DESIGN AND DEVELOPMENT OF REMOTE MEASUREMENT FOR PRIME MOVER USING ARDUINO AND FR HOPE RFM12B

MOHD AKMAL BIN MHD YUSOF

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Abstract

This project aims to develop a remote measurement system for agricultural prime mover for in-field testing. The system is important especially for government agency such as MARDI which is entrusted to carry out research and development in agriculture including developing agricultural prime mover. RF system has been chosen as the remote wireless system to be used in this project.

The hardware system consists of a measurement system, a transmitter and receiver system and a data monitoring system. The measurement system consists of Honeywell 1228-2K Torque sensor & FUTEK CSG110 Strain gauge amplifier. The Honeywell torque sensor was chosen because it is a general purpose torque sensor which is able to monitor start up, running and stall torque levels and rotational speed. Besides that, it also has low non-linearity, repeatability and hysteresis specifications. The FUTEK amplifier is necessary because of the limited ADC resolution of our Arduino UNO.

The transmitter and receiver system consists of HopeRF RFM12B-433-D RF module and Arduino UNO microcontroller. The RFM12B is a transceiver module which can either transmit or receive RF signal. It was chosen because it is cheap and secure, has medium range and able to transmit multiple data at the same time. Arduino UNO was chosen because it is easily configured, widely available, cheap and fully capable of executing the tasks expected of a microcontroller in this project.

The data monitoring system is developed using National Instrument LabVIEW. It was chosen because its graphical programming is more intuitive and easier to develop than traditional textual programming.

The developed system has been tested and proven to be able to carry out decent measurement of two simultaneous data from a range of 100 meters. However, to improve the system, more tests need to be done to determine if more data could be sent at the same time.

Abstrak

Projek ini bertujuan untuk membangunkan sebuah sistem pengukuran jarak jauh untuk pengujian traktor pertanian di tanah lapang. Sistem ini amat penting terutamanya untuk agensi kerajaan seperti MARDI yang bertanggung jawab menjalankan penyelidikan dan pembangunan dalam bidang pertanian termasuklah pembangunan traktor pertanian. Sistem RF telah dipilih sebagai sistem jarak jauh untuk projek ini.

Sistem perkakasan projek ini terdiri daripada sistem pengukuran, sistem pemancar dan penerima dan sistem pemantauan data. Sistem pengukuran tersebut terdiri daripada penderia tork Honeywell 1228-2K dan penguat tolok terikan FUTEK CSG110. Penderia tork Honeywell tersebut dipilih kerana ia adalah penderia tork serbaguna yang mampu memantau tahap tork pada keadaan mula, berjalan dan berhenti dan juga mampu memantau kelajuan putaran. Di samping itu juga, ia mempunyai spesifikasi ketaklinearan, keterulangan dan histeresis yang rendah. Penguat FUTEK itu pula diperlukan kerana resolusi ADC Arduino UNO kami adalah terhad dan tidak mampu mengambil bacaan penderia tork Honeywell dengan baik.

Sistem pemancar dan penerima pula terdiri daripada modul RF HopeRF RFM12B-433-D dan mikropengawal Arduino UNO. RFM12B adalah sebuah modul penmancar-penerima yang boleh menghantar atau menerima isyarat RF. Ia dipilih kerana harganya yang murah, mempunyai jarak komunikasi yang sederhana dan mampu menghantar beberapa data pada satu-satu masa. Arduino UNO pula dipilih kerana konfigurasinya yang senang, mudah didapati, murah dan berkemampuan untuk menjalankan tugas-tugas mikropengawal dalam projek ini dengan berkesan.

Sistem pemantauan data pula dibangunkan menggunakan National Instrument LabVIEW. Ia dipilih kerana ia menggunakan pengaturcaraan grafik yang lebih mudah dan intuitif untuk dibangunkan berbanding pengaturcaraan teks.

Sistem yang dibangunkan tersebut telah diuji dan terbukti mampu untuk melakukan pengukuran dua data serentak yang baik pada jarak 100 m. Walau bagaimanapun, untuk menambah baik sistem tersebut, lebih banyak pengujian perlu dilakukan untuk menentukan sama ada lebih banyak data boleh dihantar pada satu-satu masa.

Acknowledgement

Alhamdulillah, all praise be to Allah the Almighty Who has allowed me to complete the research project.

I would also like to thank my supervisor, Dr Mahidzal bin Dahari who has given me guidance and support throughout my studies and especially during the course of this project.

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

ADC	Analog-to-Digital Converter
AM	Amplitude Modulation
ASK	Amplitude Shift Keying
CNC	Computer Numerical Control
FM	Frequency Modulation
FSK	Frequency Shift Keying
GDP	Gross Domestic Product
MARDI	Malaysian Agricultural Research and Development Institute
PC	Personal Computer
PTO	Power Take-Off
RF	Radio Frequency
ADC	Analog-to-Digital Converter

1.0 Introduction

Agriculture is an important sector in Malaysia and contributes 7.7 % of GDP to the nation in 2011 (Department of Statistics, 2012). In agriculture production, mechanization plays a very important role. Agricultural machines help to increase productivity and reduce labor dependence. As the national population continues to increase and issues such as green house effect and environmental pollution arise, continuous advancement and improvement in agricultural machines are being done to produce more productive, energy saving and environmental friendly machine. Besides that, research and development have also been done by the government under MARDI to produce Malaysia own agricultural prime mover. Prime mover or tractor is one of the most important components in agricultural machine. By developing its own prime mover, Malaysia can boost its local manufacturing industries, reduce dependencies on foreign products and get a better after sales support.

Part of an agricultural machine development work is to measure its mechanical properties such as torque and speed. For example, the traction, axles torque and power of a high clearance tractor are measured to determine the tractor’s power requirement and performance. Besides that, by measuring the torque and speed of a tractor Power Take-Off (PTO) powering a rotor tiller, the exact power requirement of the rotor tiller and the quality of soil tillage it produces can be determined (Othman et al., 2012).

During design stage, torque and speed are measured in lab under controlled condition. However, to get the real performance of the developed tractor, on field evaluation must also be done. This is because physical factors such as temperature, humidity, dust and the condition of the soil where the tractor will be used will affect its performance. A system where data can be collected off field while the evaluation is done on field would greatly assist such evaluation.

1.1 Remote measurement

Remote measurement or telemetry is a:

> Highly automated communications process by which data are collected from instruments located at remote or inaccessible points and transmitted to receiving equipment for measurement, monitoring, display, and recording. Transmission of the information may be over wires or, more commonly, by radio. (“Telemetry,” 2013)

Therefore, based on the definition, remote measurement is definitely the system we should use to replace the on-field measurement. Two radio remote measurement modules which are proven and are widely used have been considered which are RF and ZigBee.

1.2 Radio Frequency (RF)

RF is a type of wireless communication which uses radio wave in the range of 3 kHZ to 300 GHz. To send data through an RF carrier wave, the data needs to be modulated by changing the shape of the carrier waveform. Some of the modulation methods are amplitude modulation (AM) & frequency modulation (FM) for analog signals and amplitude shift keying (ASK) & frequency shift keying (FSK) for digital signals. AM and ASK work the same way by changing the amplitude of the carrier wave according to the data it carries (frequency does not change). Similarly, FM and FSK work by changing the frequency of the carrier wave according to the data it carries (amplitude does not change).

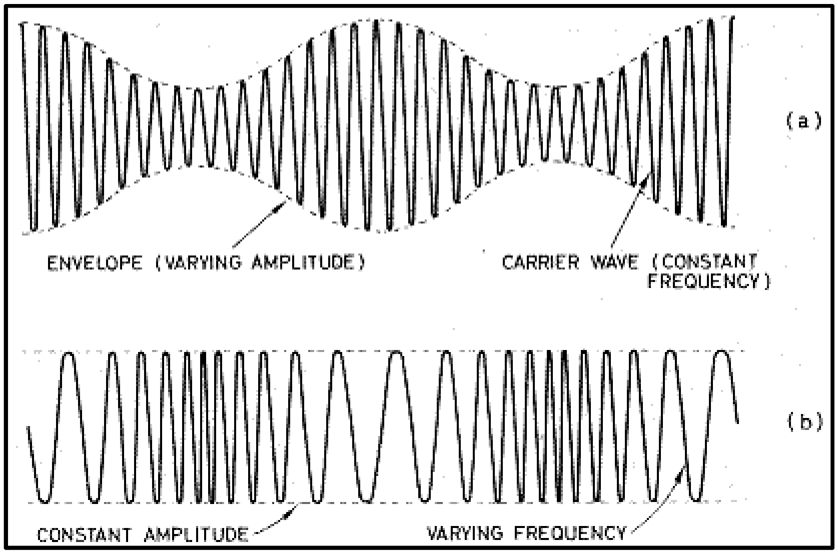


Figure 1: (a) AM signal, (b) FM signal. (Communication, 2010)

1.3 Zigbee

ZigBee is a standard communications protocol for low-power, wireless mesh networking. According to Faludi (2011):

> The network layer below ZigBee that supports its advanced features is known as IEEE 802.15.4. This is a set of standards that define power management, addressing, error correction, message formats, and other point-to-point specifics necessary for proper communication to take place from one radio to another. (p. 26)

1.4 Torque

Torque can be defined as follows:

> In physics, the tendency of a force to rotate the body to which it is applied. Torque is always specified with regard to the axis of rotation. It is equal to the magnitude of the component of the force lying in the plane perpendicular to the axis of rotation,

> multiplied by the shortest distance between the axis and the direction of the force component. Torque is the force that affects rotational motion; the greater the torque, the greater the change in this motion. (“Torque,” 2013)

Relationship between Torque, position and force is given by:

$$\tau = r \times F$$

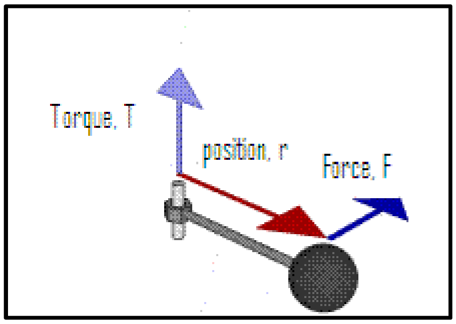


Figure 2: Relationship between Torque, position and force

1.5 Torque sensor

A torque sensor or torque meter is a device for measuring and recording the torque on a rotating system, such as an engine, crankshaft, gearbox, transmission or rotor (Wikipedia, 2013).

