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# **Advanced Condition Based Predictive Maintenance of Electric Motors in Ships**

**MR-PRO-22-010**

## **Final year Project**

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## Declaration

We hereby declare that the work contained in this report is original; researched and documented by the undersigned students. It has not been used or presented elsewhere in any form for award of any academic qualification or otherwise. Any material obtained from other parties have been duly acknowledged. We have ensured that no violation of copyright or intellectual property rights have been committed.

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# Contents

<b>Declaration</b>	<b>I</b>
<b>Table of Contents</b>	<b>II</b>
<b>List of Figures</b>	<b>IV</b>
<b>List of Tables</b>	<b>V</b>
<b>List of Abbreviations</b>	<b>VI</b>
<b>Abstract</b>	<b>VI</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Background	1
1.1.1 Maintenance	1
1.2 Problem statement	3
1.3 Objectives	3
1.3.1 Main Objective	3
1.3.2 Specific Objectives	3
1.4 Justification of the study	4
<b>2 Literature Review</b>	<b>5</b>
2.1 Operation, Subsystems and Parameters	5
2.2 Sensors	8
2.2.1 Temperature Sensor	8
2.2.2 Thermocouple Temperature Sensor	9
2.3 Pressure Sensor	9
2.3.1 Pressure Transducer	10
<b>3 Methodology</b>	<b>11</b>
3.1 D	11

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3.2	Data Analysis . . . . .	11
3.2.1	Descriptive analysis . . . . .	11
3.3	Predictive analysis . . . . .	11
3.4	Prescriptive analysis . . . . .	11
3.5	System Modelling . . . . .	11
3.6	Process chart . . . . .	12
3.7	Sensors . . . . .	12
3.7.1	External Force Sensor . . . . .	14
3.7.2	Stewart Platform as a force sensor . . . . .	14
<b>4</b>	<b>Expected Outcomes . . . . .</b>	<b>15</b>
<b>5</b>	<b>Project Budget . . . . .</b>	<b>16</b>
<b>6</b>	<b>Work Plan . . . . .</b>	<b>17</b>
	<b>References . . . . .</b>	<b>18</b>

## List of Figures

Figure 3.1	.....	13
------------	-------	----

## List of Tables

Figure 6.1	Workplan table . . . . .	17
------------	--------------------------	----

## Abstract

Maritime shipping is employed to move food, medicines, and far more at the heart of world trade. For growth and development, economical mechanisms of shipping are followed, particularly within the developing world. Machinery and equipment breakdown that occur during marine transportation cause delays, swings in supplies, production, and trigger infinite downstream effects on entire supply chains. In the shipping industry planned and reactive maintenance that is primarily practiced requires halting of vessel operations for a number of days despite the fact that no fatigue or machinery and equipment breakdown is observed. Having seen the importance of motors that are widely utilized in ships auxiliary machinery, the project focuses on creating failure predictions, additionally determining remaining useful life (RUL) for motors aboard ships, albeit also quite fascinating is the role this research plays in the monitoring of equipment on autonomous ships. This is made possible with developments in information and technology. Massive amounts of data is collected and can facilitate condition based monitoring (CBM), conduct analysis on best performance and comprehensively diagnose ship engine room equipment.

Keywords: efficiency, condition monitoring, remaining useful life, autonomous ships, performance.

# 1 Introduction

## 1.1 Background

### 1.1.1 Maintenance

As the world's industries push the boundaries of optimization and efficiency, the exponential increase in computational ability and technology The automation of "higher-level" tasks that require human intellect is now possible. This headway brings unmanned autonomous vessels within the Maritime Industry closer to mass production. The practicality of autonomous vessels can only be achieved with constant awareness of the performance and operating state of machinery in the engine room (CBM). Observations of industry practices display that industry experience in reliability is heavily based on trial-and-error test procedures. Most of the reliability research in industry still focuses on two distinct periods of the product life. The warranty period, where most of the failures are due to product malfunctions or quality related problems, and, wear-out period, where the failures are due excessive wear and use [1]. Using sensors and logging software the condition of equipment is assessed as frequently as needed, enabling efficient analysis of data that facilitates planning of predictive maintenance on-board vessels. The electric motor is the most used device for conversion from electric to mechanical energy and is used for electric propulsion, powering thrusters for station keeping, and different on-board equipment on hundreds of ships. Typically, 80-90 percent of the load installations will be electric motors[2]. Smart organizations know they can no longer afford to see maintenance as just an expense. Rather, maintenance must be integrated within the business cycle in order to guarantee predictability, growth and increase the overall quality of operations. Moving from a regime of scheduled rule-based maintenance via on-condition maintenance and ultimately to a data-driven risk-based regime can lead to more accurate and timely maintenance tasks. This smarter view of maintenance allows for achieving many practical advantages leading to lower costs and increased safety and availability of ship systems[2].



