DEVELOPMENT OF APPS FOR PREDICTIVE MAINTENANCE SYSTEM: A CASE STUDY IN HP

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature	……………………………………………
Name	……………………………………………
Date	……………………………………………

Supervisor's Declaration

I hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by Universiti Sains Malaysia.

Supervisor's Signature	……………………………………………
Name	……………………………………………
Date	……………………………………………

ACKNOWLEDGEMENT

The people you stumble upon will always have a lesson to teach you. – Aristotle

First and foremost, I would like to express my utmost gratitude to my supervisor, Dr Hasnida AB Samat, lecturer of School of Mechanical Engineering, Universiti Sains Malaysia for guiding me from the beginning of this final year project. Her willingness to spend time to advice on my progress has resulted in the completion of this project.

Besides that, the managers, engineers and technical specialist in HP Inc Batu Kawan, Penang were very helpful in providing technical know-how and sharing their working experiences. It was their motivation, words and knowledge that managed to bring the best out in me. They stressed on the values and principles which were indeed important to me as a future engineer. Special thanks to Mr. Timothy Thong, MEMS Department Manager and Mr. Chin Jia Jie, MEMS Senior Engineer for helping and supporting me throughout the completion of this project. Mr. Chin Jia Jie is very resourceful and always help me to a certain extent by providing important information or clues to complete this project.

Deepest thanks and appreciation to my parents, family, and friends for their moral support, encouragement and helpful thoughts from beginning to the ending of this project.

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This final year project collaborated with HP Inc has undoubtedly exposed me to the working life of an engineer in an industry. Hard work, perseverance and humility are the values that an engineer must possess when he or she is working. Engineers are seen as the forerunners of the growth of science and technology and should therefore carry their heads high and be proud of whom they are.

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ABSTRAK

Dalam sektor perkilangan global, industri pembuatan dari seluruh dunia berusaha untuk meningkatkan prestasi mereka dengan meningkatkan produktiviti pengeluaran antara satu sama lain untuk mengekalkan kelebihan daya bersaing dalam persekitaran perniagaan yang kompetitif ini. Kebanyakan kilang telah melaksanakan pelbagai jenis kaedah seperti meramalkan penyelenggaraan dan Objek Rangkaian Internet untuk membuat penambahbaikan dalam produktiviti. Penyelenggaraan mesin menyumbang sebanyak 60 hingga 75% daripada kos keseluruhan kitar hayat industri pembuatan. Kerja-kerja penyenggaraan untuk mesin amat penting bagi memastikan produktiviti dan kualiti produk terjamin. Aktiviti-aktiviti meramalkan penyelenggaraan boleh memberitahu individu kegagalan mesin awal dan kerja-kerja penyelenggaraan boleh diatur terlebih dahulu dengan lebih baik untuk menjimatkan kos penyelenggaraan. Kini, Objek Rangkaian Internet dalam persekitaran industri boleh manyumbang kepada pembangunan sistem inovatif serta cekap yang bertujuan untuk meningkatkan kecekapan operasi di kilang-kilang pintar generasi baru. Dalam kertas ini, kaedah atau sistem untuk meramalankan penyelenggaraan telah dibangunkan untuk menentukan masa yang paling berkesan atau tepat untuk melakukan penyelenggaraan kepada mesin. Kertas kerja ini membentangkan rangka semantik untuk pengumpulan data, sintesis data dan perkongsian ilmu dalam persekitaran awan untuk meramalkan penyenggelaran. Hasil daripada kertas kerja ini adalah satu aplikasi ‘Android’ yang akan memberitahu pengguna untuk melaksanakan penyelenggaraan pada masa yang tepat.

ABSTRACT

In global manufacturing, manufactures from various nations aim to enhance their performance by improving their manufacturing productivity among one another in order to maintain a competitive advantage in this harsh business environment. Most of the manufactures have implemented different kinds of manufacturing tools and methods such as Predictive Maintenance (PdM) and Internet of Things (IoT) to make improvements in productivity. Maintenance and support may account for as much as 60 to 75% of the total lifecycle cost of a manufacturing system. Proper maintenance of manufacturing equipment is crucial to ensure productivity and product quality. PdM forecasts failures in advance so that maintenance can be better planned in order to save additional maintenance cost. IoT solutions in industrial environments can lead nowadays to the development of innovative and efficient systems aiming at increasing operational efficiency in a new generation of smart factories. In this paper, a PdM method or system is developed to determine the most effective time to apply maintenance to an equipment. This project presents a semantic framework for data collection, synthesis, and knowledge sharing in a Cloud environment for PdM. The outcome is an Android Application which informs users to perform maintenance at the right time.

Chapter 1
INTRODUCTION

This chapter will discuss about project background, problem statement, project objectives and project scope.

1.1 Project Background

Predictive Maintenance (PdM) approaches are used to examine and observe the conditions of equipment with the intention to predict when maintenance should be executed. The key is “the right information in the right time”. By understanding which equipment needs maintenance, maintenance work can be better planned (spare parts, people, etc) and what would have been “unplanned stops” are converted into shorter and fewer “planned stops” [1]. This increases plant availability. This approach also ensures cost savings over time-based preventive maintenance because maintenance work is only done when needed. From Mazenko (2016), PdM brings several cost savings as it reduces the time the equipment is being maintained, minimize the production hours lost to maintenance, and limits the cost of spare parts and suppliers. In short, the main goal of PdM is to prevent unexpected equipment failures. Meanwhile, Internet of Things (IoT) is the concept of connecting any device to the Internet and to other connected devices. Machines with sensors connected to an IoT platform, which integrates data from the different devices and applies analytics to share the most valuable information with applications built to address specific needs. These powerful IoT platforms can pinpoint exactly what information is useful and what can safely be ignored. This information can be used to detect patterns, make recommendations, and detect possible problems before they occur. For an example, predicting maintenance before the machine undergoes failures. Hence, this study aims to develop a PdM as a monitoring system with the aid of IoT for HP Malaysia Manufacturing (HPMM), Batu Kawan, Penang to carry out maintenance more effectively and efficiently.

