MOTOR CONDITION MONITORING USING WIRELESS SENSORS

By

AHMAD SYAHIR BIN SUFIAN

DISSERTATION

Dissertation Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Electrical & Electronics Engineering Programme
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Approved by,

____
(Dr Fawnizu Azmadi Bin Hussin)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
December 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

AHMAD SYAHIR SUFIAN

ABSTRACT

The main aim of the project is to develop a wireless system that can be integrated with an existing wired system to monitor several variables/conditions of an electric motor. The objective was to build a prototype wireless motor condition monitoring with the usage of Zigbee modules. The main task in this project was to manage a temperature sensor, transmitter, and a receiver to communicate with each other. Raw data collected from the sensor will be transmitted from transmitter to the receiver to monitor the condition of the motor. The project focuses on the transmitter side's mobility, by reducing bulky parts and ensuring longer battery life, in order to reduce maintenance costs. Judging from the actual performance of the Zigbee, it can be concluded that it have potential to manage thousands of wireless nodes with a single receiver as coordinator. However, for industrial usage, it's still a doubt whether it is feasible for the Zigbee to act as a serial cable replacement as part of condition monitoring. Several external and internal factors had to be considered as the layout of a plant or offshore platform may contain obstacle and machineries that are may affected by the radio frequency signal of the Zigbee. It is also cannot be denied that interference may occur, resulting in bad signal quality thus affecting the transmission and receiving of the signal. Currently, to be on the safe side, we can say that Zigbee is more reliable for small scale wireless system such as home automation. And, as for industrial condition monitoring, the current practice of using serial cable and Ethernet cable to transmit the status of motor, is still reliable despite that it requires extra cost on installation, maintenance, and the cables themselves. With the accelerated advancement of technology, new technology are being developed and it is not impossible that one day a new equipment or system of wireless technology might have the ability to successfully replacing the serial cable. So, wireless condition monitoring can be implemented in the industry or other relevant field.

ACKNOWLEDGEMENTS

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ABBREVIATIONS AND NOMENCLATURES

ADC	= Analog to Digital Converter
API	= Application Programming Interface
DCS	= Distributed Control System
GUI	= Graphical User Interface
LAN	= Local Area Network
LR-WPAN	= Low Range Wireless Personal Area Network
MCC	= Motor Control Centers
PAN ID	= Personal Area Network Identification Details
PIC	= Programmable Interrupt Controller
RF	= Radio Frequency
WSN	= Wireless Sensor Networks
UART	= Universal Synchronous Receive Transmit

CHAPTER 1
INTRODUCTION

1.1 Background of Study

In current economic recession, management trend of downsizing has become common by reducing the size of the workforce. Companies were focusing more on reducing costs as much as possible, without sacrificing the quality of work. Hence, remote condition-monitoring has been given more importance as a way to ensure quality with fewer personnel. [1] Inexpensive wireless monitoring system enables plants to ease the maintenance work for personnel by downsizing the vast job scope only towards machinery that really requires attention.

By using the approach of wireless sensor networks, it means that we are implying non-intrusive measure for motor maintenance. This was achieved by establishing a Wireless Sensor Networks (WSN) that will provide constant report of motor conditions to the main data centre, allowing the person-in-charge to monitor and plan the suitable measure to be taken should there be any faults occurred. [2]

Two-thirds of consumed electrical energy in the industries came from motor-driven systems. Mostly were from induction motors. [3] Current setup of motor usually uses signals obtained from Motor Control Centre (MCC), transmitted via Ethernet cable, and connected to a Distributed Control System (DCS) or a computer to monitor certain variables and conditions of the running motors. The initial costs of laying those cables, and maintaining both the sensors and cables are usually higher than the costs of those sensors themselves. By opting to wireless system, industries are able to reduce the overall costs which include costs of maintenance, installation, and materials. [3]

1.2 Problem Statement

It was estimated that the industries were wasting too much energy on motor-driven system. This is due to most motors were either installed oversize, or under-loaded. [2] Hence, contributes to the low efficiency of energy consumption by these motors usage. Suggestions given to overcome these problems mostly were monitoring of current energy-usage condition of the plant. Therefore, low-cost methods are needed to monitor those motors conditions, especially small and medium-sized motors. [8] However, non-intrusive methods were preferred as it will not comply with the productivity of the plant or require plant shutdown to be implemented.