Making failure predictions and determination of remaining useful life (RUL), realizes significant benefits not limited to: work style reforms, reduction in crew workload in that monitoring is done autonomously, improved safety from preventing accidents before they happen, and ensuring efficient optimal operation. In future more equipment will be added in a modular manner to realize better optimal performance.

With preventive and corrective maintenance still pronounced and used in the marine industry, mechanical systems such as plants, machinery and equipment components are being replaced or overhauled after some interval. Marine mechanical systems' parts could be replaced within the fixed maintenance or scheduled interval when they are still functional thus leading to unnecessary replacement or repair or maintenance costs. Likewise, the Plants Machinery and equipment system parts may have exhausted their operation lifetime before the maintenance interval reaches. This may lead to the breakdown of the mechanical systems, thus resulting in corrective maintenance. Hence, such traditional maintenance approaches are becoming less effective towards the reliability, safety and maintainability of marine mechanical system

Detection of operation anomalies is the kind of predictive maintenance that can be carried out even when no data from previous failures in the equipment is available. When available, machine-learning models based on binary classification are used to predict failures in the near future in order to plan repairs or substitution of equipment[2].

There are several parameters to be considered:

- Temperature
- Pressure
- Vibration

The parameters temperature and pressure were considered because they are prime indicators of a motor's operating performance.

## 1.2 Problem statement

Out of 880 accidental errors in ship related incidents 62 percent are attributed to human failure; of this, 22 percent are shipboard related operations. Engine room failures are caused by a majority of three ways, either by: Natural mechanical failure, Electrical failure of components and whole systems, Human negligence, and poor competency in engine room procedures, Inaccurate diagnosis, and sub-par prevention measures. These accidents are more notably recognized when they result in internationally felt effects such as oil spills damaging large swathes of marine ecosystems or when loss of life of crew members is realized. But with greater significance but less spoken of - the loss of millions in profits in maintenance and shipping costs incurred to the vessel's owner that would otherwise have been used more productively. While it is impractical to try and eliminate accidents in the engine room, this design proposal seeks to provide a solution to improving efficiency and mitigating downtime by implementing strategies to reduce human through the automation of engine room condition monitoring [3].

## 1.3 Objectives

### 1.3.1 Main Objective

To monitor the health of ship motors improving reliability and preventing downtime in ships.

### 1.3.2 Specific Objectives

1. To develop a predictive maintenance algorithm for electric motors in ships.
2. To be able to determine the remaining useful life of electric motors.

## 1.4 Justification of the study

Electric motors serve as a critical component for any facility. However, electric motors can be prone to any number of issues that lead to motor faults and failures. Failures disrupt business operations, decrease productivity, and adversely impact a company's bottom line.

Motor inspection processes have shifted from manual scrutiny to semi-automated and fully-automated inspection. This will replace the time-consuming task of manual review, significantly increasing productivity while preventing missed inspection as well as errors. Traditionally maintenance involves routine inspection and repair done manually. This cannot completely prevent the risk of machine downtime and will also result in the unnecessary early replacement of usable parts [4].

The purpose of this project is to alert about problems occurring in the motor and trying to mitigate the risk of unexpected failure. A well-planned predictive maintenance is the key to long life operation of motors. In ships unexpected failure causes downtime which deeply eats into profits. The traditional approach is to repair and replace equipment after a period of time but this cannot prevent downtime due to malfunctions, which put a halt to operations and incur massive losses. Advanced monitoring is implemented on parts that are about to break down and can be discovered in advance to accurately determine the time for repair and risk of unexpected shutdown can be prevented. [4]

Although Reactive and preventive maintenance will always have a part in operations, Predictive maintenance is the next big step forward in the evolution of asset management. In fact, the ability to connect assets and feed information into a central system gives organizations the power to turn data into powerful insights and automatically take corrective, preventive or predictive action.