1.6 Agricultural prime mover

Agricultural prime mover or also known as tractor is a:

> High-power, low-speed traction vehicle. The two main types are wheeled and continuous-track...Tractors are used in agriculture, construction, and road building, for pulling equipment such as plows and cultivators, for pushing implements such

> as bulldozers and diggers, and for operating stationary devices such as saws and winches...The tractor revolutionized farming, displacing draft animals and many farm workers. (“Tractor,” 2013)

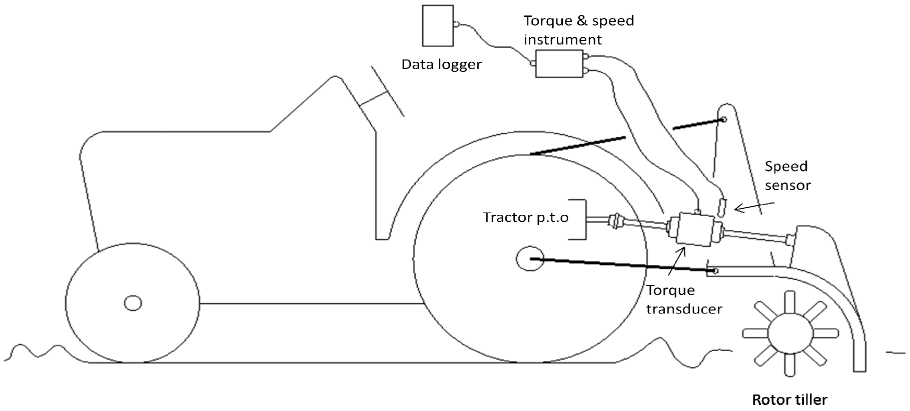


Figure 3: Measuring power requirement of a rotor tiller. (Othman et al., 2012, p. 10)

1.7 Objectives

Following are the objectives of this project:

1. To design and develop a measurement system for agricultural prime mover which measures its mechanical properties

2. To integrate the measurement system, an RF system and a LabVIEW program as a remote measurement system for agricultural prime mover

1.8 Outline of research approach

Following is the outline of research approach:

1. Literature review is done to investigate current approaches towards remote measurement of agricultural prime mover

2. Preliminary study is done to determine hardware and software specifications

3. The hardware system is developed and tested

4. The software system is developed and tested

5. The integrated system is developed and tested

6. Results are presented and discussed

7. Research is concluded

1.9 Summary

The first chapter starts by presenting the introduction to agriculture & agricultural mechanization and their importance to the nation. After that, the importance of this research project to the nation's agricultural industry was discussed. The chapter continues by presenting an overview of the important terminologies used in this project such as remote measurement, Radio Frequency, Zigbee, torque & torque sensor and agricultural prime mover. It finishes by giving the outline of the research approach. In the next chapter, literature review will be presented and discussed.

2.0 Literature review

As discussed before in the previous chapter, the development of a remote measurement system is essential in developing an agricultural prime mover, specifically in testing its performance at the open field. Therefore, several literatures have been reviewed to identify the current methods used to develop such a remote measurement system. Even though our system will be used on agricultural prime mover, remote measurement systems applied on other platforms will be relevant as well because the implementation is similar.

Madni (2009) argued that wireless sensor-based control was gaining attention because of reduced costs, better power management and easy deployment in remote areas. However, there were some operational challenges regarding the system such as when different RF links have to be used to satisfy the requirements of bandwidth, payload, delay, jitter, range, noise immunity and others (including cost) for communication. The paper proves that wireless based measurement is feasible nowadays compared to twenty years ago when measurement equipment need to be mounted on the tractor itself as discussed by Papworth (2004).

Zhai and Hu (2010) presented a method of remote monitoring and controlling system of CNC machine based on embedded Internet. It consisted of an embedded Ethernet communication module to facilitate the communication between a control PC, a field monitoring host and various CNC machine tools. Their method proves that wireless monitoring is feasible, but since they used Ethernet, their method would not be applicable to our project as Internet connection is not yet reliable enough to be used around our test area.

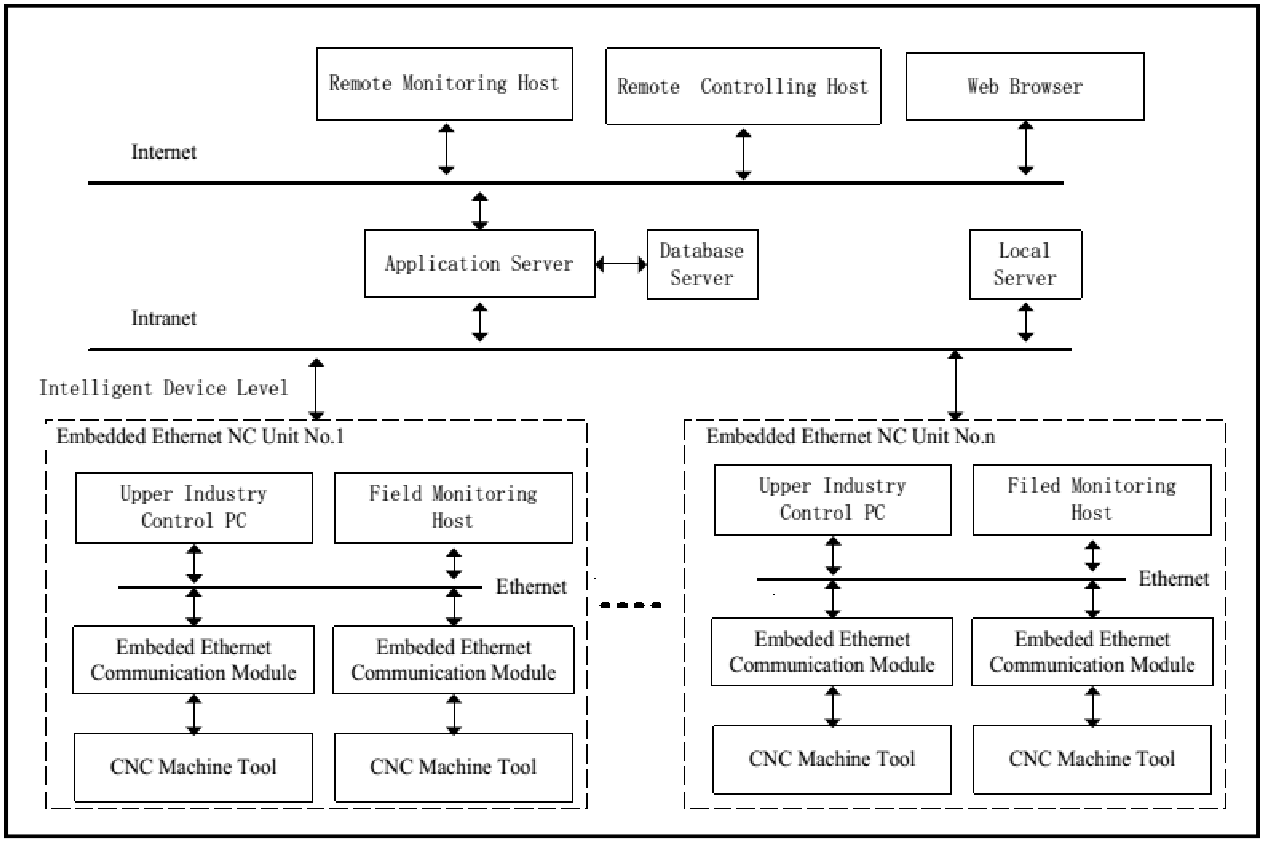


Figure 4: The architecture principle diagram of the NC-RMCS based on embedded Internet (Zhai & Hu, 2010, p. 506)

Yi-chu et al. (2005) developed a M3S (Multiple Master Multiple Slave) powered wheelchairs with appropriate manipulating controls system to provide the disabled enough mobility in daily lives. It consisted of a CAN (Controller Area Network) bus, a SAF (Safety) bus, a POW (Power) bus, several input and output devices, CCM (Control and Configuration Module) and intermediate devices. They argued that the CAN bus was used for data transmission because of its anti-interference abilities and high speed. To ensure proper communications between the large numbers of devices, the CAN has a system similar to postal address. Each CAN bus and all CAN mailboxes have their individual CAN ID (Identifier) and when the CAN IDs of a CAN message and a CAN mailbox matches, the CAN message received will be accepted by the CAN mailbox. The system also utilized an

RF (Radio Frequency) wireless module to overcome the limitation of communication distance between a powered wheelchair and the local monitoring center. It was demonstrated that the maximal distance for transmission in outdoor testing was around 100 meters. Their method shows that RF is reliable enough to be used for a medium distance communication.

