DEVELOPMENT OF MACHINE LEARNING USER INTERFACE FOR PUMP DIAGNOSTICS

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidates for any degree.

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This thesis is the result of my own investigation, except where otherwise stated.

Other sources are acknowledged by giving explicit references.

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
ANN	Artificial Neural Network
API	Application Programming Interface
CFD	Computational Fluid Dynamics
CM	Condition Monitoring
CSS	Cascading Style Sheet
DAQ	Data Acquisition System
DCAE	Deep Contractive Auto-Encoder
EDCAE	Ensemble deep contractive auto-encoder
EDT	Electric Diagnostic Technique
FFT	Fast Fourier Transform
GUI	Graphical User Interface
HTML	Hyper Text Markup Language
IoT	Internet of Things
JS	JavaScript
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
MDP	Markov decision process
MFS	Machine Fault Simulator
ML	Machine Learning
MLP	Multilayer perceptron
Mobile UI	Mobile User Interface
NPSH	Net Positive Suction Head
NPSHa	Net Positive Suction Head Actual
NPSHr	Net Positive Suction Head Require
OS	Operating system
PVC	Polyvinyl chloride
RMS	Root Mean Square
SVM	Support Vector Machine
TDA	Time Domain Analysis
UI	User Interface
VS Code	Visual Studio Code

PEMBINAAN ANTARAMUKA PENGUNA MODEL PEMBELAJARAN MESIN UNTUK DIAGNOSTIK PUMP

ABSTRAK

Projek ini focus kepada kerja pembinaan antaramuka pengguna yang boleh menyambung dengan pembelajaran mesin yang menggunakan Microsoft Azure untuk tujuan diagnosis pam. Pam air merupakan mesin yang boleh menukar tenaga putaran mekanik kepada tenaga hidraulik dalam bentuk tenaga tekanan. Walaupun pam air direka untuk senang penyelenggaraan, tinggi kecekapan dan mudah dikendalikan, tetapi keadaan penyumbatan pam air tidak dapat diperhatikan dari rupa luaran. Penyumbatan di saluran masuk pam boleh menyebabkan peronggaan atau kerosakan komponen pam dan meningkatkan kos penyelenggaraan. Pembelajaran mesin merupakan salah satu kaedah yang dapat mencegah masalah ini dengan membina satu model pembelajaran mesin untuk classifikasi tahap sekatan aliran dalam pam empar. Model pembelajaran mesin ini menggunakan data analisis getaran dan akustik dalam bentuk domain masa dan domain frekuensi yang dikumpul daripada eskperiment penyumbatan aliran di makmal getaran. Algoritma Mesin Sokongan Vektor (SVM) digunakan dalam pembelajaran mesin melalui aplikasi MATLAB R2021a. Keputusan pembelajaran mesin menggunakan algoritma Mesin Sokongan Vektor (SVM) akan digunakan dalam aplikasi Microsoft Azure Machine Learning. Antaramuka pengguna dibina mengunnakan Visual Studio Code (VSC)dengan pengekodan CSS, HTML dan JS sebaga laman sesawang. Antaramuka pengguna ini akan disambungkan kepada model pembelajaran mesin Azure dan memberi pengguna untuk akses kepada model ini melalui sebarang peranti yang mempunyai akses kepada internet.

DEVELOPMENT OF MACHINE LEARNING USER INTERFACE FOR PUMP DIAGNOSTICS

ABSTRACT

The main objectives for this project are focusing on the development of user interface that can connect with the machine learning build in Microsoft Azure for pump diagnostic purpose. Water pump is a very common hydraulic machine which will convert the rotational mechanical energy become hydraulic energy while the hydraulic energy is in the form of pressure energy. Even though the water pump is designed to be low-maintenance, highly efficient, and simple to operate, but we cannot observe the blockage condition of the water pump from its exterior due to the fully enclosed system. The blockage of the pump inlet could result in cavitation or mechanical parts breakdown which would increase the maintenance cost. Machine Learning is one of the ways as a preventive method by applying the data collected from the clogging experiment in the vibration lab to build up a machine learning model for classification of flow blockage levels in the centrifugal pump. The data collected for this machine learning model is using the statistically significant features from vibration and acoustic analysis. The features extracted of time domain and frequency domain in vibration and acoustic will use as database of a Support Vector Machine (SVM) algorithms by using MATLAB R2021a. The result from the SVM algorithms will be used as database for the machine learning in Microsoft Azure. Build up a user interface by using Visual Studio Code (VSC) to run the coding of Cascading Style Sheet (CSS), Hyper Text Markup Language (HTML) and JavaScript (JS) as a webpage and connect to Azure Machine Learning Model and this will allow the user from using the model from a webpage when they have active internet with any devices.

CHAPTER 1

INTRODUCTION

1.1 Project Background

Water pump is a mechanical device commonly use to transferring fluid from one point to another, and there are two categories of water pump have been created which is centrifugal and positive displacement pump. A centrifugal pump is device design using a rotating impeller to move for all kind a liquid and the centrifugal pump work excellent with low viscosity liquid with high flow rate. Positive displacement pump or sometime called rotary pumps is designed to deliver a fixed amount of flow through the mechanical contraction and expansion of a flexible diaphragm. Application of positive displacement pump is on some cases that solid material or particle might appear in the liquid or the liquid have characteristics of high viscosity such as maple syrup with working condition of low flow rate with high pressure.(*Types of Water Pumps for Construction*, n.d.)

