [15].

Maintenance scheduling has also benefited from AI integration, as intelligent systems can automatically track inspection intervals and alert engineers to upcoming or overdue maintenance requirements, ensuring compliance and operational continuity [8]. AI-based documentation tools further minimize human error by ensuring that critical information and minor anomalies are consistently recorded during maintenance activities [6]. These capabilities collectively enhance maintenance reliability and accountability.

A major advantage of AI in aircraft maintenance lies in its predictive maintenance capability. Embedded sensors installed in critical aircraft components, such as engines and landing gear, continuously transmit real-time data to AI systems. By

analyzing performance metrics, environmental conditions, and component health indicators, AI can detect subtle deviations and abnormal patterns that may indicate impending failures [11]. Industry applications have demonstrated that AI-driven platforms can predict engine failures with high accuracy, enabling proactive maintenance actions and reducing unplanned downtime [11], [17].

Recent studies further confirm that AI-supported aircraft maintenance enhances operational efficiency, safety, and sustainability. AI-assisted diagnostics have been shown to improve fault detection accuracy and facilitate faster, more informed decision-making processes [7]. Additionally, AI adoption has been associated with reduced maintenance costs and improved operational safety across multiple aircraft systems [1]. By continuously analyzing large-scale operational data, AI enables targeted maintenance interventions before minor irregularities escalate into critical failures, such as detecting slight changes in engine vibration patterns at an early stage.

Given these advancements, this study investigates the perceptions of mechanical engineers regarding the use of AI in aircraft maintenance. Understanding engineers' views is essential, as they are the primary users of AI-based maintenance technologies. The findings of this research are expected to provide valuable insights for AI developers, airline executives, maintenance engineers, researchers, and passengers. The growing interest in AI-driven maintenance solutions and their increasing adoption within the aviation sector underscore the relevance and timeliness of this investigation [12].

Methods

Participants of the Study

This study has queried mechanical engineers working in aircraft maintenance in Oman, as they are the ones who work in this specified field where the use of AI is prominent. They have also been able to give clearer insights as users of this technology. The participants have been collected using snowball and purposive sampling, as the subjects need to be mechanical engineers, and the mechanical engineers have helped connect their colleges to the study.

Research Instrument

The required qualitative data were gathered through interviews, as it is the most suitable for gathering this type of data. The interview questions were designed specifically for this study and have not been adapted from any other studies, and the interview questions will be semi-structured. Additionally, the research questions have been validated by the research supervisor, panelists, and a mechanical engineer working in aircraft maintenance. Additionally, the interviews will either be conducted online or face-to-face, depending on the participants' time and availability.

Data Collection Procedure

The approval from the principal was obtained to conduct the study and interview the mechanical engineers. Then the consent of the mechanical engineers was obtained. Fifteen mechanical engineers were interviewed based on the number of available and free participants. After acquiring the data through the interviews, the collected data was analyzed. The data gathered is not to be shared or discussed publicly with and between other individuals prior to or post-data analysis aside from those directly involved, as this is confidential information that should not be tampered with by anyone except those with direct access.

Data Analysis

The gathered data have been transcribed first and organized to be more comprehensible. The data were reread to fully immerse themselves in it with regards to the context and took notes on initial impressions of the gathered data. Specific labels or codes were assigned to the data, which were categorized into broad labels or codes through thematic analysis. Finally, the codes were grouped, themes and patterns were identified in the data, the findings were contextualized and the meanings were explored.

Results and Discussion

Table 1 summarizes the key factors influencing the use of artificial intelligence in aircraft maintenance, categorized into several interconnected themes, including AI-assisted aircraft inspection, safety and efficiency, safety control, implementation of AI tools, enhanced efficiency and accuracy, analytical purpose, and overall enhancement of aircraft maintenance through AI adoption. The findings reveal a complex interaction between enabling and constraining factors that shape mechanical engineers' experiences with AI in their professional practice.

The implementation of AI tools in aircraft maintenance was widely perceived as offering substantial benefits, particularly in improving operational efficiency and safety. Participants highlighted AI's ability to predict potential failures well in advance, thereby reducing unplanned downtime and extending aircraft service life. By automating routine inspections and diagnostic tasks, AI systems allow maintenance teams to focus on higher-value activities, leading to improved operational performance and cost reduction. These findings are consistent with previous studies emphasizing the role of predictive maintenance and IoT-enabled monitoring in identifying mechanical issues before they escalate into major failures [6].

The results further indicate that AI-driven automation enhances inspection accuracy by detecting faults that may not be visible to the human eye, thus minimizing the risk of oversight during maintenance procedures. This observation aligns with prior research demonstrating that AI-based performance monitoring systems improve fault detection and reduce unexpected maintenance interruptions [4]. The capability of AI systems to identify subtle abnormalities at an early stage is directly linked to the predictive maintenance framework discussed in this study, reinforcing their contribution to proactive maintenance strategies.

In addition, the findings support existing literature suggesting that AI integration is likely to transform aircraft maintenance into a safer, more efficient, and more sustainable practice. AI-enabled prediction and management of maintenance requirements contribute to reducing unscheduled downtime while prolonging component lifespan, thereby achieving a balance between operational efficiency and safety [18]. Overall, the results demonstrate that AI adoption in aircraft maintenance positively influences engineers' ability to maintain safety standards, optimize maintenance planning, and enhance overall system reliability, while also highlighting the need to address practical and organizational challenges associated with its implementation.

Table 1. The Perceptions of Mechanical Engineers on Artificial Intelligence (AI) Being Used in Aircraft Maintenance, in Terms of Inspections and Repairs.

Theme	**Code**	**Evidence**
The Implementation of AI tools in aircraft maintenance	Enhancing the Safety in Aircraft Maintenance	"AI minimizes human error by automating complex analysis and detecting issues that may be missed during manual inspections."
	Improving the efficiency of Aircraft Maintenance	"AI tools reduce the time needed for inspections and repairs by quickly analyzing vast amounts of data, allowing maintenance crew to focus on critical tasks."
	Cost Reduction in Aircraft Maintenance	"Though gradual adaptation and careful regulation are essential for long-term success."
	Adopting AI in Aircraft Maintenance	"Though gradual adaptation and careful regulation are essential for long-term success."
	AI use in aircraft maintenance	"Increase safety, reduce downtime, and optimize cost."
The Implementation of AI tools in aircraft maintenance	AI enhances the accuracy efficiency and safety of inspections	"AI plays a crucial in modern aircraft inspections by enhancing accuracy, efficiency, and safety."
	AI-Driven Drones	"Some maintenance organizations use drones to do their inspection that scan the whole external of the aircraft.""
	Historical Data Analysis	"Predictive Maintenance through data analysis. -AI systems analyze historical data from aircraft sensors."
	Detection of hidden damage	"Ability to predict when components might fail as damage that human inspectors might miss."

