IDENTIFICATION OF PIPELINE CRACKING AREA IN UNDERWATER ENVIRONMENT

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DECLARATION

I declare that this thesis entitled "IDENTIFICATION OF PIPELINE CRACKING AREA IN UNDERWATER ENVIRONMENT" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name :

Date :

APPROVAL

I hereby declare that I have checked this report entitled "IDENTIFICATION OF PIPELINE CRACKING AREA IN UNDERWATER ENVIRONMENT" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature	:	....
Supervisor Name	:	....
Date	:	....

DEDICATIONS

To my beloved mother and father

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ABSTRACT

Underwater pipelines are usually used to transport oil and natural gas in huge quantities and over long distances. Cracking in underwater pipelines is hard to be detected and the cracking had caused a large number of past accidents throughout the world. The main problem for detecting the cracking area or location is the poor visibility in underwater environment. The objectives of this study are to develop image processing method in identifying the cracking area using real underwater pipeline's images and analyse the pipeline cracking area in different types of artificial underwater environment. In the proposed system, the images of cracking pipeline were collected and undergoes image processing algorithm, which include grayscale image, image filtering, image thresholding and edge detection. Then, contour method was used to find the coordinates of the cracking area from the processed images. Two experiments were designed to fulfil the objectives. The first experiment is to identify the pipeline's crack using the images from real underwater environment, while other experiments are to determine the pipeline cracking area using images from artificial underwater environment in different conditions. In the first experiment, suitable filter, threshold method and edge detector are chosen for the system. The percent error of the proposed system is determined in Experiment 2 for different conditions. For the result of Experiment 1, the proposed system is including Gaussian filter, simple thresholding and Canny edge detection. From Experiment 2, the performance of the proposed system is the best in the condition of low turbidity level with high lighting level. The condition of high turbidity level with low lighting level had the worst performance as the resulted percent error had reached more than 70% and half of the cracking parts cannot be found in this condition. Therefore, turbidity and lighting conditions is important for image processing.

ABSTRAK

Saluran paip bawah air biasanya digunakan untuk mengangkut sejumlah besar minyak dan gas melalaui jarak yang panjang. Bagaimanapun, retakan yang ada pada saluran paip bawah air susah untuk dikesan dan retakan tersebut telah menyebabkan berlakunya kemalangan yang berjumlah besar dalam seluruh dunia. Masalah yang terbesar bagi mengesan retakan tersebut adalah disebabakan penglihatan yang buruk ketika berada di bawah air. Tujuan kajian ini adalah untuk mengkaji penggunanaan teknik pemprosesan gambar dalam mengesan kawasan retakan pada saluran paip bawah air yang sebenar dan menganalisis kawasan retakan pada saluran paip yang berada dalam pelbagai keadaan persekitaran bawah air buatan. Dalam sistem yang dicadangkan, gambar-gambar retakan paip telah dikumpul dan teknik pemprosesan gambar telah dijalankan di mana teknik tersebut merangkumi menukar gambar asal kepada gambar skala kelabu, menapiskan gambar, mengambangkan gambar and *edge detection*. Selepas teknik pemprosesan gambar, teknik *Contour* telah digunakan untuk mencari koordinat kawasan retakan daripada gambar yang telah diproseskan. Dua eksperimen telah dijalankan untuk memenuhi tujuan kajian ini. Eksperimen pertama adalah untuk mengenal pasti retak saluran paip dengan menggunakan gambar dari persekitaran bawah air sebenar, manakala eksperimen lain adalah untuk menentukan saluran paip kawasan retak menggunakan imej daripada persekitaran bawah air buatan dalam keadaan yang berbeza. Dalam eksperimen pertama, penapis, kaedah ambang dan *edge detector* yang sesuai dipilih untuk system tersebut. Peratus kesilapan sistem ditentukan dalam Eksperimen 2 untuk keadaan yang berbeza. Untuk hasil Eksperimen 1, sistem yang dicadangkan termasuk penapis *Gaussian*, penguncian mudah dan *Canny edge detection*. Dari Eksperimen 2, prestasi sistem yang dicadangkan adalah yang terbaik dalam keadaan tahap kekeruhan yang rendah dengan tahap pencahayaan yang tinggi. Keadaan paras kekeruhan yang tinggi dengan tahap pencahayaan rendah mempunyai prestasi terburuk kerana kesilapan peratus telah mencapai lebih daripada 70% dan separuh daripada bahagian retak tidak dapat ditemui dalam keadaan ini. Oleh itu, tahap kekeruhan dan pencahayaan adalah penting untuk pemprosesan imej.

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CHAPTER 1

INTRODUCTION

This chapter describes the motivation and problem statement to give an idea of the contribution of the research study. The objectives and scope of the study are also described.