Typically, a plant usually lets its machineries to run until breakdown, and practices Preventive Maintenance. Recently, Predictive Maintenance has becoming much preferable as it will greatly reduce maintenance costs of a plant. [1] This includes placing sensors mostly on critical machines for process and vibration monitoring. The sensors will then be connected with cables, ended at a termination box. If those panels are not connected with a computerized monitoring system, user has to go to those panels and use hand-held meter to obtain readings. The main disadvantage of the system is the high cost of installation and maintenance of those wiring and sensors. What needed is a cost effective method to eliminate the wirings for these monitoring systems. [1]

Following the proposed approach, two new non-intrusive methods are proposed for estimating the efficiencies of in-service induction motors, using air-gap torque estimation and a modified induction motor equivalent circuit, respectively. These methods are original because of their non-intrusive and sensor less characteristics, which enable their application in a WSN architecture. The experimental results show that both methods achieve accurate efficiency estimates within ±2-3% errors under normal load conditions, using only a few cycles of input voltages and currents. [2-3]

1.3 Objective

The main objective of this project is to construct a prototype of wireless system to monitor the condition of electric motor. The prototype will consist of these items:-

1. A Transmitter
2. A Receiver
3. A Central Supervisory Station (CSS)
4. Sensor (LM35 Temperature Sensor)

For ease of viewing and access, a graphical user interface (GUI) will be developed or a graph will be tabulated using data collected.

1.4 Scope of Study

The scope of the project will emphasize on building a prototype system that uses both transmitter and receiver, based on a centre data system. Modeling process will be carried out using X-CTU software to configure the system. The scope will be applied to achieve these:

- To assess the reliability and potential of using WSN to coexist with current wire and cables system.
- To ensure transmitter and receiver communicates with each other, providing vital information needed to asses motor conditions.
- To develop a GUI that is user-friendly and can be configured for custom readings.

CHAPTER 2
LITERATURE REVIEW

2.1 Wireless History and Standards

Wireless technology allows people to be connected practically where ever they go. Cell phones and other portable communication devices allow users to contact emergency services without a landline or power outlet. Wireless communications offer a great sense of safety and security. One of the largest benefits people get from advances in wireless technology is convenience. Wireless technology has removed a lot of hassle associated with cords and cables. Portable devices can now use wireless technology to transfer data without being physically connected to a computer or any other devices. Thus, there are three main "standards" in the current advancement in wireless technology. [6]

Standards are like type of connectivity that differentiates one type of standards to another. The three main standards are: [6]

1. Bluetooth (IEEE 802.15.1)
2. GSM
3. Wi-fi (IEEE 802.11)

2.2 Connection between Motor Maintenance and WSN

Motor maintenance can be done in various ways. There are a lot of different arguments and opinions on how to do it. All in all, it mainly depends on the management and the budget fitted for maintenance works. One of the most economical ways is by applying condition based monitoring. [1] This method requires condition monitoring, which consists of data collection, storage and analysis. These data will then be used to do diagnosis to see the current condition of the motor, and prognosis to see how long the motor can be operated until it breaks down.

The maintenance using this method helps in downsizing the number of maintenance personnel. Alongside with that, the processes involved are instrumentation processes which include placing sensors on critical machines to monitor process and machine's vibration. [1]

By relating this with the situation in the problem statement, wireless system was proposed as the most suitable medium for monitoring system. It can greatly reduce installation cost, time consumption, and increases mobility. However, some of this method's disadvantages are issues on reliability, latency, and powering. [5]

Due to the reliability issue, reliability was considered as secondary consideration. The wireless system development objective is not to totally replace wired system, but to co-exist both wired and wireless system together. Non-critical tasks were suited to be handled by wireless to reduce the overall costs. [1]

2.3 Project's Significance

In motor condition monitoring, there are three main aspects that needed to be monitored whenever the motor is operating. These three aspects needed serious attention in a monitoring system due to their effects towards the motor operation, including damaging motor parts or components, especially if not calibrated properly. The three main aspects are:

2.3.1 Voltage

Common power quality problems that have connection with voltage are overvoltage, transients, phase voltage imbalance, power factor, and reactive power. Excessive overvoltage results in saturation of the iron core, wasting energy through eddy currents and increased hysteresis losses. Drawing excessive current results in excess heat output due to copper losses. The additional stress of overvoltage on motors will decrease motor lifetime. [14]

2.3.2 Frequency

One of power quality problem relating with frequency is harmonics. Harmonics are current and voltage waveforms at multiples of the fundamental frequency of the 50 Hz (or 60 Hz) main supply. "Triplen" harmonics (odd multiples of the third harmonic) result when phase voltages are not balanced in a three phase power system and add in the neutral, causing wasteful currents to flow. The possible effects if the level of harmonics, known as total harmonic distortion becomes too high include damage to sensitive electronic equipment and reduction in the efficiency of the HV transformer. [14]

2.3.3 Temperature

Usually, an AC motor will run around 80% of its rated operating temperature, to ensure longer motor lifespan. However, bad built quality of heat sink, overvoltage, radiator failure, or nature causes may increase an AC motor’s temperature. When the temperature rises, it may damage the motor’s windings, or increases its derating factor causing shorter motor life time. In an operation, this situation is called T5, and normally the motor will trigger shutdown mechanism, thus halting the whole process.