Enhanced Efficiency and Accuracy	Efficient inspections with AI tools	"AI tools are increasingly being utilised in aircraft inspections to enhance efficiency."
	Workload minimization	“It will help to minimise the workload."
	Increased efficiency with AI tools	“AI tools in aircraft inspections boost speed, safety, and accuracy.”
	AI-enhancing Aircraft Repairs	“AI tools in aircraft repair boost efficiency and accuracy.”
The Use of AI tools in aircraft maintenance	Diagnostic support	"AI tools are utilised in aircraft repairs by offering diagnostic support during repair procedures."
	AI Maintenance Alerts	“AI is used for aircraft maintenance schedules and repairs; it keeps track of essential schedules and alerts the operator on incoming repairs.”
Enhanced aircraft maintenance with AI use	AI makes maintenance more proactive, precise, and efficient	“AI has revolutionized aircraft maintenance by making it more proactive, precise, and efficient. Its greatest strength lies in its ability to prevent issues before they escalate.”
	AI enhancing workflow and productivity	“Artificial Intelligence is increasingly integral to aircraft maintenance and repair, streamlining tasks, enhancing safety, and reducing downtime.”
Safety and Efficiency	Improved and Automated Diagnostics	“AI systems quickly identify issues and suggest solutions, this is used at Rolls-Royces engine monitoring.”
	Operations are safer and more efficient	“Making operations safer and more efficient.”
Analysis Purposes	Programmed Analysis	“Using a program, it tells the inspector what the defects are.”
Safety Control	Safety improvement	"AI tools are increasingly being utilised in aircraft inspections to enhance...safety."

In Table 2, the study identifies several key advantages and disadvantages of artificial intelligence in aircraft maintenance, categorized into distinct themes including data accuracy, predictive capabilities, enhanced efficiency, cybersecurity risks, safety control, improved maintenance practices, reliance on AI systems, cost efficiency, consistency in quality, work liability, and limitations of AI technologies. The findings demonstrate a complex interaction between enabling and constraining factors that shape mechanical engineers’ experiences with AI in their professional environment.

The implementation of artificial intelligence in aircraft maintenance offers substantial benefits, particularly through its predictive capabilities and operational efficiency improvements. AI systems analyze large volumes of operational and condition-monitoring data, enabling proactive and targeted maintenance interventions that prevent minor anomalies from escalating into major failures [17]. This aligns closely with the findings of the present study, which emphasize early fault detection and predictive decision-making as key contributors to enhanced safety and reduced unplanned downtime.

Furthermore, advances in machine learning have extended AI applications beyond maintenance diagnostics to include flight planning, predictive scheduling, and reduction of human error in maintenance decision-making. These developments reinforce the study's findings regarding AI's role in minimizing manual errors and improving maintenance accuracy. AI-enabled visual inspection systems, in particular, have been shown to outperform traditional inspection methods by providing real-time detection of component degradation and subtle anomalies that may not be visible to the human eye [5]. This supports participants' perceptions that AI improves inspection reliability and consistency in quality.

Despite these advantages, the findings also highlight significant concerns that may hinder full-scale AI implementation in aircraft maintenance. Participants expressed apprehension regarding cybersecurity risks, data privacy breaches, system dependency, and liability issues arising from over-reliance on AI-driven decisions. While many existing studies focus predominantly on the performance and efficiency benefits of AI adoption [5], [17], they often provide limited discussion on associated risks. In contrast, the present study explicitly acknowledges these limitations, emphasizing that cybersecurity vulnerabilities, data leaks, and accountability challenges remain critical barriers to widespread AI adoption.

Overall, the results suggest that while artificial intelligence has strong potential to enhance safety, efficiency, and predictive maintenance in aircraft operations, its successful implementation depends on addressing technical, organizational, and ethical challenges. Balancing AI-driven automation with robust cybersecurity frameworks, regulatory oversight, and human expertise is essential to ensure safe, reliable, and sustainable integration of AI into aircraft maintenance practices.

Table 2. Mechanical Engineers' Perceived Benefits and Detriments of Artificial Intelligence's (AI) Use in Aircraft Maintenance.

Theme	**Code**	**Evidence**
AI Improved Maintenance	More Capable than Traditional Methods	"AI improves aircraft maintenance by predicting issues early, speeding up diagnostics, optimizing schedules, reducing costs."
	Outperforms traditional methods	"All offer key advantages over traditional methods; they enable predictive maintenance, reducing unexpected failures and downtimes, improve inspection accuracy with automated AR and robotics, minimizing human error."
	AI Improved Maintenance over Manual Maintenance	"AI makes maintenance fast, safer and more cost-effective than manual, time-based approaches."
	Improved Safety, Cost Efficiency, and Time Efficiency in Maintenance	"It promotes safety, cost efficiency, lesser ground time for maintenance, and lessens the risk of expensive repairs in the future."
Limitations of AI	System Reliability	"AI always depends on the internet connection or computer; it will simply not work without them."
	Rigidity compared to flexibility	"They lack on Flexibility"
	Limited intuition	"They lack on Intuition"
	Vulnerability to Data Loss	"The only disadvantage of AI is the possibility of missing data if the hard drive is corrupted."

The Accuracy of Data in Aircraft Maintenance	Increased Accuracy in finding problems	"AI can detect minute defects or anomalies that may be overlooked by human inspectors."
	Data Quality and Integrity	"Ai is only as good as the data it processes. Inaccurate or incomplete data could lead to faulty predictions or diagnostics."
	Fast Decision-Making	"AI analyses complex datasets rapidly, providing actionable insights within minutes."
Work Liability	Vulnerability from failure	"Vulnerabilities if Technology fails"
	Negative reactions to AI implementations	"Workforce resistance to change"
	Reduce in Human oversight and critical decision-making	"AI requires specialized skills which may necessitate retraining the workforce and it can reduce human oversight, potentially impacting critical decision-making in safety sensitive scenarios."
Consistency in Quality	AI Ensuring Top Aviation Standards	"AI programs are designed to follow the highest standard of aviation, unlike traditional methods that depend on human judgment."
	Consistency and Standardization	"Unlike human operators, AI does not suffer from fatigue or bias, ensuring consistent quality in inspections and repairs."
Economic Barrier	High Initial Cost	"Disadvantages of using AI in aircraft maintenance include high initial costs."
	High Hardware, Software, and Training Cost	"Implementing AI system involves significant investment in hardware, software, and training."
Cybersecurity Risks	Security Concerns in Aircraft Maintenance	"The integration of AI increases the risk of cyberattacks, which could compromise sensitive aircraft systems."
	AI Implementation Challenges and Risks	"Implantation cost, dependence on quality data and cybersecurity risks as AI systems are vulnerable to hacking."
Reliance on AI in Aircraft Maintenance	Dependence on Technology	"Over Reliance on AI could lead to reduced manual skills and critical thinking among technicians."
	Reduced Human Oversight	"Reduced human oversight, which may lead to missed nuanced issues that skilled technicians could detect."

Safety Control	Safer than traditional methods	"Enhancing safety compared to traditional methods."
	Safety Enhancement	"It helps both maintenance personnel and operators to promote the safety of personnel and aircraft."
Predictive Capabilities	Proactive failure detection	"One of the most powerful advantages of AI is its ability to predict potential failures before they occur."