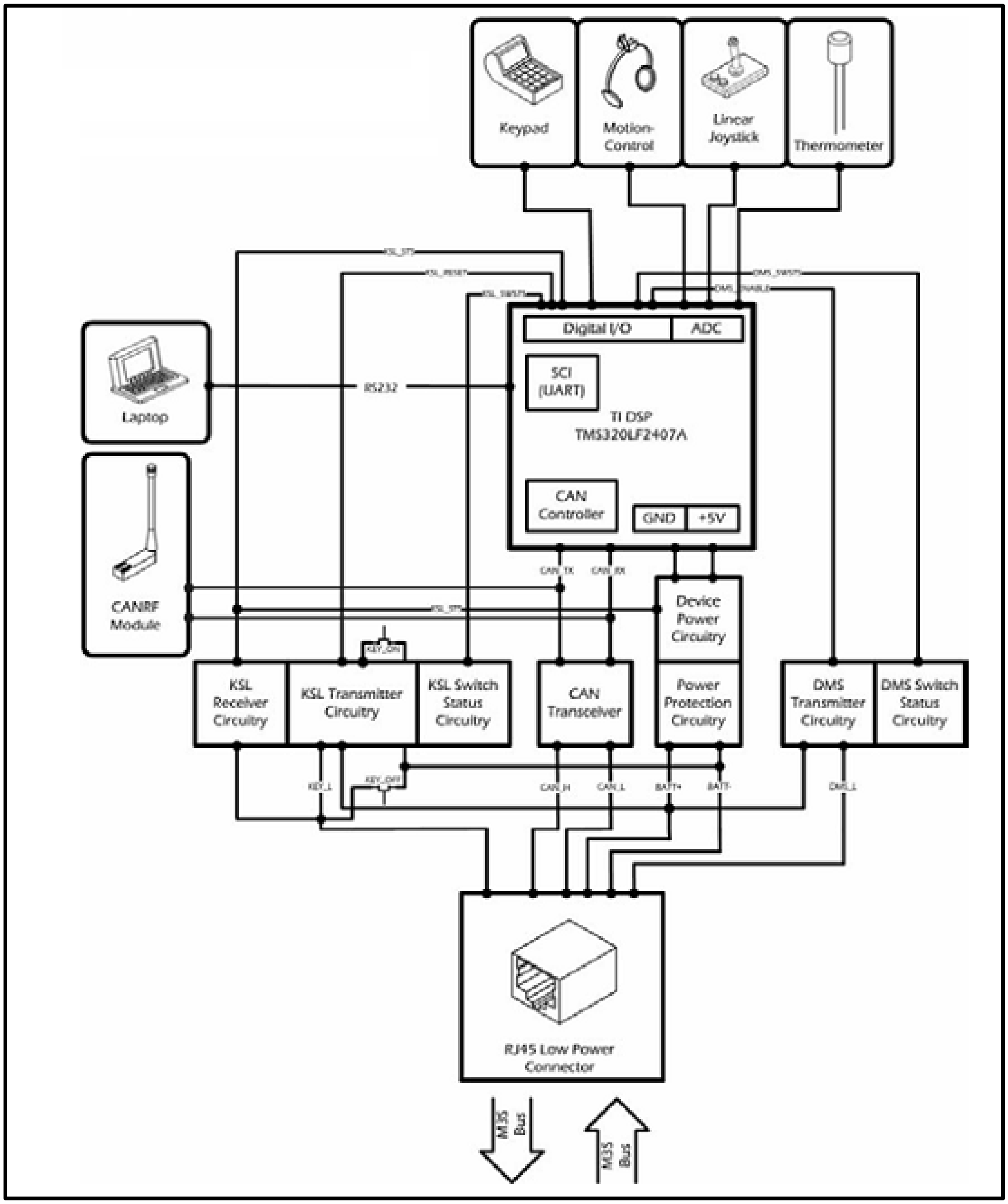


Figure 5: Design of input device (Yi-chu et al., 2005, p. 582)

Ying-Wen and Cheng-Yu (2006) used an embedded board with interface modules to implement a remote electronic measurement system which included power supply, signal generator and oscilloscope. Similar to the previous paper by Zhai and Hu (2010), this system also connected to the Internet to make remote connection by using TCP/IP modules. They argued that their embedded board could replace a computer and had the advantages of being more mobile, low cost & programmable and could execute real-time operation. In addition, they also argued that their data acquisition system was comparable to popular data acquisition software such as LabVIEW despite being much cheaper. This paper proves that it is possible to develop a low cost data acquisition system with comparable performance to commercial product.

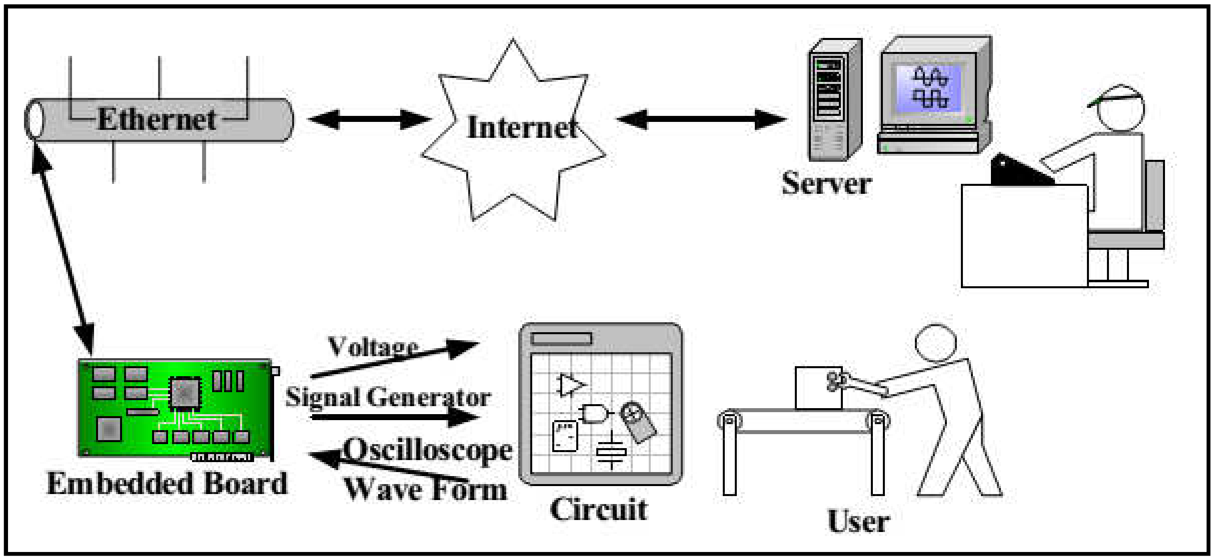


Figure 6: The embedded remote electronic measurement system architecture (Ying-Wen & Cheng-Yu, 2006, p. 1312)

Mihajlovic et al. (2012) described an application where data are collected via RF wireless communication in public frequency band. It used a low cost RF modules and encrypted data transmission. They explained that such RF system had two advantages compared to similar solutions that used frequency of 2.4 GHz or similar; firstly, it was cheaper especially if the network contained a lot of nodes and secondly, it was not affected by barriers and not limited to places where there was only line of sight. Moreover, compared to the GPRS system, the RF system did not require expensive modem and did not require monthly payment for data collection. Besides that, despite only using cheap microcontroller, the system was able to do decent monitoring and sensing. The system was also able to carry out data transmission securely using encryption. This paper gives us the motivation to develop a similar low cost, decently capable, secure RF monitoring system for our project.

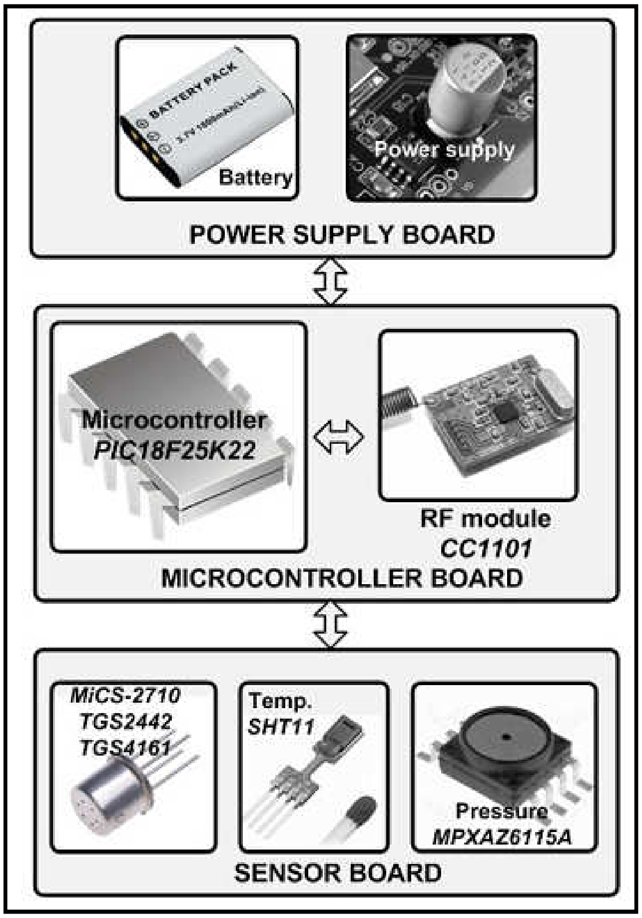


Figure 7: Hardware blocks of system for air quality monitoring (Mihajlovic et al., 2012, p. 55)

2.1 Summary

Several papers relating to our project have been discussed. Paper byYi-chu et al. (2005) is particularly interesting because they proved that besides reliability and high speed, range is also an important factor in development of a wireless communication system, which they attained by using RF. Besides that, Mihajlovic et al. (2012) proved that a decently capable RF monitoring system could be developed with low cost. Both of these papers gave us the greatest motivation to develop our project.

3.0 Methodology

As outlined in Chapter 1.8, the research project begins by doing literature review on papers related to the project. The literature review is presented and covered in the previous chapter. The next step is to present the preliminary study on our research project to get an overview of the project's hardware and software requirement.

3.1 Preliminary study

Our project consists of hardware and software components. The hardware system is responsible for measuring the data of the tested prime mover, transmitting the data and receiving it at the base station. On the other hand, the software system is responsible for monitoring and logging the data at the base station. Therefore, our hardware system would consist of sensor components, microcontrollers and wireless modules while the software system would consist of a computer with the monitoring and logging program. Figure below shows the simplified version of our system’s block diagram:

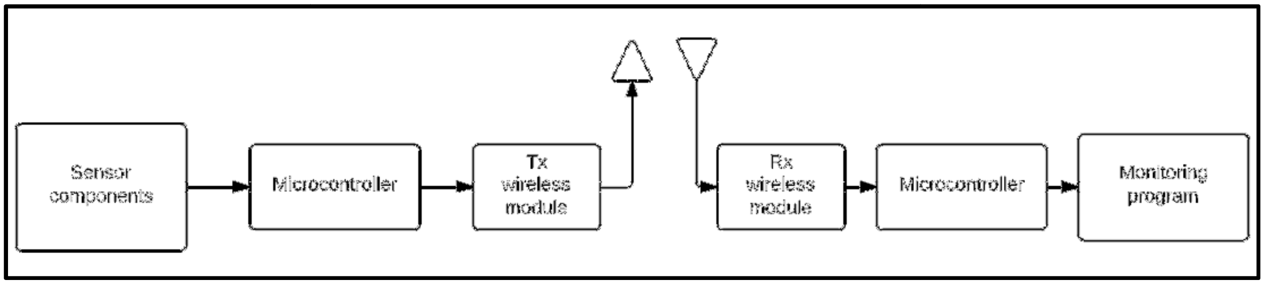


Figure 8: Simplified block diagram

3.1.1 Sensor components

The first component to be considered in developing this project is the sensor system. A typical application of our project is to measure the power requirement of a rotor tiller in the land preparation (Othman et al., 2012). Power can be related to torque by:

$$P = \tau \times 2\pi \times \omega$$

Therefore, a general purpose torque sensor which is able to monitor start up, running and stall torque levels and rotational speed would be sufficient. Besides that, a good torque sensor should have low non-linearity, repeatability and hysteresis specifications. Non-linearity is defined as “the maximum Deviation of the Calibration Curve from a straight line drawn between the no-load and Rated Load outputs, expressed as a percentage of the Rated Output and measured on increasing load only” (Futek, 2007) . Non-repeatability is defined as “the maximum difference between transducer output readings for repeated loadings under identical loading and environment conditions” (ibid.). Hysteresis is defined as “the maximum difference between the transducer output readings for the same applied load” (ibid.).

