REAL-TIME AIR CONDITIONING UNIT MONITORING SYSTEM WITH ANALYTICS FOR PREDICTIVE MAINTENANCE

Jhon Michael Falcunitin
Marcelino Jr. C. Labayo
Lyka Eunice A. Titular

College of Engineering
First Asia Institute of Technology and Humanities, Tanauan City, Batangas, Philippines
falcunitinmichael13@gmail.com marcelino.labayo07@gmail.com lykaeunicetitular@gmail.com

Abstract

With the increasing reliance on air conditioning systems for indoor comfort and climate control, innovative approaches are imperative to enhance efficiency, reduce costs, and extend equipment lifespan. This study presents a comprehensive investigation into a real-time air conditioning unit monitoring system integrated with advanced analytics for predictive maintenance. Using wireless sensor networks and different learning algorithms, the advanced system is capable of collecting real-time data, including temperature, vibration, voltage and current flow from air conditioning (AC) units. It addresses problems in monitoring and performing maintenance late or excessively early in AC units. In the study, a comprehensive look at different predictive analytical algorithms are carefully identified and evaluated. The result is a system with a graphical user interface for displaying current value parameters and predictive insights. By combining these technologies, maintenance is kept to a minimum, the life of the equipment is lengthened, and continuity is ensured. This feature will significantly lessen the delay and hassle in manual monitoring of AC units in FAITH Colleges and other schools and establishments where the system may be deemed applicable and necessary. The integration of real-time monitoring with predictive analytics sets a new benchmark for AC unit maintenance, pushing the frontier of smart home and industrial applications.

1. 0 INTRODUCTION

There is an unprecedented heat wave underway in South Asia, placing the lives of hundreds of millions of individuals in jeopardy with dangerously high temperatures surpassing 100 degrees Fahrenheit. The region has suffered above-average temperatures for weeks and cities across it broke monthly April records (Harvey, 2022). As the world heats up, billions of people need the 120-year-old technology, air-conditioning. This used to be considered a luxury but in the age of climate change, it is a necessity for human survival. According to the study done by Scientific American, among the approximately two billion air conditioning units presently being utilized worldwide, the majority are concentrated in affluent nations in North America and East Asia, with Europe following at a considerable distance due to its typically milder climate. In the hottest areas of the globe, air conditioning ownership stands at a mere 12%, in stark contrast to the more than 90% observed in the United States and Japan. However, as populations experience increased prosperity and temperatures continue to escalate, this pattern will undergo a significant and remarkable shift.

In the Philippines, given its country's tropical climate characterized by hot temperatures and humidity levels throughout the year, air conditioning has become an integral part of modern living, leading to its widespread adoption in commercial, industrial, and residential settings (Statista Research Department, 2023). Based on the SRD analysis, in 2021, the demand for air conditioning devices in the Philippines amounted to approximately 822 thousand units, the lowest number within half a decade. Air conditioning systems are one of the essential parts of every establishment.

Air conditioning systems play a vital role in maintaining comfortable and conducive learning environments in educational institutions, particularly in universities. The use of window-type air conditioning units has become widespread in various settings as it offers convenience and affordability. This air conditioning unit requires proper maintenance to ensure optimal performance and longevity (Metropolitan Air Conditioning, 2023). Proper maintenance can measurably extend the overall lifespan of a machine. One of the most important parts of an air conditioning system that needs maintenance is the compressor. According to this, temperature, and vibration sensors were simply used to mitigate the system. Moreover, electrical problems are most common in systems that get turned on and off, so voltage and current must be given importance (Pathak, 2022). Considering how much people rely on air conditioning systems, it is necessary to look into the adoption of predictive maintenance. As stated by Trivedi S. et.al. (2019), predictive maintenance is a strategy that makes use of sensors to check the condition and get an indication about the precise time for carrying out maintenance.

Performing maintenance excessively early, prior to the full development of any critical issues, may result in unnecessary costs. Engaging in unnecessary maintenance activities can result in the expenditure of labor, resources, and operational downtime that could have been prevented. The additional expenditure can affect the overall operating budget, particularly in the context of large-scale HVAC systems. Moreover, regular, and unnecessary maintenance activities may lead to the system experiencing wear and tear due to disassembling and reassembling, thereby reducing the equipment's overall lifespan. However, delaying maintenance until an issue becomes severe can have more significant negative consequences. It might lead to increased energy consumption due to decreased efficiency, which can escalate utility costs over time. Furthermore, if a minor problem escalates into a major malfunction, it can result in system downtime, discomfort for occupants, and even potential damage to other components of the HVAC system. Emergency repairs and replacements often come at a premium, driving up costs.