Conclusion

The data suggests that AI significantly enhances efficiency, accuracy, and safety in the performance of aircraft maintenance; it enhances inspections, performs predictive maintenance, and limits human error. It decreases downtime, optimizes schedules, and ensures consistent quality in diagnostics and repairs, contributing to cost efficiency. In addition, the data implies benefits to the implementation of AI in aircraft maintenance which include detection of failures due to predictive capabilities, enhancing overall efficiency in the maintenance process, ensuring safety in the maintenance process, improving maintenance by speeding up diagnostics, ensuring consistent cost efficiency in aircraft repairs, and keeping the consistency in quality. It is also prevalent that the implementation has challenges such as high initial costs, dependency on data and technology, and potential cybersecurity risks such as system failure and hacking. There is also a risk that the undue reliance on AI would erode a technician's critical thinking and ability to perform tasks with their hands. Workforce resistance to change further complicates the path to adoption. Further, the dependence of AI on connectivity and hardware presents various vulnerabilities to operational disruptions. While AI brings transformative benefits, meeting technical, economic, and workforce challenges will be imperative for sustainable and safe aircraft maintenance practices.

Acknowledgements

Acknowledgement is given to Dante M. Dayawon for assisting in connecting with the participants of the study and aiding them in the distribution of the survey questionnaires.

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Track C – Engineering Innovation, Computing & Intelligent Systems

Paper Cod in Book 2: *C04*
Paper Page Range in Book 2*:* *97–100*

Development of Machine Learning to Predict Fracture Progression in Oil Shale Reservoirs while Hydraulic Fracture Operation

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Abstract

Hydraulic fracturing is a widely applied technique to increase oil and gas recovery, but predicting fracture progression in shale reservoirs remains difficult due to the complexity of subsurface formations and their nonlinear behavior. Inaccurate predictions can reduce efficiency, increase costs, and create environmental risks such as aquifer contamination or unwanted fracture growth into adjacent zones. This research develops a machine learning based predictive framework, implemented in Python using AI codes and libraries, to monitor fracture progression and improve hydraulic fracturing design in Oman's oil shale reservoirs. Simulation data were generated to study the effect of three operational parameters operation time, injection fluid rate, and fluid viscosity on fracture geometry. Four machine learning algorithms were tested: Linear Regression, Decision Tree, Random Forest, and Support Vector Regression. Model performance was evaluated using statistical indicators, including R^2 and RMSE, to measure accuracy and reliability. Results showed that the Decision Tree model consistently outperformed the others by effectively capturing nonlinear relationships and providing accurate predictions for two of the three studied parameters, while Random Forest delivered strong performance for one parameter. In contrast, Linear Regression and Support Vector Regression struggled with complex data. The findings demonstrate that Python-based machine learning can be a powerful tool for predicting and monitoring fracture progression, enabling better treatment design, reducing risks to sensitive zones, and minimizing environmental impacts. This work highlights how artificial intelligence can drive smarter, data driven, and more sustainable energy solutions in oil and gas operations.

Keywords: *Hydraulic Fracturing, Oil Shale Reservoirs, Machine Learning Prediction, Artificial Intelligence, Fracture Progression, Sustainable Engineering.*

Introduction

Oman, one of the biggest oil producers in the Middle East, is defined by complex and difficult desert terrains that present unique challenges for hydrocarbon extraction. Shale formations dominate a significant portion of its subsurface geology, accounting for over 80% of drilled sections and serving as key reservoirs for oil and gas production **[1]**. To be economically viable, these unconventional formations require advanced stimulation techniques. One of the most important technologies in this context is hydraulic fracturing **[2]**. This technique involves injecting high-pressure fluid into the wellbore to create and propagate fractures in the reservoir rock, increasing permeability and production. Recent research has highlighted the importance of controlling fracture geometry and propagation in multi-well developments to avoid interaction with sensitive zones such as freshwater aquifers and adjacent wells **[3]**. Oil shale reservoirs frequently have pre-existing natural fractures that can interact with induced fractures to form complex fracture networks. These interactions can cause unpredictable fracture growth outside the target zone, making fracture prediction and control difficult in field operations **[4]**. Advanced simulation tools, such as 2D and 3D hydraulic fracturing models, have been developed to predict fracture behaviour, but their effectiveness is often limited in highly heterogeneous and anisotropic shale formations. This study aims to close this gap by combining pre-modelling simulation analysis with developing of ML-based predictive models. The goal is to determine the impact of key operational parameters—operation time, injection fluid rate, and dynamic viscosity—on fracture behaviour, as well as to compare the performance of various machine learning algorithms in predicting fracture-related outcomes in oil shale formations.

Materials and Methods

The methodology of this research followed a structured two-stage process. The first stage involved data generation through simulation, wherein a series of physics-based models were implemented in Python to simulate hydraulic fracture propagation. These simulations were based on established three-dimensional (3D) models, aiming to produce a comprehensive dataset. The generated data captured the influence of key operational parameters including operational time, fluid injection rate, and fluid dynamic viscosity on fracture geometry and pressure distribution.

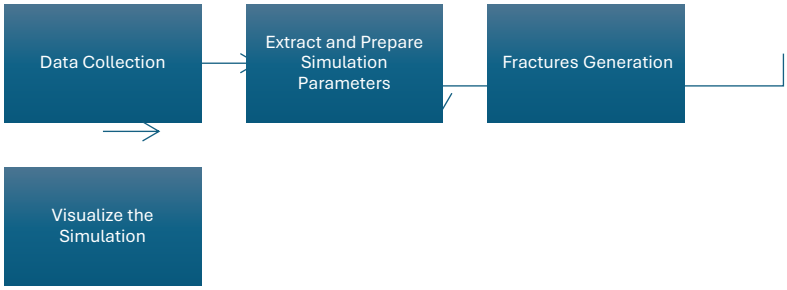

Figure 1. Workflow of the simulation process.

Upon completion of the simulation phase, the second stage comprised the machine learning workflow. Initially, an Exploratory Data Analysis (EDA) was conducted to identify trends, correlations, and anomalies within the dataset. The processed data were subsequently divided into training (80%) and testing (20%) subsets to ensure robust model evaluation. Four machine learning algorithms Linear Regression (LR), Decision Tree (DT), Random Forest (RF), and Support Vector Regression (SVR) were developed and trained using the training subset. Model performance was then assessed on the testing subset utilizing two key evaluation metrics: the Coefficient of Determination (R^2), to measure the proportion of variance explained by the model, and the Root Mean Squared Error (RMSE), to quantify predictive accuracy.

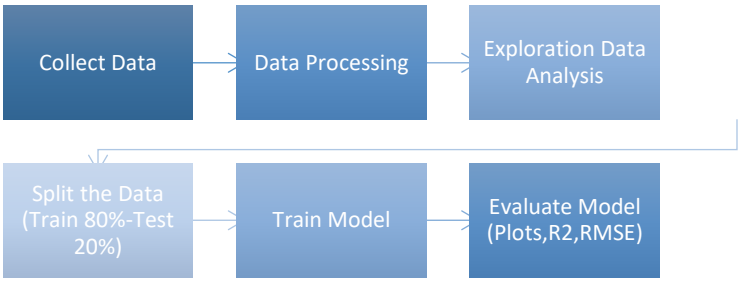

Figure 2. Machine learning model development workflow.