1.2 Problem Statement

About 80% of time reacting to issues or problems are being spent by organizations instead of preventing it [3]. Maintenance is being put ahead by PdM to aid in forecasting failures and monitoring the gross performance for further higher cognitive process. This results in reduction of cost and time saving. Organizations that executes PdM could expect to see portentous stabilization in asset reliableness and nurture in cost efficiency as:

- Increase in production
- Increase in Return on Investment (ROI)
- Elimination of breakdowns
- Reduction in downtime
- Reduction in maintenance cost

From Venkatesh (2007), the conventional way of Preventive Maintenance (PM) is a daily maintenance (inspection, oiling, re-tightening and cleaning) designed to sustain the condition of instruments and to avert foundering through the prevention of downturn, periodic scrutiny or diagnosing the condition of equipment. The service life of an equipment can be elongated by doing PM, just like how human's life is perpetuated by preventive medicine. However, the prospect of circumventing a potential foundering is extremely low for PM, as there is a huge possibility that the system could anyhow fail right after an organized maintenance. Thus, additional costs of repair are being imposed by PM. Such additional costs are reduced by PdM by scheduling maintenance if and only when a potential breakdown symptom is identified.

1.3 Project Objectives

The objectives of this final year project are:

- To determine the condition of in-service equipment in order to predict when maintenance should be performed.
- To build an Android Application using historical data and available database from HPMM for a PdM system.

1.4 Project Scopes

This final year project will work closely with HP MEMS Department team to collect data and create databases using analytical tools and presenting this data in simple way and easy to understand format to help Equipment team in taking actions and decisions. I will be placed as a Technical Intern in HPMM from 1st November 2017 to 30th June 2018.

Chapter 2

LITERATURE REVIEW

This chapter will discuss and provide review from previous research about PdM and IoT.

2.1 Corrective, preventive and predictive maintenance.

This section will be a discussion based on research study by Palem (2013) on why PdM is said better than preventive and corrective maintenance.

2.1.1 Corrective Maintenance

Corrective maintenance (CM) does not have any specific maintenance plan in place which is known as the classic Run-to-Failure reactive maintenance. The machine is conjectured to be fit unless it is proven otherwise. The advantages and disadvantages of CM are shown in Table 2.1.

Table 2.1: Advantages and Disadvantages of CM

Advantages of CM	Disadvantages of CM
I. Machines are not over maintained. II. No overhead of condition monitoring or planning costs.	I. Higher risk of collateral damage and secondary failure. II. High manufacturing downtime. III. Overtime labor and higher cost of spare parts.

2.1.2 Preventive Maintenance

Preventive maintenance (PM) is the common periodic maintenance strategy that's actively utilized by all makers and operators within the industry nowadays. An optimal breakdown window is pre-calculated (at the time of component installation supported by a large vary of models describing the degradation process of equipment) and a PM schedule is set out. Maintenance is carried-out on those periodic intervals, presumptuous that the machine goes to breakdown. The advantages and disadvantages of this approach are shown in Table 2.2.

Table 2.2: Advantages and Disadvantages of PM.

Advantages of PM	Disadvantages of PM
I. Fewer catastrophic failures and collateral damage. II. Greater control over spare-parts and inventory. III. Maintenance is performed in controlled manner, with a rough estimate of costs well-known ahead of time.	I. Calendar-based maintenance: Even when there are no faults machines are still repaired II. There will still be unscheduled breakdowns.

2.1.3 Predictive Maintenance

PdM is a rising alternative different to the above two that employs prophetical analytics over real-time data collected (streamed) from parts of the machine to a centralized processor that detects variations within the useful parameters and detects anomalies which will doubtless cause breakdowns. The real-time nature of the analytics helps establish the useful breakdowns long before they happen however shortly when their potential cause arises. Historical information can also be used to study the trend of past failures and more analytics is done to predict breakdowns. The advantages and disadvantages of this approach are shown in Table 2.3.

Table 2.3: Advantages and Disadvantages of PdM.

Advantages of PdM	Disadvantages of PdM
I. Unexpected breakdown is reduced or even completely eliminated. II. Parts are ordered when needed and maintenance performed when convenient. III. Equipment life is maximized.	I. High investment costs. II. Additional skills might be required.

Based on the previous three sub-sections, it can be concluded that PdM is the best approach to be used. PdM doesn't avoid failures however rather what it avoids is that the high costs related to the failures by providing early warnings of the failures in order that engineers can decide when and where to address them before they actually happen. However, several area units are still confused with the term Preventive and Predictive Maintenance. This issue will be highlighted in the next sub-section.

2.1.4 Preventive and Predictive Maintenance

This sub-section will be explaining Preventive and Predictive Maintenance in a simplified way. Taking engine oil as an example, a typical PM strategy demands automobile operators to replace the engine oil once after 3,000 to 5,000 kilometres travelled. No concern is given to the exact condition of vehicle or performance capability of the oil. In other words, in PdM strategy, the operator has a way of knowing or somehow determine the real condition of the vehicle and also the oil lubrication properties. The operator gains the potential to elongate the vehicle usage and suspend the vehicle till it has progressed 10,000 kilometers or maybe pre-pone the oil change just in case of any uncommonness.

From the state above, PdM can be deduced that it imparts such profound insights into the machine operations and full functionality status giving rise to best maintenance schedules with improved machine availability. In conclusion, PdM can be justified as a relevant topic and a magnificent field of research for this final year project.