As stated by Rustagi M. et.al. (2022), predictive analysis modeling is an iterative process that applies to a dataset, and then based on the requirement, modeling techniques have been applied. Predictive analytics makes it possible for organizations to determine risk in prior, opportunities, and tendencies and be able to make strategies for appropriate measures and this can happen only when accurate predictions are done through organized and unorganized information. This proposed project will serve as an improvement of what is already available today as it includes unique features that could have made the existing studies more useful and significant.

This proposed study is based on the first-hand experiences and observations of the proponents; and the responses given by the persons involved in monitoring the air conditioning units in the institution. The study was conducted at First Asia Institute of Technology and Humanities (FAITH Colleges), where there are 388 air conditioning units in the entire school premises. Most of the air conditioning units were window-type air conditioners with a total of 288 units. An interview was conducted to establish the main problem, which is the conventional scheduled-based maintenance done at school without prior information about the status of air conditioning units. As stated by Engr. Jaime IV J. David, administrator of Plant and Facilities at FAITH Colleges, regular preventive maintenance was done every 6 months in every air conditioning unit.

According to the recorded data from Engr. Jeffcaster Comel, during the latest regular preventive maintenance at FAITH Colleges, 34% of the total air conditioning units were defective or not working. Some of the faults found on the units were defective indoor and outdoor boards, broken air swing, noisy motor, no louver, no power supply, damaged coil, defective capacitor, fins, defective cover, broken control button, burnt plug or outlet, and high vibrations effect. On the other hand, 66% of the units were still in good condition. The actions taken were cleaning for good condition units and for damaged units it is either replacement of the component, repair, or replacement of the whole unit.

Considering all the parameters that may affect the quality of air conditioning units in between the 6 months interval, the proponents thought of implementing a real-time air conditioning unit monitoring system with predictive analytics. The proposed project was a monitoring system wherein real-time data will be collected using vibration, temperature, voltage, and current sensors. Data will be collected through a sensor node which will transfer the data through a device using a wireless network. The sensor-based data will be processed by the microcontroller, then the algorithm will be the one to predict if the air conditioning unit is still in good condition. This feature will significantly prolong the life of the air conditioning unit and at the same time, it lessens the delay and hassle in manual monitoring of the air conditioning units not only in FAITH Colleges but also in other schools and establishments where the system may be deemed applicable and necessary.

2. 0 REVIEW OF RELATED WORK

2.1 Air Conditioning System

According to Cityline Air Conditioning (2019), the air conditioner's compressor holds paramount importance as a vital component in the system's overall functionality. Much like the human body, where the heart pumps blood, the compressor provides energy to the refrigerant, enabling it to cool the home effectively. In this analogy, the thermostat acts as the brain, regulating the system's operations, and the refrigerant serves as the circulating blood. Considering the compressor's critical role, any malfunction in this aspect can have severe repercussions on the system's overall performance, potentially impacting the comfort and functionality of the entire home. Hence, ensuring the proper functioning and maintenance of the compressor is imperative for a flawlessly operating air conditioning system.

2.2 Monitoring System

Shukla et al. (2022) proposed online monitoring of motor parameters like current, temperature, vibration, and humidity with the use of IoT and observation of its online trending using a web server. Data can be accessed as graphs and widgets by visiting the web page. The benefit of this project is that it allows for real-time monitoring of the motor from any remote location, and in the event of an irregularity, operating employees can take the necessary actions to prevent an extensive breakdown. The proposed system could assist industry personnel in the online monitoring of motors, and the work can be expanded in the future to include defect or fault prediction and classification. Furthermore, the purpose of this real-time monitoring of a 1-pH induction motor is achieved by continuously monitoring the parameters using various sensors. To sense the parameters of RMS current, vibration, temperature, and voltage, the ACS 712 current sensor, the ADXL acceleration sensor, the DHT 11 temperature sensor, and the voltage sensor circuit are utilized. All data collected will be tracked according to the instructions programmed into the ESP32 module.