For this project, author focuses more on implementation of monitoring the motor’s temperature via wireless system instead of old wired system. The other two parameters voltage and frequencies require more effort in conceptual understanding and bigger capitals, thus considered not feasible for the level of degree’s final year project.

2.4 Comparisons of Wireless Technologies

Table 1: Comparisons of Wireless Technologies [2]

	Wireless LAN/ Bluetooth	**LR-WPAN**
IEEE Standard	802.11 / 802.15.1	802.15.4
Range of Signal	Long range	Short range
Power Consumption	High	Low
Rate of Data Flow	High and constant flow of data	Low and interval data flow
Production Cost	Expensive	Cheap
Product Size	Big	Small

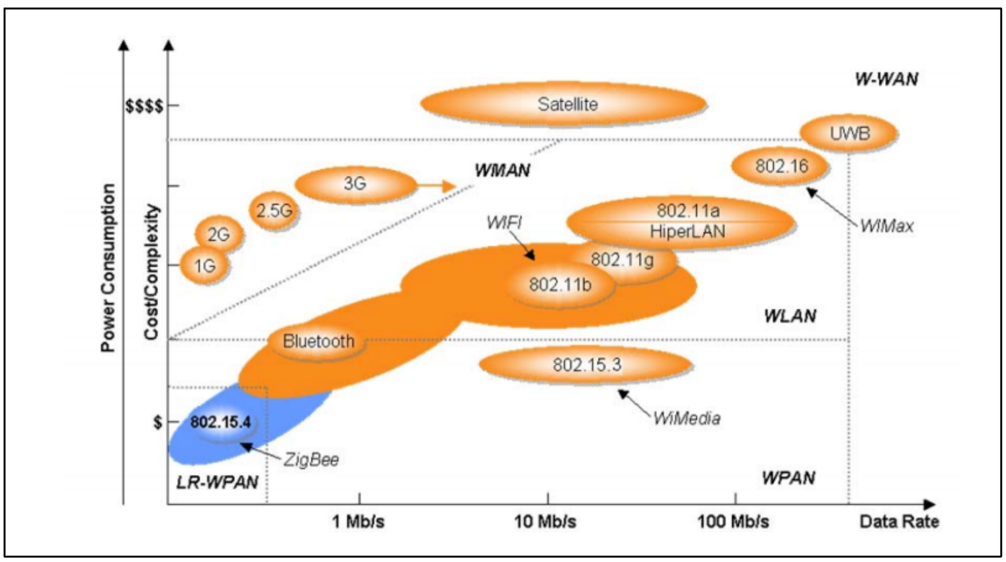

Figure 1: A Comparison of IEEE Standard 802.15.4 with Other Wireless Technologies [2]

2.5 IEEE 802.15.4 Standard (Zigbee)

With the recent advances in wireless technologies, new types of wireless networks had been developed. The WSN technology targets primarily very low cost and ultra low power consumption applications, with data throughput and reliability as secondary considerations. Fueled by the need to enable inexpensive WSNs for the monitoring and control of non-critical functions in the residential, commercial, agricultural, and industrial applications, the concept of standardized low-rate wireless personal area network(LR-WPAN) has emerged.[12] In October 2003, the LR-WPANs concept finally became the IEEE 802.15.4 standard, also known as “Zigbee”. [4]

Due to the several properties of LR-WPAN such as low cost, low data rate, and short range, Zigbee became the best candidate for this project.

2.5.1 Frequency Channels

The IEEE 802.15.4 supports two frequency bands; low and high. The low frequency band is at 868 or 915 MHz, while the high frequency band is at 2.4 GHz. Both high and low frequency uses the same basic packet structure for low duty-cycle operation. The low frequency band may offer better service and less traffic, but the high frequency band has better signal reception. [3]

2.6 Networking Topology

Point-to-point wireless data transmission system is an example of recent technological advances in communication system. It is now can be considered as practical and cost-effective for industrial use. For a Zigbee system, the advantage of this system if compared with cellular communication system is it does not require an infrastructure and complex protocol to function. The point-to-point system with Zigbee enables short distance, multi-access, ad-hoc based, communication links.

A Zigbee system allows two possible network topologies; the star topology and the mesh topology. [2] We can see the format of topologies in the figure below. However, in this project, we will incorporate a more basic network topology, called as point-to-point networking. This is due to the simplicity of equipments we use in this project setup, which includes array of sensors, a transmitter module, and a receiver module. The module that acts as transmitter, will receive the data from sensor, which later will be transmitted via radio signal to the module that acts as receiver. The process of transmitting and receiving data will keep on repeating over and over again, at the desired cycle rate.