Results and Discussion

In the simulation phase, the influence of key operational parameters on fracture geometry was investigated. The results indicated that as operational time increases, the fracture radius extends significantly while the fracture width decreases, with the rate of change slowing as the system approaches equilibrium. A higher fluid injection rate was found to produce fractures that are both longer (larger radius) and wider, following a nonlinear pattern. Conversely, increasing the dynamic viscosity of the fracturing fluid resulted in the creation of wider, but shorter, fractures.

For the predictive modeling phase, four machine learning algorithms (Linear Regression, Decision Tree, Random Forest, and Support Vector Regression) were evaluated on their ability to predict fracture radius, fracture width, and net pressure. Performance was measured using R-squared (R^2) and Root Mean Squared Error (RMSE). The tree-based models, Decision Tree (DT) and Random Forest (RF), proved to be overwhelmingly superior. For predicting fracture radius, the DT model achieved a perfect R^2 of 1 with a minimal RMSE of 0.0518, with the RF model performing nearly as well. This high performance was even more pronounced when predicting fracture width and net pressure. Both the Decision Tree and Random Forest models demonstrated perfect accuracy for these variables, achieving R^2 scores of 0.9999 or 1 and an RMSE of 0. In stark contrast, Linear Regression struggled, and the Support Vector Regression (SVR) model failed to capture the complexity of net pressure, resulting in a negative R^2. Overall, the Decision Tree was identified as the most effective model, demonstrating a robust capacity to predict the complex, nonlinear behaviors inherent in hydraulic fracturing data.

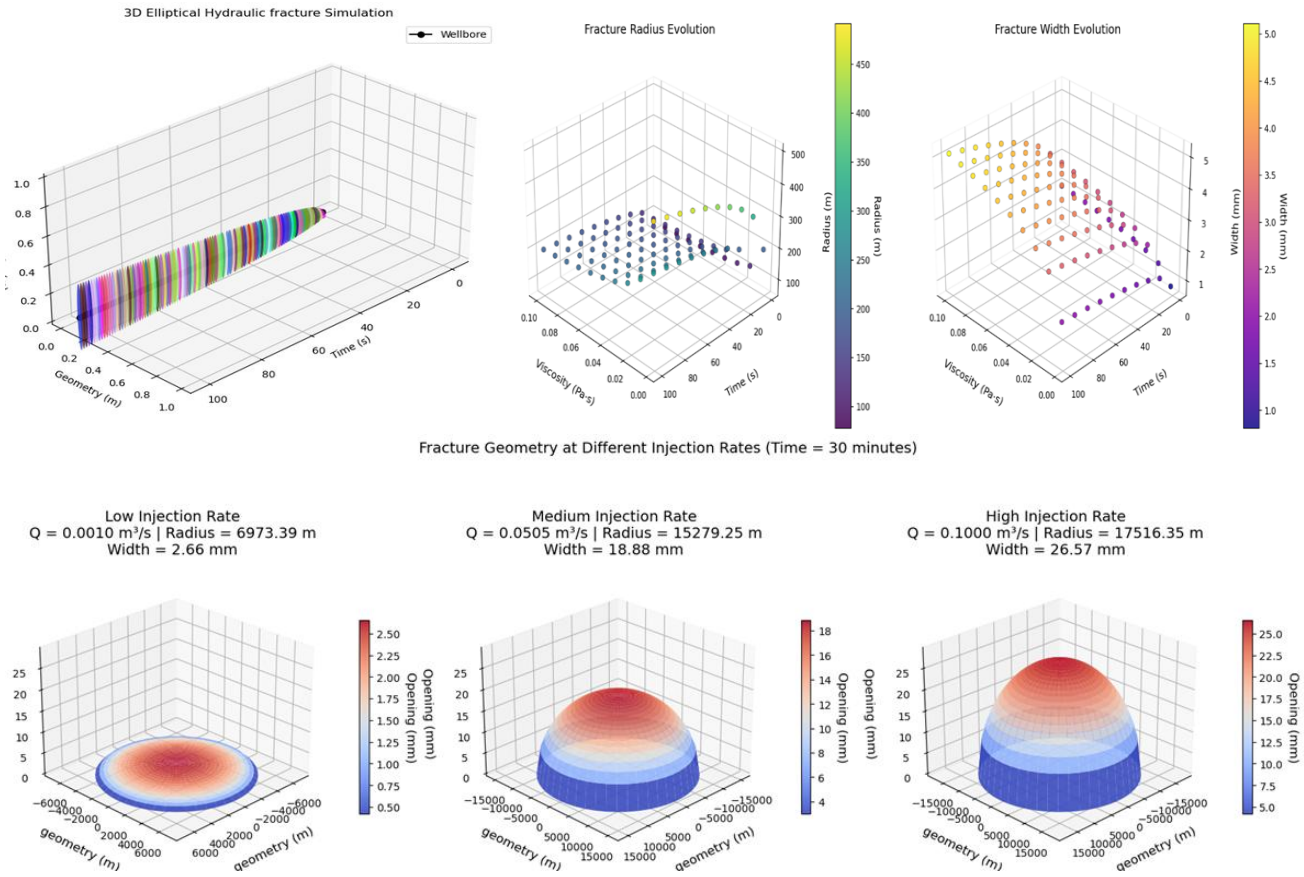

Figure 3. Simulation results showing fracture geometry under influencing parameters.

Table 1. Model performance (R^2 values) for different machine learning algorithms.

Model /RMSE	Net Pressure (MPa)	Radius (m)	Width (m)
LR	3.5613	4.4032	0
RF	0.518	0.0582	0
DT	0.3982	0.0518	0
SVR	2.3901	1.4426	0

Table 2. Model performance (RMSE values) for different machine learning algorithms.

Model /R^2	Net Pressure (MPa)	Radius (m)	Width (m)
LR	0.56	0.937	0.868
RF	0.9907	1	0.9999
DT	0.9945	1	0.9999
SVR	0.8030	0.9932	-2.03

Conclusion

This research used simulations analysis and machine learning techniques. The aim of this research was to develop prediction models to predict fracture progression in oil shale reservoirs while hydraulic fracturing operation. Before developing prediction model, simulations were run to study the impact of three parameters: operation time (s), injection fluid rate (m3/s), and dynamic viscosity (Pa. s). The simulation results revealed important insights into how each parameter influences fracture propagation, providing a solid foundation for model development. The three key parameters: Net Pressure (MPa), Fracture Radius (m), and Fracture Width (m) using four machine learning algorithms: Linear Regression (LR), Decision Tree (DT), Random Forest (RF), and Support Vector Regression (SVR). The models were evaluated using the performance metrics Root Mean Squared Error (RMSE) and R^2 Score. The results demonstrated that the performance of machine learning models varied depending on the parameter being predicted. The Random Forest model showed the highest accuracy in predicting fracture radius. This suggests that no single model consistently outperformed the others across all parameters. Instead, model selection should consider the specific target output and data characteristics. Both Linear Regression and Support Vector Regression performed less effectively, especially in capturing non-linear or complex relationships within the dataset.