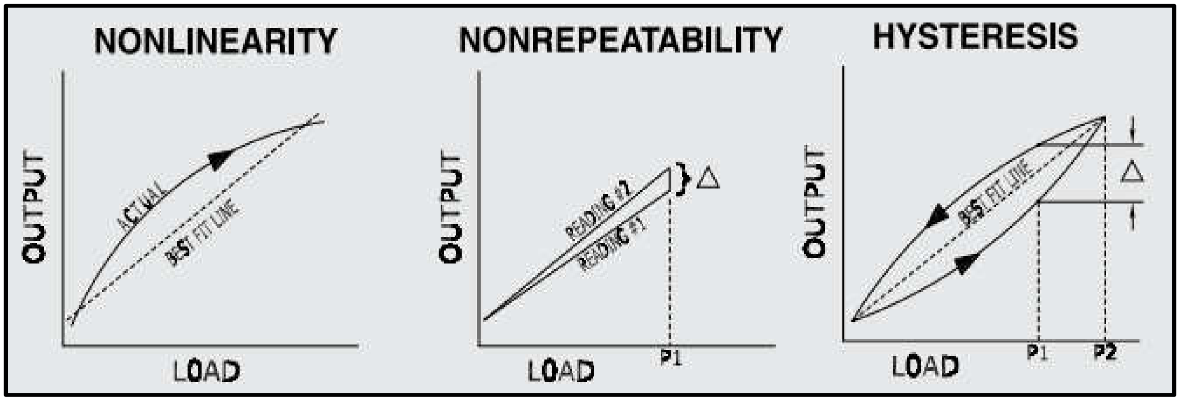


Figure 9: Non-linearity, non-repeatability and hysteresis explained ((Futek, 2007) with small amendments)

3.1.2 Wireless module

There are several factors considered when choosing the wireless module such as range, speed or data rate and cost. In our project, a wireless module with the range of 100 m and data rate of 250 kbps would be sufficient for the purpose of measuring an agricultural prime mover performance. Besides that, a low cost module would be preferred because of financial restraint. In addition, the wireless module must be able to transmit and receive several types of data e.g. speed, torque, current etc. at the same time. This is very important because usually, several parameters need to be measured at the same time in order to get the real performance of a prime mover.

Two wireless modules which meet our requirements have been considered which are Zigbee and RF. In addition of meeting our previously mentioned system requirements, they are also widely available and easily integrated into the measurement system. Below are the differences between two popular RF and Zigbee modules:

Parameters	**RFM12B (HopeRF)**	**XBee (Digi)**
Available Frequencies	433 MHz, 868 MHz & 915 MHz	2.4 GHz
Power supply	2.2-3.8 V	2.1-3.6 V
Interface	SPI	Serial
Data rate	256 kbps	250 kbps

Table 1: Comparison between RFM12B and XBee wireless modules

3.1.3 Microcontroller

Microcontrollers are needed at both the Transmitter side and Receiver side. At the Transmitter side, it collects analog data from our torque sensor via its analog input pins, converts the data to digital data and output it to the wireless module for further processing. Because it collects data, it essentially acts as a data logger. There are 2 most important specifications of a good data logger. These are its sampling rate and resolution. For example, if a drive shaft has a maximum rotational speed of 10000 rpm (167 revolutions per second), a microcontroller with a maximum sampling rate of 100 samples per second will not be able to handle the speed data according to Nyquist Theorem. Likewise, if the output voltage of a speed sensor increases from 0 to 0.05 Volts for an increase from 0 to 1 km/h, a microcontroller which can only measure voltage change of 0.1 V will not be useful, which explains the importance of resolution.

At the Receiving side, the microcontroller acts as an interface between the wireless module and the monitoring program. Therefore, it must have the capability of communicating with the computer via serial communication. Besides that, a microcontroller which is easily configured, widely available and cheap is also essential in making this project a success.

3.1.4 Monitoring program

Using a microcontroller at the receiving side would already enable us to log data decently. However, the data would not be displayed real time which would be more convenient for the purpose of monitoring the data measurement. There are many ways to develop a monitoring program, either by using traditional textual programming language such as C, Pascal or Visual Basic or by using more recent graphical programming language such as National Instruments LabVIEW. The advantages of graphical programming over textual programming are summarized below: (Corporation, 2013a)

- Intuitive
- Interactive Debugging Tools
- Automatic Parallelism and Performance
- Abstraction of Low-Level Tasks

3.2 Hardware system development

After studying our project's requirement, we have decided to settle on the following hardware and software to complete our project:

Component	**Description**
Sensor	Honeywell 1228-2K Torque sensor & FUTEK CSG110 Strain gauge amplifier
Wireless module	HopeRF RFM12B-433-D
Microcontroller	Arduino Uno
Monitoring program	National Instrument LabVIEW

Table 2: Summary of system components

Our hardware prototype consists of a Transmitter module and a Receiver module. The Transmitter module consists of a breadboard connecting the torque sensor, the Arduino microcontroller and the RF module while the Receiver module consists of a breadboard connecting the Arduino microcontroller, the RF module and LabVIEW. Each breadboard also contains an antenna, three 4.7 kΩ resistors and three 10 kΩ resistors.

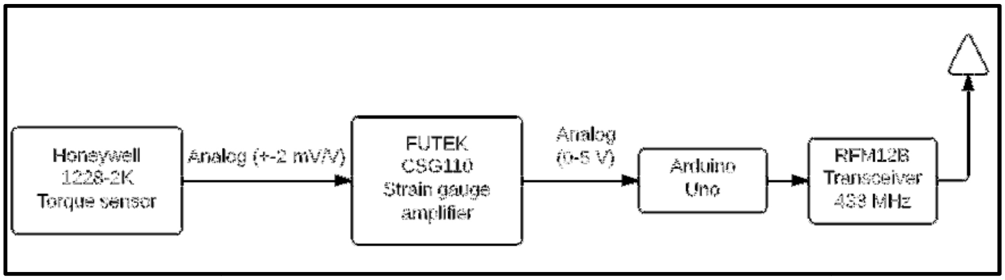


Figure 10: Block diagram of Transmitter module

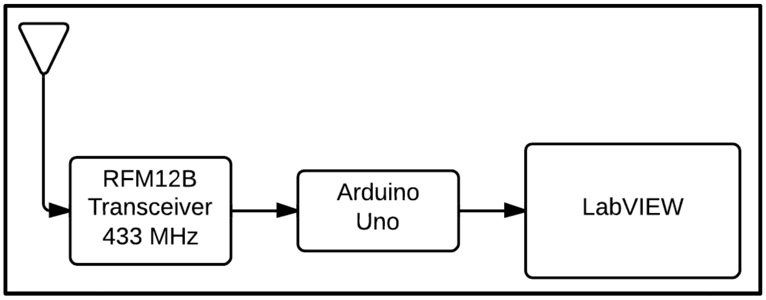


Figure 11: Block diagram of Receiver module

3.2.1 Torque sensor and in-line amplifier

In order to measure the torque and speed of a prime mover, a suitable torque sensor needs to be used. Honeywell 1228 Flange Drive Torque Sensor has been chosen because of the reasons explained in 3.1.1. Some of its features are:

1. 225 to 2250 Nm capacity
2. 0.15% non-linearity and hysteresis
3. 0.05 % repeatability
4. 5000 rpm maximum speed

Figure 12: Honeywell 1228 Flange Drive Torque Sensor (Honeywell, 2008, p. 1)

The analog to digital converters (ADC) in the Arduino have a 10-bit resolution. For Arduino UNO, the default reference voltage is 5 V which means that the smallest detectable voltage variation is

$$Smallest\ detectable\ voltage\ = \frac{Voltage\ range}{Resolution} = \frac{5V}{(2^{10} - 1)} = 4.9\ mV$$

The electrical output of the Honeywell torque sensor is specified as 2 mV/V at the rated capacity of 225 Nm. This means that the electrical voltage output of the sensor put at 225 Nm rated capacity utilizing 10 volts excitation will be 20 mV at 225 Nm or 0.2 mV for each Nm of applied torque. Thus, a 4.9 mV resolution will not be enough. To increase the Arduino's resolution, its internal reference voltage of 1.1 V could be used, but this still gives the smallest detectable voltage of 1.1 mV, which is still not enough. Another way to further increase its resolution is to use an external voltage source as its reference voltage. However, there will be issue of noise and stability. Therefore, the best option is to use an in-line amplifier to amplify the torque sensor output signal.

Figure 13: FUTEK Model CSG110 (Futek, 2013, p. 1)

FUTEK CSG110 Strain Gauge Amplifier has been chosen because it is capable of amplifying most of the commercial torque or load transducer output for torque or load measurements. This is because it can provide interchangeable bridge excitation voltage of either 5 or 10 volt. The 10 volt excitation is mostly applicable to the torque or load transducer made of 350 ohm strain gauge bridge, such as our torque sensor, while the 5 volt excitation is applicable to 240 ohm strain gauges bridge to avoid overloading excitation current specified by the amplifier. Based on calibration work made by Othman et al. (2012), the resolution after amplification is 41 mV for each Nm of applied torque. Therefore, the use of the amplifier will enable Arduino to detect the smallest change in the torque sensor measurement. Some of the features of FUTEK CSG110 are:

1. 1 kHz, 10 kHz, and 25 kHz bandwidth available
2. Overvoltage protection
3. Reduced noise from 100 mV to 15 mV (85% improvement from previous model)
4. Bipolar Output, Differential Input

5. ±5 or ± 10 VDC Outputs DIP Switch Selectable Output, Unipolar Bidirectional Voltage (0-5-10 VDC) also available
6. 0–20 mA, 4–20 mA, 0–16 mA, 5–25 mA DIP Switch Selectable Output, Bidirectional Current (4-12-20 mA) also available
7. Bridge Excitation Selectable 5 or 10 VDC
8. Ranges: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 10.0 mV/V (DIP Switch Selectable)