Water pump have advantages of high efficiency with low power consumption, but there still have some problem might happen and the problem would cause pump failure and need to be replaced. The problem that most commonly happen in centrifugal pump is flow blockage, while flow blockage will become impeller-clogging phenomena when flow blockage has not solved for a certain period.(Zhaoa, 2016)

Comparing with breakdown maintenance and cause the project or service stop working, the experts generally agree that monitoring the operation of the centrifugal pump with aid of machine learning is significant to diagnose and prevent the faulty happen to the pump failing catastrophically to reduce downtime (Tiwari et al., 2021).

The impeller-clogging phenomenon in centrifugal pumps is such a kind of the fault that leads to increase the vibration and reduce the performance of pumps and by referring to the vibration and acoustic produced from the centrifugal pump. The vibration and acoustic signals contain the characteristics of failure present in rotating machines (Jahangiri & Roknizadeh, 2018). Vibration and acoustic monitoring have been proven to be effective in detecting faults within the centrifugal pump, we can do a prediction of the status of the pump using machine learning model with the data collected from the vibration lab. Some of the Pump manufacturer have start to provide some new product with on-board sensor to ease the process of data analysis process, the pump with on-board sensor are recommended to apply in an inaccessible environment (Cao & Yuan, 2020). Accelerometers and microphone are used to collect the vibration and acoustic data respectively in this project.

1.2 Problem Statement

Blockage in the inlet of a centrifugal pump is a significant early sign of issues that cause cavitation in centrifugal pump. Clogging of the pump inlet might result in a smaller area of fluid passage and higher fluid velocity. The fluid pressure to become lower, and cavitation bubbles will form if the pressure of fluid falls below the saturated vapour pressure. Besides, it generates loud noise and vibration due to the unstable flow of fluid.

Nowadays, centrifugal pump inspection is highly dependent on the instrument, such as the flow transducer. However, the outlet pressure measurement only will be alerted when large deviations occur, and conventional instruments do not diagnose the source of the problem. The current general supervision method does not allow early detection of minor faults and unable to diagnose the cause of the problems.

1.3 Objectives

This project aims to achieve the following objectives:

1. Create machine learning model that can identify flow blockages in centrifugal pump based on vibration and acoustic signals against time-frequency domain.
2. Develop a user interface framework by using Microsoft Visual Studio Code that can access from any devices with active internet connection.
3. Connect the user interface with the machine learning model to diagnostic the pump.

1.4 Scope of Project

Using data collected from the experiment about flow blockage of the centrifugal pump by using experimental rig in Vibration laboratory. The equipment used in the experiment are two accelerometers, a microphone and a tachometer being installed to the centrifugal pump and experimental rig to collect vibration, acoustic and rotational speed of the centrifugal pump. There are six blockage conditions of a centrifugal pump were discussed in this project which is 'no blockage', 'inception', 'development', 'mild', 'severe' and 'mild and unstable'. The blockage condition at water inlet of the centrifugal pump is simulated by adjusting the inlet opening valve. The data achieved from the experiment will be used as data for supervised machine learning process. Pre-processing the vibration, acoustic and rotational speed of the centrifugal pump data collected by converting them into frequency domain by using fast Fourier transform (FFT). Statistical features extracted from the time domain and frequency domain of raw data for the three sensors will be. MATLAB machine learning by using Support Vector Machine (SVM) have been selected after comparing with among all the algorithms available.

Applying the final data achieved by using MATLAB in Microsoft Azure Machine Learning with a classification algorithm to train a machine learning model that can predict the health condition of a centrifugal pump and export the model for build user-interface purpose. The machine learning will do a prediction of the health condition of the when provide with some statistical feature value to the model. Build up a webpage user interface by using Visual Code Studio which can bring connection to the Microsoft Azure machine learning model for key in the input data and simulate the machine learning model to predict the centrifugal pump health condition.

CHAPTER 2

LITERARURE REVIEW

2.1 Introduction to Centrifugal Pump

Figure 2.1 show the exploded view of a centrifugal pump and the figure is showing the flow of water entering and leaving the pump. Centrifugal pump is a commonly used devices in industry especially in building ventilation systems and cooling tower. Referring to the Figure 2.1 show the fluid will entering the centre hole in between of the centrifugal pump axially. The hole of the of the pump known as the impeller eye after it will operate along with the rotating blades and transfer the fluid exits horizontally. The momentum transfers the fluids with the impeller blades will generate tangential and radial velocity and acquires additional radial velocity which is centrifugal forces. The fluid will leave the impeller by gaining both speed and pressure as it flung radially to the volute. The volute is designed to be a snail-shaped diffuser in order to decelerate the fast-moving fluid leaving the trailing edges of the impeller blade and increase the fluid pressure to direct the flow to the discharge pipe. (Çengel & Cimbala, n.d.)

There are three types of centrifugal pumps which is forward-inclined blades, backward-inclined blades, and radial blades. However, the backward-inclined blades have the highest efficiency as it requires the least amount of turning the fluid flows in and out.

Centrifugal pump can be used to move fluid around the system or transfer fluid from one tank to another. Fluids such as water, sewage, and petroleum are transferred using the centrifugal pump in the industry.