## 2 Literature Review

### 2.1 Operation, Subsystems and Parameters

Every day we rely on a wide range of machines, but every machine eventually breaks down unless it's being maintained.

The control, monitoring and maintenance of ships equipment's is fundamental for the quality and performance of productive process. Sensors and actuators play an important role in operation of various machines such as pumps, generators, among others, so they must always be in proper working condition. To guarantee this, machines are constantly monitored and types of maintenance of their components are performed. Corrective maintenance is performed in the case of a critical failure in the equipment and causes an unplanned downtime of the production line. Scheduled maintenance is performed periodically and equipment is checked and replaced, if necessary, in order to avoid unplanned downtime. Industry has begun to perform condition-based maintenance where predictive equipment status is used to plan a maintenance [5].

Condition monitoring is a type of maintenance inspection where an operational asset is monitored and the data obtained is analysed to detect signs of degradation, diagnose the cause of faults, and predict for how long it can be safely or economically run. There are five general categories of Condition Monitoring techniques—vibration monitoring and analysis; visual inspection and non-destructive testing; performance monitoring and analysis; analysis of wear particles in lubricants and of contaminants in process fluids; and electrical plant testing. Condition Monitoring needs good quality data such as that obtained by carefully run tests. However, much useful information can often be obtained from a plant's permanent instrumentation once repeatability is established[6]. The basic principle of condition monitoring is to indicate the occurrence of deterioration by taking physical measurements at regular intervals. Condition-based maintenance policy is used to inspect and replace the system according to the observed deterioration level.

Predictive maintenance is referred to as the use of data, machine learning techniques, and statistical algorithms to predict the most likely failure outcome of systems [7]. The machinery data collected by monitors say sensors (wired or wireless), is analysed in order to provide a consistent forecast on when a given component or machinery should be replaced or maintained thus optimizing on maintenance cost and downtime. Predictive maintenance is a branch of condition-based maintenance. Condition based maintenance (CBM) is described as a maintenance practice that tolerates and detects the failure of a system during operation through continuous monitoring of the system during operation[8].

Marine vehicle managers and marine technical experts claim that installation of more sensors and cables for monitoring purposes, will only have an impact on maintenance the of marine systems only if the maintenance crew apply hand-in-hand other maintenance aspects like visual inspections, vibration measurements, regular oil analysis and enriching the maintenance information base with performance parameters [8].

Remaining Useful Life (RUL) is the time remaining for a component to perform its functional capabilities before failure. The concept of Remaining Useful Life (RUL) is used to predict life-span of components (of a service system) with the purpose of minimizing catastrophic failure events in both manufacturing and service sectors. This project involves acquiring real data from a normal working pump at its different stages in life. This will be done using multiple sensors attached to the pump at different times under different working conditions. Over time, the installed sensors will generate more and more data which can be used to improve the initial models and make near-perfect failure predictions.

Currently the industry is majorly relying on sensors for condition monitoring which has facilitated decision making under time constraints. The time between the point where a potential failure occurs and the point where it deteriorates into a functional failure can be seen as an opportunity window during which decision-making algorithms can recommend actions with the aim to eliminate the anticipated functional failure or mitigate its effect. The system can record and monitor pressure and temperature conditions of an industrial motor and transmit the data through a wireless network to a data logging

centre. The current prototype was developed using open-source software and hardware and can successfully identify abnormal motor conditions from sensor input values that exceed predefined set-points.

The widespread use of sensors in industry allows for data acquisition, which, combined with advanced methods of analysis, can significantly improve and optimize production. Therefore, the data can be used not only to monitor the current state of the process and devices, but also to predict this state. The application of predictive methods to sensory data representing production process, including machine condition, allows for early identification and prediction of the faulty or hazardous process state or machine break down[7].

