MACHINE MONITORING SYSTEM FOR THREE-AXIS MILLING MACHINE

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2022

Faculty of Mechanical and Manufacturing Engineering Technology

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A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Manufacturing Engineering Technology (BMMW) with Honours

Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this project entitled “Machine Monitoring System For Three-Axis Milling Machine ” is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : Hazimi Hilmi

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Date : 28 January 2022

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Manufacturing Engineering Technology (BMMW) with Honours.

Signature : 

Supervisor Name : Ts. Dr. Kamran Latif

Date :

DEDICATION

Special dedication to my beloved mother

Zunaidah Bt. Zainal

Her encouragement and guidance has always been an inspiration to me along with this journey of education.

ABSTRACT

In this new era of manufacturing industries with the Fourth technological revolution (IR 4.0), the smart factory is getting much attention as an answer for the factory of the future. IR 4.0 is about automation and the improvement of technology and advanced devices used by various systems. As a result, the topic of Internet of Things (IoT) based machine monitoring systems has caught the attention of the researcher. The Internet of Things (IoT) can reduce manufacturing costs, improve uptime and help operators gain process insight. Since CNC machining is an important role in manufacturing industries, the demand for smart factory is also increasing. Remote monitoring system is one of the component in building a smart factory. It is important to able to monitor machines efficiently in order to increase operation performance. Most CNC machine is still using the human machine interface or HMI to monitor the machine. This requires machine operator to monitor each machine individually. It can slows down the whole operation and increase the idle time and labour cost. This thesis will be about the design and development of a machine monitoring system by utilizing virtual component-and IoT technologies to monitor the three-axis CNC milling machine. The objective is to able to monitor important parameters of the CNC machine while running such as the cutting tool temperature, voltage, current and the spindle motor's RPM. To achieve these objectives, the system is implemented using a Microcontroller such as an Arduino board and multiple sensors. Compared to the traditional monitoring system like EPL bus, by utilizing the IoT technologies to the monitoring system, the machine condition data can be transmitted and stored wirelessly to computers or smartphones. The industrial monitoring system has grown in popularity in recent years, a industrial owner is looking for ways to monitor their operation line and their industrial values. From these systems, data from multiple machines can be received altogether at once in real-time. These systems also embody a sort of primary unit for enabling the 'Smart Factory' revolution.

ABSTRAK

Dalam era baharu industri pembuatan dengan revolusi teknologi Keempat (IR 4.0), kilang pintar itu mendapat perhatian ramai sebagai jawapan untuk kilang masa depan. IR 4.0 adalah mengenai automasi dan peningkatan teknologi serta peranti canggih yang digunakan oleh pelbagai sistem. Hasilnya, topik sistem pemantauan mesin berasaskan Internet of Things (IoT) telah menarik perhatian penyelidik. Internet Perkara (IoT) boleh mengurangkan kos pembuatan, menambah baik masa operasi dan membantu pengendali mendapatkan cerapan proses. Memandangkan pemesinan CNC adalah peranan penting dalam industri pembuatan, permintaan untuk kilang pintar juga meningkat. Sistem pemantauan jarak jauh adalah salah satu komponen dalam membina kilang pintar. Adalah penting untuk dapat memantau mesin dengan cekap untuk meningkatkan prestasi operasi. Kebanyakan mesin CNC masih menggunakan antara muka mesin manusia atau HMI untuk memantau mesin. Ini memerlukan pengendali mesin untuk memantau setiap mesin secara individu. Ia boleh melambatkan keseluruhan operasi dan meningkatkan masa terbiar dan kos buruh. Tesis ini adalah mengenai reka bentuk dan pembangunan sistem pemantauan mesin dengan menggunakan komponen maya-dan teknologi IoT untuk memantau mesin pengilangan CNC tiga paksi. Objektifnya adalah untuk dapat memantau parameter penting mesin CNC semasa berjalan seperti suhu alat pemotong, voltan, arus dan RPM motor gelendong. Untuk mencapai objektif ini, sistem ini dilaksanakan menggunakan Pengawal Mikro seperti papan Arduino dan pelbagai sensor. Berbanding dengan sistem pemantauan tradisional seperti sistem komunikasi EPL, dengan menggunakan teknologi IoT kepada sistem pemantauan, data keadaan mesin boleh dihantar dan disimpan tanpa wayar ke komputer atau telefon pintar. Sistem pemantauan industri semakin popular sejak beberapa tahun kebelakangan ini, pemilik industri sedang mencari cara untuk memantau talian operasi dan nilai perindustrian mereka. Daripada sistem ini, data daripada berbilang mesin boleh diterima secara serentak dalam masa nyata. Sistem ini juga merangkumi sejenis unit utama untuk membolehkan revolusi 'Kilang Pintar'.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First and foremost, I would like to thank all my lecturers for their encouragement and guidance in the past semesters especially my supervisor Ts. Dr Kamran Latif. The success of the project would not be possible without his comments and support throughout completing this project. I also want to thank all technicians and laboratory assistants for contributing the information needed in order to start the project. Their time and effort are very much appreciated.