2.2 Internet of Things (IoT)

The idea of IoT was first derived from the network of radio frequency identification (RFID) system by the Automatic Identification Center entrenched in Massachusetts institute of technology (MIT) in 1999. In this system, all the items can be connected to the Internet by radio frequency identification information such as sensing device. Its main function include:

- Information acquisition
- Information transmission
- Information processing
- Information apply-effect

Today, the main aim of information and communications technology (ICT) has been developed from satisfy the communication between people to realize the connection between the people and things, things and objects. The IoT make people in a world of information and communication technology. The connection of at any time, any place, to anyone, has been prolonged to connect anything, and that's IoT as shown in Figure 2.1.

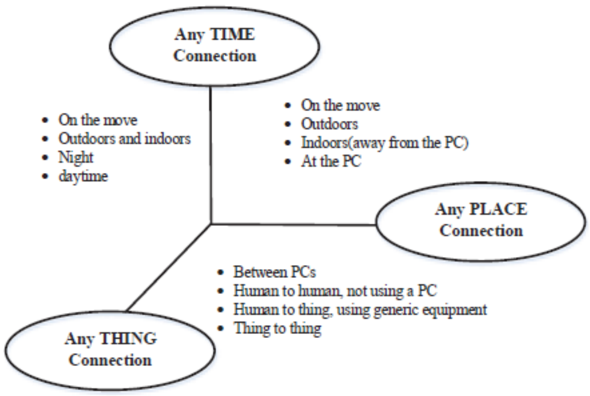


Figure 2.1: Connection dimensions of IoT.

Sensor network and detection technology is the idea and foundation of IoT. Sensors can sense the thermal, mechanical, optical, electrical, acoustic and displacement signals and provide the most original information for the network system of processing, transmission, analysis and feedback. From Yanjing et al. (2013), with the continuous development and improvement of science and technology, the conventional sensor is gradually realizing the miniaturization, intelligent, informatization and networking, and it is experiencing an improvement process from dumb sensor to smart sensor and embedded Web sensor.

In short, sensors provide real time data to detect variations and anomalies that can potentially lead to breakdowns. It can be concluded that one should clearly understands the relationship between sensors and IoT first before constructing the predictive model for maintenance. IoT is one of the seven pillars in Industry 4.0. Based on Kagermann et al. (2013), one of the major or essential problem in implementing IoT is the key promoters of Industry 4.0 only describe the vision, the idea aims at, the basic technologies, and selected scenarios, but a clear definition is not provided. As the term itself is unclear, companies are facing difficulties when it comes to identifying and implementing Industry 4.0 scenarios. Hence, Hermann et al. (2016) have come up with a standard design principle of Industry 4.0 for all practitioners which will be discussed more detail in the next section. Companies should take the standard design principles into account when implementing Industry 4.0 solutions.

2.3 Standard Design Principle for Industry 4.0

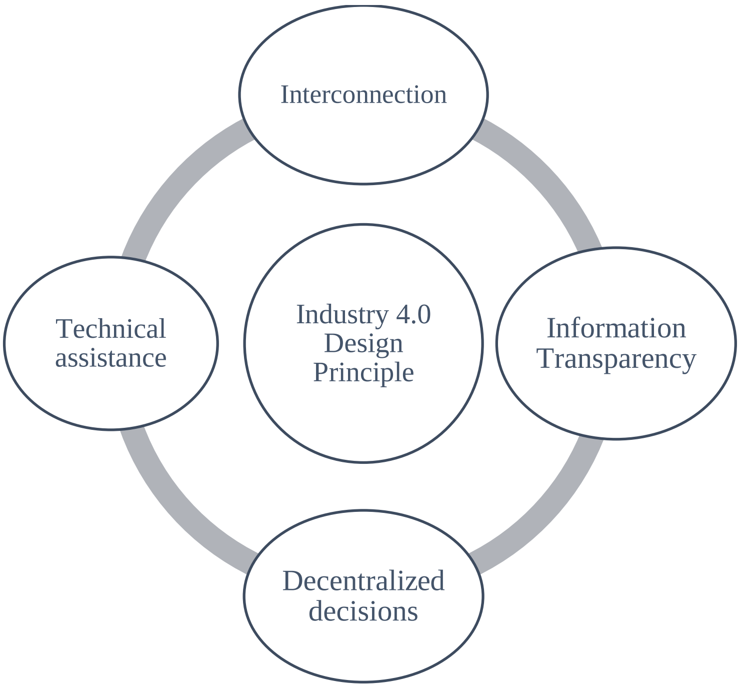


Figure 2.2: Four design principle of Industry 4.0 by Hermann (2016).

2.3.1 Interconnection

Machines, devices, sensors and people are linked together over the IoT and Internet of People (IoP) which forms the Internet of Everything (IoE). IoE allows interconnected gadgets and people to share information and this premises a joint collaboration for reaching common goals. There are three types of collaborations which are human-human collaboration, human-machine collaboration, and machine-machine collaboration. For connecting machines, devices, sensors and people with each other, a common communication standard is crucial. Such standards allow flexible combination of modular machines from various vendors.

2.3.2 Information Transparency

Information transparency is allowed by the increasing range of interconnected objects and people. The combination of the physical and virtual world allows a new shape of information transparency. Information from virtual world consists of electronic document, drawings, and stimulation models whereas information from physical world includes position and conditions of a tool. To analyse the physical world, raw sensor data must be aggregated to higher value context information and interpreted. To create information transparency, the data analytics results need to be embedded in assistance systems that are accessible to all IoE participants. For process-critical information, real time information provision is crucial.

2.3.3 Decentralized decisions

Decentralized decisions are based totally on interconnection of objects and people as well as transparency on information from inside and outside a manufacturing facility. The fusion of interconnected and decentralized decision makers permits to utilize a person with global information and at the same time for better decision making and increasing overall productivity. The IoE participants accomplish their duties as autonomous as possible. From a technical point of view, decentralized decisions are allowed by Cyber-Physical Systems (CPS). Their embedded computers, sensors, and actuators enable to monitor and control the physical world autonomously.