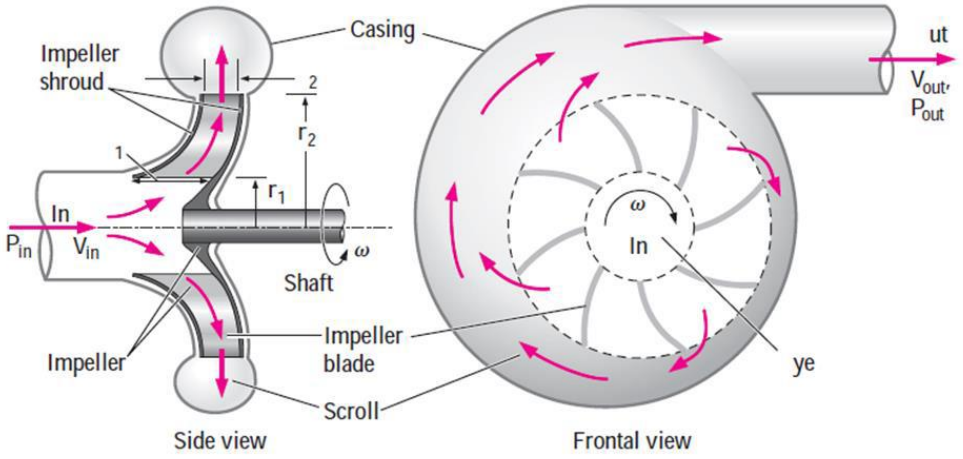

Figure 2.1 Exploded view of a Centrifugal Pump(Çengel & Cimbala, n.d.)

2.1.1 Flow Blockage in Centrifugal Pump

Flow blockage in a centrifugal pump is happen frequently in industrial application which is due to deposit of organic material or through chemical reactions at the pump inlet or outlet and resulting the drop of pump efficiency. Flow blockage have high possibility to cause a sudden breakdown of the pump because the high temperature generated by the pump's motor to centrifugal pump axial shaft and impeller cannot reduce on time. (Isermann, 2011) When the fluid pump might contain materials such as rags that clog the passage which might decrease the flow rate. Flow blockage of the suction pipe will cause restriction flow of fluid and eventually lead to cavitation in the centrifugal pump.

Flow blockage in centrifugal pump might happen due to several reasons depends on the location and pumping fluid. There is some solid object that easily found in the centrifugal pump such as loose rags, natural detritus and grass and those objects is the main factor who contribute to the blockage of a pump. Other than that, pipe liner disintegration and air trapped at the suction inlet of the pump will lower the flow capacity as well(Panda et al., 2018) Moreover, the flow blockage will bring result in

impending or development of cavitation on the impeller vane. The side effect when cavitation happen are vibration of the axial shaft, impeller shroud cracking, excessive noise and vibration of the pump casing. (*Flow Recirculation In Centrifugal Pumps*, n.d.)

2.1.2 Cavitation in Centrifugal Pump

Cavitation is a phenomenon of air bubbles happen in centrifugal pump impeller when pressure differences at the impeller and vapour pressure of liquid. The air bubbles will expand as it approaches boiling point and collapses abruptly and leads to damage to the metal part, especially the impeller blades and resulting the impeller blades crack, the pump vibration and crackling noise. The cavitation high possibility will happen when the flow rate is higher than the designed flow rate or reduction of suction pressure or rising of suction temperature. (Mckee et al., n.d.)

Cavitation is one of the challenging fluid flow abnormalities that leads to detrimental effects. Cavitation causes degradation of pump performance and leads to noise and vibration. There are several types of cavitation such as shear cavitation, attached cavitation, travelling cavitation and vortex cavitation. Cavitation occurs in several situations such as the wall geometry that gradually decreases in flow area will impose high velocity and pressure drop, high unsteadiness characteristics of a particular flow which yield pressure drop in fluid flow, etc. (Maxime et al., 2016)

Net positive suction head (NPSH) curve is designed by the pump manufacturer where cavitation usually happened during the actual NPSH (NPSHa) is lower than the required NPSH (NPSHr). The actual NPSH is calculated by the characteristics found in the pump's suction nozzle, whereas the required NPSH is the net positive suction head required to avoid cavitation. According to Figure 2.2, the centrifugal pump shall operate within the flow rate before the interception of NPSHa and NPSHr to prevent cavitation.

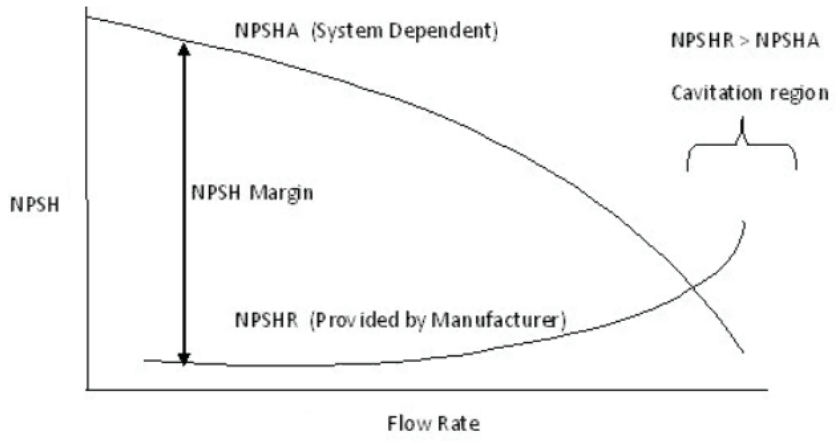

Figure 2.2 Graph of NPSH against flow rate. (*Net Positive Suction Head - Centrifugal Pumps*, n.d.)

There are a few symptoms that indicate cavitation is taking place within the centrifugal pump. The bubbles collapsing at high-pressure areas exert enormous local stresses on the pump surface that results in pitting. Besides, the cavities collapsing under high pressure causes sharp crackling sound and vibration. Furthermore, the vapour bubbles in the passages around the impeller impede the flow of fluid. As a result, the discharge flow rate is reduced, causing low pump efficiency. (Mckee et al., n.d.)

There are some corrective methods that could be made to prevent cavitation damage effectively, such as replacing the impeller with cavitation resistant material like stainless steel. Besides, redesign the impeller's geometry to reduce losses and improve flow characteristics or place the inducer at the suction part of the pump to increase the pressure before fluid reaches the impeller.(Mckee et al., n.d.)