The aim of this project is to present a data-driven method analysing sensory data to predict machine failure or identify its deteriorating condition, so that users can plan maintenance work and avoid unplanned downtime. This method was prepared based on real-life data with the assumption that the created solution will be used in industry as a result of the implemented project.

Predictive maintenance is based on the prognostic and health management technology, which supposes that the remaining useful life of equipment can be predicted. However, due to uncertainty of prognostics there could be wrong decisions regarding the remaining time to failure.

Currently, the most promising strategy of maintenance for various technical systems and production lines is the predictive maintenance (PM), which can be applied to any system if there is a deteriorating physical parameter like vibration, pressure, voltage, or current that can be measured[4].

Motors in various applications start deteriorating due to various reasons. Thus, the monitoring of their condition is of prime importance for sustaining the operation and maintaining efficiency. Motors are the backbone of industry; they start degrading due to different reasons such as long period of operation, variations of power supply, or harsh en-

vironment; which gradually lead to permanent damage. Consequently, it becomes crucial to monitor the operation continuously [2].

Industry reliability surveys suggest that ac motor failures may be divided into five categories, including (IEEE, 1997):

- bearing: 44%
- stator winding: 26%
- rotor: 3%
- shaft: 5%
- others: 22%.

even though the replacement of defective bearings is the cheapest fix among the causes of failure, it is the most difficult one to detect. Motors that are in continuous use cannot be stopped for analysis.

## 2.2 Sensors

### 2.2.1 Temperature Sensor

A temperature sensor is a device, typically, a thermocouple or resistance temperature detector, that provides temperature measurement in a readable form through an electrical signal. It measures the degree of hotness or coolness in an object. There are many types of temperature sensors, but, the most common way to categorise them is based upon the mode of connection which includes, contact and non-contact temperature sensors[9].

Contact sensors include thermocouples and thermistors because they are in direct contact with the object they are to measure. Whereas, the non-contact temperature sensors

measure the thermal radiation released by the heat source. Such temperature meters are often used in hazardous environments like nuclear power plants or thermal power plants.

In this project the contact type of temperature sensor was selected due to the nature of data to be collected from the bearings.

### **2.2.2 Thermocouple Temperature Sensor**

A thermocouple is a device for measuring temperature. It comprises two dissimilar metallic wires joined together to form a junction. When the junction is heated or cooled, a small voltage is generated in the electrical circuit of the thermocouple which can be measured, and this corresponds to temperature.

In theory, any two metals can be used to make a thermocouple but in practise, there are a fixed number of types that are commonly used.

No power supply is needed for a thermocouple, but the voltage that it generates is extremely small (measured not just in millivolts, but microvolts) and very nonlinear, requiring hardware and/or software to convert it to a temperature value.

## **2.3 Pressure Sensor**

They are instruments or devices that translate the magnitude of the physical pressure that is being exerted on the sensor into an output signal that can be used to establish a quantitative value for the pressure. There are many different types of pressure sensors available, which function similarly but rely on different underlying technologies to make the translation between pressure and an output signal[10].

There are different types of pressure sensor and these include the industrial pressure transducer, the liquid pressure transducer, and the micro pressure transducer, among others.



### **2.3.1 Pressure Transducer**

Pressure transducers can come in a number of shapes and sizes, but the majority of transducers have a cylinder-shaped centre which houses the diaphragm and the measurement pressure chamber, a pressure port at one end which is typically a threaded, bolted, barbed fitted, or open, and on the other end a location for signal transmission[11].

## **3 Methodology**

### **3.1 D**

### **3.2 Data Analysis**

The data collected from the sensors will be analyzed using custom software created using vim. Graphs will be generated to compare the performance of each component.

#### **3.2.1 Descriptive analysis**

Using exploratory data analysis prior and current running status is determined

### **3.3 Predictive analysis**

Achieved by building predictive models. The required replacement parts as well as time required for maintenance can be determined.