2.3.4 Technical Assistance

As the complexity of production increases, where CPS form complex or complicated networks and make decentralized decisions, human needs to be helped by assistance system. These systems need to aggregate and visualise or imagine information comprehensibly to ensure that human could make informed decisions and solve urgent problems on short notice or quick observe.

The four design principles discussed above can be used as a guiding tool or reference to assist in building the predictive model at initial or design stage.

2.4 Application of IoT in PdM System

From Dong et al. (2016), even though China's coal mine fabrication safety state improved yearly and the accident, death toll, and one million tons mortality rates have fallen drastically, but there is still a certain gap compared with other main coal producing countries in the world. Generally, coal mining operation are influenced by gas, coal dust, roof, water, fire and other hazards. However, low degree of informationization is the main element to restrict coal production safety. At present coal mine, low degree of informationization causes the following problems:

I. Unbalanced evolution as a whole.

II. Poor of sensible development plan.

III. Lack of necessary information and it is hard to realize the communication and data sharing.

IV. Innovation capability is insufficient.

V. Big data and cloud intelligence is overlooked.

The only solution for the problems mentioned above is by executing IoT into China's coal industry to gather and scrutinize data and implementing the right corresponding action based on the analysed data. In Dong's research, IoT is used to prognosticate and perform maintenance at the right time. The PdM system composed of equipment state monitoring station, coal mine monitoring centre, and remote PdM system [10]. The system composition is as shown in Figure 2.3.

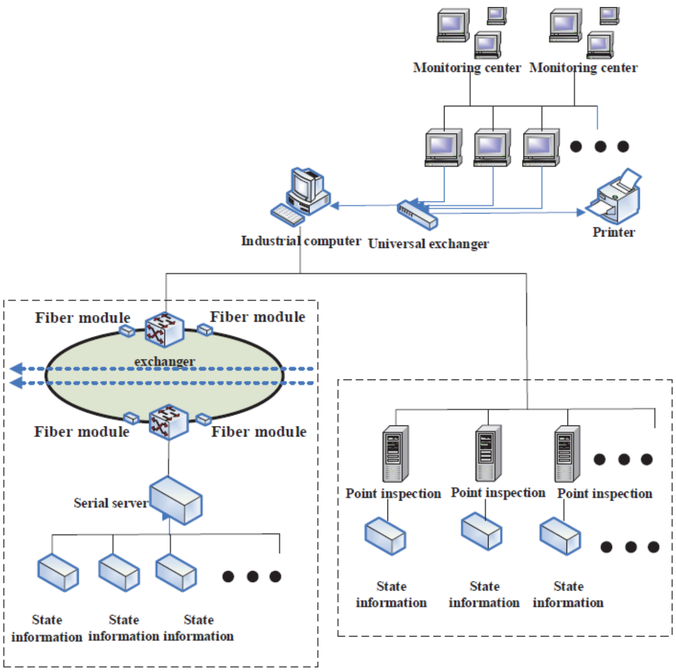


Figure 2.3: Composition of PdM system by Dong (2016)

The explanation of each system is explained in Table 2.4.

Table 2.4: The explanation of PdM system.

PdM System	Explanation
Monitoring station.	Communicate with mine monitoring center by using wireless network and it doesn't need the mine network bandwidth.
Mine monitoring centre.	Collect parameters information from the equipment monitoring sub-station and connect to the remote PdM center through the wireless network or cable.
Remote PdM center.	Obtain the monitoring data by communicating with mine monitoring terminal and the analysis results were sent to the database.

Experts and technicians offers analysis and maintenance proposal through the obtained parameter values and transmit them to the monitoring terminal in the form of statements through the network. One limitation of this research is that the monitoring terminal is not portable. It is placed at the coal mine dispatching centre, where it displays the real-time equipment operating condition, and also the parameter will be transmitted to the remote health identification centre. In this research, the monitoring terminal will be portable. Portable monitoring terminal can either be a smart phone or a tablet and it is to realize the mobile office. The user could monitor the equipment operation status anytime and anywhere.

Efthymiou et al. (2012) presented a review on the PdM approaches, strategies and tools in production systems and suggested an integrated PdM platform. The platform consists of three pillars, named data acquisition and analysis, knowledge management, and a sustainability maintenance dashboard. Data acquisition and analysis is responsible for assembling and storing data utilizing advanced multi embedded sensors and a web repository and secondly for analysing the data in order to discover any possible deviation from the nominal condition. Knowledge management aims to assist the fault diagnostics and the efficient storing of past information of failures via the semantics technology. The knowledge management pillar consists of the ontology that is the main scheme for the knowledge repository and the advanced inference engine. Maintenance dashboard addresses the requirement for a user friendly and intuitive presentation of maintenance critical information that will support maintenance engineers in their decisions.

The authors further explained maintenance in higher cognitive steps. The maintenance decision making step can be analysed into two sub-steps which are diagnostics and prognostics. Diagnostics deals with the identification and the quantification of the desecration that has occurred, while prognostics involves the prediction of the damage that is yet to occur [12] [13]. Diagnostics includes fault detection, fault isolation and fault identification whereas prognostics includes Remaining Useful Life (RUL) prediction and confidence interval estimation. Fault detection is in charge for detecting and reporting an unusual operating condition, fault isolation is concerned with determining components that is failing or has already failed and fault identification deals with the estimation of the nature and the magnitude of the fault. The remaining useful life prediction strives to identify the lead time before a failure criterion is reached, while the confidence interval estimation seeks to quantify the confidence interval of the RUL prediction.