2.2 Experimentations with Centrifugal Pumps

Based on Panda (2018) research, the centrifugal pump is mounted on the fixed base of Machine Fault Simulator (MFS) with an operating temperature of 299K. Water is used as the pumping fluid, and the experimental setup is designed in a closed loop. There are two tri-axial accelerometers attached to the pump casing and bearing housing.

The vibration data are collected at 20kHz sampling frequency. Five different blockage conditions are simulated by manually modulating the pump inlet valve, as depicted in Figure 2.3. Based on the observation of this research, cavitation occurred when the blockage is 50% and 66.6% as the air bubbles started to appear. The cavitation effect rises as the blockage level increases. Besides, the pressure condition of the pump discharge outlet recorded shows the pipe pressure decreased as the cavitation level increases. Similarly, another researcher also creates pipe blockage by adjusting the inlet valve. (Irfan et al., 2019)

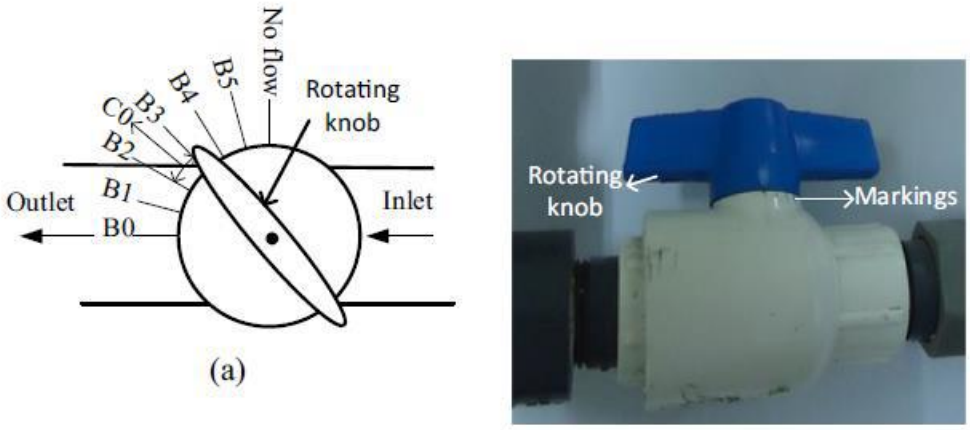

Figure 2.3 Manual modulating valve of the pump inlet.(Panda et al., 2018)

2.2.1 Position of Accelerometer

Accelerometers are widely used in numerous experiments as vibration sensors. It can operate in a wide range of frequencies, reliable for vibration measurement and easy to install on the machine. The optimal mounting position of the accelerometer on the centrifugal pump is axial to the suction position. The vibration signals will be pre-processed by using Data Acquisition System (DAQ) to amplify and filter the signal with a suitable sampling rate. It is found that the RMS and peak values being the best parameters of time domain for detecting cavitation. (Altobi & Sabari, 2016) Besides, the tri-axial accelerometer can be installed on the pump casing and bearing housing to capture vibration signals. (Panda et al., 2018).

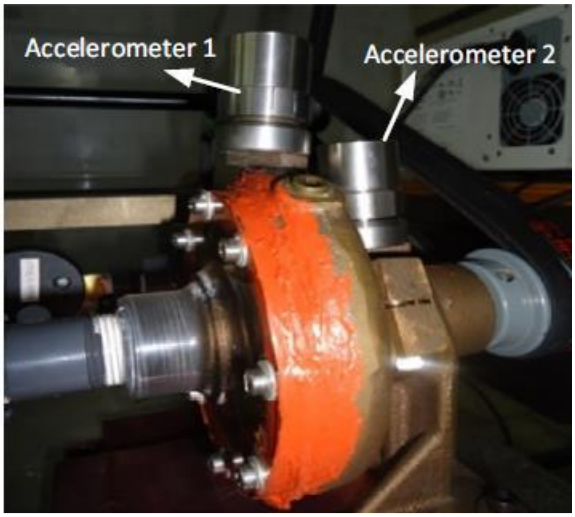

Figure 2.4 Position of accelerometers on centrifugal pump. (Panda et al., 2018)

2.3 Diagnostic of Fault in Centrifugal Pump

Condition monitoring (CM) is usually used to predict cavitation with the parameters of the pumping process, especially the suction pressure. However, some implementations of CM using pressure sensors are intrusive since the sensors are in contact with the pumping fluid. Besides, tapping the sensors in the pipe might lead to leakage issues. Therefore, pressure sensor is disqualified, especially for dangerous fluid. Alternatively, vibration sensor has significant advantages as a non-intrusive sensor, and it can contribute information for a wide range of rotating machinery faults. (Kléma et al., 2005)

Rotating machinery will generate specific oscillation from various components such as the rotating shafts, blades or rotor. The oscillation will be more pronounced when there are turbulent flows of fluid or cavitation. Besides, arise vibration might depend on the flow rate and rotational speed as well. Therefore, defects in the centrifugal pumps can be detected by using sensors such as oscillation velocity sensors, oscillation accelerometers or piezoelectric sensors. (Isermann, 2011)

Aside from that, electric diagnostic technique (EDT) does not require additional sensors as it uses the sensors that already installed in the centrifugal pump to monitor

the motor line current and voltage. Laboratory Virtual Instrument Engineering Workbench (LabVIEW) software can be used to measure the three-phase line current and transform it to two-phase d-q current.(*Getting Started with LabVIEW*, n.d.) The statistical characteristics of the d-q current plot can be employed to categorize the pump faults. The flow chart of the EDT condition monitoring system is explained in Figure 2.5. The d-q patterns are unique for a healthy pump, impeller faults, and pipe blockages. Thus, it can be a visual indicator for the pump health's condition. (Irfan et al., 2019) Computational Fluid Dynamics (CFD) has been employed to predict the performance of centrifugal pump with applied mathematics, physics, and software to visualise the flow within the pump and how it affects the machinery within the pump. This method yields high accuracy, time and resources saving and provides flow visual ability. (Maxime et al., 2016)

