Faculty of Industrial and Manufacturing Technology and Engineering

PORTABLE OIL SKIMMER DEVELOPMENT VIA KANSEI ENGINEERING WITH ANALYTICAL HIERARCHY PROCESS FOR OIL SPILLAGES RECOVERY

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DEDICATION

I dedicate this thesis to my beloved family, whose unwavering support, love, and encouragement have been the cornerstone of my academic pursuit. Your belief in my abilities has been the driving force behind every stride I have taken in this scholarly journey. Through the late nights, the challenges, and the triumphs, your unwavering faith in me has been my source of strength and determination.

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I dedicate this thesis to all of you, with heartfelt gratitude for being my pillars of strength, my guiding lights, and my unwavering sources of love and support. This achievement is as much yours as it is mine, and I embark on the next chapter of my journey with the profound knowledge that your love and encouragement will continue to illuminate my path.

ABSTRACT

The alarming impact of oil spills on the environment necessitates immediate control and recovery measures. There are different types of recovery method such as mechanical method, chemical, in-situ burning and biological method. The mechanical technique consists of boom and skimmer. The boom and skimmer are used together for the oil recovery process. However, the integration of boom presents containment challenges, and the current market of skimmers are heavy-duty and large-sized skimmers causes deployment difficulties in confined areas such as lakes, rivers, ponds, and treatment plants. Furthermore, during the design stages, the focus has traditionally been on technical requirements while neglecting user requirements. However, the dependency solely on technical requirements overlooks critical design factors such as robustness, safety, ease of use, and portability. Therefore, the objective of this reseach is to design and develop the Portable Oil Spill Skimmer (POSS) with consideration of user requirement during the initial design phase. To bridge this gap, Kansei Engineering method was employed to gather both user and technical requirements for the POSS during the early design process. Analysed data obtained from Kansei Engineering led to the identification of crucial design elements that must be considered in the design of a portable oil spill skimmer. Subsequently, five design concepts were generated, and the Analytical Hierarchy Process (AHP) was utilised for decision-making process. The AHP result indicates that design (D3) identified as the best design. Result of AHP was validated using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method. The robustness of the AHP result was confirmed through Sensitivity Analysis. Moreover, design optimisation was conducted in simulations analysis to analyse the proposed design before fabrication. Structural analysis simulations revealed a maximum stress of 23.27 MPa, maximum deformation of 9.8169×10^{-5} mm/mm, and a safety factor of 12.74 indicating that POSS has a sturdy stucture. Additionally, Computational Fluid Dynamics (CFD) simulations demonstrated that the propellers could generate 72.8 N of thrust force, capable of overcoming the hull drag of 27.11 N, indicating the skimmer's maneuverability. Further simulation was conducted to implement baffles in the oil tank to mitigate oil sloshing effects. The result indicates that there was a of 67.21% torque reduction in sloshing compared to an oil tank without baffles. The portability characteristics of the POSS satisfies 7 portable meta-heuristics and heuristics standard. Besides that, the speed of POSS was experimented, which indicates that the POSS is capable to travel at a speed of 3.72 Knots. Last but not least, the oil recovery capacity of the POSS was analysed and efficiently recovers at a rate of 8 ml/min with 90 % efficiency. As a future recommendation, it is feasible that POSS to be further developed with solar panels instead of batteries for optimum performance.

PEMBANGUNAN PENYIRING MINYAK MUDAH ALIH MELALUI KEJURUTERAAN KANSEI DENGAN PROSES HIERARKI ANALITIKAL UNTUK PEMULIHAN TUMPAHAN MINYAK