Efthymiou study has several benefits contrasts to other research. The quality of retrieved data is guaranteed by the sensory systems of advanced accuracy and the noise removal is achieved by the following Symbolic Dynamic Filtering approaches (SDF). Reasoning mechanisms, IF-Then Rules, and similarity measurements are used to provide a systematic and automatic way for the detection, identification and isolation of failure without requiring skilled personnel. The rule based system will allow the systematic storing of past failures and its solution. In the occurrence of a new failure, a similarity mechanism performs a systematic search to find the closest match case. This case is then retrieved and its solution, after the proper modification is proposed for the new failure. Finally, dashboard provides a quick insight of the maintenance problem, cause, solution and planning for engineers. A dashboard system could be an additional feature for this research too.

Lindstrom et al. (2017) addresses intelligent and sustainable production in the sense of combining and integrating online PdM and continuous quality control. The rationale for combining and integrating these are that if the online predictive maintenance does not indicate a need for maintenance and the production process parameters look adequate, but the production process output is not adequate, this is an indication that maintenance is needed now or soon (i.e., reactive) if the process cannot be adjusted by changing the production parameters to restore the output quality wanted. Thus, the continuous quality control can be used as an additional indicator for maintenance need. These two concepts can be merged into the same data collection/monitoring/analytics platform, as both are based on using sensor data combined with additional data, which is modelled in order to obtain input for decisions (suitably visualized to be understandable) and to enable warnings or notifications as well as potentially automatic shutdowns or graceful degradation schemes in case serious problems occur but are not adequately predicted. The paper has opened the mind and view to implement PdM in an unalike or uncommon approach using quality control as a tool or indicator.

2.5 Literature Findings

The major findings of this studies focus on detecting variations within the threshold values or any anomalies which will cause breakdowns in machines. Then, the PdM system should be able to perform analytics on the variations and anomalies to inform users to perform maintenance. The biggest challenge here is to study the previous historical data of the machine and relate it with event data in order to define the threshold value or anomalies. This thesis will define threshold value by using quality control as an indicator [14]. The historical data will then be studied to identify any values beyond the threshold to detect any possible trend of failures. The PdM system will inform users to perform maintenance when any values exceed threshold.

This research has some research gap between other researches. First and foremost, this study is only able to perform PdM on one particular machine. If the study is successful and positive outcomes is shown, then the PdM approaches will be duplicated to other machines. Besides that, unlike other research which sensors are used to collect data, this study will only able to work with historical data and available database due to restrictions by HPMM, Batu Kawan, Penang. Hence, a concept will be generated first to test the entire system. If it turns out to be successful, investment in sensors and firmware will be done later for real-time monitoring.

Chapter 3

RESEARCH METHODOLOGY

This chapter will explain a summary of research methodology that is being used to ensure the project is working well as desired. A System Development Life Cycle (SDLC) that details the project work from beginning till end is proposed. SDLC is a multistep process which begins with initiation, analysis, design, implementation and continues through the maintenance and disposal of the system.

3.1 System Development Life Cycle

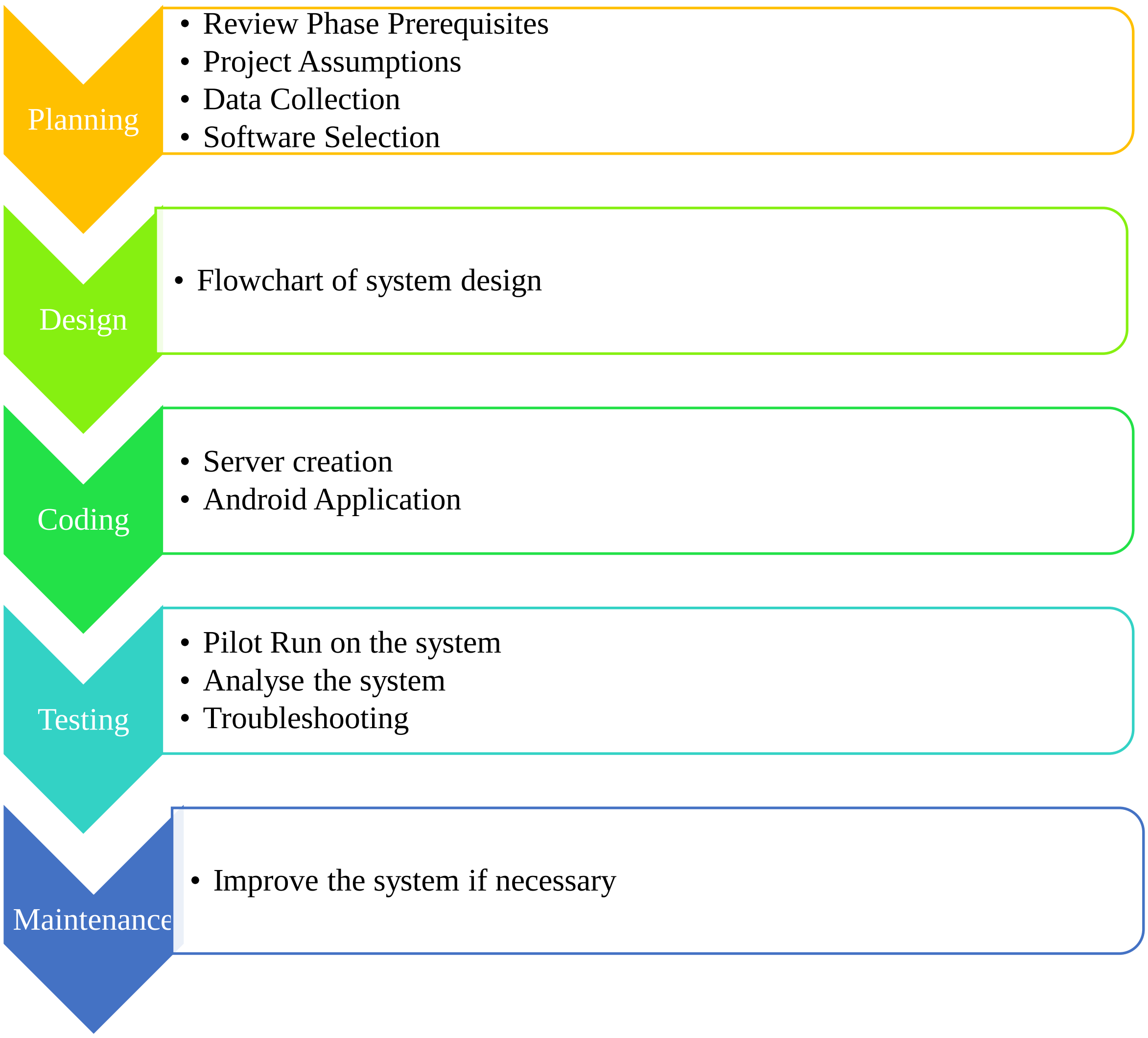


Figure 3.1: SLDC Flowchart.