Next, I would also like to take this opportunity to thank my faculty. Faculty of Mechanical and Manufacturing Engineering Technology (FTKMP) for providing facilities and knowledge for me to complete this project successfully. I am glad to be one of the students to study at this faculty and gain priceless knowledge,

I would also like to thank all my friends, especially my classmates who have helped me in some way to complete this project. The completion of this project is part of everybody's effort and time for giving me thoughtful advice and information.

Finally, my honourable appreciation goes to my families who have been providing countless support and encouragement throughout my study at Universiti Teknikal Malaysia Melaka (UTeM). Their continuing support is part of the reason why I am able to complete this course and project.

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LIST OF SYMBOLS AND ABBREVIATIONS

Cm	-	Centimeter
Mhz	-	Megahertz
Khz	-	Kilohertz
A	-	Ampere
mA	-	Milliampere
DC	-	Direct Current
AC		Alternating Current
V		Volt
IR 4.0	-	Fourth Industrial Revolution
ICT	-	Information and Communication Technology
IoT	-	Internet of Things
CNC	-	Computer Numerical Control
HMI	-	Human-Machine Interface
RPM	-	Revolution Per Minute
LAN	-	Local Area Network
EPL	-	Power Link
DIY	-	Do It Yourself
I/O	-	Input Output
USB	-	Universal Serial Bus
IDE	-	Integrated Development Environment
CPU	-	Central Processing Unit
SRAM	-	Static Random Access Memory
IR	-	Infrared
VI	-	Virtual Instrument

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CHAPTER 1

INTRODUCTION

1.1 Background

The Fourth Industrial Revolution (IR 4.0) is transforming the way we live, work and relate to our surroundings. IR 4.0 is based on the latest advances in information and also communication technology (ICT). Internet of things (IoT) and mobile technology allow us to collect and transfer data much more efficient (Klaus, 2016). The collected data can be stored through cloud storage technology. Today, in the era of the technology revolution, the demand for a smart factory is increasing as a solution for the factory of the future that represents an advanced manufacturing system able to integrate the entire production process including the way to design, produce, and market into ICT to deliver customized products at a minimum cost and time. On top of that, this smart factory model could play an important role in reducing environmental impacts on sustainable manufacturing (HyungJung, et al., 2019).

Since CNC machining has become an important role in the manufacturing industry. The high demand for automated manufacturing requires faster, more efficient and intelligent CNC monitoring systems (University, 2018). The monitoring system has been a topic of interest for a researcher for the last few decades. In CNC machining, the cutting tools play an important role in the machining processes. In order to ensure high quality and accurate machining, the cutting tools are needed to be in good working condition. Several factors will determine the cutting tools performance such as rate of temperature, vibration and cutting load (Yuan, et al., 2020).

The machine tool can be affected by changes in the surrounding temperature of the workshop. It is also affected by the heating of the spindle motor and frictional heat of mechanical motion during the cutting process. The other things which affect include cutting heat and the cooling medium. It leads to an uneven temperature rise of various parts of the cutting tool. As a consequence, the machine tool shape accuracy and machining accuracy start changing (Anon., n.d.).

During the cutting process, the speed of the spindle motor is a very important machining parameter. A typical CNC machine's spindle motor could go from about 7,000 to 18,000 RPM (Revolution Per Minute) (Ryan, 2014). Improper spindle speed can cause a rough finish and an inaccurate dimension to the final product. On top of that, the cutting tool could chip or shatter if it exceeds the maximum speed rating. It could also shorten the life span of the spindle motor or even broke it, which can cost a lot of fortune to fix.

1.2 Problem Statement

In some developed countries, most manufacturing companies faced a lack of workforce and a decline in labour productivity due to the ageing population and slow birth rates. They are trying to improve productivity by adopting smart factories. For example, some companies would pair a small human workforce with technologies, including 3-D printing, industrial robots, and computerized machines at their factory (Rick, et al., 2017). Besides, various industrial policies implementing smart factories are being executed by the government in the private sector to overcome the economic crisis (Liue & Xun, 2017). However, some small and medium-sized enterprises standing at the lower layer of the supply chain in the manufacturing industry tend to be more labour-intensive and orientated towards short-term operations rather than long-term strategy because of various reasons such as the high cost of implementation for the smart factory (Wen-Hsin, et al., 2019).