2.3 Maintenance Strategies

Sonawane et al. (2022) proposed a study about condition monitoring together with predictive maintenance of electric motors and other equipment. This paper describes a Machine Learning architecture for Predictive Maintenance, based on the Machine Learning approach. The system was tested on a real industry example, by developing the data collection and data system analysis, applying the Machine Learning approach, and comparing it to the simulation tool analysis. Furthermore, the main elements of the distribution system assessment of this study are increased machine productivity, improved repair time and product quality, increased machine life, and thoughtfully planned repair resources. The software used for its implementation is the following: Arduino IDE (for coding ESP32 Microcontroller), Fritzing (for Circuit Designing), ThingSpeak (for Cloud Storage), and Spyder (for ML Code). Sensors will be used to monitor and collect data. The data collected will be passed to NodeMCU Microcontroller. NodeMCU microcontroller was chosen because it supports inbuilt Wi-Fi. Hence data can be directly stored in cloud storage over the internet. The Cloud Storage that will be used for storing data is ThingSpeak Cloud. It supports data storage along with visualizations. Once enough data is collected it can be exported into Excel .csv format. The data exported from ThingSpeak Cloud is the dataset that will be used as a dataset for Machine Learning. Pre-processing steps such as exploration, cleaning, and transformation of the dataset will be done using Python. Machine learning prediction models such as Random Forest, Decision Tree, Naïve Bayes, etc. can be used for the predictive maintenance of motors and to predict failures in motors.

3.0 METHODOLOGY

3.1 Supervised Machine Learning

The research paradigm is presented in Fig. 1. The proposed system is designed to monitor and analyze the real-time status of an air conditioning unit using various sensor inputs. The inputs include current, voltage, vibration, and temperature data inside the system. These sensor inputs are collected and processed by a microcontroller connected to the sensors. After processing, more data is gathered to give the machine learning algorithms training. The algorithms will then be assessed according to their accuracy after being trained and tested on these data. The air conditioning unit's current status is then ascertained by applying the algorithm with the highest accuracy. Finally, data from the past and present, including the condition of the air conditioner, will be shown via a graphical user interface.

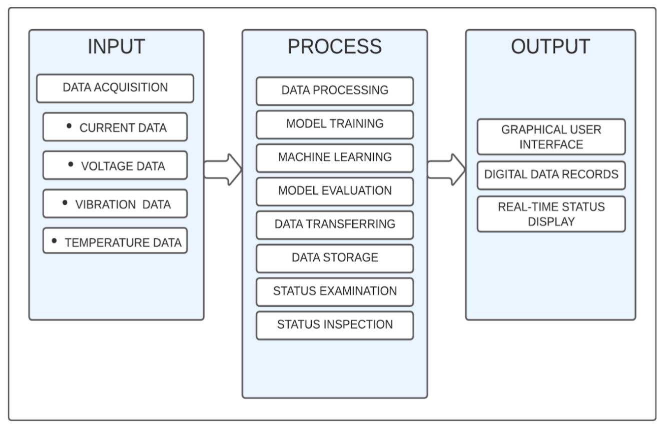


Fig. 1. Research Paradigm

3.2 Method of Data Collection

To develop the method of data collection explained in this part, the researchers analyzed various literature and studies found on reliable online sites. The objectives, materials, methods used, and the results of the existing studies were noted to serve as a basis. Also, to have a prior idea of the data collection setting, a focused interview with Engr. Jaime IV J. David, the administrator of Plant and Facilities at FAITH Colleges was conducted. With this type of interview, the researchers asked a series of questions about the main problem of the proper maintenance of air conditioning units in the school, particularly in the Mabini Building.

In this project, the proponents will utilize the use of three models of air conditioning units, specifically Panasonic, Condura and Hitachi. The study utilized existing algorithms obtained from online sources. Nevertheless, the researchers employed their own dataset to train and evaluate the air conditioning unit monitor with predictive maintenance.

Different parameters such as current, voltage, vibration, thermal condition, and airflow rate of air conditioners were included in the training dataset. Through the system's sensors, the parameters were collected and analyzed by a microcontroller connected to the sensors. The processed data will be saved to the cloud-based server as data storage.

4.0 RESULTS AND DISCUSSION

4.1 Prototype Setup

Fig. 2. Prototype Setup

The setup is composed of an air conditioning unit, laptop, and wireless sensors including voltage, current, vibration and temperature sensors. This setup would allow the user to simply monitor and predict the status of the air conditioning unit system.