Acknowledgments

This research Funded by the Ministry of Higher Education, Research, and Innovation (Undergraduate Research Grant)

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Track C – Engineering Innovation, Computing & Intelligent Systems

Paper Cod in Book 2: *C07*
Paper Page Range in Book 2*:* *101 –104*

Impact of Principal Component Analysis on Clustering Algorithms: A Comparative Study of K-Means, DBSCAN, and HDBSCAN on High-Dimensional Music Data

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Abstract

High-dimensional music datasets encompassing features such as danceability, energy, tempo, and acousticness present valuable opportunities for clustering and analysis. This study evaluates the effectiveness of three unsupervised clustering techniques, K-Means, DBSCAN, and HDBSCAN, on a dataset of 170,653 songs. We applied Principal Component Analysis (PCA) to reduce the dataset's dimensionality and assessed its impact on clustering performance using metrics such as the Davies-Bouldin Index (DBI) and the Calinski-Harabasz Index (CHI). The results showed that PCA significantly improved the performance of the K-Means algorithm, lowering the DBI from 188.58 to 16.38 and raising the CHI from 7,579.25 to 26,987.73 for a cluster count of 27. Similar enhancements were observed for 29 clusters, highlighting the adaptability of the K-Means algorithm to PCA-driven dimensionality reduction. PCA had a substantial impact on DBSCAN but a subtle effect on HDBSCAN among density-based methods. It reduced the DBI to 6.60 and increased the CHI to 1,440.92 for DBSCAN across 27 clusters, while for HDBSCAN across 29 clusters, it reduced the DBI to 5.30 but slightly decreased the CHI to 1,328.86. Although PCA's effect varies across density-based algorithms, it enhances K-Means clustering by improving separation and compactness and substantially improves DBSCAN while having a mixed impact on HDBSCAN. These results underscore the importance of nonlinear dimensionality reduction techniques and hyperparameter optimization.

Keywords: *Principal Component Analysis (PCA), K-Means, DBSCAN, HDBSCAN, Clustering.*

Introduction

In the digital music era, vast datasets containing musical attributes such as song titles and release dates are accessible. These include metrics such as danceability, energy, acousticness, and tempo. However, high-dimensional data poses challenge due to their complexity and dimensionality [1]. It is essential to select meaningful features and eliminate redundant ones. Research on high-dimensional music feature clustering involves various approaches and techniques for organizing and analyzing music data [2]. The literature emphasizes the importance of feature engineering and dimensionality reduction for classifying and clustering music data [3]. This study aims to explore clustering techniques for grouping songs based on intrinsic attributes in high-dimensional music datasets. Clustering analysis is widely used in fields such as image analysis, pattern recognition and machine learning [4,5]. Clustering, as an unsupervised learning technique, examines unclassified data, dividing it into subsets based on shared attributes. Unlike classification tasks, clustering groups data points solely based on their features. This study evaluates the performance of K-Means [6], DBSCAN (Density-Based Spatial Clustering of Applications with Noise) and HDBSCAN (Hierarchical Density-Based Spatial Clustering of Applications with Noise) using the Davies-Bouldin Index (DBI) and Calinski-Harabasz Index (CHI) as clustering metrics. Additionally, it examines the effects of PCA [7] on clustering performance in high-dimensional datasets.

Materials and Methods

This study used K-Means clustering (partition-based) and DBSCAN and HDBSCAN (density-based). DBSCAN identified 27 clusters, HDBSCAN 29. K-Means used cluster counts from DBSCAN and HDBSCAN. Clustering performance was evaluated using DBI and CHI. PCA improved the clustering algorithms' performance and visualized the dataset.

Dataset

In this study, we employed a Music Recommendation System that utilizes the Spotify Dataset, which was obtained from Kaggle. This dataset contains 170,653 songs with both numerical and categorical features. Numerical features include danceability, energy, acousticness, instrumentalness, tempo, loudness, valence, and popularity. Categorical features include song titles, artists, release dates, durations, and explicitness. We selected fifteen numerical features.

Clustering Algorithms

The K-Means algorithm is an iterative method that uses centroid updates to achieve optimal solutions. It groups data into k clusters; each cluster's centroid is the dataset mean. The number of clusters is specified in advance. This algorithm is fast, straightforward, and suitable for low-dimensional data. It is also simple and efficient, though it requires predefined cluster numbers and is sensitive to initial centroids and outliers. DBSCAN is a powerful clustering algorithm that can identify noise and outliers in data. It can detect complex shapes and is fairly robust. However, its results are sensitive to hyperparameters and may be affected by high-dimensional data [8]. The HDBSCAN algorithm is based on hierarchical clustering, like the DBSCAN algorithm, but it uses varying density thresholds to identify stable clusters. Although HDBSCAN's ability to automatically determine the number of clusters is advantageous over manual input, its performance can suffer due to computational intensity and poor parameter tuning in large datasets. Each method offers distinct advantages and disadvantages depending on the data structure and analysis requirements. This study aims to compare the K-Means, DBSCAN, and HDBSCAN algorithms from different perspectives to identify the most effective clustering method for music datasets.

Dimension Reduction

Principal component analysis (PCA) reduced the dimensionality of the dataset. This allowed us to visualize clusters and examine the impact on the efficiency of the algorithms [2]. PCA creates a new set of features that represent the variance in the dataset. During this process, the dataset is transformed, with each component representing the direction of maximum variance. PCA simplifies the dataset by retaining its significant patterns and relationships.

Experimental Results and Discussion

There are two types of performance metrics: external and internal. External metrics use true labels, while internal metrics don't. In this study, internal metrics—specifically DBI and CHI—were employed to evaluate clustering performance. The DBI assesses both cluster compactness and separation, with lower values indicating better clustering. In contrast, the CHI measures the ratio of between-cluster variance to within-cluster variance, where higher values signify improved clustering performance. We evaluated the clustering performance of the K-Means, DBSCAN, and HDBSCAN algorithms using DBI and CHI metrics, along with the impact of PCA. Table 1 presents the experimental results for each method with and without PCA. Applying principal component analysis (PCA) significantly improved the clustering performance of all algorithms, as indicated by the sharp decrease in DBI values, which showed more compact and well-separated clusters. K-Means benefited the most, with CHI values rising markedly after PCA, reflecting stronger inter-cluster separation. DBSCAN achieved higher CHI scores with PCA, indicating improved separation. HDBSCAN, on the other hand, showed slightly lower scores, possibly due to reduced density variations. Overall, PCA improved the quality of clustering, particularly for centroid- and density-based methods. One of PCA's key contributions is its ability to visualize data in lower dimensions [7]. By applying PCA, we can observe how K-Means, DBSCAN, and HDBSCAN distribute data points and separate clusters more clearly.