Running a shop floor in a factory with sustainability and effectiveness has been a challenge to ensure higher machine availability and reduce idle time by continuously monitoring the shop floor. Generally, conventional factories have limited communication between operators and machines. Because of this, the operators are responsible for monitoring the machines. It can be a problem especially when the operator is running multiple machines and if there is a problem it may cause the operation to stop until the problem is solved. The idle time is increased and become unproductive. Due to these challenges, some factories have adopted a remote monitoring system for their operation. Remote monitoring can reduce the unnecessary time and energy consumption for watching machines and allow time to be spent on other more valuable tasks, such as maintenance and production optimization (Gaughran, et al., 2007).

Nowadays, most modern manufacturing factories widely use computer numerical control (CNC) to manufacture parts. Conventionally, while setting up and running a machine tool on a machining shop floor, operators can monitor operational data via a specific human-machine interface (HMI) of the machine tool and are responsible for checking an operational status and changing workpieces after machining a part (Ardanza, et al., 2019). This manual process requires a large number of labor and time. Therefore, a real-time monitoring system is needed to reduce idle time and labor costs. Besides, this monitoring system can also reduce energy consumption and improve the environment (Vijayaraghavan & Dornfeld, 2010).

In recent years, the global warming has become a big problem. The use of energy is the number one cause of greenhouse gas emissions. This is linked to the burning of fossil fuels for electricity. A good CNC machine requires less energy. To ensure the CNC machine is running efficiently we can monitor the voltage and current making sure that it is

not wasting energy. By saving energy we can not only save the environment but also reduce the cost of manufacturing.

Thus, the machine monitoring system can let us know what is going on with the machine in real-time. After receiving the information, immediate action can be taken to improve the machine operability. It also will enhance the capability of the machines for future decision making. This solution can benefit the shop floor efficiency by preventing and promoting predictive maintenance (HyungJung, et al., 2019).

1.3 Research Objective

The main aim of this research is to build a machine monitoring system for a 3-axis CNC milling machine by utilizing virtual components and IoT technologies. Specifically, the objectives are as follows:

a) To design and develop a virtual component technology-based CNC machine monitoring system with IoT implementation.

b) To implement the developed CNC machine monitoring system on a 3-axis CNC milling machine.

c) To validate the system by demonstrating the ability, efficiency and effectiveness of the system.

1.4 Scope of Research

The scope of research for this project will cover the following :

- Utilization of virtual components and IoT technologies to the system.
- Purpose of measuring the chosen parameters.
- Advance data collection method.
- Type of sensors that are suitable to use.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

As the manufacturing industries experienced the Fourth Industrial Revolution, the method uses to collect data from the machine is also changed. Although there are changes in the data collection method, the system for machine monitoring remains the same. With IoT technologies a new way to monitor the CNC machine can be developed with proper data collection methods.

Based on previous research, the demand for CNC machining is increasing in some countries which means that the demand for machine monitoring systems is also increasing. In 2020, the global CNC market was valued at USD 34960 million and could reach USD 41980 million by the year 2027. The market for CNC machines is segmented by product applications such as machinery manufacturing, automotive, aerospace and others.

There is a variety of CNC machines available in the market right now. Some of them are big and industrial worthy and some are them are small which is designed for personal use. In this project, a smaller size CNC machine is going to be used. The advantages of using a smaller CNC machine for this project is that it is cheap, easy to set up and use but also have the same working process as a bigger CNC. A smaller CNC machine is also good for rapid prototyping of this project.

The existing machine monitoring system uses a period Local Area Network (LAN) protocol like the Power Link (EPL). This existing system can be pricey and the

implementation of an EPL communication bus in a very PC-based industrial machine system is bestowed.

On the other hand, IoT can be cheaper, more efficient and have a lot of new possibilities. The IoT platform collects data and combine it from different devices and apply analytics to share data with applications to address the industry-specific needs. Important features of IoT is huge in the area of artificial intelligence, devices, sensors, communication and active engagement. Today, the application of IoT includes the sector of energy, health care, education and many more.