1.1 Motivation

Nowadays, fluids such as water, oil, natural gas and carbon dioxide have been moved in huge quantities and long distances using pipelines. Pipelines system are generally divided into two: onshore pipelines (land pipelines) and offshore pipelines (underwater pipelines) [1]. For the underwater pipeline, financial losses in term of fluid losses and environmental problems may be occurred due to poor maintenance of the pipeline and safety issues [2]. From 2003 to 2018, there is a large number of underwater pipeline accidents that occurred throughout the world.

The British Petroleum (BP) company owns the largest offshore deepwater oil field, Thunder Horse field in Gulf of Mexico, that processes 200 million cubic feet of natural gas and 250 thousand barrels of oil per day [3,4]. After the occurrence of Hurricane Dennis in July 2005, Thunder Horse platform was found leaning badly. When the platform was being repaired, it was discovered that the underwater pipelines of platform are brittle and full of cracks due to poor welding job [5].

PETRONAS gas pipeline explosion in Sarawak, Malaysia occurred early in the morning of 10 June 2014. The location of the incident was in the district of Lawas, Sarawak. The people in Lawas town were shocked seeing the fireball that burned for almost 2 hours. The RM4 billion project (Sabah-Sarawak interstate gas pipeline) owned by PETRONAS had been temporarily stopped after the explosion occurred. Fortunately, there were no lives lost in the incident [6]. This incident is caused by the cracking pipeline due to soil movement [7].

In 2015, an underwater pipeline under Moscow's Moskva River in Russia that used to transport oil, exploded due to cracks in the pipeline. The flames and smoke could be seen 16 km away from the explosion site. Three bystanders, including a child were being admitted to the hospital for respiratory problems caused by the plumes of black smoke and there was no occurrence of death in this accident [8,9].

An oil spill from the Poplar pipeline into the Yellowstone River just upstream of Glendive, Montana was discovered on Jan 2015. More than 30 thousand gallons of Bakken crude oil was spilled into the Yellowstone River due to the cracked pipeline. The incident had affected the quality of drinking water near Glendive and the surrounding towns. The oil cleanup on Yellowstone River took a few months to complete since the ice on the river prevented the cleanup [10,11].

Alaska's Cook Inlet is well known for its marvelous mountain view and the habitat of the endangered beluga whales. In Feb 2017, a Hilcorp helicopter noticed that bubbles of natural gas were floating at the surface of Cook Inlet. The natural gas was bubbling up from the cracked underwater pipeline which used to transport natural gas to the offshore oil drilling platforms. It was then found out that the leakage was started a few months earlier in Dec 2016. 210,000 to 310,000 cubic feet of the natural gas had been leaked into the watershed every day and posed a toxic threat to the people and marine life of Cook Inlet [12,13].

On July 24, 2018, an oil spill occurred in Cliff Head Alfa platform, Perth. Australia-based Triangle Energy confirmed the incident and reported that the main cause of the incident was the small crack in the pipeline. Fortunately, there were no people or wildlife harmed since the oil spill was in the range of 0 to 10,000 litres [14].

In conclusion, the cracking of underwater pipeline is the main reason causing most of the incidents mentioned above. The incidents had caused financial losses and human life or marine life losses. This has motivated me to do the research on the identification of underwater pipeline cracking area.

1.2 Problem Statement

Currently, pipelines are an effective medium to transport oil and natural gas in the underwater environment. After the pipeline has been used for years, failures may occur. The failures are generally due to inherent defects, external damage or old-aged pipelines. Underwater pipeline accidents have been increased occasionally because of the cracking in the pipelines [1]. There are some problems being faced when the cracking detection is carried out in underwater environment.

The main problem is the poor visibility in underwater environment. Visibility is commonly defined as the distance at which an object can been seen. The degree of visibility in underwater environment mainly depends on the light penetration and turbidity level. Light penetration depends on light level, incidence angle of light rays and roughness of water surface. Light level is low in cloudy or rainy day causing poor visibility in underwater environment. Water can absorb wavelength of light rays to different degree making the colour shift in the water. The characteristic coloration of the water will also cause the light level in the water drops. For the incidence angle, the higher the distance from equator of earth, the lower the incidence angle, more light being reflected, making less light enter the water. As an example, the seawater near the coast of New Jersey is more cloudy that that of Bonaire ocean which located near the equator. In the case of water surface's roughness, ocean with choppy waves will have poor underwater visibility since it reflects more light rays compared to calm ocean. Turbidity means the cloudiness of a fluid caused by the large number of suspended particles that absorb and scatter the light, and hence reduce the fluid visibility. Turbidity may be affected by decomposed plant and animal matter, algae, silt or clay. Tides, heavy rain, storm, urban run-off, landslide and bank erosion can also increase the number of suspended particles and affect the turbidity level. Sea with choppy waves in stormy day stirs up the sediments from the sea bottom, causing high underwater turbidity level. Runoff has caused almost 240 million tons of topsoil washed from Mississippi River to the Gulf of Mexico every year. The high turbidity level in underwater environment makes poor visibility and increases the difficulty in detecting the cracks and repairing work [15,20,21,22].