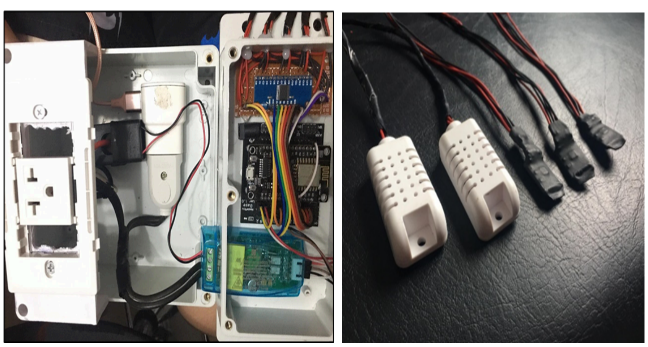


Fig. 3. Prototype (Hardware)

The hardware part of the prototype includes a microcontroller (ESP8266), Voltage and Current Sensor (PZEM004T), three vibration sensors (ADXL335) and two temperature sensors (DHT22). In addition, the box includes hooks specifically designed for flexible positioning, allowing it to be hung on walls, rods, and even air-conditioning units, thereby improving accessibility.

4.2 Prototype Deployment

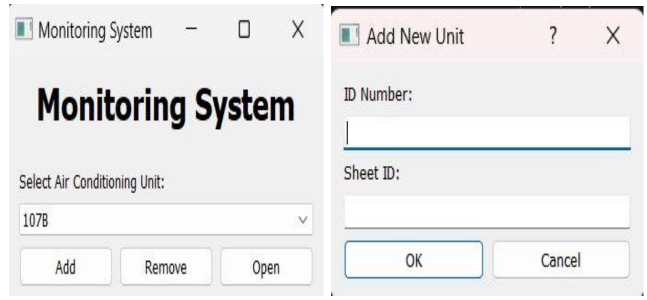


Fig. 4. Interface for functions of air conditioning unit's GUI

Figure 4, which is the graphical user interface (GUI) represents a key component within the air conditioning unit monitoring system, serving as a critical conduit for user interaction within the realm of research. The GUI simplifies the process of managing and monitoring air conditioning equipment by incorporating a number of features. People have the option to input unique unit IDs (IDs) coupled with matching spreadsheet IDs to allow for convenient unit integration into the system, which guarantees proper data organization. Additionally, the GUI provides a precise method for removing units from the database, requiring users to designate specific unit IDs for deletion. It also acts as an access to real-time monitoring interfaces, providing users access to performance metrics, and extensive data visualization. In addition to improving user experience, this GUI design greatly increases the effectiveness and efficiency of the air conditioning unit monitoring system in the context of research.

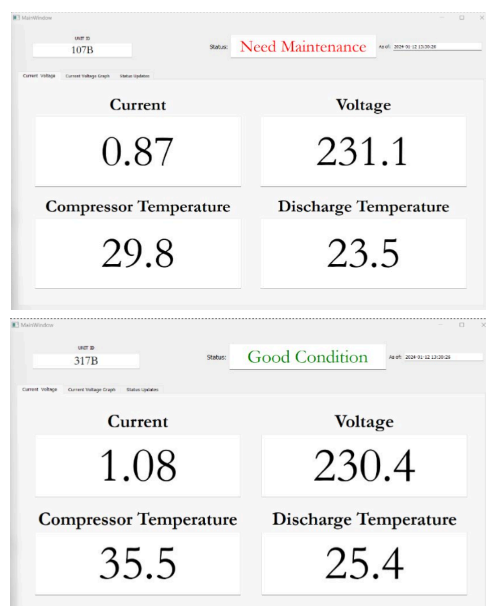


Figure 5. Screenshots of the results of the GUI window for the predictive analytics of the air conditioning unit monitoring system.

Figure 5 shows the GUI window for the predictive analytics of the air conditioning unit monitoring system. Firstly, prominently featured within the interface is the Unit ID, serving as a unique identifier for the currently displayed unit. Users can readily identify the specific unit under observation. Secondly, the GUI displays sensor values crucial for monitoring unit performance, including current, voltage, compressor temperature, and discharge temperature. This real-time data presentation enables users to assess the operational status of the air conditioning unit accurately. Additionally, the interface includes a graphical representation of sensor values, presenting trends and fluctuations over time for enhanced analysis and diagnosis. Moreover, the system shows the prediction of the current status of the air conditioning unit using sensor values, providing valuable foresight for maintenance and optimization efforts. Lastly, users can reference the date of the last prediction change, ensuring transparency and accountability in system updates. This comprehensive GUI design empowers users with the information and tools necessary for effective monitoring and management of air conditioning units.

Table 4.1 Predictive Maintenance System Validation Testing Results

	"Good Condition"	"For Cleaning"	"Need Maintenance"	Total
Validation Accuracy	89/100	95/100	77/100	261/300
	89%	95%	77%	87%

Table 4.1 The validation testing results for the predictive maintenance system were obtained through meticulous evaluation within the actual setup. One hundred samples were systematically collected, and each sample underwent a comprehensive manual examination to verify the system's output against the desired outcomes.