Figure 3.1 shows the stages involved to implement this project from beginning till ending. Each stage is completed step by step to ensure complete success of the project. This can be also done successfully by making sure the Gantt chart follows the sequences of SLDC flowchart.

3.2 Planning

Planning is the first phase in SLDC. It reviews the objectives, project scope and all information required to complete the project as desired. The planning phase involves four elements which are review phase prerequisites, project assumptions, data collection and software selection.

3.2.1 Review Phase Prerequisites

It is important to review the following prerequisites at this phase which was completed during Research Plan:

- The needs of the project continue to be validated.
- The project scope and objectives are clearly defined.
- The Gantt chart is fully defined.

3.2.2 Project Assumptions

Project assumptions are generally one of the factor to determine the success of the project. The assumptions are accepted as true or as certain to happen without proof to generate a successful project. In this project, the main idea is to study the trend of failures of a machine. Since sensors are not allowed to install yet, the trend of failures only can be studied from historical data. The output of the project can be used as a guideline for future works when sensors are implemented for maintenance in HP Production Floor.

3.2.3 Data Collection

Data collection is a stage that collects information about the project resources and requirements, literature studies and the software to be used. The literature studies which incorporates the journals and research papers related to this project are collected and studied. The study is not only just to evaluate the features of each studies but also to evaluate the limitations. These limitations can be addressed to develop a better system later on.

In this project, data are mainly harvested from several databases which shows a trend of failures. These failures act as a guideline to develop the code for the Android Application.

3.2.4 Software Selection

In this project, software are mainly used to arrange and manage data, to create server and to create the Android Application. After harvesting data from database, Microsoft Excel is used to arrange the data neatly. Charts are displayed using the data in Microsoft Excel to observe trends which helps in predicting failures. Microsoft Excel is an extremely powerful tool to manipulate, analyse and present big data. Businesses and industries often rely on Microsoft Excel. This provides another advantage over other software because it is common and popular resource in today's businesses. XAMPP is used to create server. XAMPP is an open source cross-platform web server solution consisting mainly of the Apache HTTP Server, mySQL database, and interpreters for scripts written in the PHP and Perl programming languages.

On the other hand, MIT App Inventor 2 is used to build the Android Application. MIT App Inventor 2 is one of easiest way to develop the Android Application and the codes is like connecting the jigsaw puzzle unlike Android Studio which uses the language of Java. Besides that, MIT App Inventor 2 has the ability to update its program from time to time easily and therefore we can ensure this application works optimally in the user's android mobile phone. This is important to update the status of the machine time to time to monitor its health.

3.3 Design

This phase defines the elements of a system, the components, the security level, modules, architecture and the different interfaces and type of data that goes through the system. A general system design can be sketched roughly with a pen and a piece of paper to determine how the system will look like and how it will function. Later, a detailed and expanded flowchart of the system design is proposed and it will meet all functional and technical requirements, logically and physically. In short, a flowchart is a crucial step to provide a clear view on how to design the system. To comply with the problem statement, this system is designed to automatically inform the users to perform maintenance when needed.