Secondly, the use of inspection tools may have some errors when remoting the pipelines' conditions. Crack detection and repair works are done by divers or inspection tools such as remotely operated vehicles (ROV) and pipeline inspection gauges (PIG). By comparing to divers, inspection tools can be operated in greater depth of water and longer time, however they may have some weakness such as expensive, vulnerable to failure, uncontrollable and hard to adapt to changes in pipeline direction and diameter [18,19]. Inspection tools also face problem when they lose connection from the server system. The result of underwater pipeline survey cannot be received if the connection between the inspection tools and server system. Furthermore, fatal accidents may occur in underwater environment. In oil and gas industry, saturation diver is the one who go to the seabed to do maintenance and reparation on underwater pipelines. The most dangerous thing for the divers is the differential pressure. The pressure differences are due to different depth where water rushes to a body with great force. The force can be hundred pounds per square inch making divers in high risk of drowning. When diving to any depth, divers are breathing pressurized air. Those inert gases in the pressurized air are compressed and dissolve in the blood and body tissues. If the gases do not diffuse out after the diver come out from the water, the gases will form bubbles and become millions of tiny explosives in the body of the diver. Decompression sickness may occur and cause fatality. The longer the time taken for diving, the higher the risk for the divers [16,17].

Due to the problems stated, an underwater pipeline cracking area identification system will be developed.

1.3 Objectives

The objectives of the research study are as follows:

a) To develop image processing algorithm to identify the cracking area in underwater pipeline from actual images.
b) To analyse the pipeline cracking area in different types of artificial underwater environment.

1.4 Scopes

The scopes of the research study are:

a) The image processing algorithm is used to identify the crack area, not to detect the crack.
b) The pipeline cracks are identified in four different types of water environment: which are
    - low turbidity level with high lighting level
    - low turbidity level with low lighting level
    - high turbidity level with high lighting level
    - high turbidity level with low lighting level
b) The technique used are image processing method including grayscale image, image filter, thresholding, edge detection

c) Area is determined using contour method.
d) The images from real underwater environment may not mention the light and turbidity level.
e) OpenCV-Python is used for the image processing algorithm.
f) SJCAM SJ4000 Wi-Fi Action Camera is the only used camera for Experiment 2.
g) For Experiment 2, the cracked PVC pipes' images are captured at the water height of 20 cm.
h) For Experiment 2, the distance between the lenses and cracked PVC pipes is about 8cm.

1.5 Thesis Outline

This report and project is about an underwater pipeline cracking area identification system. In this report, motivation for developing this system is covered in Chapter 1. Besides, the objectives and scope of the system are also stated in this chapter. In the following chapter, the review of previous related work of the environment mapping is discussed. In Chapter 2 also, some basic principles and theories are defined and stated. The experiment setup and type of the experiment is discussed in Chapter 3. In Chapter 4, the results are analysed and discussed, followed by a conclusion in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

This chapter describes the background of underwater pipeline system and different types of cracking pipeline. Next, related works on cracking pipeline detection methods are discussed. Lastly, the advantages and limitations of each method are discussed and summarized.

2.1 Underwater Pipeline System

Pipelines are the most suitable method to transport oil and natural gas in underwater environment as pipelines can be constructed at the water depths that more than 1000m. The installation of underwater pipeline system includes several components such as well heads, risers and subsea manifolds. Figure 2.1 has shown the installation of the underwater pipeline system for oil production purpose [23].

The oldest underwater pipeline in the world was the outfalls that was built in 19th century. For oil industry, the earliest underwater pipeline was short and long loading pipelines. The pipelines were built on shore and linking them into the water. The first underwater pipeline for petroleum industry was constructed in Gulf of Mexico (1947), which is located 17km from the land and 6m into the water. Underwater pipelines in earlier stage were constructed within the depth that reachable for the divers, almost 300m deep. Nowadays, the underwater pipelines are mostly placed in the depth more than 1000m. There are several projects that having the pipeline placed between 1500m and 2500m in the water. For example, pipelines in Black Sea was installed up to almost 2200m [1].

In [23], the lifespan of a pipeline is mentioned can be over 40 years. Failure incidents are counted as a part of life for the pipeline. Inherent effects mainly cause post-commissioning failure per unit time increased. The design of pipeline generally depends on the following criteria: stress-related principles, material selection and welding requirement and lastly internal and external pressures. These criteria may affect indirectly affect the lifespan of a pipeline. Besides, failure incidents may also cause by external damage like storms and anchors. Therefore, the pipeline design may also need to consider many other issues such as the age-related issues, seabed type and condition, temperature, tidal currents, waves and submarine landslide.

