UNIVERSITI PUTRA MALAYSIA

TRAINING OF THERMOELECTRIC GENERATOR MAINTENANCE USING VIRTUAL REALITY IN OIL AND GAS INDUSTRY

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By

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TRAINING OF THERMOELECTRIC GENERATOR MAINTENANCE USING VIRTUAL REALITY IN OIL AND GAS INDUSTRY

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Faculty : Engineering

Major oil and gas companies in recent years have advocated for the design and development of virtual maintenance training system for the greater benefit of people and the environment, focusing on sustainable development. The oil and gas industry often require people to work in hazardous environments; these environments are constantly increasing in size and complexity, hence companies continue to look for new more cost-effective ways of doing training for maintenance. Furthermore, VR training platform eliminates injuries from the training session. Providing training to a fresh maintenance worker is highly risky as they might have zero knowledge on TEGs and its handling. Hence, implementation of VR training platform will eliminate the risk of accidents in the maintenance area. This research work was conducted in companies where the business scope includes thermoelectric generators (TEG). The aim of this work is to design and develop virtual reality (VR) system for maintenance training of the cooling system in oil and gas industry. Evaluation of the efficiency in implementing series of training through the Virtual Reality (VR) system was performed and finally process performance data was compared. The activity of removing and installing heat pipe in thermoelectric generator in onshore pipeline activity was selected for the VR training platform. Maya software was used to design heat pipe system. Meanwhile, Unity 2017 software was used to create heat pipe assembly and VR interfaces. VR training platform was built using a personal computer, HTC Vive was used as monitor base and controller, and SteamVR 1.2.1 and VRTK 3.1.0 sub-component of Unity software were used. The developed VR software was evaluated by ten maintenance workers in the oil and gas industry, associated with the TEG companies. The effectiveness of the developed VR training platform was also studied. Evaluation of the experts gave a mean score of 2.73 out of 5 for pre-questionnaire and 3.27 out of 5 for post-questionnaire of the VR software, indicating that the software developed has potential of providing effective and significant training to the maintenance personnel after VR training had been done in VR environment. Furthermore, the effectiveness of the VR training platform was compared with the existing

maintenance training method. Maintenance workers verified that they have gained beneficial input and experience in VR training platform compared to the existing maintenance method. Finally, the research provides a framework for oil and gas industry adoption with VR technology. This framework was evaluated by ten industrial experts in oil and gas industry and which recommends the VR technology adoption for the oil and gas industry based on its remarkable points in each department of the industry. The framework will help policy makers, managers, designers, engineers, and researchers to decide more easily and efficiently for technology implementation in VR. The developed framework was validated using another set of questionnaire survey. Overall for framework applicability on VR adoption, seven of the respondent agree that the framework is applicable to oil and gas industry while three of the respondent commented that the framework need a certain adjustment and still good enough to helps workers in oil and gas industry for training program, comprehensive approach, covers all major aspects of VR adoption in Kuwait oil and gas industry, and it provides a straightforward guidance even for beginners.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

LATIHAN PENYELENGGARAAN GENERATOR TERMOELEKTRIK MENGGUNAKAN REALITI MAYA DALAM INDUSTRI MINYAK DAN GAS

Oleh

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April 2021

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Beberapa tahun kebelakangan ini, syarikat minyak dan gas utama telah mula menyokong perancangan dan pengembangan sistem latihan penyelenggaraan secara maya untuk manfaat yang lebih besar bagi para pekerja dan persekitaran, memfokuskan pada pembangunan kelestarian. Industri minyak dan gas sering memerlukan orang bekerja di persekitaran berbahaya; persekitaran ini terus meningkat dari segi ukuran dan kerumitan, oleh itu syarikat terus mencari kaedah baru yang lebih menjimatkan untuk melakukan latihan untuk penyelenggaraan. Selain itu, platform latihan realiti maya (VR) dapat mengurangkan risiko kecederaan dalam sesi latihan. Latihan kepada pekerja penyelenggaraan baru amat berisiko tinggi kerana mereka mungkin tidak mempunyai pengetahuan mengenai TEG dan kaedah pengendaliannya. Oleh itu, pelaksanaan platform latihan realiti maya (VR) berupaya mengurangkan risiko kemalangan di kawasan penyelenggaraan. Kerja penyelidikan ini dilakukan di syarikat-syarikat di mana ruang lingkup perniagaan merangkumi penjana termoelektrik (TEG). Tujuan kerja penyelidikan ini adalah untuk merancang dan mengembangkan sistem realiti maya (VR) untuk latihan penyelenggaraan sistem penyejukan dalam industri minyak dan gas. Penilaian kecekapan dalam pelaksanaan siri latihan melalui sistem realiti maya (VR) dilakukan dan akhirnya data diproses serta prestasi sistem dibandingkan. Kegiatan mengeluarkan dan memasang paip haba di generator termoelektrik dalam aktiviti saluran paip darat dipilih untuk platform latihan realiti maya (VR). Perisian Maya digunakan untuk merancang sistem paip haba. Sementara itu, perisian Unity 2017 digunakan untuk membuat pemasangan paip haba dan antara muka VR. Platform latihan VR dibangunkan menggunakan komputer peribadi, HTC Vive digunakan sebagai pangkalan monitor dan pengawal, dan SteamVR 1.2.1 dan VRTK 3.1.0 sub-komponen perisian Unity turut digunakan. Perisian VR yang dikembangkan dinilai oleh sepuluh pekerja penyelenggaraan dalam industri minyak dan gas, yang berkaitan dengan syarikat TEG. Keberkesanan platform latihan realiti maya (VR) yang dikembangkan juga dikaji. Penilaian para pakar memberikan skor 2.73 dari 5 untuk pra-kaji selidik dan