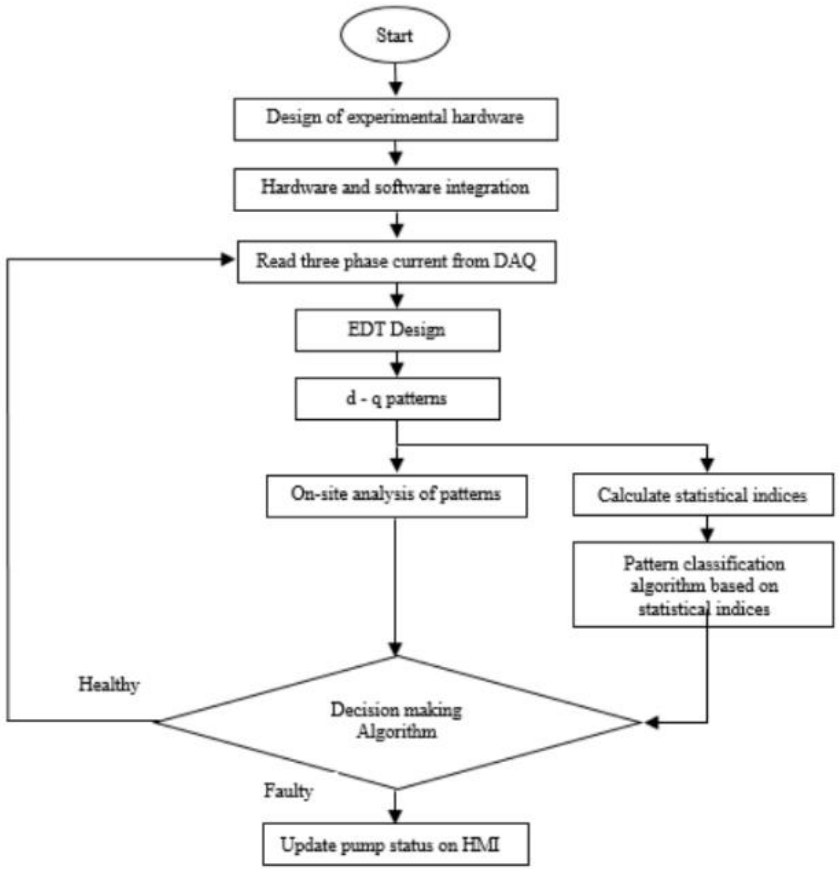

Figure 2.5 Flow chart of EDT condition monitoring system.(Irfan et al., 2019)

2.3.1 Acoustic and Vibration Signal

Based on the research done by Al-Obaidi in 2020 have used three different approaches for cavitation detection such as vibration technique that uses accelerometer sensor, acoustic technique using microphone sensor and the determination of pressure at suction and discharge using pressure transducer.(AL-OBAIDI, 2020) The Fast Fourier transform technique is apply in the transformation of the database in time domain signals becomes the frequency domain, where the frequency elements of the signals can be used to represent the mechanical condition of the machine components.

Al-Obaidi has claims that the levels of vibration and acoustic amplitudes are lower when the centrifugal pump operates in a low flow rate range as compared to a high flow rate. Flow rates with high vibration amplitudes that correspond to the NPSH performance graph are considered with cavitation. Furthermore, Cavitation Detection Index technique is implemented where the features are normalised by dividing actual values of statistical features to the maximum values in time domain analysis (TDA).

Based on the research result, the author states that the vibration signal is more sensitive as compared to the acoustic signal in determining the development of cavitation. The acoustic technique is incapable of capturing entire changes within the pump, whereas the vibration technique can capture small changes. The normalize values of mean results for vibration and acoustic as threshold can be used to detect cavitation. Lastly, the author concluded that the sensor with a low-frequency range is preferred to determine cavitation in a centrifugal pump as it has better sensitivity and lower cost.

In addition, machine learning using artificial neural network (ANN) for fault diagnosis using vibration signals has been experimented as well. Multilayer perceptron (MLP) which is a feed forward network is used in this case. The time domain features

of vibration signals achieved 100% accuracy compared to the frequency domain feature. Less computation cost is required for a time domain-based machine learning model. The input vector that includes data acquired for all four measuring points has a better result than the input vector that process data from each bearing. (Sepulveda & Sinha, 2018)

Ensemble deep contractive auto-encoder (EDCAE) can handle data collection under noisy environment. Deep contractive auto-encode (DCAE) is designed to learn invariant feature representation automatically. The model can manage noisy data effectively due to the Jacobian penalty term in DCAE. The combination of DCAE, fisher discriminant analysis and Softmax classifier able to produce accurate diagnosis result. It shows that EDCAE is more effective in coping with noisy data than other DCAE methods. (Zhang et al., 2020) In this review, EDCAE method shown to be capable of managing data collection for intelligent fault diagnosis of machine even in a noisy environment. As some of the environmental noise could not be avoided due to the location of a pump in a noisy ambience.

Most of the researcher works uses vibration data of the centrifugal pump for flow blockage and cavitation detection. Acoustic data is rarely discussed in machinery intelligent diagnosis.