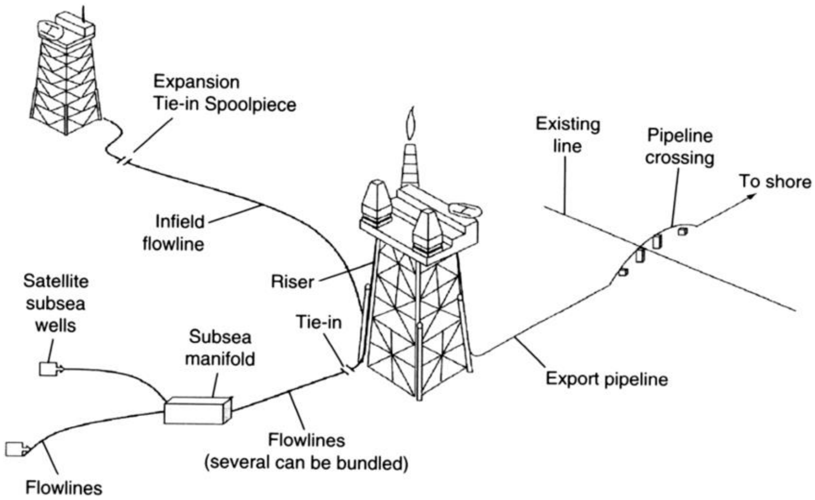

Figure 2.1 A Seafloor Oil Production Facility with A Number Of Components [23]

2.2 Types of Crack in Underwater Pipeline

Cracks weaken the structural integrity of pipeline. Cracking may happen due to the factors: base material of pipeline, welding work, heat affected zone (HAZ) and dents or defects. There are several types of cracking in underwater pipelines and four of them are discussed in this section.

2.2.1 Stress Corrosion Cracking (SCC)

Stress corrosion cracking (SCC) is a crack formed from corrosive environment. It has a marked loss of mechanical stress with small amount of metal loss. It is a hazardous and fatal mechanism and may cause majority of subsea disaster. The vulnerability to SCC is affected by applied stress level, material of the pipeline and environmental conditions. Most of the underwater pipelines are made of steel. SSC happens due to the anodic reaction of the steel with the corrodents such as chloride ion (Cl-), oxidants, hydrogen sulphide (H2S) and oxidants like elemental sulphur present in the water. The synergistic action of H2S in acidic solution is known as sulphide stress corrosion. Sulphide stress corrosion is resulted from localized alloy embrittlement by hydrogen atom [1,24,25,26].

There are three basic mechanisms of SCC which are active path dissolution, hydrogen embrittlement and film-induced cleavage. The most active path for the accelerated corrosion is the gain boundary where segregation of impurity element can trouble the passivation of a material. The gain boundary corrosion can occur without the presence of stress where the crack walls is still passivated. The presence of applied stress is to open up the cracks and faster the corrosion rate. The maximum crack growth rate for active path corrosion is 10-2 mm/s but the usual rate is 10-8 mm/s. In the case of hydrogen embrittlement, hydrogen is small enough to dissolve in all materials. Region of high triaxial tensile stress will attract hydrogen to it when the metal structure destroyed. The dissolved hydrogen will assist in the fracture of metal and then lead to metal embrittlement. The cracking of this mechanism may be intergranular or transgranular and the maximum crack growth rate is 1 mm/s. For film-induced cleavage, ductile material is generally passivated with brittle film. The crack that formed by corrosion in the brittle film can propagate the ductile material. De-alloyed layer is the brittle film that lead to film-induced cleavage. Transgranular cracking is expected from the film-induced cleavage process [26].

2.2.2 Hydrogen Induced Cracking (HIC)

Hydrogen induced cracking (HIC) is one of the cracking that occurs in the steel underwater pipelines. The occurrence of HIC is due to metallurgical (strength, alloying element, microstructure, etc.) and environmental factors (pH, temperature, aggressive ions, etc.). Underwater pipeline is used to transport crude oil and natural gas. The formation of HIC is when the hydrogen sulphide (H2S) in the crude oil reacts with the water and hydrogen is formed. At the same time, hydrogen is also formed when H2S reacts with the iron in the steel pipeline. The hydrogen atom is small enough to diffuse through the wall of pipeline and cause embrittlement. The more the hydrogen being trapped in the space of pipe wall, the higher the hydrogen pressure. This causes the stress in the steel pipeline greater than its tensile strength. Steel is a ductile material and high stress may cause lamination. When the laminations are formed near to each other, stresses will force the lamination to join to form HIC. HIC's cracks are usually