ABSTRAK

Kesan tumpahan minyak yang berlaku secara besar-besaran terhadap alam sekitar perlu dikawal segera dan langkah-langkah pemulihan perlu dijalankan. Terdapat beberapa jenis kaedah pemulihan minyak seperti kaedah mekanikal, kaedah kimia, pembakaran terbuka dan biodegradasi. Kaedah mekanikal terdiri daripada "boom" dan "skimmer". "Boom dan "skimmer" digunakan bersama untuk proses pemulihan minyak. Walau bagaimanapun, penggunaan "boom" mempunyai kelemahan dalam mengawal sebaran tumpahan minyak, dan kebanyakan "skimmer" di pasaran dunia bersaiz besar dan digunakan untuk tugasan yang tahan lasak. Ini menimbulkan kesukaran untuk menggunakan "skimmer" di kawasan terpencil seperti tasik, sungai, kolam dan loji rawatan. Tambahan pula, pada peringkat reka bentuk awal produk industri, keperluan teknikal lebih diberi tumpuan secara tradisinya dan mengabaikan keperluan pengguna. Namun demikian, kebergantungan semata-mata pada keperluan teknikal akan mengabaikan faktor reka bentuk kritikal seperti keteguhan, keselamatan, kemudahan penggunaan dan mudah alih. Oleh itu, objektif penyelidikan ini adalah untuk mereka bentuk dan membangunkan "Portable Oil Spill Skimmer" (POSS) dengan mempertimbangkan keperluan pengguna semasa proses reka bentuk awal. Untuk merapatkan jurang ini, Kejuruteraan Kansei telah digunakan untuk mengumpulkan keperluan pengguna dan teknikal untuk membangunkan POSS semasa proses reka bentuk awal. Analisis data yang diperoleh daripada Kejuruteraan Kansei membawa kepada pengenalpastian elemen reka bentuk penting yang perlu dipertimbangkan dalam reka bentuk POSS. Selepas itu, lima konsep reka bentuk telah dihasilkan, dan Proses Hierarki Analitik (AHP) telah digunakan untuk membuat keputusan. Didapati bahawa reka bentuk (D3) dikenal pasti sebagai pilihan yang terbaik. Hasil dan kekukuhan AHP telah disahkan melalui pengunaan kaedah Teknik untuk Keutamaan Pesanan oleh Keserupaan dengan Penyelesaian Ideal (TOPSIS) dan analisis sensitiviti. Setelah itu, simulasi pengoptimuman reka bentuk telah dijalankan untuk menganalisis reka bentuk yang dipilih sebelum proses fabrikasi. Analisa simulasi struktur menunjukkan bahawa POSS mempunyai struktur yang kukuh kerana mempunyai ketegasan maksimum sebanyak 23.27 MPa, maksimum "deformation" 9.8169 x 10^-5 mm/mm, dan faktor keselamatan sebanyak 12.74. Selain itu, simulasi "Computational Fluid Dynamics (CFD)" menunjukkan bahawa kipas POSS mampu menjana 72.8 N daya tujahan, mengatasi seretan badan kapal sebanyak 27.11 N. Simulasi selanjutnya menilai pengunaan sesekat dalam tangki minyak untuk mengurangkan kesan kocakan minyak semasa pelbagai senario operasi. Simulasi menunjukkan bahawa terdapat pengurangan kilas sebanyak 67.21 % dalam kocakan minyak berbanding tangki minyak tanpa sesekat. Ciri mudah alih POSS memenuhi 7 kriteria mudah alih meta-heuristik dan heuristik. Selain itu, kelajuan POSS telah diuji dan menunjukkan bahawa POSS mampu bergerak pada kelajuan 3.72 Knots. Akhir sekali, kapasiti pemulihan minyak POSS telah dianalisis dan POSS mampu memulih minyak dengan cekap pada kadar 8 ml/min dengan kecekapan 90 %. Untuk cadangan masa hadapan, POSS boleh dibangunkan lagi dengan panel solar untuk prestasi yang lebih optimum.

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LIST OF ABBREVIATIONS

UTeM	-	Universiti Teknikal Malaysia Melaka
OSRR	-	Oil spill Response and Recovery
NPD	-	New Product Development
POSS	-	Portable Oil Spill Skimmer
MCDM	-	Multicriteria Decision Making
AHP	-	Analytical Hierarchy Process
KE	-	Kansei Engineering
FEM	-	Finite Element Model
CFD	-	Computational Fluid Dynamics
TOPSIS	-	Technique for Order of Preference by Similarity to Ideal Solution
FEA	-	Finite Element Analysis
DCE	-	Discrete Choice Experiment
PIS	-	Positive-Ideal Solution
MCDA	-	Multi-Criteria Decision Analysis
QFD	-	Quality Function Deployment
MOPSO	-	Multi-Objective Particle Swarm Optimisation
ELECTRE	-	Elimination and Choice Expressing Reality
VIKOR	-	VIekriterijumsko KOmpromisno Rangiranje
ANP	-	Analytical Network Process
DEMATEL	-	Decision Making Trial and Evaluation Laboratory
TRIZ	-	Theory of Inventive Problem Solving
IR	-	Integrated Rough
DEA	-	Data Envelopment Analysis

MAIRCA	-	Multi-Attribute Ideal Real Comparative Analysis
FFTA	-	Fuzzy Fault Tree Analysis
WMSD	-	Work-Related Musculoskeletal Illness
HFACS	-	Human Factor Analysis and Classification Scheme
FAHP	-	Fuzzy Analytical Hierarchy Process
SCOR	-	Supply Chain Operations Reference
ASIM	-	AHP-SCOR Integrated Model
SWOC	-	Strength, Weakness, Opportunity and Challenge
FMECA	-	Failure Mode Effect and Criticality Analysis
EOQ	-	Economic Order Quantity
ROQ	-	Reorder Quantity
BOCR	-	Benefits, Opportunities, Costs, and Risk
VOC	-	Voice of Customer
FTOPSIS	-	Fuzzy Technique for Order Preference by Similarity to Ideal Solution
PuCC	-	Pugh's Controlled Convergence
PROMETHEE	-	Preference Ranking Organisation Method for Enrichment Evaluation
HBWFAD	-	Hierarchical Best-Worst Fuzzy Axiomatic Design
FAD	-	Fuzzy Axiomatic Design
FBWM	-	Fuzzy Best-Worst Method
PERMA	-	Positive Emotions, Engagement, Relationships, Meaning and Achievement
CNC	-	Computer Numerical Control
IMM	-	Injection Moulding Machines
FKES	-	Forward Kansei Engineering System
BKES	-	Backward Kansei Engineering System
HKES	-	Hybrid Kansei Engineering System