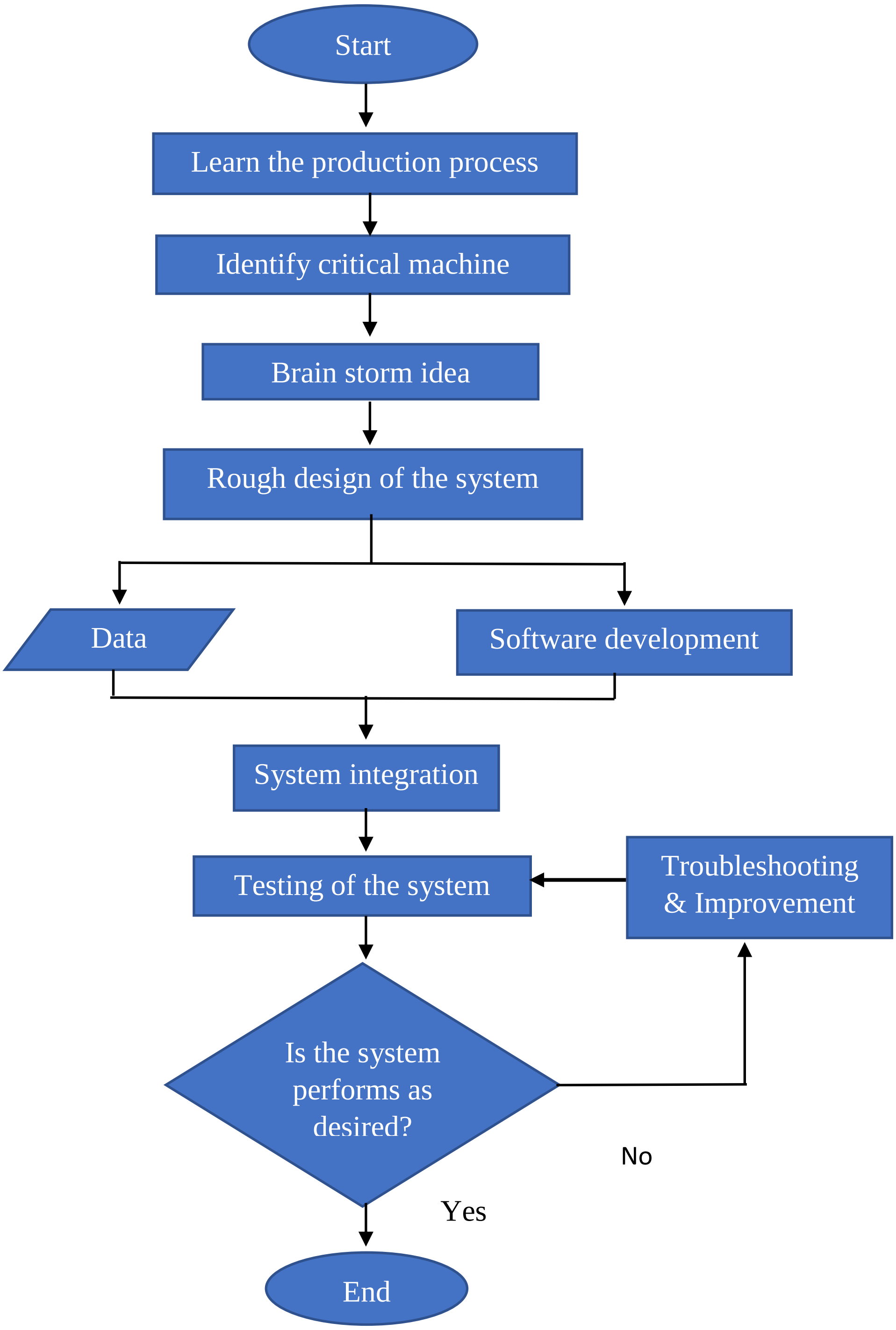


Figure 3.2: Flowchart of the system design.

3.4 Coding

This phase comes after a complete understanding of the system requirements and specifications. It is the actual construction process after having a complete and illustrated design for the desired system. In the Software Development Life Cycle, the actual code is written here. In this project, the code is developed to create server and to build an Android Application to inform users to perform maintenance at the right time. Further discussions on coding are well explained in Chapter 4 and Appendices.

3.5 Testing

This phase brings different components and subsystems together to create the whole integrated system and then introducing the system to different inputs to obtain and analyse its outputs and behaviour and the way it functions. In this project, the machine is defined as a button in the Android Application. The button must turn into red colour whenever maintenance is needed. On the other hand, the button should be in green colour if the machine health is good. The system should be tested to ensure it is working as desired. If not, the system will undergo troubleshooting until it works as desired.

3.6 Maintenance

In this phase, periodic maintenance for the system will be carried out to make sure that the system won't become obsolete. This will include replacing the old hardware and continuously evaluating system's performance which also includes providing latest updates for certain components to make sure it meets the right standards and the latest technologies to face current security threats. Any future works to further improve the system will be discussed more detailly in Chapter 5.

Chapter 4

RESULTS AND DISCUSSIONS

This chapter will explain and discuss the stages on how to create the Android Application from scratch and the process of testing it.

4.1 Overall Project Development Flow

At initial stage, the production processes in HP are studied and the critical component is identified to perform PdM. Then, ideas are brain stormed to design the PdM system. The variables of the data inputs of the system are clearly defined and software development are done using the data inputs. The software development includes server creation using the data inputs and programming for Android Application. Next, the entire system is integrated. After combining both database and Android Application using the same Internet Protocol (IP) Address, test on the systems were carried out to verify the system's functions. Troubleshooting and improvement on the system were carried out until the system performed as desired.

4.2 Production Processes in HP

MEMS department in HPMM Batu Kawan, Penang is responsible for the process of Barrier, Drilling, Attach, and Plating for 6" Print Head fabrication as shown in Figure 4.1.

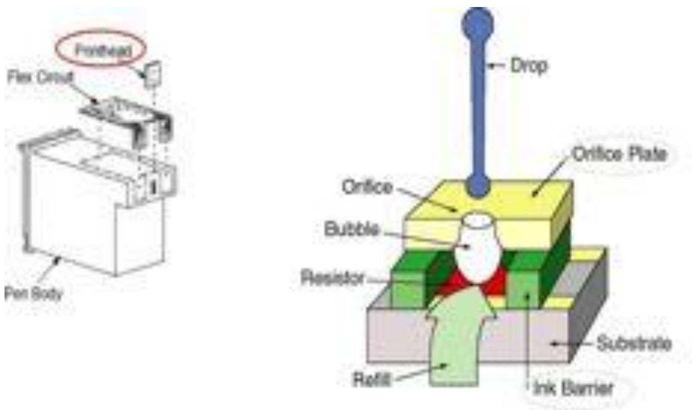


Figure 4.1: Print Head (Engine) for all HP Inkjet Printers.

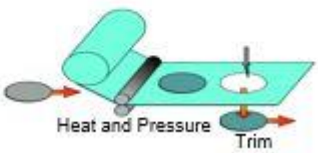
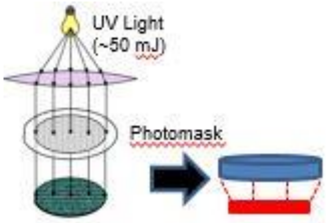
4.2.1 Barrier, Drilling, Plating, and Attach Processes

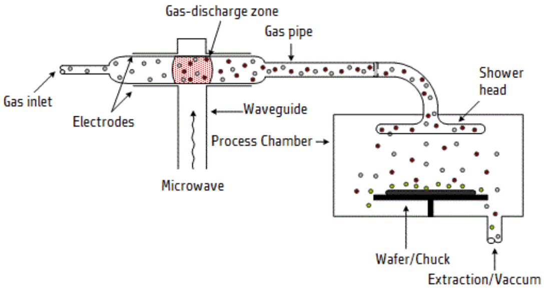
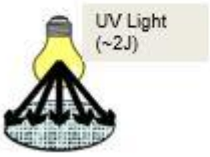
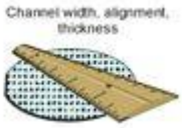
This sub-section will discuss the four main processes to produce the print head.