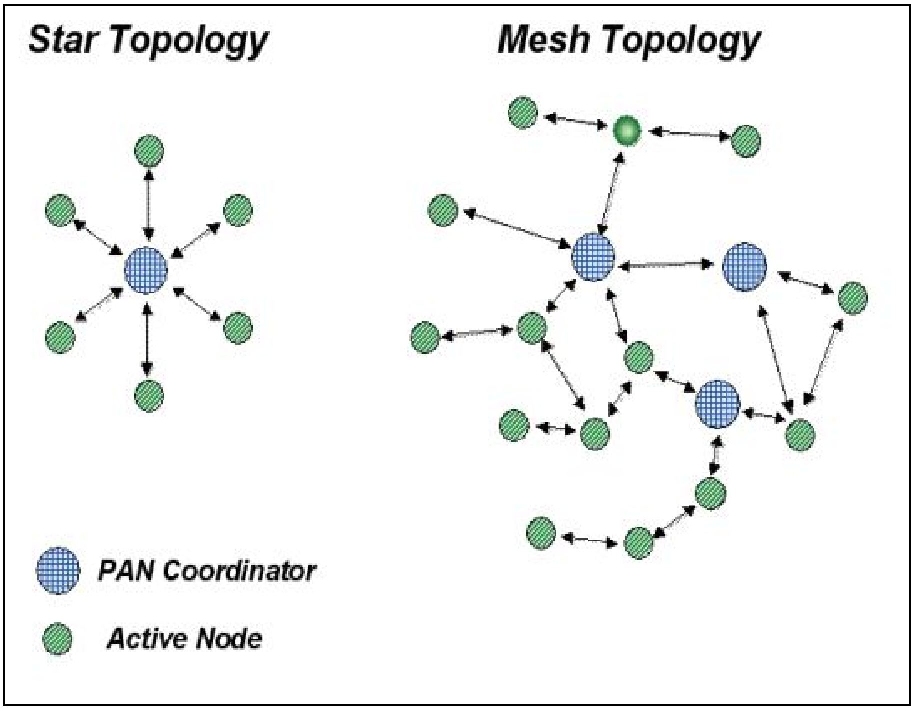

Figure 2: Star Topology and Mesh Topology

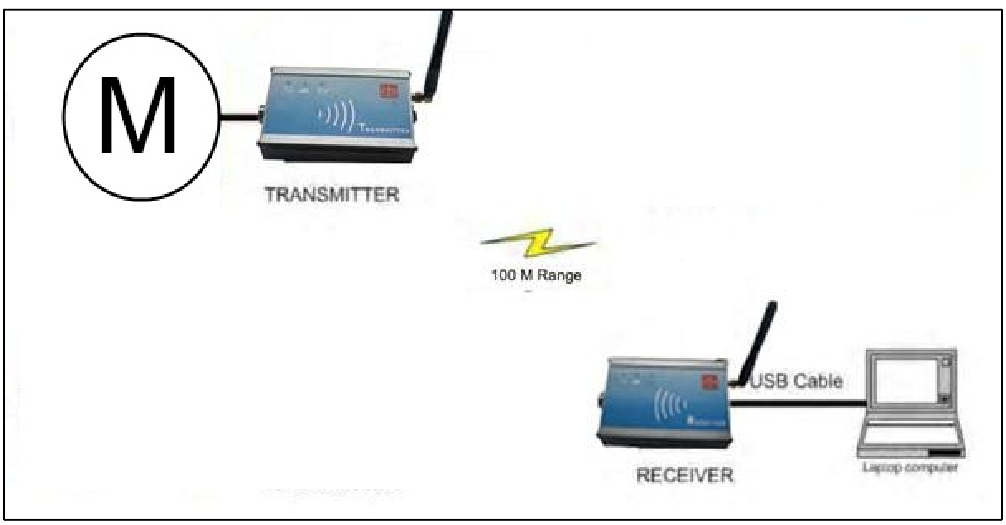

Figure 3: Simplified Point-to-Point Topology for the Project

Figure 3 above shows how the topology for this project will be, consisting of transmitter at the motor's side (including sensors), and receiver at the data receiving side, alongside with a computer.