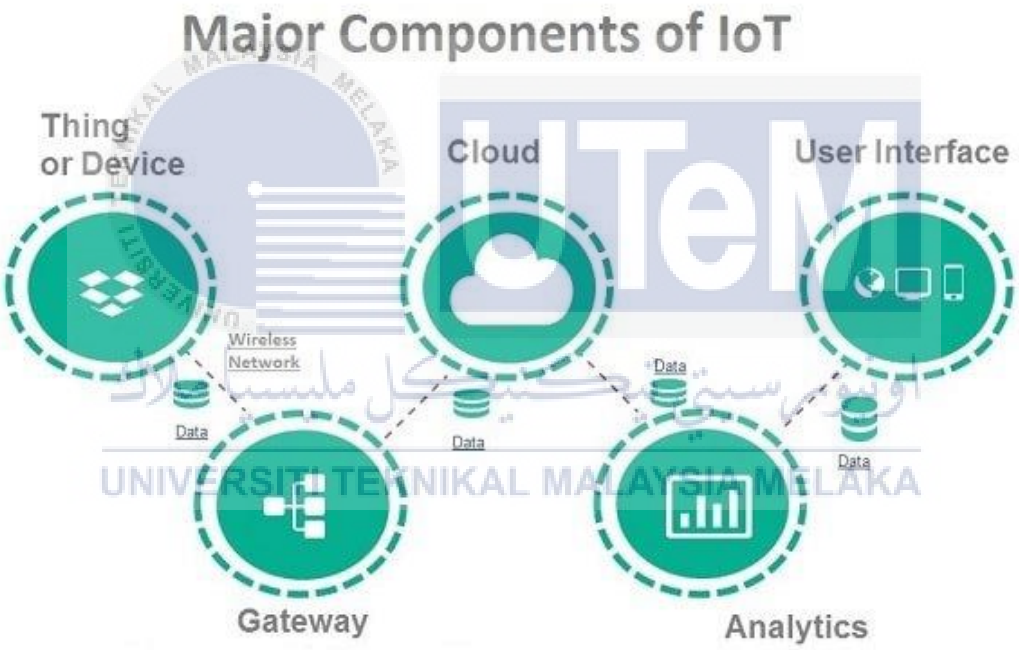

Figure 2.1 How IoT Works (Rajiv, 2021)

There is some hardware available that can be used for developing IoT technology systems. IoT hardware includes devices such as routing, bridges and sensors. This device is used for managing tasks and function such as security, action specification, communication and detecting specific actions and goals. The IoT hardware component can vary from a

low-power board or single-board processor that is used to improve and increase the functionality of the system.

An example of IoT board hardware is the Arduino board which is a single-processor board. There is a variety of Arduino board models and the most famous is the Arduino UNO board. Another popular hardware is the Raspberry Pi which is a tiny computer about the size of a palm and has can incorporate an entire web server. For something of its size, Raspberry Pi has enough processing power to run Windows 10 operating system or IoT Core. Other alternative devices in the market right now are Beagle Bone, Shark Cove, Nanode, Waspmote and many more.

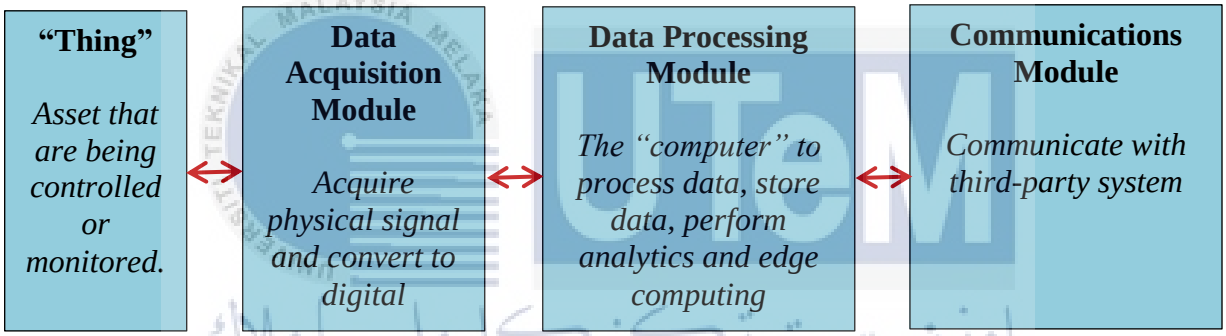

Figure 2.2 IoT Hardware - Building Blocks (Elizalde, 2016)

For this project, a small 3-Axis CNC milling machine is going to be used because it is easy to set up and good for prototyping. Any modifications required to the machine or the monitoring system can be done in a short time. If the monitoring system is successful with the smaller CNC machine, it should also work with bigger size CNC machines since the concept of the monitoring system didn't change.

2.2 CNC 3040 3-Axis CNC milling machine

CNC 3040 is a small CNC milling machine that is popular among hobbyists, amateurs, DIY enthusiasts or beginner machinists. The "CNC 3040" is a reference to its

work area which is 300 x 400 mm. Compared to CNC 3018 which is an older version and limited to cutting only hardwood, with some upgrades, the CNC 3040 can cut harder material such as aluminium. With the compact size of the machine and diverse cutting ability, the CNC 3040 is a great candidate for testing the monitoring system.

Figure 2.3 CNC3040 3-Axis CNC Milling Machine

Table 2.1 Main technical details of the CNC3040 3-Axis CNC Milling Machine

Specifications	Detailed
Axis	3 Axis
Interface	LPT port or UBS port
Limit Switch	Yes
Tool Auto-checking	Yes
Spindle Motor	800W/1.5KW/2.2KW
Type of Screw	Ball Screw
Machine Dimension	600mm x 510mm x 480mm
Rack Material	6061 and 6063 Hard Aluminum alloy