untuk 3.27 untuk pasca-soal selidik perisian VR, yang menunjukkan bahawa perisian yang dikembangkan berpotensi memberikan latihan yang efektif dan signifikan kepada petugas penyelenggaraan. Selanjutnya, keberkesanan platform latihan VR dibandingkan dengan kaedah latihan penyelenggaraan konvensional. Pekerja penyelenggaraan mengesahkan bahawa mereka telah memperoleh info dan pengalaman yang bermanfaat dalam platform latihan VR berbanding dengan kaedah penyelenggaraan konvesional. Akhirnya, penyelidikan ini menyediakan kerangka untuk penerapan industri minyak dan gas dengan teknologi VR. Kerangka ini dinilai oleh sepuluh pakar industri dalam industri minyak dan gas dan yang mengesyorkan penggunaan teknologi VR untuk industri minyak dan gas berdasarkan markah yang memberangsangkan di setiap jabatan industri. Rangka kerja ini akan membantu pembuat dasar, pengurus, perancang, jurutera, dan penyelidik membuat keputusan dengan lebih mudah dan cekap dalam pelaksanaan teknologi dalam VR. Rangka kerja yang dikembangkan disahkan menggunakan satu set tinjauan soal selidik yang lain. Secara keseluruhan untuk penerapan kerangka pada penggunaan VR, 85% responden setuju bahawa kerangka tersebut sesuai untuk diadaptasi di dalam industri minyak dan gas sementara 15% responden menyatakan bahawa kerangka tersebut memerlukan penyesuaian tertentu tetapi masih cukup baik untuk membantu pekerja di industri minyak dan gas untuk program latihan, pendekatan komprehensif, merangkumi semua aspek utama penerapan VR dalam industri minyak dan gas Kuwait, dan ini memberikan panduan langsung bahkan untuk pemula.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
CAD	Computer Aided Design
CAL	Computer Aided Learning
CFP	Clean Fuel Project
CHIVE	Cable Harnessing In Virtual Environment
EAI	External Authoring Interface
HMD	Head Mounted Displays
HTML	Hypertext Markup Language
HVO	Hydrotreated Vegetable Oil
ICT	Information and Communication Technologies
KNPC	Kuwait National Petroleum Company
KPC	Kuwait Petroleum Corporation
LNG	Liquefied Natural Gas
MAA	Mina-Al-Ahmadi Refinery
MAB	Mina Abdullah Refinery
NC	Numerical Control
PC	Personal Computer
POI	Percentage of Improvement
QA	Quality Assurance
SET	Simultaneous Engineering Teams
SGIS	Silicon Graphics International
TEG	Thermoelectric Generators
TQ	Total Quality Management

VA	Virtual Assembly
VE	Virtual Environment
VP	Virtual Prototyping
VR	Virtual Reality
VRML	Virtual Reality Modelling Language

CHAPTER 1

INTRODUCTION

1.1 Preliminaries

This chapter provides a brief overview of the research presented in this thesis. The background work of this research area is first reviewed. The research statement, objectives and hypotheses are then outlined. Finally, the layout of the remaining structure of the thesis is presented.

1.2 Introduction

Interactive 3D technology is a versatile way to portray and observe dynamic, potentially dangerous processes or environments in a safe manner (Zhou et al., 2019). Virtual reality can be described as the transformation of external data into a visual image. That helps explain complex ideas simply, because virtual way of perceiving information is more convenient and simple for human beings (Lee et al., 2020). Engineers can analyze dangerous situations and mitigate possible incident-prone areas using Virtual Reality technologies in secure virtual environments; the opportunity to make and learn from errors when executing complex procedures and directions is a cornerstone of how training and instructional solutions are designed (Aziz et al., 2018). Within this 'learning by doing' approach, a user can quickly identify a problem, ask questions, or receive just-in-time mentoring about any consequences of his actions. The objective of all operators training is to improve a skill set as rapidly and effectively as possible. The realism associated with Virtual Reality training greatly accelerates learning and skill acquisition. In fact, the combination of VR and traditional training has been proven (Kozlak et al., 2013). Hence, it can be concluded that, visualisation is the best approach to train someone, to provide knowledge to someone and to make someone learn fast.