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

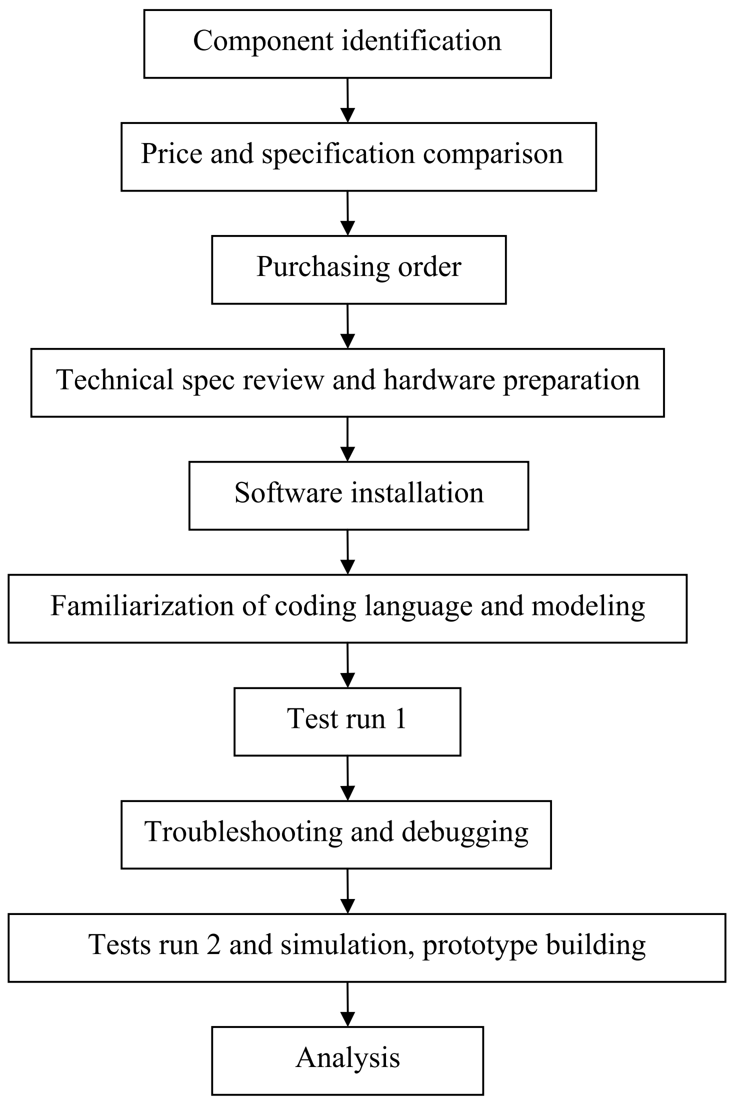

Figure 4: Procedure Identification

3.2 Project Descriptions

This main component of this project will be using an 802.15.4 IEEE wireless technology, also known as Zigbee. The other name for it is Low-Rate Wireless Personal Area Network (L-R WPAN). It was chosen as the medium because of its criteria which includes short distance, low production cost, and small size rendering it suitable for this project.

Zigbee supports two frequency bands; a low band at 868/915 MHz, and a high band at 2.4 MHz. The low band offers better quality of service, and will be most likely not too crowded. So interference from external signal should be less. [9] The first phase of this project will focus on connecting the transmitter and receiver. Should that the first phase succeeded, the next phase will be to implement sensor and to gather data from it. Additional sensors and GUI will be made if there is a need to upgrade and to revise the built system.

3.3 Main Components

Orders had been made via the internet for the purchase of hardware for the project. Some considerations were made on either to choose local or international distributor for the purchase. Due to stock availability and price comparisons, oversea vendor from sparkfun.com had been chosen to do a bulk-order alongside with other students who require the same components. Below is the list of components ordered so far:-

1. XBee 1mW Wire Antenna
2. WRL-08687 XBee Explorer USB
3. WRL-09132 XBee Explorer Regulated

Other than that, the project also requires some other tools, such as:-

- Laptop (as central supervisory station, CSS)
- Thermal sensor
- C language compiler

3.4 Applicability Analysis

The applicability of the proposed system is improved from the following aspects:

3.4.1 Power Consumption

Power consumption or battery life it one of the crucial factor that will affect the design of a WSN. In this application, power consumption limitations can be simply neglected because in industrial plant all the WSN sensor devices are installed either in a Motor Control Centre (MCC) or on the motor frame. In both situations, the power can be supplied from power adaptor/converter. [2]

3.4.2 Condition Monitoring Accuracy

The condition monitoring results are mainly provided for the industrial plant managers to make their planning decisions. Rough estimates need to be made in order to decide on motor health conditions. However, undeniably, there will be some differences between condition at the field and at the monitoring station. This will affect the accuracy of the data transmitted. [2]

3.5 Potential Challenges

However, realization of WSN need to satisfy the constraints introduced by factors such as fault tolerance, scalability, signal range, co-existence issue, cost, wireless security, and harsh environment. Further works are still done in order to rectify these problems.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Product Selection

To accomplish this project, market survey and researches had been done in order to choose the best product that suits this project. Considerations were made by comparing several types of wireless from different types, and different specifications.

Manufacturers and component suppliers also were taken into consideration since different price tag and after-sales services might affect this project afterwards. Components with higher prices were considered to be overkill for this project, since we were restricted within RM500 range of budget. After sales service was also one of the considering factor because, later on when we have to program the transmitter and receiver, problems might occur. Vendor that offers good service is the best option.

Datasheet and specifications of the product also play an important part in the selection of components. Selection was made by comparing the best specification to suit this project that is about motor condition monitoring. Only specs that really matters were taken into consideration.