Table 1. Comparison of Clustering Performance with and without PCA.

Algorithm	**Number of Cluster**	**DBI (Without PCA)**	**CHI (Without PCA)**	**DBI (With PCA)**	**CHI (With PCA)**
K-Means	27	188.58	7,579.25	16.38	26,987.73
DBSCAN	27	46.09	232.71	6.59	1,440.91
K-Means	29	76.18	8,106.60	9.43	26,434.25
HDBSCAN	29	38.04	1,453.56	5.29	1,328.85

When the DBSCAN algorithm was applied to the dataset with the PCA, out of a total of 170,653 songs, 1,374 were classified as noise points and assigned a cluster label of -1. The clusters were visualized in two dimensions, as illustrated in Figure 1.

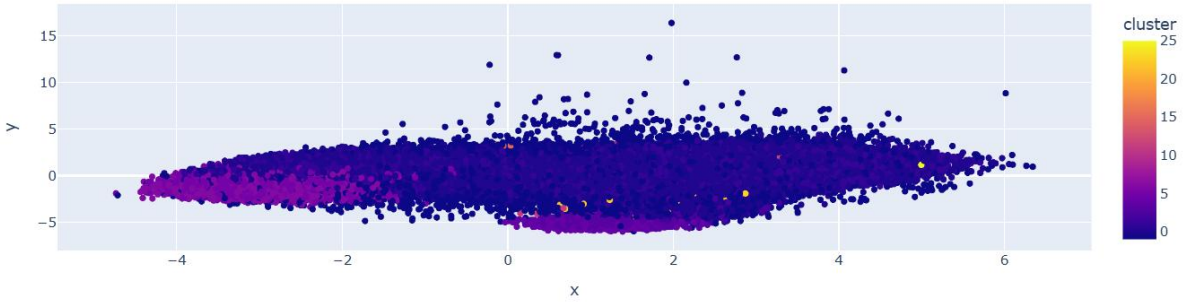

Figure 1. After applying PCA to the DBSCAN algorithm.

The DBSCAN algorithm was configured with an epsilon (eps) value of 1.5 and a minimum samples value of 8, resulting in the formation of 27 clusters. PCA not only enabled clearer visualization but also improved the computational efficiency of the DBSCAN algorithm. When the HDBSCAN algorithm was applied with PCA, 12,236 out of 170,653 songs were identified as noise, resulting in the formation of 29 clusters. Figure 2 presents the visualized clusters generated by the HDBSCAN algorithm after PCA was applied.

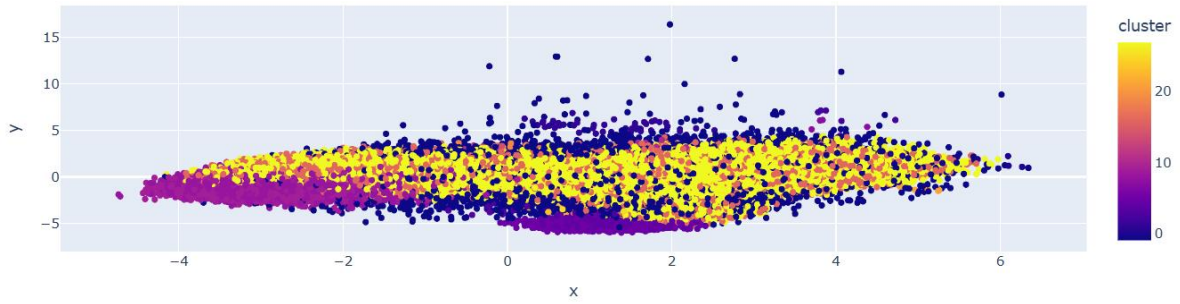

Figure 2. After applying PCA to the HDBSCAN algorithm.

In the K-Means algorithm, the number of clusters was set to match the clusters formed by the DBSCAN and HDBSCAN algorithms. When the cluster number was set to 27, no noise data were identified among the 170,653 songs, and the clustering results are visualized in Figure 3. Similarly, when the cluster number was set to 29, no noise data was obtained, and the clustering results are visualized in Figure 4.

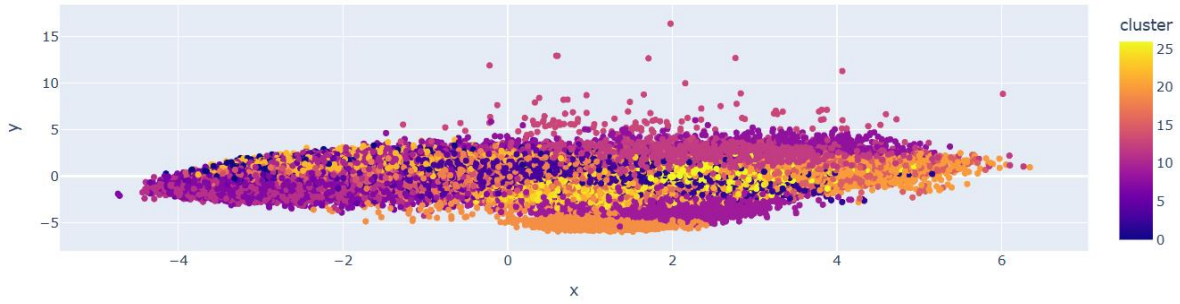

Figure 3. After applying PCA to the K-Means with 27 clusters.

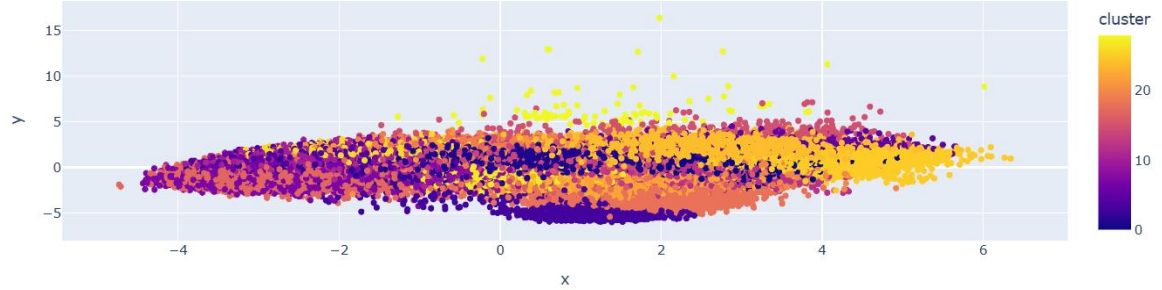

Figure 4. After applying PCA to the K-Means with 29 clusters.

In conclusion, PCA improves K-Means by increasing compactness and separation. PCA has limited impact on HDBSCAN, suggesting less influence from dimensionality reduction methods. PCA works well with linear structures, but outcomes vary with density-based algorithms due to different settings and dataset nature.