2.4 Introduction to Machine Learning

Machine learning (ML) is an Artificial Intelligence (AI) application that uses data analytical tools to learn and identify features from data. ML can also be defined as a computational method using experience to improve performance or to make accurate predictions. (*Foundations of Machine Learning, Second Edition - Mehryar Mohri, Afshin Rostamizadeh, Ameet Talwalkar - Google Books*, n.d.) It can make a decision

with minimal human intervention. Machine learning consists of three major categories which are supervised learning, unsupervised learning and reinforcement learning. Supervised learning uses a dataset comprising both inputs and desired output to train the machine learning model to predict the outcome of new input. Classification and regression are categorised as the supervised learning algorithm. Unsupervised learning uses data with only input and identifies the pattern of the data set by clustering. Besides, reinforcement learning employs a rewards system where it will be rewarded by interacting with its environment. For instance, the Markov decision process (MDP) is commonly used in autonomous vehicles or playing game against human opponent. (Guan et al., 2018)

2.4.1 Types of Machine Learning

In all the algorithms available in machine learning can be classify as three main set of algorithms. These three main set of algorithms can be classified as supervised learning, unsupervised learning and reinforcement learning algorithms. Below these three types of machine learning have their subset with different respective function.

The supervised learning algorithms have characteristics of using data with labelling to perform the simulation with to get the result of classification or regression. The result of classification is most likely answering a two-choice question or a multiple possible (categories) question, while the regression is using algorithms to answer a predict value question by with the relationship of the value in database. Referring to the Figure 2.6, the supervised learning model will keep improve the machine learning model, if there found an error during prediction an output.

The unsupervised learning model is similar to the supervised learning model, and the differences of the unsupervised learning model is using a unlabelled data and

the algorithms will need to discover the relationship by comparison value in database to fine out the hidden patterns or data groupings for the following prediction by referring to Figure 2.6. Unsupervised learning is used in clustering, while clustering is using for discovering the structure available in the data, this method has highly potential to locate out similarities and differences about the information contain in database. By using the finding of relationship in data make unsupervised learning as a one of the good options for image recognition, behaviour segmentation, reduce group data analysis, cross-selling strategies, and customer segmentation. Unsupervised learning can reduce the number of features in a machine learning model is because the algorithms behind grouping all the messy data into a few groups, so the number of features will reduce after the simulation.

Reinforcement learning is one of the machine learning models not usually use in processing data because reinforcement machine learning model is use in robotic and Internet of Things (IoT) application by using a set of sensor readings at one point in time is a data point. The algorithms behind the reinforcement learning is let the model learn with motion or action thru using the sensor but not data. When the algorithms have successfully recognized and perform a very good response to the action given, then a reward signal will be given to the reinforcement learning model to let the model know the response is what is correct. If the process of recognize and gibe reward signal is keep going on for the reinforcement learning model, then the model will keep learning have become more advance or smarter. Unfortunately, the reinforcement learning model in Microsoft Azure because this module is not available in the Azure Machine Learning server this recent but hope the module can added into the server in future.

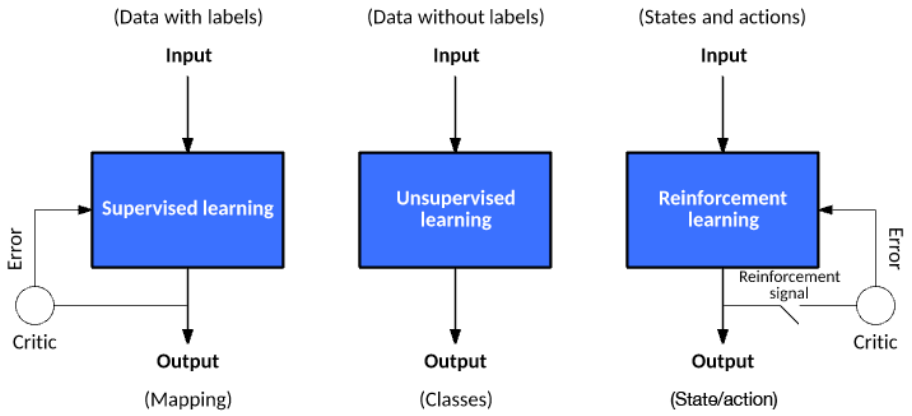

Figure 2.6 Learning model for differentiate with supervised, unsupervised and reinforcement learning in machine learning. (*Models for Machine Learning - IBM Developer*, n.d.)

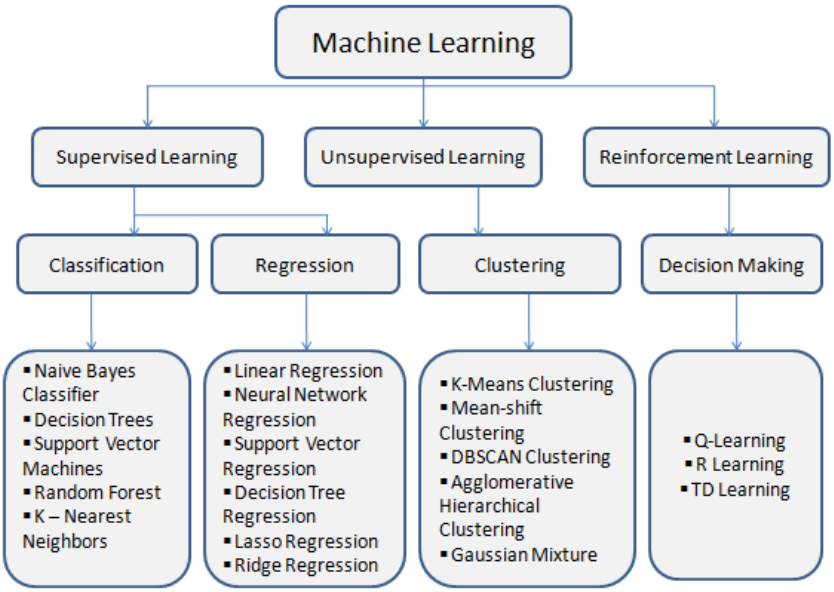

Figure 2.7 Classification of the machine learning algorithms under each type of machine learning.(*Machine Learning Algorithms | Introduction to Machine Learning*, n.d.)