ISM - Interpretive structural modelling

PLS - Partial Least Squares

SD - Semantic Differential

CAD - Computer-Aided Design

ABS - Acrylonitrile Butadiene Styrene

PVC - Polyvinylchloride

PC - Polycarbonate

USV - Unmanned Surface Vehicle

PP - Polypropylene

PET - Polyethylene Terephthalate

UP - Polyester

GFRP - Glass-Fiber Reinforced Plastic

CR - Consistency Ratio

RPM - Rotation Per Minute

ORR - Oil Recovery Rate

ORE - Oil Recovery Efficiency

CI - Consistency Index

LIST OF SYMBOLS

α	-	Alpha
β	-	Beta
T	-	Time
t_o	-	Time for Sampling
t_i	-	Length of Time
Z	-	Standard Normal Distribution
n	-	Number of Respondent
ES	-	Effect Size
N	-	Number of Item
$\bar{c}$	-	Average Covariance Between Items-Pairs
$\bar{v}$	-	Average Variance
λ_{max}	-	Eigen Value
V_{oil}	-	Volume of Collected Oil
Vt	-	Total Volume of Oil and Water Collected

LIST OF APPENDICES

LIST OF PUBLICATIONS

The followings are the list of publications related to the work on this dissertation/master project/project paper:

Ramanathan, R., Abdullah, L. and Mohamed, M.S., 2021, November. The utilisation of Kansei Engineering in designing conceptual design of oil spill skimmer. In *Symposium on Intelligent Manufacturing and Mechatronics* (pp. 434-447). Singapore: Springer Nature Singapore.

Ramanathan, R., Abdullah, L., Mohamed, S. and Fauadi, M.H.F.M., 2022. A Review of User-Centred Design Methods for Designing a Portable Oil Spill Skimmer. *Nature Environment & Pollution Technology*, 21(4).

Ramanathan, R., Abdullah, L., Fauadi, M.H.F.M., Mohamed, M.S.S. and Kamaludin, K.N., 2023. A Hybrid of Kansei Engineering (KE) And Analytical Hierarchy Process (AHP) to Develop Conceptual Designs of Portable Oil Spill Skimmer. *IIUM Engineering Journal*, *24*(1), pp.183-198.

Ramanathan, R., Maslan, M.N., Abdullah, L., Fauadi, M.M., Ali, M.M. and Chairat, A.N., 2023. Optimization of Oil Tank Design to Minimize Liquid Sloshing in Portable Oil Spill Skimmer. *Journal of Advanced Manufacturing Technology (JAMT)*, *17*(2).

Ramanathan, R., Abdullah, L., Fauadi, M.M., Mohamed, M.S., Aras, M.S.M. and Chairat, A.N., 2023. Mechanical Stress-Strain Analysis of A Portable Oil Spill Skimmer Frame for Response and Recovery Activities. *Journal of Advanced Manufacturing Technology (JAMT)*, *17*(1).

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Over the last decades, oil spills have been one of the world's most significant issues for a long time and are the leading cause of water pollution (Nelson and Grubesic, 2018). The oil cleanup takes months to restore the surrounding areas.

Each year, there are reports of thousands of minor and several major oil spills related to tanker operations. Annually, the global oceans receive a volume of oil that surpasses one million metric tonnes. This is due to the high demand for oil and transport over the years (Cakir et al., 2021). In addition, industries, and individuals' unintentional or negligent release of used gasoline solvents and lubricants greatly aggravates the overall environmental problem.

Many techniques in Oil Spill Response and Recovery (OSRR) are able to solve the oil spillage issue. Mechanical techniques, chemical techniques, open burning, and biodegradation are the methods used to clean up oil spills (Li et al., 2016). In the mechanical technique, a boom and skimmer method are used to tackle oil spill issues. Boom acts as a barrier that controls the movement of oil from spreading, and the skimmer functions as an oil suction machine to remove oil from the water surface.

Furthermore, the product development process is one of the most crucial processes that need to be taken into consideration as it helps designers design and develop a new product. A manufacturing company's ability to compete and succeed depends significantly on the introduction of new products. However, not every new product development (NPD)