3.2.2 Arduino Microcontroller

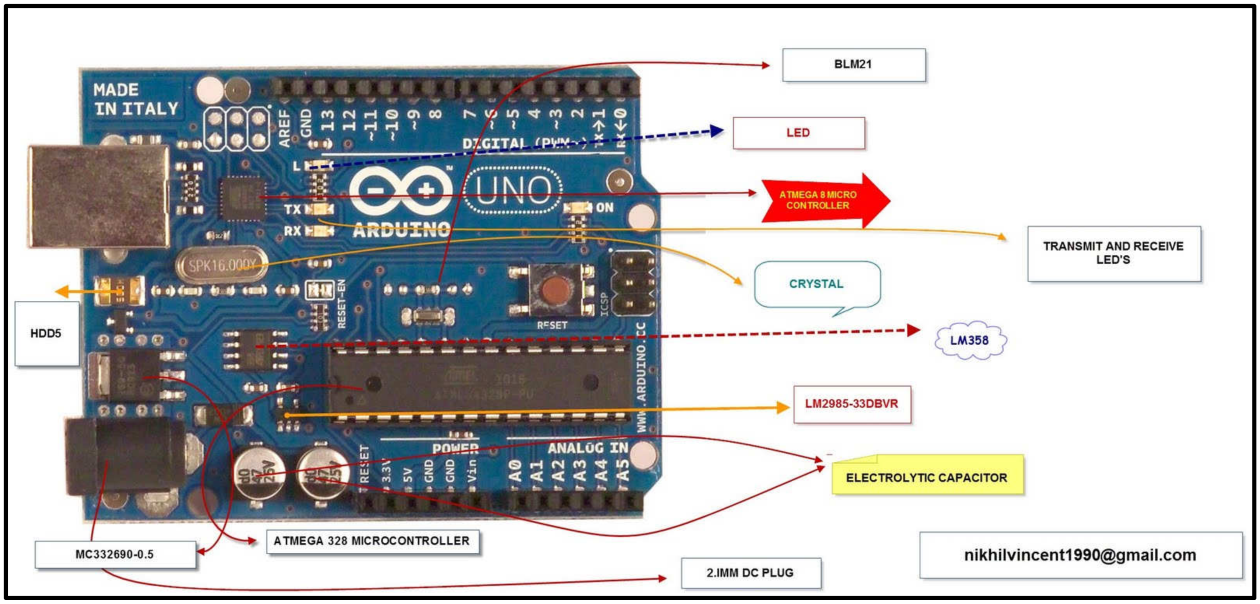


Figure 14: Description of Arduino Uno board (Geekgoing.blogspot.com, 2011)

As explained before, the microcontroller works as an interface between the sensors, the wireless modules and the monitoring program. Because of the reasons previously mentioned in 3.1.3, Arduino microcontroller is chosen. Its ADC has a 10-bit resolution, which would be adequate to sample our torque sensor output provided that an in-line amplifier is used as explained in 3.2.1. It can sample up to 517 samples per second (Stuff, 2013), which would be sufficient for our torque sensor which has a maximum speed of 5000 rpm (83 revolutions per second). It is a popular, open source electronics prototyping platform based on flexible, easy-to-use hardware and software. Because of its popularity, there are so many voluntary supports available on the internet which makes developing a system using an Arduino easy and fast. There are many models of Arduino but Arduino UNO was chosen among the others because it is the cheapest and sufficiently good for our application. Following are some of its features:

Spec	**Desciption**
Microcontroller	ATmega328
Operating Voltage	5V
Clock Speed	16 MHz
Power	Computer through USB or external 7-12 V
Memory	32 kb Flash, 2 kb SRAM, 1 kb EEPROM
I/O	14 digital pins operating at 5 V, 40 mA with internal pull-up resistor of 20-50 kOhms. 6 analog inputs of 10 bits resolution
Communication	UART TTL (5V) serial, I2C (TWI) and SPI
Programming	Using Arduino software
USB over current protection	Resettable polyfuse protecting computer's USB ports from shorts and over current
Physical	6.858 cm (length) x 5.334 cm (width), 4 screw holes for easy attachment to a case

Table 3: Summary of Arduino UNO spec

3.2.3 Programming Arduino

At the Transmitter side, Arduino collects analog data from our torque sensor via its analog input pins, converts the data to digital data and output it to the RF wireless module for further processing. To use the Arduino with the RF wireless module, there are several things to keep in mind:

1. Both Transmitter and Receiver must be set to the same frequency
2. Both Transmitter and Receiver must be set to the same Network Group. A Network Group can be described as a room; everyone in the room can talk to each other but cannot talk to nor hear someone in a different room. (OpenEnergyMonitor, n.d.-b)
3. The Transmitter and Receiver cannot have the same Node ID. A node ID can be described as the name of a person in the room (ibid.).
4. Any kind of data that fits within a 66-byte buffer can be sent. (Margolis, 2011, p. 488)

3.2.4 RF Module

Figure 15: RFM12B module (OpenEnergyMonitor, n.d.-a)

The RF module used in this project is HopeRF's RFM12B-433-D. It is a single chip, low power, multi-channel FSK transceiver designed for use in the 433 MHz band. It supports 250 network groups and 31 Node IDs.

3.2.5 Hardware system circuit diagram

After presenting which hardware components were chosen and why they were chosen, the components were assembled according to Figure 16. Both the Transmitter and Receiver have the same electrical connection. The only difference between them is the way Arduino is programmed. The RFM12B modules are designed for 3.3 volts and the resistors shown in below are needed to drop the voltage to the correct level (Margolis, 2011, p. 488).

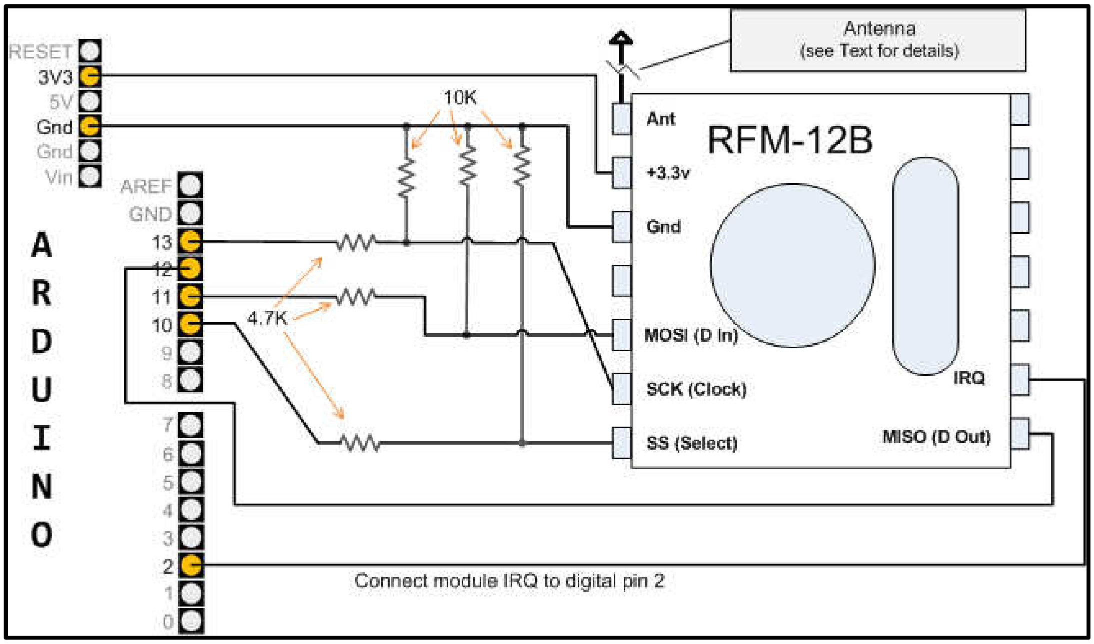


Figure 16: Arduino Uno to RFM12B connection (Margolis, 2011, p. 486)

3.3 Software system development

Our software system main functions are to display the data received by the receiver module at the base station and log them for future use. Because of the advantages of graphical programming over textual programming mentioned in 3.1.4, LabVIEW has been chosen as the tool to develop our monitoring program. LabVIEW is “a highly productive development environment that engineers and scientists use for graphical programming and unprecedented hardware integration to rapidly design and deploy measurement and control systems” (Corporation, 2013b). A LabVIEW program capable of receiving serial data from Arduino in real time, plotting the data on a graph and logging the data into the computer has been developed.

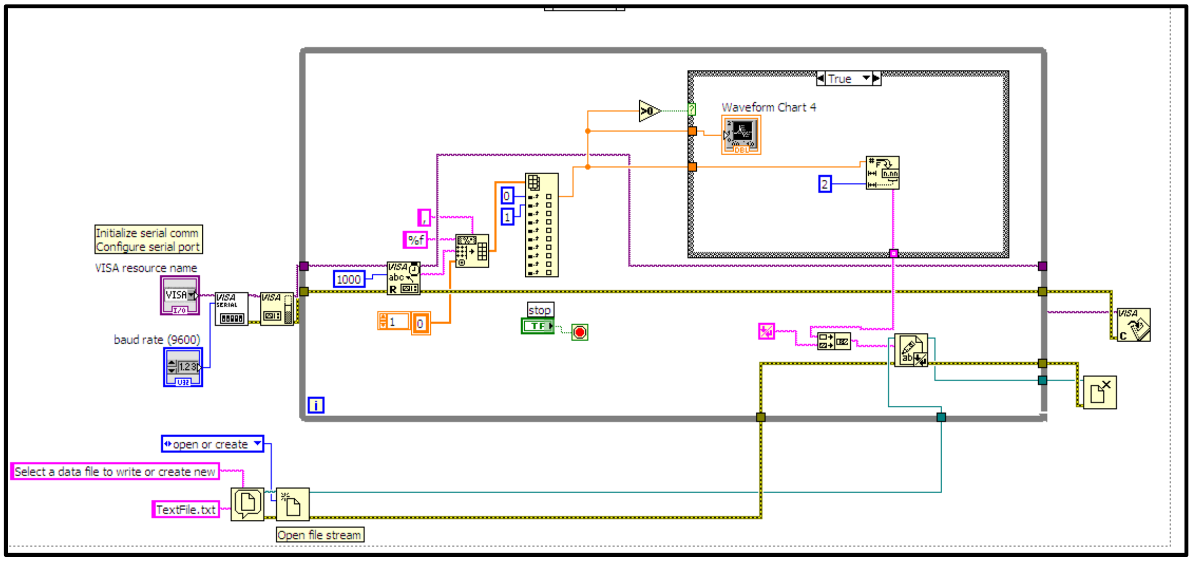


Figure 17: Data monitoring program developed using LabVIEW

3.4 Integrated system development and testing

Finally, after the hardware and software system were developed and tested separately, they were integrated to become a complete system. To verify the performance of our integrated system, two parameters are considered:

1. Accuracy of data transmission

   Accuracy can be defined as "1: freedom from mistake or error: correctness" (“Accuracy,” 2013). In our measurement system, data transmission accuracy can be defined as the number of data received at the base station which matches the data transmitted from the prime mover. Besides that, in real situation, our measurement system will be measuring several parameters (e.g. torque, speed) at the same time. Therefore, the accuracy must also be measured against number of parameters transmitted.