Conclusion

This study evaluates the performance of clustering algorithms such as K-Means, DBSCAN, and HDBSCAN with the PCA dimensionality reduction method. The effect of PCA was assessed using DBI and CHI metrics. The results demonstrate that PCA led to significant improvements, particularly for the K-Means algorithm, which produced more distinct and compact clusters with lower DBI and higher CHI values after PCA. In contrast, the density-based algorithms showed varied effects: DBSCAN exhibited substantial improvements (marked CHI increase to 1,440.91), while HDBSCAN showed only partial improvements (slight CHI decrease to 1,328.85). However, their performance remained constrained by the density structure of the dataset and the choice of hyperparameters. In the future, the effects of non-linear dimension reduction methods on clustering algorithms can be explored. Hybrid approaches could be investigated to improve clustering performance in high-dimensional datasets.

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Track D – Health, Environment & Human Performance Studies

Paper Cod in Book 2: *D03*
Paper Page Range in Book 2*:* *105 – 109*

Emergence of Integrated Smart Healthcare System: A Comprehensive Review of Internet of Health Things for Medical Diagnostics and Treatment

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Abstract

The Internet of health things (IoHT) is the new avenue of technology to connect smart gadgets to the human body for the collection of physiological variables and assist healthcare professionals in making informed decisions. In a traditional medical care facility, the record of the patient is routinely updated on a standalone digital system, making it difficult for medical staff to assemble and analyze the electronic health record of the patients. To overcome this problem, the existing healthcare system is transformed into a highly connected system to gather data on a centralized ecosystem. The required record is accessed for an expert medical opinion to diagnose and take anticipatory actions. This research article aims to conduct a comprehensive survey on the wireless body area sensory network, communication system, and protocols incorporated in the layered architecture hence, cause efficient delivery of information. The complex operation of the health care system is elaborated into explicit illustrations for easy understanding of medical and technology managers. The applications of diverse segments of the smart medical-care system and associated challenges of the internet-connected health system are thoroughly deliberated. With the implementation of IoHT, the efficiency for diagnosis of disease, cost optimization, and provisioning of medical care at home are substantially upgraded.

Keywords: *Biosensors, wearables, Smart Health, Healthcare protocols, Smart hospitals*

Introduction

The Internet of things in the health sector is a widely accepted technology all over the world. With the built-in feature of ubiquity in IoT, the devices connected to healthcare are accessed from every corner of the globe. Smart gadgets installed for this purpose are designed to interact with existing internet infrastructure. There is a huge scope of automation in all applications installed for IoT. The advent of the Internet of Things (IoT) has revolutionized every field of society. In pursuit of a healthy and prosperous lifestyle, the use of information and communication technology remained tremendous in the last decade. Several types of smart gadgets like sensors and actuators in the form of wearable devices are implanted at desired locations to acquire tons of data for smart decisions [1]. Also, helps to fast-tracking ambient information to remotely located practitioners and take action accordingly. The perceived data from these wearable gadgets are channelized to centralized servers in order to integrate, process, and store information for effective utilization [2]. In this context, the implementation of the Internet of Things and wireless technologies has a notable role in determining the real-time health condition of patients and further communicating with healthcare givers [3]. Internet of health things has initial growth of 24 billion US $, the upward trend is recorded, and projected growth of 135 billion is expected in 2025 as illustrated in Figure 1.

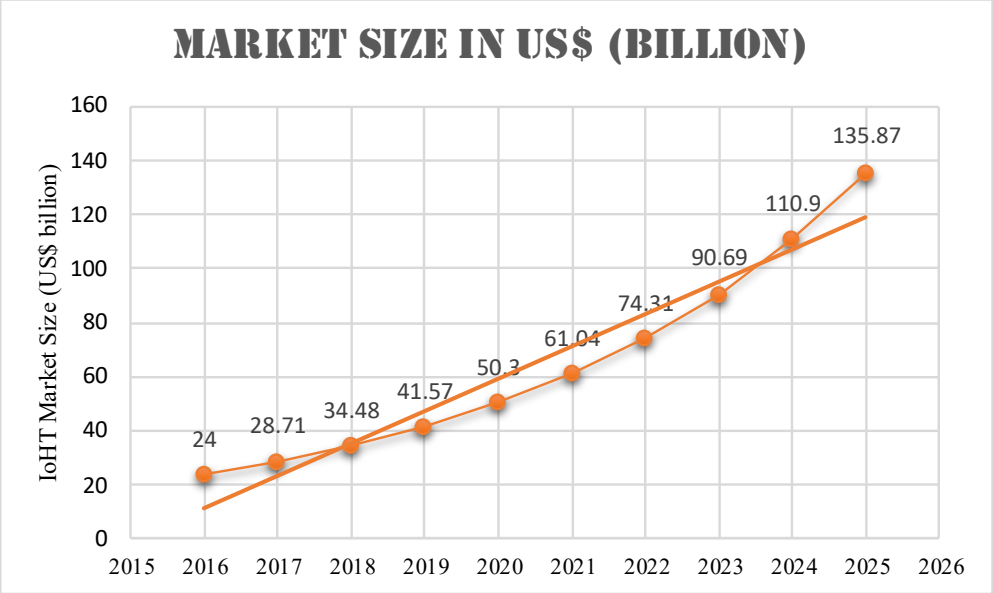

Figure 1. Worldwide market IoHT healthcare market.

The remainder of this research article is organized as follows: section 2 covers the literature review whereas Section 3 encompasses the basic architecture of the Internet of Health things that describes three crucial layers. In Section 4, different applications of the Internet of Things in the healthcare sector are thoroughly debated. The challenges presenting a barrier to the prevalence of technology are elaborated in Section 5. The discussion and conclusion are presented in sections 6 and 7 respectively and section 8 covers research limitations.

Related Work

Several scholarly research works have been analyzed to review and highlight the comparison perform in this study. Various perspectives of big data analysis and cloud computing are thoroughly covered in healthcare industries. In addition, numerous cutting-edge tools, methodologies, and applications acquired to get benefit from big data [4]. By exploring the possibility and application of augmented reality for the treatment and diagnosis of disease, detailed studies have been conducted on hardware and software are reviewed. The devices installed on the body of the patient are responsible for collection the data. The applications of such devices are encircled comprehensively in order to personalize the Internet of Health things [5]. Furthermore, the monitoring of vital activities in the case of emergency scenarios is performed with the assistance of Radio Frequency Identification(RFID) tags and the application of IoT is tested experimentally [6]. To implant reliable wearable devices on the human body at sensing layers, meticulous selection, and determining the strength and weaknesses of such devices are explored comprehensively [7]. To further strengthen the emergency department resource preservation frame is interlinked with a cloud computing system to play a role in the recording of real-life situations of patients during their stay at the hospital [8]. In war-like situations, the application of IoT to leverage the well beings of soldiers is studied. The position of soldiers is traced with the help of global position tracking and their connectivity with the cloud is secured with cryptographic algorithms [9]. IoT devices are put down in the secure framework of blockchain technology due to their built-in security features [10]. Being extremely sensitive, healthcare is made more secure with the help of a comprehensive system of monitoring termed a Healthcare Monitoring System. In this regard, a review study to discover different applications and weaknesses in the IoT-based system is reviewed to improve the overall quality of healthcare of patients [11]. Mobile health system for an elderly patient is a pivotal part of a smart city or home. Hence, the effective framework to extend emergency care to aged fellows, particularly during emergency cases. Hence, mHealth is considered as a reliable solution for elderly people to monitor their health with smart devices [12]. The framework comprised sensors being implanted on the mobile body to monitor healthcare activities. It is further validated by simulations [13]. Overall suitability of different components in miscellaneous models of IoT in the healthcare system and the lesson learned were thoroughly brought under discussion. Short and long-range communication and storage technologies were identified. In addition, security to cloud services has been declared as a big blow to existing IoHT infrastructure and suggested artificial intelligence as a reliable solution to the issue. However, different security threats require a detailed study that was not encircled in the study [14].