### **3.4 Prescriptive analysis**

This will provide insights on how to create desired outcomes i.e reduce load by 5% for increased service life

### **3.5 System Modelling**

The predictive maintenance algorithm for motors system will be obtained from governing equations from which a transfer function will be generated from the linearized model. The transfer function will be used to generate a state space model for the system. The

observed sources of faults and their relative frequency. Such sources can be the core components of the machine or its various sensors (such accelerometers and flow meters). The process measurements through sensors. The number, type and location of sensors, and their reliability and redundancies all will create both algorithm and comparative model. The sources of faults will translate to observed symptoms. Such cause-effect analysis will require extensive processing of data from the available sensors. Physical knowledge about the system dynamics will result in mathematical modeling of the system and its faults and from the insights of data. Understanding system dynamics will involve detailed knowledge of relationships among various signals from the machinery (such as input-output relationships among the actuators and sensors), the machine operating range, and the nature of the measurements (for example, periodic, constant or stochastic). The ultimate maintenance goal, such as fault recovery or development of a maintenance schedule

### 3.6 Process chart

From the generated models on, simulations will be performed using the different controllers and the responses and other metrics will be plotted out for further analysis using NumPy and Pandas python libraries . Values such as rise time, settling time and stochastic response will be observed to determine the system performance.

### 3.7 Sensors

Sensors will be used to collect data from the system as it runs. These include:

1. Humidity sensor
2. Temperature sensor
3. Flow rate sensor
4. Pressure sensors

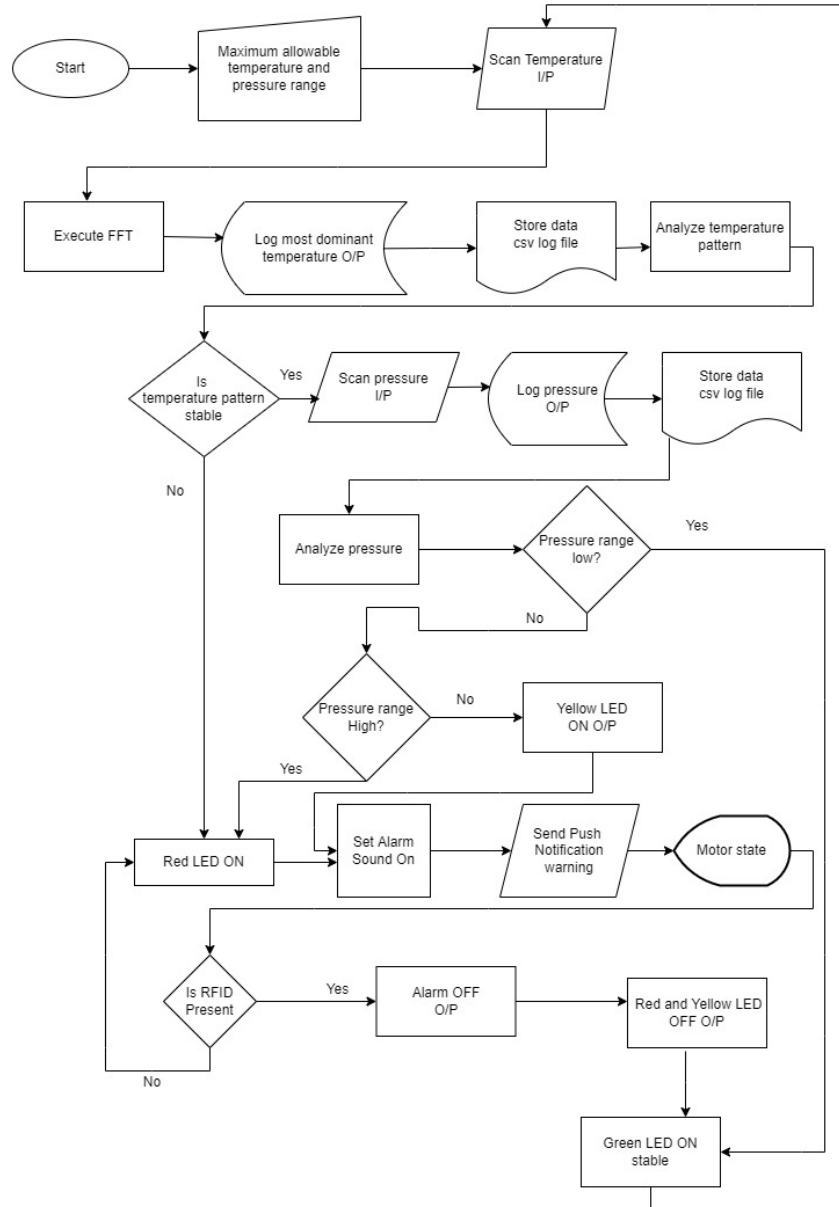


Figure 3.1:

5. Voltage sensor

6. Current sensor

These sensors will be used by the controller to observe system performance and optimize for each parameter.