2. Range of data transmission

   Similarly, in real situation, the prime mover carrying our measurement system will be moving, and thus its distance from the receiver base station will also vary. Therefore, the range of data transmission must be varied to determine the minimum and maximum distance our measurement system can work.

Therefore, several experiments have been done to measure the performance of our system. These are:

3.4.1 Experiment 1

Objective: To determine the sampling rate of Transmitter's ADC for two analog inputs

Apparatus:

- 1 Transmitter board. The Arduino was programmed according to Figure 18
- 1 laptop with LabVIEW installed
- 1 NI USB-6008 Multifunction I/O
- 2 USB printer cables
- 2 wires

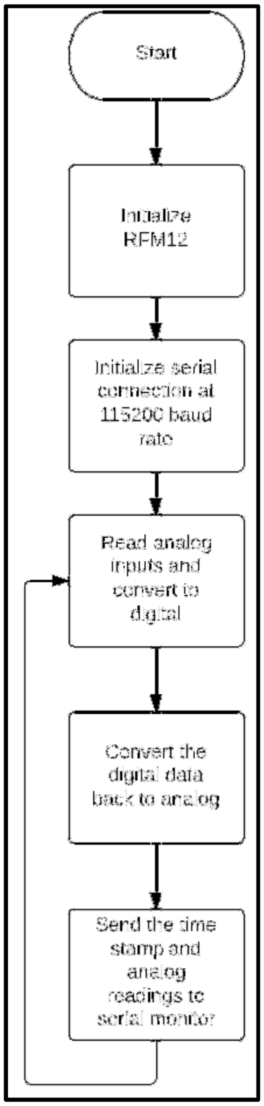
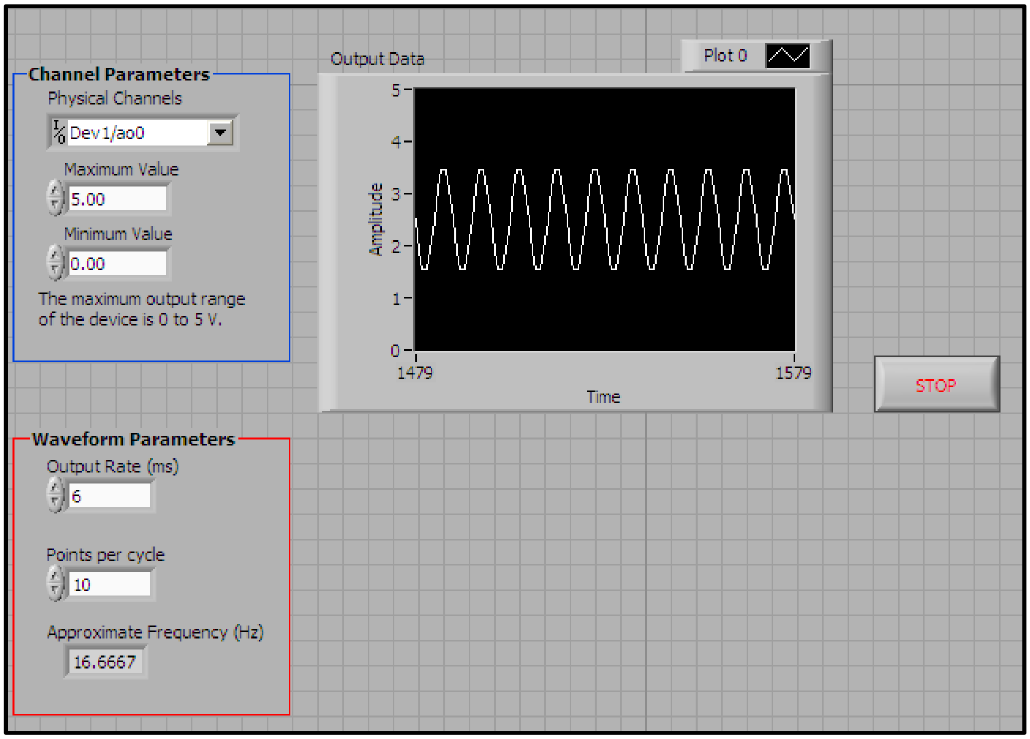


Figure 18: Arduino software flow chart for Experiment 1

Procedure:

1. Two samples analog signal of 0-5V sine waves were generated using LabVIEW.



Channel Parameters

Physical Channels: Dev1/ao0

Maximum Value: 5.00

Minimum Value: 0.00

The maximum output range of the device is 0 to 5 V.

Waveform Parameters

Output Rate (ms): 6

Points per cycle: 10

Approximate Frequency (Hz): 16.6667

Figure 19: Generated sine wave in LabVIEW

2. The LabVIEW generated analog signals were sent to the analog input pins A2 and A3 of Arduino Transmitter board through NI USB-6008 Multifunction I/O pin AO0 and AO1.
3. The Arduino serial monitor program was run at 115200 baud on laptop and the data was recorded.

3.4.2 Experiment 2

Objective: To determine the transmission rate of the Transmitter module for two analog inputs

Apparatus: Similar to Experiment 1 except that Arduino was programmed according to Figure 20

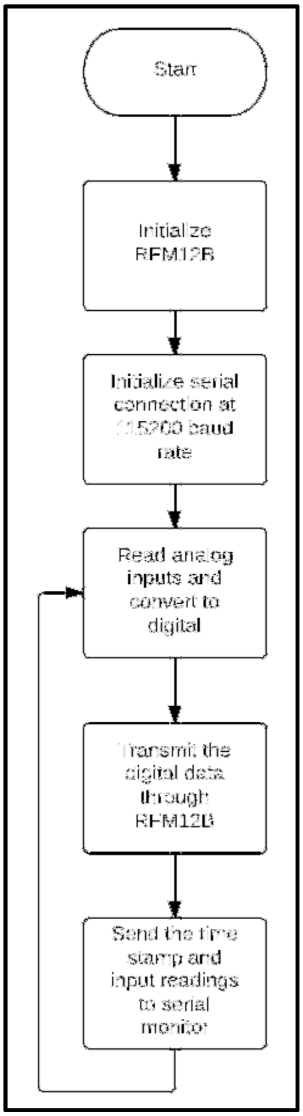


Figure 20: Arduino software flow chart for Experiment 2

Procedure: Similar to Experiment 1

3.4.3 Experiment 3

Objective: To determine the maximum range of data transmission

Apparatus:

- 1 Transmitter board. The Arduino was programmed according to Figure 20
- 1 Receiver board. . The Arduino was programmed according to Figure 21
- 1 laptop with LabVIEW and signal generator program installed
- 1 laptop with LabVIEW and monitoring program installed
- 1 NI USB-6008 Multifunction I/O
- 3 USB printer cables
- 2 wires

Procedure:

1. Apparatus was arranged with the range set to 50 m.
2. Two samples analog signal of 0-5V sine waves were generated using LabVIEW on Laptop 1.
3. The LabVIEW generated analog signal was sent to the analog input pin A2 and A3 of Arduino Transmitter board through NI USB-6008 Multifunction I/O pin AO0 and AO1.
4. The monitoring program on Laptop 2 was run and the received signal graph was recorded.
5. Step 1-4 was repeated with the range increased in 50 m steps i.e. 100 m, 150 m, 200 m until no signal could be received at Laptop 2.