2.4.1(b) Classification (Supervised Learning)

Based on the literature survey above, most of the authors seemingly prefer Support Vector Machine (SVM) as a machine learning model for the fault identification of centrifugal pump. SVM can produce high accuracy in machine condition monitoring and fault diagnosis classification as it is excellent in generalization. (Widodo & Yang, 2007)

SVM is commonly used for the classification of two classes of data. However, it can also be done for higher-dimensional space with multiple attributes. The hyper-plane is used as a decision boundary in higher-dimensional space that distinct between classes. A more significant distance between the surrounding data points and the hyper-plane indicates a satisfactory classification. Alternatively, the larger the margin, the lower the generalization error of the classifier. (Bordoloi & Tiwari, 2017) Hyperparameters of SVM are C penalty and gamma, where they play a vital role to build a robust and high accuracy model. SVM also can perform non-linear classification with kernel functions. The kernel functions can prevent over fitting of the model, which may occur due to the model's high dimensionality. There are several kernel functions such as linear, polynomial, Gaussian RBF. (Widodo & Yang, 2007)

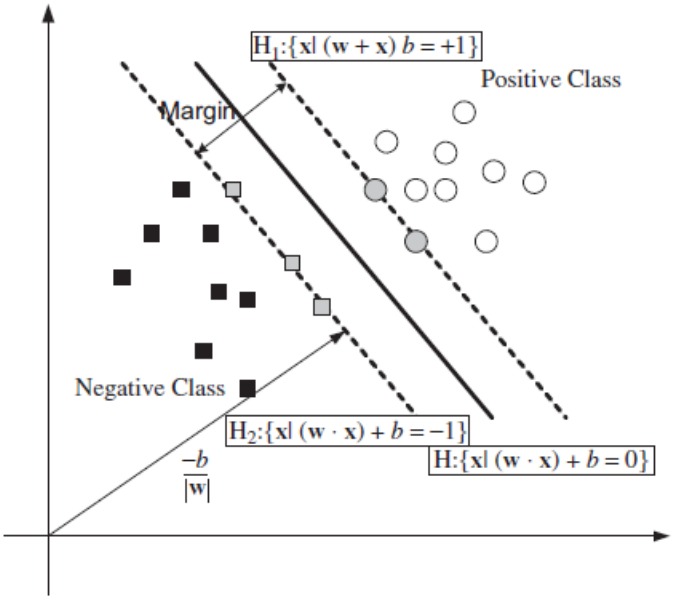

Figure 2.8 Classification of two classes with SVM which shows a linear boundary. (Widodo & Yang, 2007)

2.4.1(c) Regression (Supervised Learning)

The machine learning algorithm must estimate and comprehend the relationships between variables in regression tasks. Regression analysis is very helpful for prediction and forecasting since it concentrates on one dependent variable and a number of other changing factors. Regression can be explained, in other words, by the model's focus on simulating the relationship between variables, which is then repeatedly improved utilising a model's prediction error. The workhorse of statistics, regression approaches have found a home in statistical machine learning. Regression can be used to describe both the class of problem and the class of algorithm, which may cause confusion. Regression is a process. Linear and logistic regression are two examples of regression methods.

2.4.1(d) Clustering (Unsupervised Learning)

People usually will be using a labelled data during planning to a prediction a result by using a machine model. With the aid of the labelled data can help the machine learning model to make relationship by the programmer or at some condition, removing some unused data in database also can help to reduce the period required for training a machine learning model. If the database for training is incomplete and the user also not sure which parameter or variable is useful, the programmer will be very difficult to produce a predicted data to forecast some situation possible happen in future. Clustering unsupervised is introduced to overcome this kind of situation from happening but clustering unsupervised machine learning model is require a large dataset for the algorithms to train and predict the group of data that have similar features.

The process of grouping some similar features data is known as clustering. The definition of the clustering machine learning model is involves assembling collections of related data (based on defined criteria) in a kind of group. The most unsupervised learning clustering model are K-means clustering, followed by Hierarchical Agglomerative Clustering.

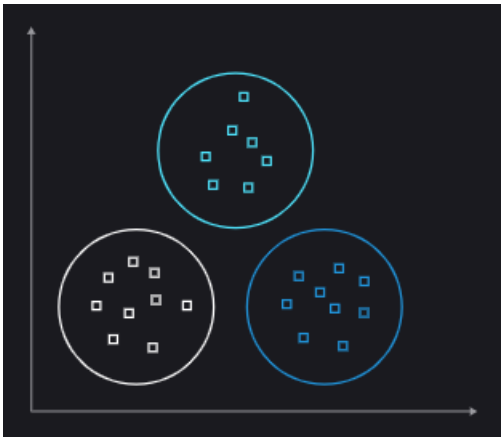

Figure 2.9 K-Means algorithms classify data into cluster.(*Machine Learning Algorithms | Microsoft Azure*, n.d.)

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2.5 User Interface

User interface (UI) is the medium for human interact and communicate with computer by using a device. There are two kind of user interface that are commonly used in the market which are web application also known as website or graphical user interface (GUI) and mobile application or mobile user interface (mobile UI). (*What Is User Interface (UI)? Definition from SearchAppArchitecture*, n.d.).