4.3 Evaluations of Different Algorithms in terms of Accuracy

Fig. 6 is the evaluations for various models used in predictive models, the evaluations visual representations or summaries of the performance metrics and results of different algorithms used in the predictive modeling process. The primary focus of these screenshots is the accuracy metric. These evaluations are conducted to assess how well a model is performing in terms of its ability to make accurate predictions on a given task or dataset.

Algorithm	Accuracy (%)
Decision Tree	100
K Nearest Neighbors	99.832
SGDC	94.44211
Support Vector Machine	99.902
AdaBoost	91.74017
Voting Regressor	97.88231
Gaussian Naive Bayes	93.11214
Gradient Boosting Regressor	98.79463
Linear Regression	86.04202
Logistic Regression	96.54207

Fig.63. Evaluations for various models used in predictive model

5.0 CONCLUSION

The researchers developed a Real-Time Air Conditioning Unit Monitoring System with Analytics for Predictive Maintenance, using a wireless sensor network to monitor air conditioning unit parameters in real-time. The system successfully implemented current, voltage, temperature, and vibration parameters. Different supervised predictive algorithms were evaluated based on accuracy. The system was implemented using a microcontroller with a WiFi module and a graphical user interface. The prototype's overall performance was evaluated using accuracy, with the highest accuracy being achieved by Decision Tree. Other algorithms included Linear Models, Support Vector Machines, Nearest Neighbors, Gaussian Processes, Naive Bayes, Decision Trees, and Ensembles. The system's overall performance was evaluated using accuracy, with the highest accuracy being achieved by the Decision Tree.

6.0 RECOMMENDATIONS

The following suggestions have been made by the researchers after they finished the Real-Time Air Conditioning Unit Monitoring System with Analytics for Predictive Maintenance. First off, a more potent microcomputer device is advised for a better outcome if you want a faster processing speed for real-time updates. Aside from that, the integration of cutting-edge sensor technologies, which can offer more precise and in-depth information on air conditioner performance, should also be investigated. This might involve the application of AI-driven sensors, IoT sensors, or other cutting-edge technologies. Additionally, expand the categorization or classification of the state instead of just good and bad. Moreover, consider categorizing units based on their lifecycle stage. Labels like "New and Reliable," "Mid-Lifecycle," "Aging but Functional," and "End of Lifecycle" can guide maintenance decisions and budgeting for replacements. Lastly, allow users to set customizable thresholds for various parameters based on their specific requirements. This empowers users to define what constitutes acceptable or unacceptable performance in their unique contexts.

7.0 ACKNOWLEDGMENT

We extend our profound gratitude to all the individuals and organizations whose unwavering support and valuable contributions made this research study possible. Our hearts are filled with gratitude for each and every one of you.

First and foremost, we express our deepest appreciation to **Almighty God** for granting us the strength, determination, and unyielding desire to pursue this research endeavor. Without His guidance and blessings, we would not have been able to navigate the challenging journey of completing this study and achieving our future aspirations.

Our sincere thanks to **Engr. Francis M. Malabanan** and **Engr. Adonis S. Santos**, our esteemed research adviser. Their mentorship and unwavering support were instrumental in shaping the course of this research. From the inception of the project to the final stages, their patience, recommendations, suggestions, and encouragement provided us with the confidence and expertise needed to fulfill all the requirements with excellence. Special thanks to **Ma. Arabela C. Roxas** for helping us in our paper.

We would also like to extend our heartfelt appreciation to the **Physical Plant and Facilities Administrator of FAITH Colleges, Engr. Jaime J. David IV**. His participation and invaluable assistance from the very beginning were integral to the success of this study. Their candid feedback and cooperation played a crucial role in refining our research, ensuring its relevance and potential impact.