4.2 Selection Criteria

Below listed are the main criteria that were taken into consideration, in order to choose the best components for this project.

4.2.1 Price

Since the budget of the project is limited within RM500, spending too much on a component that is expensive is overkill to the project. At first, a product named Rabbit MiniCore RCM5600W was considered to be the main component. However, a much cheaper and feasible option had appeared. A Zigbee module from Sparkfun named XBee 1mW Antenna had lower price with medium specifications for the project, suits best for the main component. Budget had to be tight since we have to save up some money to spend on other components and auxiliaries tools needed to accomplish this project.

4.2.2 Power Consumption

Since mobility is a scope in this project, power consumption is considered as part of it. The transmitter stationed at the motor will require 3.3 V from a power source. Battery from 9 V will be needed alongside with a voltage regulator to suits the power needed by the transmitter. On the bright side, a Zigbee module does not consume high amount of power. It uses very little amount of power, thus reducing maintenance cost. Mobility was also improved by using the 9 V batteries, since its size is small and can be easily swapped when required.

4.2.3 Data Flow Rate

For this project, we does not need high and constant rate of data flow such as in wireless LAN or Bluetooth module. A Zigbee module has a low and relaxed data flow. Data packets were sent from the transmitter to the receiver in interval. Since the project is mainly to focus on remote motor monitoring, real-time condition of the motor is not really necessary. The faster the data flow rate is, more power will be consumed, shortening the lifespan of the battery at the transmitter. Frequent replacement had to be made, thus restricting system's mobility.

4.2.4 Signal Range

For a condition monitoring system, a long range of signal is not necessary. Normally, signal from transmitter will be collected by a receiver from nearby Central Supervisory Station (CSS). The location of the CSS is usually nearby to ease immediate action to be taken should there be any emergency or corrective measures need to be done. For this, Zigbee is the best option since it has low range of signal, suitable for this project.

4.2.5 Product Size

A smaller component size is the best criteria for the component selection. Smaller size ensures better mobility for the system.

4.3 Product Purchasing

Since the Zigbee module that we needed for the project is not available on ready stock at nearby stores, we had to purchase it from online store. Below are some of the links to the online stores that we had done comparisons of pricing, postage costs, after sales services, and several other relevant factors:

- www.cytron.com.my
- www.bizchip-components.com
- www.escol.com.my
- www.sparkfun.com

After several discussions, we had decided to purchase in bulk, altogether with parts that other students needed for their projects, to save on delivery costs. Our supervisor's credit card was used to do the purchasing. The items were due to arrive by postage 2 weeks later. Below were the figures for total and individual costing:

Items on Order

Product Name	Unit Price	Quantity	Subtotal
XBee 1mW Wire Antenna	$20.66	14	$289.24
XBee Explorer USB	$24.95	5	$124.75
XBee Explorer Regulated	$8.96	13	$116.48
		Subtotal:	**$530.47**
		Shipping and Handling: +	$27.11
		Grand Total:	**$557.58**
		Outstanding Balance:	**$557.58**

Figure 5: Total Costing for Bulk Order

No.	Name	Amount Each Person Should Pay				
		Payment + Ship (USD)	Ratio	Actual amount to be paid to Dr. Fawnizu	DUTY TAX (RM143.05)	Final amount to be paid to Dr. Fawnizu
1	Zainol Amir Hafizuddin	88.71	0.159	RM289.57	-RM119.18	RM170.39
2	Muhammad Gaddafi	63.76	0.114	RM208.13	RM23.84	RM231.97
3	Ahmad Syahir	88.71	0.159	RM289.57	RM23.84	RM313.41
4	Afiq	88.71	0.159	RM289.57	RM23.84	RM313.41
5	Zul Zarif	138.99	0.249	RM453.71	RM23.84	RM477.54
6	Zafirah Syaza	88.71	0.159	RM289.57	RM23.84	RM313.41
	Total	557.58	1.000	**RM1,820.13**	**RM0.00**	**RM1,820.13**

Figure 6: Costing per Individual

4.4 Product Confirmation

While waiting for the arrival of these ordered items, we continued on extensive literature reviews to understand depths of this project and its' scopes. Two weeks later, the items arrived safely via postage. Below are the pictures of items ordered for the project of motor condition monitoring system:

Table 2: Ordered Products Listing

No.	Item Name	Quantity
1	XBee 1mW Wire Antenna	2
2	XBee Xplorer USB	1
3	XBee Xplorer Regulated	2