4.2.1.1 Barrier Process

The barrier process is adapted from the name ‘ink barrier’. Ink barrier defines the firing chamber volume, defines the ink inlet channel and acts as an adhesive between the thin film and orifice plate. The process of barrier is summarised in the Table 4.1.

Table 4.1: Barrier process

Process	Descriptions
Process 1: Pre-Clean + SCA 	The wafers are cleaned with ozone and then coated with Silane Coupling agent (SCA) to promote adhesion. Machine: SMS, V3
Process 2: Lamination 	A layer of the Barrier Material is laminated onto the wafer using heat and pressure. Machine: LAM
Process 3: Align, Expose & Bake 	Using photolithography technology, the pattern on the mask is transferred onto the wafer and then transferred to the Bake track for baking (partial curing). Machine: SVG
Process 4: Detape 	The Mylar on top of the Barrier material is peeled off. Machine: DETAPER

Process 5: Develop  	The unwanted Barrier Material is etched off. (area not exposed to UV light). Machine: SEMITOOL
Process 6: Ashing  	Plasma is used to remove any organic residue on the wafer. Machine: ASHER
Process 7: UV Cure  	The barrier pattern formed is partial cured in order for it to withstand the downstream process. Machine: FUSION UV
Process 8: Metrology  	Measurement of the critical dimension is done. (Resistor Opening). Machine: IVS
Process 9: Visual Inspection  	Sample check is done for any visual defects (residue, bridging, etc) under microscope. Machine: SMARTSCOPE

4.2.1.2 Drilling Process

The drilling process creates slots that allow ink to flow from pen body through print head to firing chambers. Slotting start from the back of the wafer to minimise damage to the thin film circuit and barrier architecture on the front of the wafer.

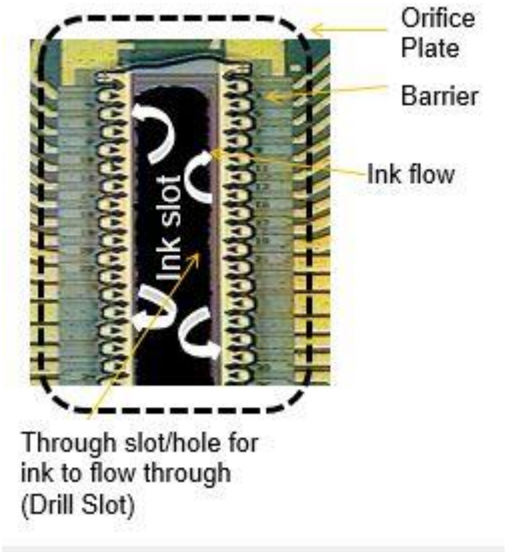


Figure 4.2: The top view of the die (with Orifice Plate removed).

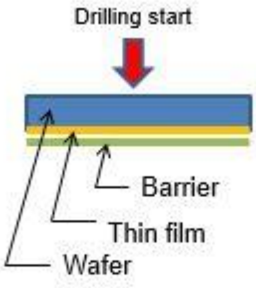
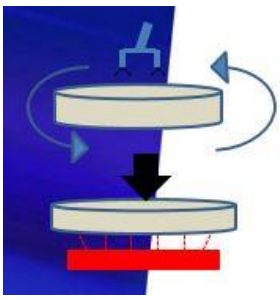
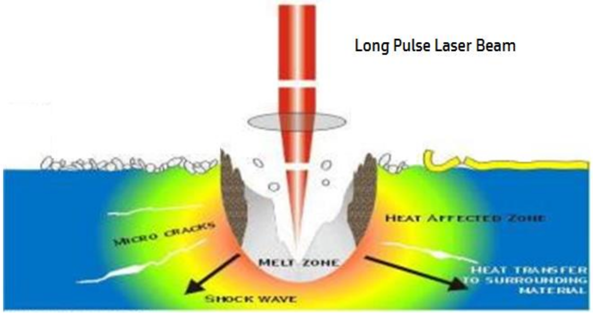
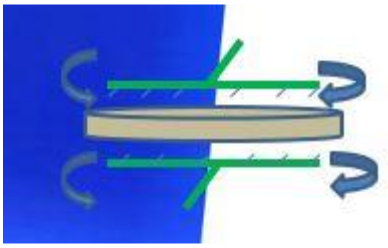
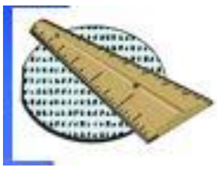


Figure 4.3: Drilling process which takes place at the back of the wafer.

The process of drilling is summarised in the Table 4.2.

Table 4.2: Drilling process.

Process	Description
Process 1: UPC Coating 	A layer of UPC (universal protective cover) is coated on the front of wafer to protect the circuit and barrier architecture during laser ablation. The wafer is baked on the hot plate to cure the UPC coating before the next process. Machine: SVG COATER

Process 2: Laser Ablation  	High power laser is used to cut slot through the wafer. Each slot is cut one at a time, the average time needed for one slot is around 5 seconds. Machine: SOLAS
Process 3:Wafer wash 	Deionized water under pressure and rotating brushes is used in this process to remove the debris and particle on the wafer after laser ablation. The UPC layer will also be removed (water soluble). Machine: ONTRAK
Process 4: Measurement 	100% inspection is done on all drill slots to ensure conformance to specification. Machine: QUICKSILVER
Process 5: Visual Inspection 	Sampling check is done for any visual defects like scratches, contamination, etc. Machine: SMARTSCOPE