8.0 REFERENCES

1. Alduais F. S. (2020). Determination of the optimal period for carrying out preventive maintenance to minimize expected total cost. *Advances and Applications in Statistics.* 65(2):227–246. Retrieved from: http://dx.doi.org/10.17654/AS065020227
2. Alduais, F. et al., (2022). Optimal periods of conducting preventive maintenance to reduce expected downtime and its impact on improving reliability. *Computational Intelligence and Neuroscience.* 2022. 1-11. Retrieved from: https://doi.org/10.1155/2022/7105526
3. Ali A. & Abdelhadi A. (2022). Condition-based monitoring and maintenance: state of the art review. *Applied Sciences*. 12(2):688. Retrieved from: https://doi.org/10.3390/app12020688
4. Bouabdallaoui, Y. et al., (2021). Predictive maintenance in building facilities: A machine learning-based approach. *Sensors*, *21*(4), 1044. Retrieved from: https://doi.org/10.3390/s21041044
5. Es-sakali, N. et al., (2022). Review of predictive maintenance algorithms applied to HVAC systems. *Energy Reports*. 8. 1003-1012. Retrieved from: https://doi.org/10.1016/j.egyr.2022.07.130
6. Ferreira, L. et al., (2021). Predictive maintenance of home appliances: focus on washing machines. Retrieved from: doi:10.1109/IECON48115.2021.9589642.
7. Mitanshi Rustagi & Neha Goel. (2022). Predictive analytics: a study of its advantages and applications. *IARS' International Research Journal*, vol. 12, 1, pp. 60-63, 2022. Retrieved from: https://www.redalyc.org/journal/6638/663872727008/html/
8. Sonawane, R. et al., (2022). Machine learning-based predictive maintenance of motors using single model analysis. *An International Open Access, Peer-reviewed, Refereed Journal*, vol. 10.5, 2320-2882. Retrieved from: https://ijcrt.org/papers/IJCRT2205280.pdf
9. Serin, G. et al., (2020) Review of tool condition monitoring in machining and opportunities for deep learning. *Int J Adv Manuf Technol* 109, 953–974. Retrieved from: https://doi.org/10.1007/s00170-020-05449-w
10. Trivedi, S. et al., (2019). Predictive Maintenance of Air Conditioning Systems Using Supervised Machine Learning. *20th International Conference on Intelligent System Application to Power Systems (ISAP)*. Retrieved from: https://doi:10.1109/isap48318.2019.9065995

9.0 ABOUT THE AUTHORS

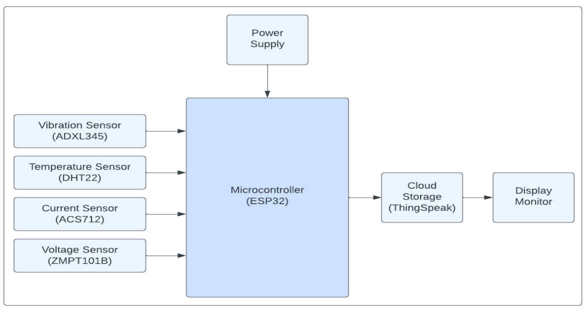
Jhon Michael Falcunitin is a graduating student from FAITH Colleges taking up BS in Electronics Engineering, currently a Design Automation Intern at Xinyx Design Consultancy Services Inc. Also Marcelino Jr. C. Labayo is a graduating student from FAITH Colleges taking up BS in Computer Engineering, currently an IC Layout Design Engineering Intern at Analog Devices Inc. General Trias Cavite. Lastly, Lyka Eunice A. Titular is a graduating student from FAITH Colleges taking up BS in Electronics Engineering, currently a IC Digital Layout Intern at Xinyx Design Consultancy Services Inc.

10.0 APPENDIX

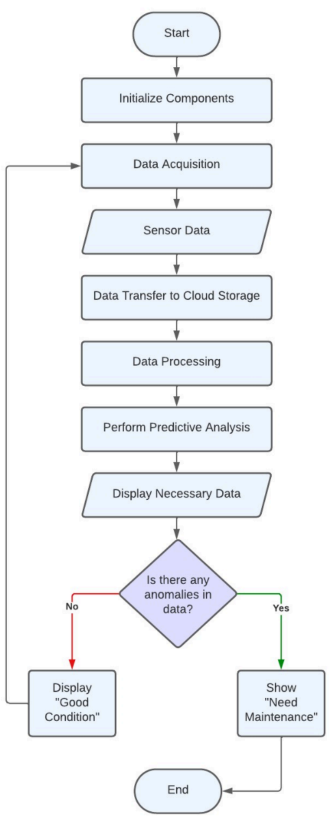
Appendix A – System Components

Hardware	Software
ESP8266	ThingSpeak
DHT22 Temperature Sensor PZEM-004T Current & Voltage Sensor	Graphical User Interface
ADXL 335 Vibration Sensor	

Appendix B – Block Diagram of the System Hardware



Appendix C – Flow Chart of the System



Appendix D – Testing Phase and Actual Setup