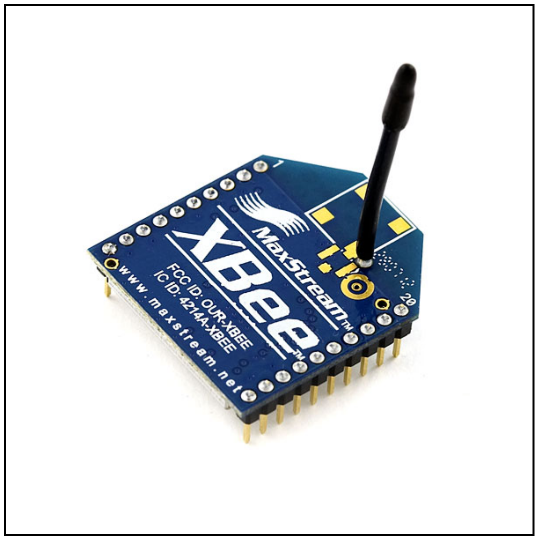

Figure 7: X-Bee 1mW Wire Antenna

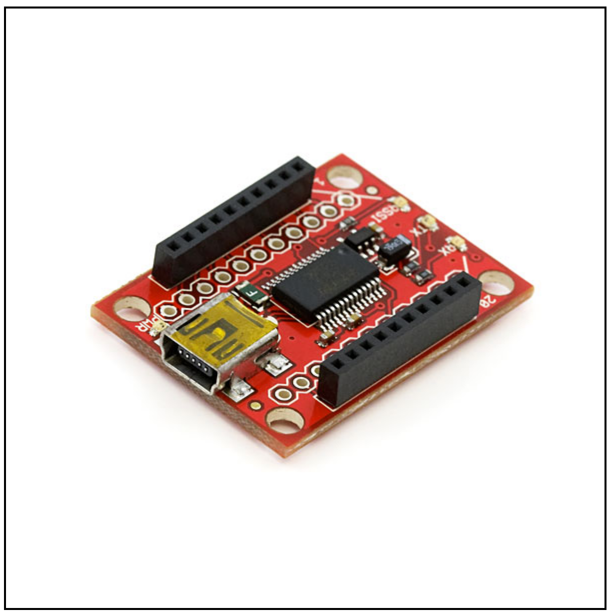

Figure 8: X-Bee Xplorer USB

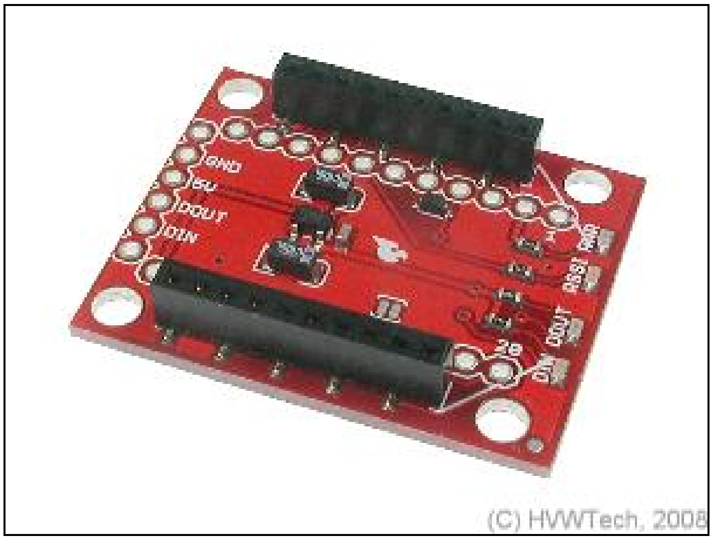

Figure 9: X-Bee Xplorer Regulated

4.4.1 Additional Item

Table 3: Additional Item

No.	Item Name	Quantity
1	USB 1.1 to USB 2.0 Cable	1

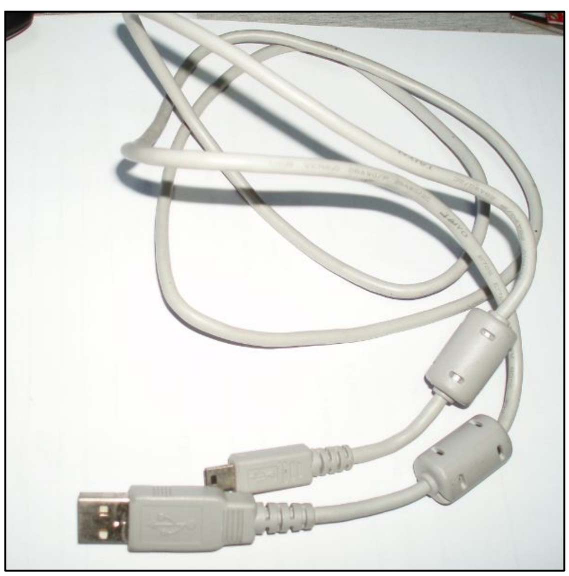

Figure 10: USB Cable

4.5 XBee Key Features

4.5.1 Long Range Data Integrity

- Indoor / Urban: up to 100’ (30m)
- Outdoor line-of-sight up to 300’ (100m)
- Transmit power: 1mW (0 dBm)