Materials and Methods – Layer-wise Architecture of IoHT

Perception layer

This layer is primarily comprised of a network of sensors – defined as a device to convert the attributes of physical quantities into electrical impulses to observe the surrounding environment. For instance, the motion of the body, glucose

level, blood pressure quantities, heart rate, body temperature, etc. These physical quantities are detected and processed through computational processors and corresponding output objectives are fulfilled. Numerous varieties in terms of capacity, requirement, and functionalities are applied to perceive these attributes [15].

IoHT Communication Technology Layer

The exchange of information at the gross root level of the sensors is carried out through wireless communication. Key features of these gadgets at the perception layer are low energy consumption, small size, and cheap price. The n**ear Field** Communication Wireless communication is conducted at a distance of less than 10 cm. Devices operating the technology work in either active (create its own RF field) or passive mode (receiving mode & function on the field of another device).

IoHT Protocol in the Application Layer

The specific set of rules is defined to execute the user-defined services at the topmost layer of the IP stack [16]. The purpose of applying this algorithm is to ascertain privacy, security, reliability, and authenticity over the entire system of communication. The protocol has numerous applications to establish machine-to-machine communication. In the case of the Internet of Things (IoT) network, sensors are required to make exchange messages with other sensors or actuators through the MQTT protocol

Applications of IoT

Telemedicine

The introduction of ICT has a crucial role in adding new features with low optimization costs in the existing healthcare systems of hospitals [17]. The rising prices of medical equipment have unprecedented instability consequences on global level in general and third-world countries in particular. The financial difficulties due to greying population above 65 years has increased the overall financial burden by 50%. This challenge with a life-critical health system is overcome by widely applying efficiency and automation in the health management ecosystem. The upgradation of existing infrastructure can be replaced by a smart system based on big data analytics, artificial intelligence, machine learning, and cloud computing technologies

Mobile health management

Various wearable devices implanted inside the human body are connected to smartphones with a customized software application to provide ambient and physiological information to a centralized cloud. They are further interlinked with healthcare agencies. Computer applications installed at distant hospitals allure healthcare professionals about any abnormalities so as, to deliver necessary and timely responses to the health of patients [18]. The next avenue in this connection is to determine and design strategies for efficient and immediate delivery of service.

Automated Wheelchair

The mobility of physiologically or physically impaired people is crucial in medical care-demanding situations. A wheelchair provides independence for a patient to reach the hospital. In this context, electric wheelchairs are introduced with additional intelligent features and implanted with a navigation system, IoT-based obstacle removal, and steering system. They are digitized with wearable devices, and smart infrared sensors and connected to the m-health units and cloud [19].

SCM of Pharmaceutical products

Data analytics by applying IoT and AI has made substantial advancements in the selection of pharmaceutical products for the treatment of diseases. These products are prepared and passed through a chain of supply running from the supplier to the retail store. Although, this is declared the most regulated industry, however, several anomalies of overstocking or shortages of drugs are reported. These complaints are more frequent during an outbreak of Covid-19 [20]. Introducing AI and IoT has greatly reduced the cost and regulated the inventory of pharmaceutical industries. Moreover, the efficiency of the SCM is improved by pulling the demand from drug stores instead to push the packages by the factories. High Tech gadgets will significantly reduce power, cost efficiency, and sensor precision.

Symptom Monitoring, Diagnosis, and Consultation

Presently, the nursing or medical technician staff are responsible for manually collecting the data about the health of the patient. The related data is acquired by placing stethoscopes, sphygmomanometers, and enquired questions verbally about the intensity of pain and consciousness. Smart gadgets like mobile phones or tablets are used to input data that is further transferred to a centralized health record. However, these may be accompanied by erroneous typing mistakes for life-critical data and bring about life-threatening situations [21]. To make the healthcare system more robust and freer from the mistakes of others, several wearable devices collect and transmit the data for an expert opinion as indicated

Challenges to the IoHT system:

Quality of Service

Numerous dimensions are used to improve the overall quality of the healthcare system namely Tangible quality, quality of safety & efficiency, quality of empathy and improvement of care & services. In this context, long-term goals should be identified for healthcare professionals and staff working in hospitals.

Accurate Data

The body area sensors are implanted to receive and transmit the correct information about the health of the patients. In the event of erroneous data from the subject has adverse effect on patient treatments. So, meticulous care should be taken before undergoing critical decisions about the health of a patient.

Economical Prices

The rising prices of biomedical equipment are posing a financial burden, particularly for third-world countries. The implementation of digitized records on the cloud has lowered the overall medical expenses. In some instances, medical staff is reluctant to upgrade the electronic health record for fear of privacy and security problems that pose barrier to improving the overall efficiency of the health system.

Security and Privacy

Maintaining, process, and protecting data from any kind of cyber-attacks has always been a challenge for healthcare centers. The integrity, confidentiality, and availability of health records are always prone to be tempered or abuse. Moreover, the storage of data on health care centralized cloud are confronted with security concerns and huge costs are expected to pay by the medical care industry

Conclusion

The Internet of Things has profoundly impacted and revolutionized the overall architecture of the Internet. IoT has introduced new dimensions in the infrastructures, retail, cities, healthcare, etc. In this regard, several informational and computational technologies have been incorporated that established the linkages with the internet. As far as the health sector is concerned, it is a sensitive matter and quick response is expected of sensing devices that further transmit the information via edge and cloud computers to decision-makers. A wide range of sensors carry the information from the body area. Moreover, the communication technologies and protocols discussed in the article have immense applications in healthcare. Numerous models like telemedicine, mobile health management, automated wheelchair, health solution for assistive populations, and pharmacy are the applications of IoHT. However, these are also associated with challenges to safeguard sensitive data against any misuse. This is a long-term process and requires huge financial capital and a strong will for effective implementation. Another challenge is to ensure the quality of service and protection of health-related data. In addition, the standardization and interoperability of medical gadgets and IoT equipments must be ensured to meet the object sets for IoHT.

Limitations

Although this research endeavor has surveyed the critical components of the internet of healthcare and encircled with different applications of the sectors. However, further deep research is required to identify the risk in each application of healthcare. Different artificial intelligence techniques like deep learning comprise of neural network with neurons and their network is suggested to identify and mitigate the risk.

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