### **3.7.1 External Force Sensor**

### **3.7.2 Stewart Platform as a force sensor**

## **4 Expected Outcomes**

1. A functional motor health monitoring device will be developed and tested.
2. The predictive maintenance algorithm will be formulated and proved from a selection of diverse methods.
3. The controller supporting circuitry will be developed with a custom printed circuit board.
4. nathan mutuma Electric motor system performance and efficiency will be optimized using insights from real-time data collected.

## 5 Project Budget

Item List			
ITEM	SPECIFICATION	QUANTITY	PRICE
Arduino	Uno Rev3, usb 2.0 Cable Type A/B	1	3000
Thermocouple Amplifier	MAX31855K	1	1600
WiFi Develop- ment Board	NodeMCU 32S ESP32/ CH340c	1	1400
Thermocouple K type	Temp range: 0- 600	1	1760
Thermocouple DH22	3.3-6v input	1	750
Power Unit	12v/5W SMPS Module	1	600
Breadboard	MB102 165*55*50mm	2	400
Jumper Wires	20cm male 20cm female	80	400
<b>Total</b>			9910

# 6 Work Plan

Week	1	2	3	4	5	6	7	8	9	10	11
Proposal Refinement											
System Modelling											
Controller Modelling											
Simulation											
Circuit Design											
Prepare Interim Report											
Presentation											

Table 6.1: Workplan table



## References

- [1] M. U. Thomas and S. S. Rao, “Warranty Economic Decision Models: A Summary and Some Suggested Directions for Future Research,” *Operations Research*, vol. 47, no. 6, pp. 807–820, Dec. 1999. [Online]. Available: <http://pubsonline.informs.org/doi/10.1287/opre.47.6.807>
- [2] J.-H. Han, D.-J. Choi, S.-K. Hong, and H.-S. Kim, *Motor Fault Diagnosis Using CNN Based Deep Learning Algorithm Considering Motor Rotating Speed*, Apr. 2019, pages: 445.
- [3] “13 common causes of motor failure.” [Online]. Available: <https://www.fluke.com/en-gb/learn/blog/motors-drives-pumps-compressors/13-common-causes-of-motor-failure>
- [4] G. Sampaio, A. Vallim Filho, L. Silva, and L. Silva, “Prediction of Motor Failure Time Using An Artificial Neural Network,” *Sensors*, vol. 19, p. 4342, Oct. 2019.
- [5] “Predictive Maintenance - an overview | ScienceDirect Topics.” [Online]. Available: <https://www.sciencedirect.com/topics/engineering/predictive-maintenance>
- [6] S. Lu, P. Zhou, X. Wang, Y. Liu, F. Liu, and J. Zhao, “Condition monitoring and fault diagnosis of motor bearings using undersampled vibration signals from a wireless sensor network,” *Journal of Sound and Vibration*, vol. 414, pp. 81–96, Feb. 2018. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S0022460X17307691>
- [7] T. Tinga, W. Tiddens, F. Amoiralis, and M. Politis, *Predictive maintenance of maritime systems: Models and challenges*, Jun. 2017, pages: 68.
- [8] D. Kimera and N. Fillemon Nduvu, “Predictive maintenance for ballast pumps on ship repair yards via machine learning,” *Transportation Engineering*, vol. 2, p. 100020, Dec. 2020.

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- [9] “Temperature Sensors: Types, How It Works, & Applications,” Jul. 2019. [Online]. Available: <https://www.encardio.com/blog/temperature-sensor-probe-types-how-it-works-applications/>
- [10] “Types of Pressure Sensor - A Guide.” [Online]. Available: <https://www.thomasnet.com/articles/instruments-controls/pressure-sensors/>
- [11] “Different Types of Pressure Transducers.” [Online]. Available: <https://www.omega.com/en-us/resources/pressure-transducers-types>