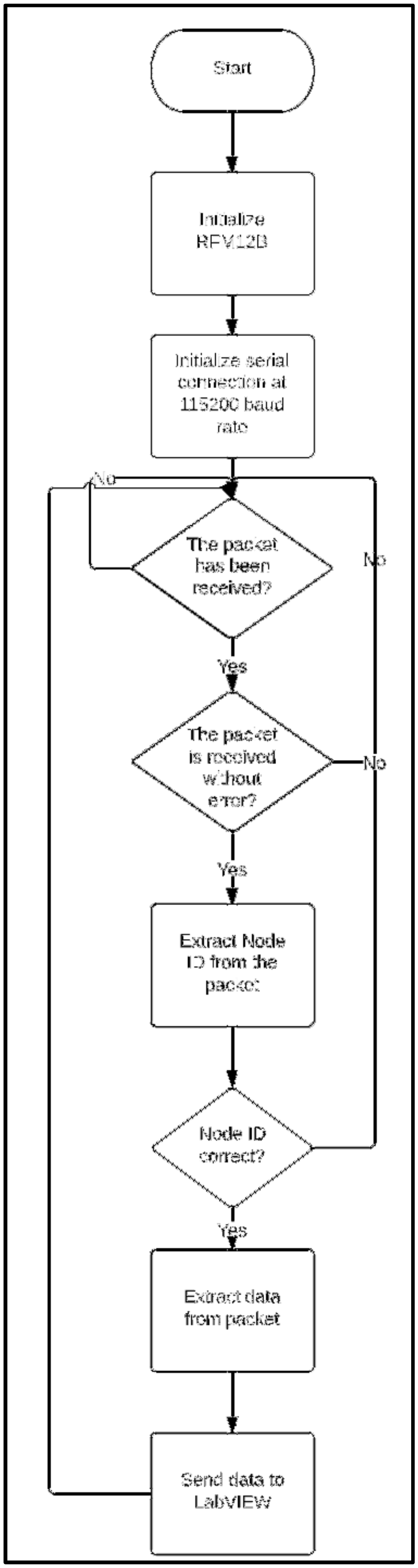


Figure 21: Arduino software flow chart for Experiment 3

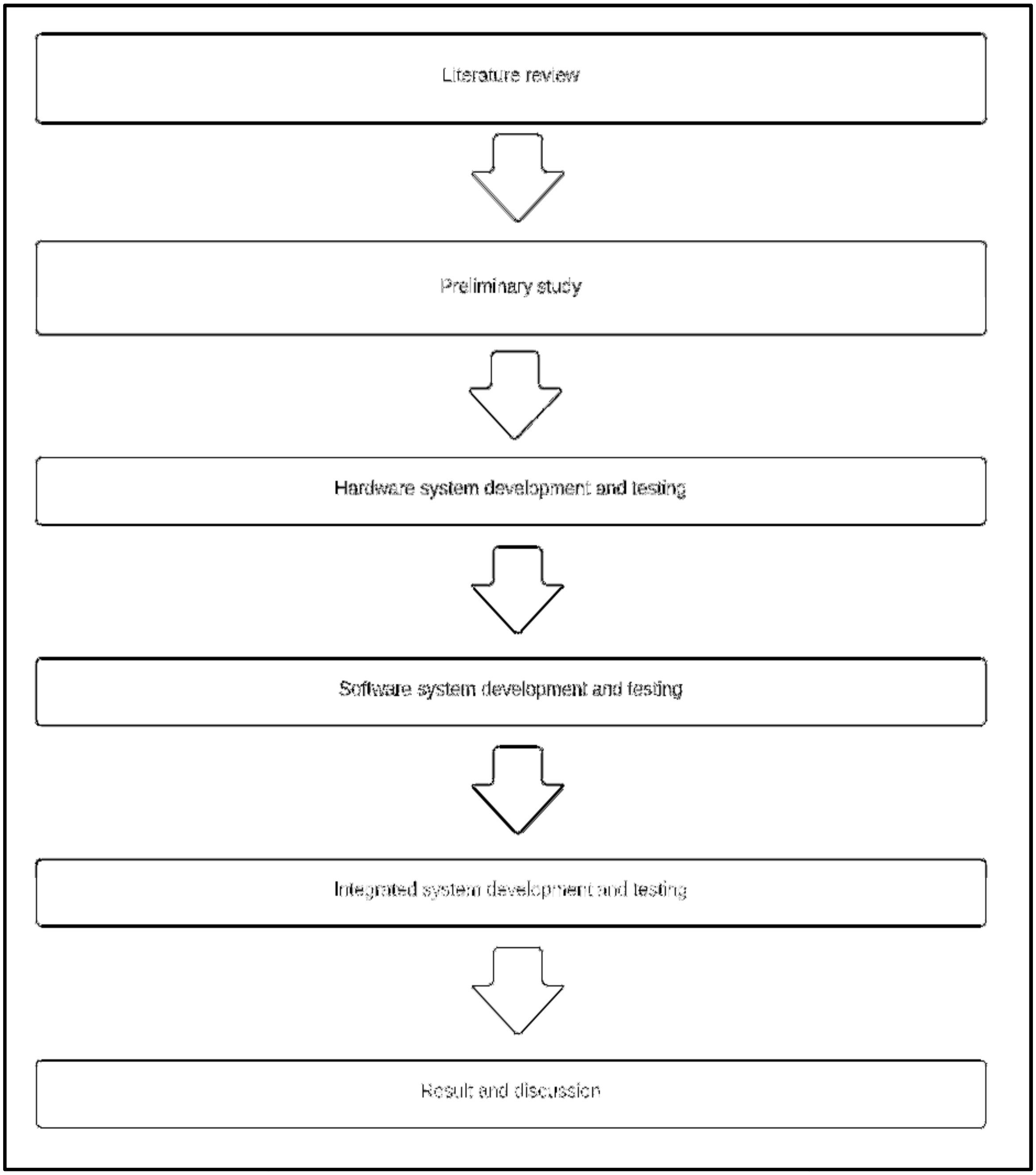


Figure 22: Methodology flow chart

3.5 Summary

This chapter covers the methodology used in designing and developing the RF remote measurement system for prime mover. It starts by presenting the preliminary study on how the hardware and software specifications were determined. The chapter continues by going in depth on the hardware and software design and development. It finishes by explaining the experiments done to test the prototype and reviewing the methodology by presenting its flow chart. In the next chapter, the experiment results will be presented and discussed.

4.0 Results and Discussion

This chapter aims to present and discuss the results of several experiments conducted as discussed previously in the previous chapter. These experiments are:

1. To determine the sampling rate of Transmitter's ADC for two analog inputs
2. To determine the transmission rate of the Transmitter module for two analog inputs
3. To determine the maximum range of data transmission

For each experiment, its result will be presented alongside the discussion of the result. This method of presentation was chosen so that it is easier to comprehend the result immediately without having to go back and forth between pages.

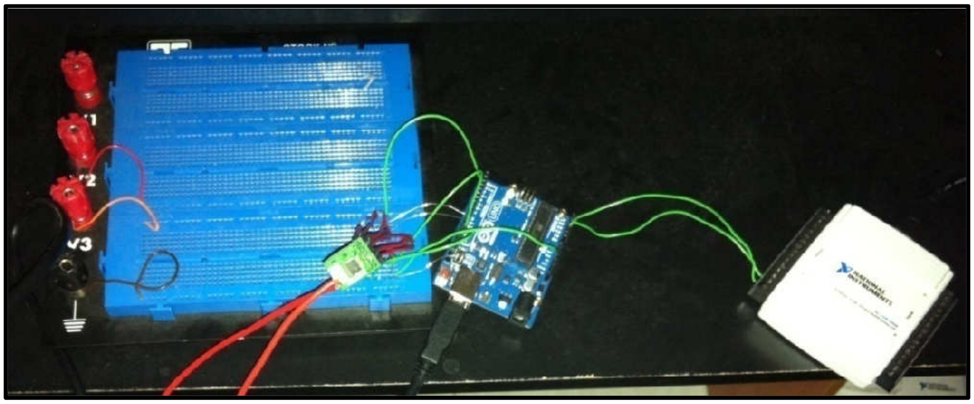
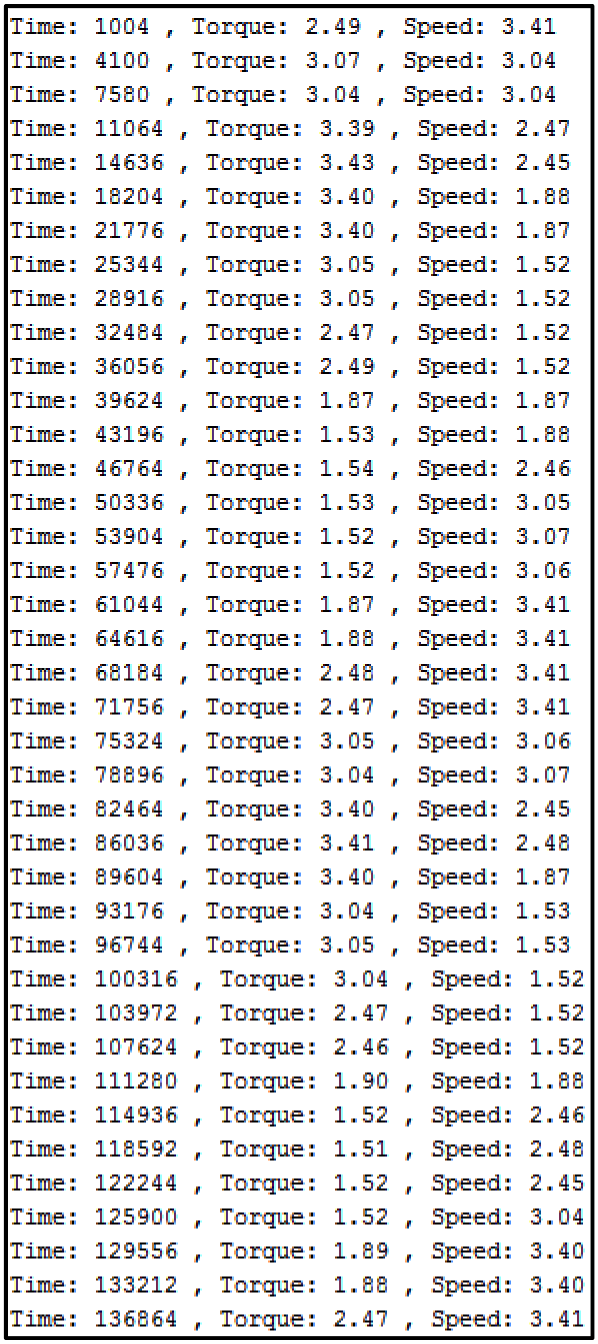


Figure 23: Experimental setup

4.1 Experiment 1



```
Time: 1004 , Torque: 2.49 , Speed: 3.41
Time: 4100 , Torque: 3.07 , Speed: 3.04
Time: 7580 , Torque: 3.04 , Speed: 3.04
Time: 11064 , Torque: 3.39 , Speed: 2.47
Time: 14636 , Torque: 3.43 , Speed: 2.45
Time: 18204 , Torque: 3.40 , Speed: 1.88
Time: 21776 , Torque: 3.40 , Speed: 1.87
Time: 25344 , Torque: 3.05 , Speed: 1.52
Time: 28916 , Torque: 3.05 , Speed: 1.52
Time: 32484 , Torque: 2.47 , Speed: 1.52
Time: 36056 , Torque: 2.49 , Speed: 1.52
Time: 39624 , Torque: 1.87 , Speed: 1.87
Time: 43196 , Torque: 1.53 , Speed: 1.88
Time: 46764 , Torque: 1.54 , Speed: 2.46
Time: 50336 , Torque: 1.53 , Speed: 3.05
Time: 53904 , Torque: 1.52 , Speed: 3.07
Time: 57476 , Torque: 1.52 , Speed: 3.06
Time: 61044 , Torque: 1.87 , Speed: 3.41
Time: 64616 , Torque: 1.88 , Speed: 3.41
Time: 68184 , Torque: 2.48 , Speed: 3.41
Time: 71756 , Torque: 2.47 , Speed: 3.41
Time: 75324 , Torque: 3.05 , Speed: 3.06
Time: 78896 , Torque: 3.04 , Speed: 3.07
Time: 82464 , Torque: 3.40 , Speed: 2.45
Time: 86036 , Torque: 3.41 , Speed: 2.48
Time: 89604 , Torque: 3.40 , Speed: 1.87
Time: 93176 , Torque: 3.04 , Speed: 1.53
Time: 96744 , Torque: 3.05 , Speed: 1.53
Time: 100316 , Torque: 3.04 , Speed: 1.52
Time: 103972 , Torque: 2.47 , Speed: 1.52
Time: 107624 , Torque: 2.46 , Speed: 1.52
Time: 111280 , Torque: 1.90 , Speed: 1.88
Time: 114936 , Torque: 1.52 , Speed: 2.46
Time: 118592 , Torque: 1.51 , Speed: 2.48
Time: 122244 , Torque: 1.52 , Speed: 2.45
Time: 125900 , Torque: 1.52 , Speed: 3.04
Time: 129556 , Torque: 1.89 , Speed: 3.40
Time: 133212 , Torque: 1.88 , Speed: 3.40
Time: 136864 , Torque: 2.47 , Speed: 3.41
```