The web application or graphical user interface is a system of interactive visual component for computer software require a screen to display the content, keyboard and mouse to giving command and instruction to run the function that have been program in backend application. The interaction platform for a mobile user interface is graphical and usually touch-sensitive display on a mobile device such as smartphone and tablet that can interact with software program or mobile application by touch screen.

User Interface is one of the objectives in this project, which to solve the problem of machine learning model need certain level of exposures and knowledge to operate and get the condition prediction of the centrifugal pump. With the help of user interface will ease for the pump user do prediction by visit the website with active internet and browser through their devices.

2.5.1 Webpage Development

The goal of user interface (UI) design is to foresee what users would need to do and make sure that the interface has parts that are simple to use, access, and comprehend. There are three important components to build up a user interface, which are interaction design, visual design and information architecture.

There are three main languages will be used to build a website which are HTML, CSS, and JavaScript. These three languages also represent for the three elements to build up a graphical user interface. Interaction design is the structure of a website UI and in this project will using HTML to format the structure. The second element for UI is visual design by using CSS to build the layout of the website UI. The information architecture is a program a function for the structure on a webpage to perform the task by using JavaScript.(*Learn Web Development Basics – HTML, CSS, and JavaScript Explained for Beginners*, n.d.; *Web Style Guide: Basic Design Principles For Creating Web Sites - P.J. Lynch, S. Horton, Sarah Horton - Google Books*, n.d.)

Figure 2.10 Webpage Development Process.(*6 Phases of the Website Design and Development Process - Infiyug Technologies*, n.d.)

CHAPTER 3

METHODOLOGY

3.1 Experiment Setup

The experimental rig setup in Vibration Lab of School of Mechanical Engineering, USM is shown in Figure 3.1 below. The water pump used in the image is Sea Pump DTM-20 centrifugal pump. The centrifugal pump will simulate the usual operation which is to pump water from the water tank to residence of an apartment and there are two butterfly handle PVC ball valves is used to control the volume of water inlet and water outlet from the pump. While in this project is to simulate the clogging problem that happen at inlet and outlet of the centrifugal pump. The water outlet will return to the water tank to ensure the water in the tank always higher than the suction port to water pump.

Figure 3.1 Experimental rig of centrifugal pump.

Sensors used in measuring physical parameters to monitor the flow blockage condition in the centrifugal pump. In Figure 3.2 below is showing the location of the sensor being added to the centrifugal pump and the function to collect vibration, acoustic and rotational speed data. The sensor been added to the experimental rig are 2 accelerometers, a microphone and a tachometer.

- Accelerometers: Two accelerometers are used in the experimental setup which is mounted on the radial axis (x-axis) and vertical axis (z-axis) of the impeller housing, as depicted in Figure 3.2. Both sensors were mounted perpendicularly. The accelerometer was used to collect vibration data generated by the centrifugal pump.
- Microphone: The microphone was deployed to obtain the acoustic signals generated by the centrifugal pump
- Tachometer: used to measure the rotational speed of the centrifugal pump. A near-infrared light beam will be emitted from the tachometer to the optically reflective strips pasted on the rotational shaft as shown in Figure 3.3. One light pulse will be returned for every shaft rotation

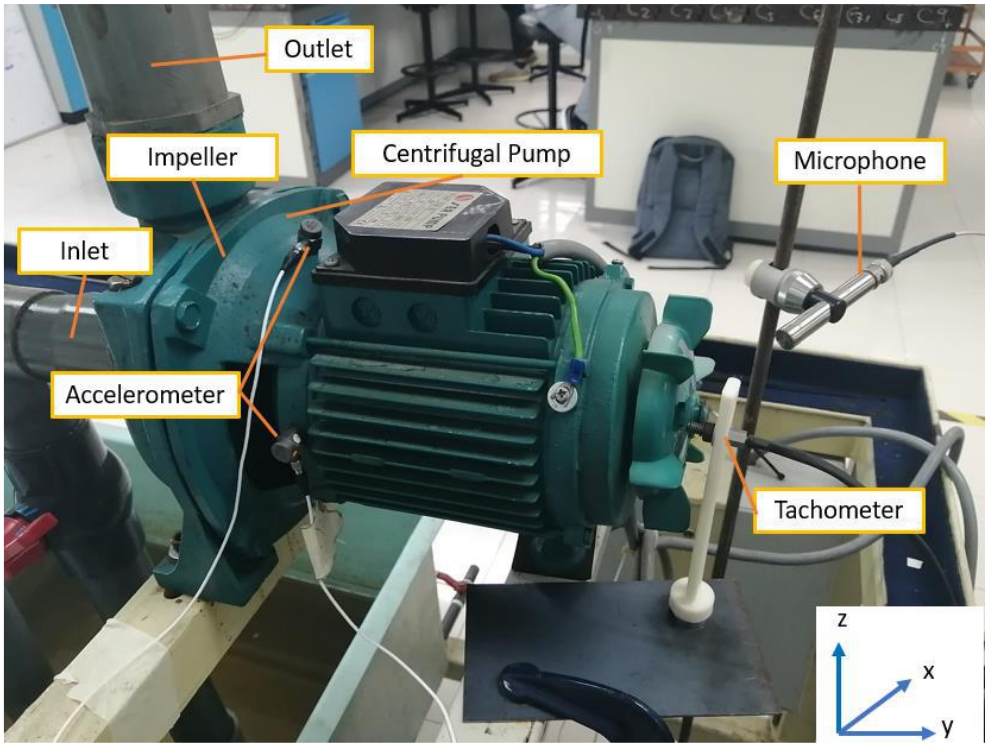

Figure 3.2 Experimental setup of sensors, data acquisition systems and centrifugal pump.

Figure 3.3 Operation of optical speed sensor where near infrared light is emitted to a reflected strip on the shaft of centrifugal pump.