A great advantage of the virtual training platform is that it can be separated from the real world in space and time and in such a way it does not disturb the work operations, and there is no need to physically build expensive training areas (Montecucco et al., 2014). It could be argued that the greatest benefit of AR and VR training scenarios and exercise play is that it can be stored digitally. This allows an evaluation to be carried out more effectively with the ability to view individual elements of the exercise. The ability of these platforms to support data and video capture of time and critical action elements is an invaluable tool for the analysis of the individual and the training provider itself. This can be used to more accurately gather lessons learned and develop corrective actions necessary for the after-action review process.

In context of oil and gas industry, VR has huge and wide perspective. As the industries are moving towards digitalization, to minimize the operational cost and maximize their profit, VR approach becomes essential at different phases. Thermoelectric generators (TEGs) are used to recover the useful energy produced, from the waste heat. The use of TEGs in oil and gas industry has increased over the decades, ranging from microwatts to kilowatts (Montecucco, 2014). The operation on TEGs comprises huge amount of both scattered and specific data. Besides that, at every stage, the operation requires complex integration between the employees of different sector of the industry. Oil and gas companies will have to use new emerging technologies to increase efficiency, reduce production costs, boost product quality, and shorten lead times in today's competitive environment (Ji, 2002).Thus, the application of Virtual Reality technologies in training processes has been shown as an interested topic in the industrial environment and researchers.

1.3 Background of the Study

VR is defined as transformation of environing information to mental illustration. VR aids in the explanation of complex ideas, as information illustration is convenient for the humankind to digest and practise. According to Napoleon Bonaparte, a good sketch is better than a long speech. Human brain works in such way that it processes images and illustrations faster than anything else does. Thousand words of instruction or work procedure can be explained easily in a single picture or more (Burdea, & Coiffet, 2003).

Human brain can visualise the scenario within a picture immediately. Rapid image processing developed over the evolution of technology and industry. The ability to distinguish the colours of berry prevented our ancestors from being poisoned. This is an example of easy learning. Pictures help to connect emotional components, making someone feel involved with the subject (Herrmann, 1997). Implementation of VR training platform offers huge advantage to the industry as it does not interrupt the operation and does not require investment on the training facilities (Hall, & Pesenti, 2017).

Oil and gas is highly important commodity in global context. The demand for oil and gas commodity increases rapidly. Introduction of technologies and innovations has made the industry more complex. The complexity results from process, poorly skilled manpower, security regulation over the global boundaries and increasing operational costs. Most of the oil and gas platform aims to minimise the operational cost and maximize the performance (Nunes, Pereira, & Alves, 2017). Introduction of VR concept into the oil and gas industry will be a bridge to tailor the industry complexity, innovations and improvise the business value.

In today's competitive world, manufacturing companies are in the midst of implementing new technologies to increase their productivity and reduce their operational costs. At the same time, the manufacturers also aim to sustain their product quality, minimise the lead-time (Ji, 2002) and improvise the inventory management. Besides that, development of science and technology has made the equipment involved in manufacturing more complex. This demands special care in context of maintenance. Hence, manufacturers need to invest huge amount to train their maintenance crew on proper handling of equipment in the industry. Implementation of VR concept in training has developed huge interest among researchers. The interests have been validated with appropriate reasons. VR technology offers realistic representation of the real world in cheaper solution. Trainings in the VR platform provide training based on real prototype models (Wang et al., 2018).

Besides that, VR training platform also uses the Computer Aided Design (CAD), which has been widely utilised in the industry. Integration of VR training platform with CAD enables the use of 3D models, which ease the development of prototypes. Oliveira et al. (2017) stated that 3D models make the interaction more interesting and makes the learning more natural by using blueprints, videos and interaction platform between students and the model. VR technologies include collaboration of several fields of knowledge, to create a platform that is fit for use based on the user expertise and requirement. VR system is able to operate on a stereoscopic cave with haptic interface or it can also be operated from a simple desktop computer. VR technology is able to operate independently on a chosen environment. The level of user, depth of interaction and simulation of models can be pre-determined before entering the VR system.

To be precise, the interactivity and simulation of VR training platform makes the system to be different from CAD tools. The third characteristic of the VR training platform is that it is simplicity. VR system is expected to be simple and easily understandable by even low-skilled user. Oliveira et al. (2007) stated that a realistic model must be built with intuitive interface and let the user experience the sensation of being in real world.