Figure 24: Result of Experiment 1

The time stamp was recorded in µs. Based on the data recorded, the time between each reading varies from 3096 to 3656 µs. The average time is 3577.3 µs. Therefore, the average sampling rate is:

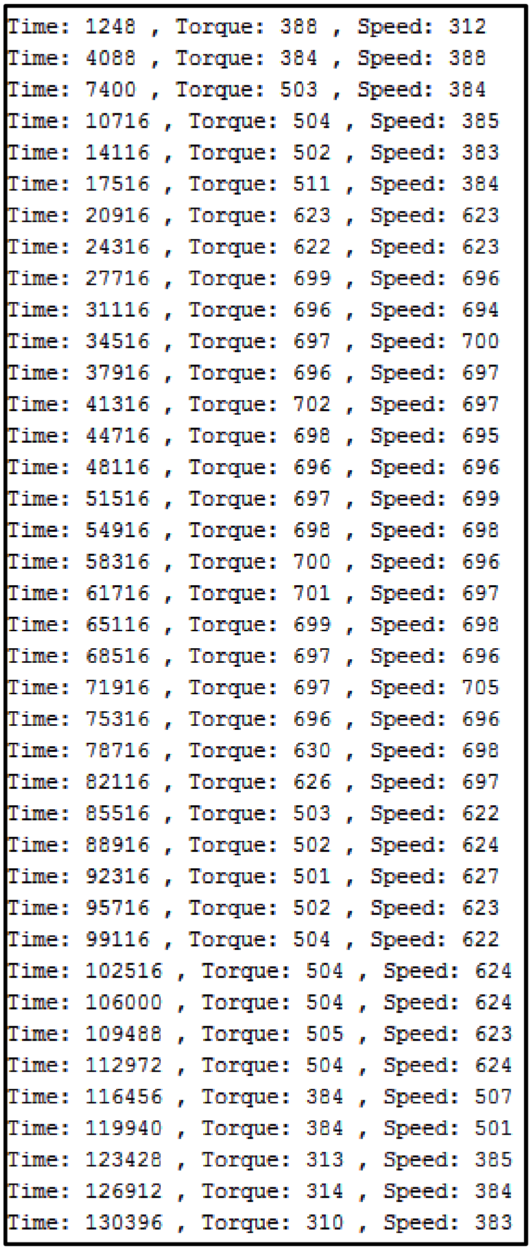
$$Sampling\ rate_{ave} = \frac{1}{Average\ time\ between\ reading}$$

$$= \frac{1}{3577.3\ \mu s}$$

$$= 280\ samples/second$$

Based on the result, it is proven that the developed system with two types of data to be transmitted is able to handle sampling rate up to 280 samples per second, which would be good enough for our torque sensor measurement which has a maximum speed of 5000 rpm.

4.2 Experiment 2

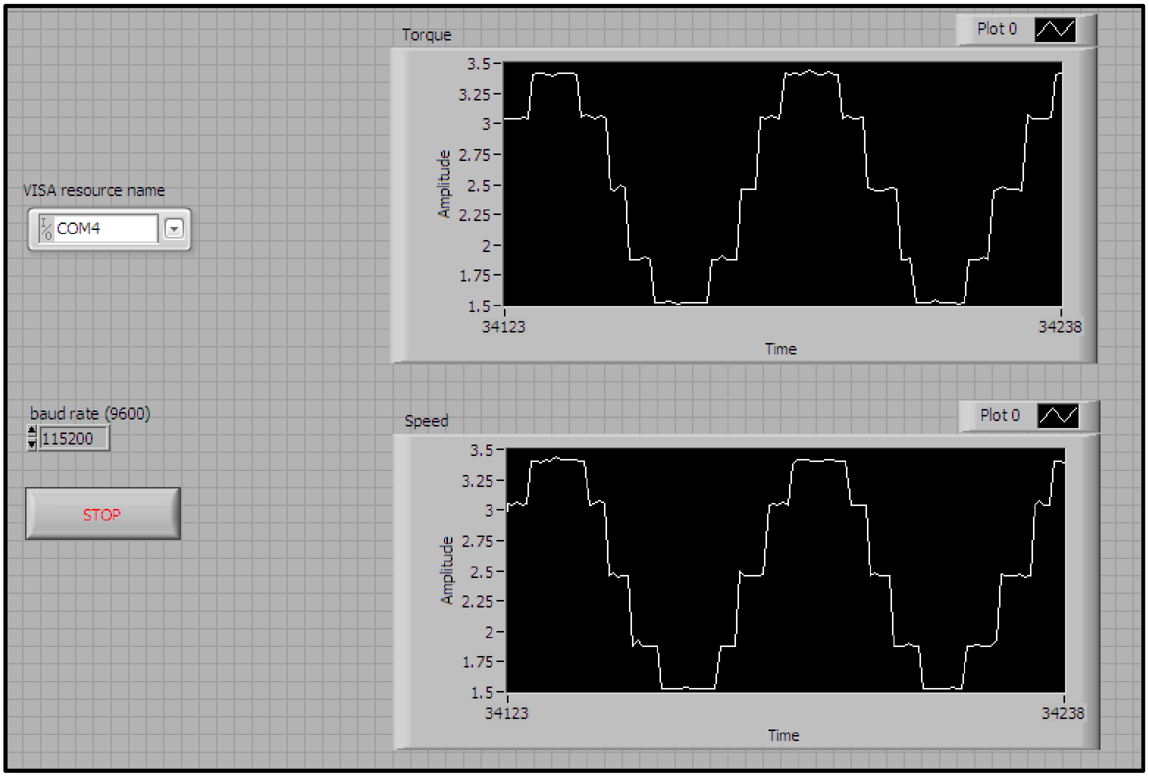


```
Time: 1248 , Torque: 388 , Speed: 312
Time: 4088 , Torque: 384 , Speed: 388
Time: 7400 , Torque: 503 , Speed: 384
Time: 10716 , Torque: 504 , Speed: 385
Time: 14116 , Torque: 502 , Speed: 383
Time: 17516 , Torque: 511 , Speed: 384
Time: 20916 , Torque: 623 , Speed: 623
Time: 24316 , Torque: 622 , Speed: 623
Time: 27716 , Torque: 699 , Speed: 696
Time: 31116 , Torque: 696 , Speed: 694
Time: 34516 , Torque: 697 , Speed: 700
Time: 37916 , Torque: 696 , Speed: 697
Time: 41316 , Torque: 702 , Speed: 697
Time: 44716 , Torque: 698 , Speed: 695
Time: 48116 , Torque: 696 , Speed: 696
Time: 51516 , Torque: 697 , Speed: 699
Time: 54916 , Torque: 698 , Speed: 698
Time: 58316 , Torque: 700 , Speed: 696
Time: 61716 , Torque: 701 , Speed: 697
Time: 65116 , Torque: 699 , Speed: 698
Time: 68516 , Torque: 697 , Speed: 696
Time: 71916 , Torque: 697 , Speed: 705
Time: 75316 , Torque: 696 , Speed: 696
Time: 78716 , Torque: 630 , Speed: 698
Time: 82116 , Torque: 626 , Speed: 697
Time: 85516 , Torque: 503 , Speed: 622
Time: 88916 , Torque: 502 , Speed: 624
Time: 92316 , Torque: 501 , Speed: 627
Time: 95716 , Torque: 502 , Speed: 623
Time: 99116 , Torque: 504 , Speed: 622
Time: 102516 , Torque: 504 , Speed: 624
Time: 106000 , Torque: 504 , Speed: 624
Time: 109488 , Torque: 505 , Speed: 623
Time: 112972 , Torque: 504 , Speed: 624
Time: 116456 , Torque: 384 , Speed: 507
Time: 119940 , Torque: 384 , Speed: 501
Time: 123428 , Torque: 313 , Speed: 385
Time: 126912 , Torque: 314 , Speed: 384
Time: 130396 , Torque: 310 , Speed: 383
```

Figure 25: Result of Experiment 2

Based on our recorded data, the average time between each data reading is 3455.4 µs. Therefore, the average transmission rate is 289 times/second. The result shows that besides having a decent sampling rate, our system is also able to send continuous RF signal in a decent speed, since the experiment setup considered the time it took to not only sample the data but also to send it wirelessly through RFM12B. Of course the high transmission rate would be unnecessary in our application, but it is good to know that a researcher is able to build a low cost but fully capable system using our setup.

4.3 Experiment 3



VISA resource name: COM4

baud rate (9600): 115200

Figure 26: Result of Experiment 3

From the graph of Experiment 3 result, it can be seen that our Receiver system works perfectly well at 50 m. The received signal is comparable to the original sample signal as in Figure 19. This proves that our system is able to transmit multiple data types at the same time within a short range. However, when the range was increased to 250 m, our receiver stopped receiving signal.

4.4 Summary

Based on our experimental result, it is proven that our system is fully capable of executing the tasks expected of it at the start of the project. It has a good range of communication and able to handle decent data sampling rate. Besides that, it is also able to transfer multiple data securely which make it ideal to be used in our agricultural prime mover measurement.

5.0 Conclusion

A remote measurement system for agricultural prime mover has been proposed. It consists of two main components which are Arduino UNO microcontroller and RFM12B RF wireless module. It also consists of LabVIEW data monitoring program. The project is important to the nation's agricultural industry by assisting in development of Malaysian own agricultural tractor.

An overview of the important terminologies used in this project such as remote measurement, Radio Frequency, Zigbee, torque & torque sensor and agricultural prime mover has been covered. Even though the definitions part seems trivial, it is very important in terms of understanding the true architecture of this system. The author definitely gains a lot of insight by defining each terminology used in this project

Several papers relating to the project have been discussed and a few of them provides further motivation to develop this project. The papers proved that that a decently capable RF monitoring system with medium range and secured transmission could be developed with low cost.

Besides that, the methodology used in designing and developing the RF remote measurement system for prime mover was presented. In depth methodology on how the selection of materials was made give significant meaning to the value of this project.

Based on our experimental result, it is proven that our system is fully capable of executing the tasks expected of it at the start of the project. It has a good range of communication and able to handle decent data sampling rate. Besides that, it is also able to transfer multiple data securely which make it ideal to be used in our agricultural prime mover measurement.

5.1 Recommendation for Future Work

There are several improvements that can be made to this project:

1. More data types could be tested instead of just two which are covered in this research project
2. Over time, more advanced microcontroller and wireless modules will be available in the market with more powerful capabilities. Therefore, research should be done continuously to keep improving the prototype in terms of its range and speed

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