1.4 Problem Statement

Heat pipes inside the TEG affected often due to the high temperature within the block valve station, which is located in desert area. Hence, there is a need of replacement of heat pipes at interval of two months, minimum. The maintenance trainings provided for TEG is mainly on the removal of heat pipes manually, which involves risky tasks. Workplace accidents involving high temperature components can be highly adverse. A research by Pantelidis (2010) revealed that 20% to 25% of industrial errors results from mistakes in training, by either the learner or instructor. Such mistakes are considered as demoralizing to the learner, harm the workplace environments and has higher tendency to damage the equipment. Such events will result in costly solution, incurring a lot of money.

Replacement of heat pipes generally requires high skilled technician, with helicopter access. Besides that, if the area is in the high temperature zone, the assigned workers must have full knowledge on the heat pipes replacement and the geographic of the location (Us et al., 2019). Pipelines goes out-of-control easily when there is power cut due to TEG shut down. It is vital to maintain the TEG in excellent working condition in order to eliminate the risk of production loss. Safe and efficient pipelines replacement requires well-trained and highly competent workers, to eliminate the occurrence of damages and other constraints. The highly qualified or experts are required to maintain the activities involving TEG compared to those engaged with liquefaction plants. Maintenance of TEG includes dangerous and naturally explosive parts. Inherent issues of TEG are observed with the aging of facilities and during the installation period. Seymour et al. (2002) and Hamilton et al. (2002) stated that 3D VR training platform are more interactive and more natural compared to blueprints or videos. Gallagher et al. (2004) seconded this statement in his research. This research revolves on the development of VR training platform to train the maintenance crew of TEG in oil and gas industry.

Recently, the use of computer tools and new technologies is highlighted to be useful in the enhancement of the design and manufacturing engineering (Gusikhin et al., 2007). Liang (2007) in line with the above statement agreed that by applying computer tools and VR technology could shorten development cycle of new products, and reduce production costs. Moreover, it is reported that VR technology benefits from remarkable sense of presence that makes it stand out from other synthetic environments (Sherstyuk et al., 2010). Without adopting to the advanced technology like VR, the oil and gas industries cannot compete with its global competitors. They need to choose the right technology for the right purpose. The developers of technologies also need to select the appropriate technology for the requirement of industry. In addition, there is a clear lacking behind the selection process of technology, especially VR. Therefore, it is essential to do the research on VR and 3D used in industries to have a complete overview of the technology that may help the industrialists, researchers and developers.

1.5 Research Objectives

The aim of this research is to develop a VR training platform for the TEGs maintenance workers in oil and gas industry. Following objectives were established:

1. To develop Virtual Reality (VR) training platform for heat pipe removal and installation in pipeline in oil and gas industry.
2. To evaluate the effectiveness of VR training platform.
3. To develop framework of adopting VR in oil and gas industry.

1.6 Scope and Limitation of Work

The overall research is done at Kuwait National Petroleum Company (KNPC) and the Ministry of Oil (Kuwait) for feedback regarding VR technology. In achieving the objectives of this study, a series of experimental work were conducted on the development of VR training platform and the validation of the VR platform. This research focuses on heat pipe removal and installation in TEGs pipeline in oil and gas industry, together with the maintenance activities related to it. The Virtual Reality (VR) application development is done by using 3D modelling software, animation software and Unity platform software. Lastly experiments are done to evaluate the effectiveness and acceptance level of virtual reality TEG maintenance training in oil and gas compared to normal conventional TEG maintenance training.

The major limitations in this study that could be addressed in future research is this study only focused on the development of Thermoelectric Generators (TEG) VR parts. VR training platform has few manifestations. Obeying the code of conduct and confidentiality, the technology used is kept confidential within the boundary of oil and gas. Hence, the design, construction of the platform, hand-over and commissioning are excluded from reporting.

1.7 Thesis Outline

This study has been conducted into six main steps: Data collection, literature research and development of survey‘s questionnaires, risk based survey‘s, survey‘s analyzing and survey‘s identifying and following with the development of production planning software based on the survey‘s results and finally the implementing a risk-ranking methodology to prioritize risks within and across projects and identify and analysis the effectiveness of the developed software. Chapter 1 provides with overviews of the study and the objectives of the study. Chapter 2 represents a comprehensive literature review from the related issues, Chapter 3 provides the methodology used in this study, Chapter 4 represents the result and discussion from surveys and finally Chapter 5 consists of the summary or conclusion of this study. In this chapter a general conclusions are presented for each sections and lastly, a recommended for future research are presented

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LIST OF PUBLICATIONS

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Faieza Abdul Aziz, Adel S M A Alsaeed, Shamsuddin Sulaiman, Mohd Khairol Anuar Mohd Ariffin & Abdul Rahman Yahya Al-Arhabi, Virtual Reality Training Platform in Onshore Pipeline, 4th International Conference on Mechanical, Manufacturing and Plant Engineering (ICMMPE2018), 14-15 November 2018, Melaka.

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