4.5.2 Advanced Networking & Security

- Retries and acknowledgements
- DSSS (Direct Sequence Spread Spectrum)
- Each direct sequence channels has over 65,000 unique network addresses available
- Source / Destination addressing
- Unicast & Broadcast communications
- Point-to-point, point-to-multipoint and peer-to-peer topologies supported
- Coordinator / End device operations

4.5.3 Low Power

- TX Current: 45 mA @ 3.3 V
- RX Current: 50 mA @ 3.3 V
- Power-down current < 10 µA

4.5.4 ADC and I/O line support

- Analog-to-digital conversion, Digital I/O
- I/O line passing

4.5.5 *Easy to Use*

- No configurations necessary for out of box RF communications
- Free X-CTU Software (Testing and Configuration software)
- AT and API Command Modes for configuring module parameters
- Extensive command set
- Small form factor

4.6 XBee Pin Signals

There are 20 pins on an XBee 1mW Wire Antenna module. Each of those pins are assigned with different functions or input. Refer table below for the pin assignment:

Table 4: X-Bee Pin Signals

Pin #	Name	Direction	Description
1	VCC	-	Power supply
2	DOUT	Output	UART Data Out
3	DIN / CONFIG	Input	UART Data In
4	DO8*	Output	Digital Output 8
5	RESET	Input	Module Reset (reset pulse must be at least 200 ns)
6	PWM0 / RSSI	Output	PWM Output 0 / RX Signal Strength Indicator
7	PWM1	Output	PWM Output 1
8	[reserved]	-	Do not connect
9	DTR / SLEEP_RQ / DI8	Input	Pin Sleep Control Line or Digital Input 8
10	GND	-	Ground
11	AD4 / DIO4	Either	Analog Input 4 or Digital I/O 4
12	CTS / DIO7	Either	Clear-to-Send Flow Control or Digital I/O 7
13	ON / SLEEP	Output	Module Status Indicator
14	VREF	Input	Voltage Reference for A/D Inputs
15	Associate / AD5 / DIO5	Either	Associated Indicator, Analog Input 5 or Digital I/O 5
16	RTS / AD6 / DIO6	Either	Request-to-Send Flow Control, Analog Input 6 or Digital I/O 6
17	AD3 / DIO3	Either	Analog Input 3 or Digital I/O 3
18	AD2 / DIO2	Either	Analog Input 2 or Digital I/O 2
19	AD1 / DIO1	Either	Analog Input 1 or Digital I/O 1
20	AD0 / DIO0	Either	Analog Input 0 or Digital I/O 0

4.7 Testing Communication of Xbee Module

Several runs were done in order to test the functionality of these modules. However, some preparations needed to be done before test run can be done. This includes installing some drivers and software suited for the XBee modules.

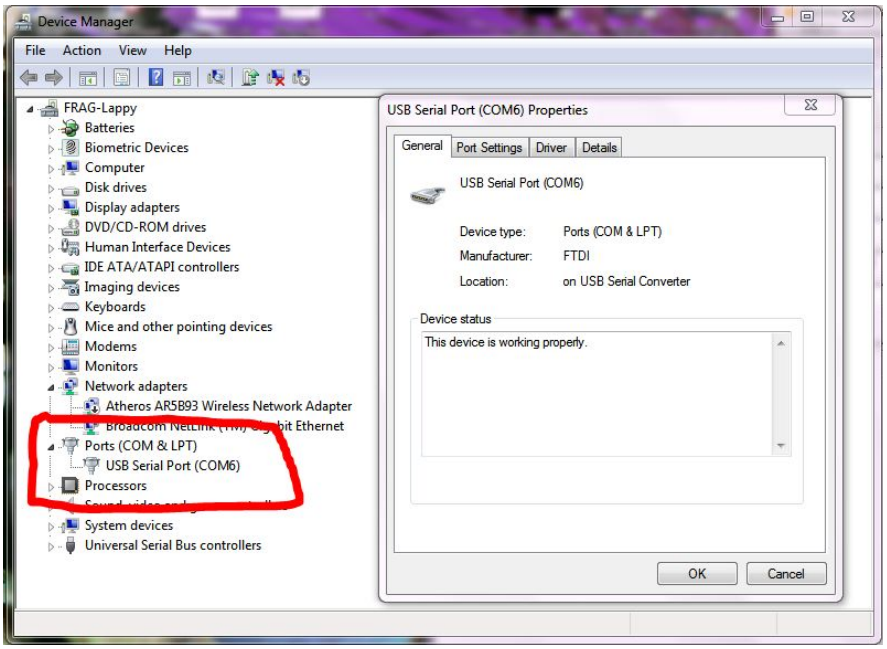

Figure 11: Port Identified as Virtual Serial Connection

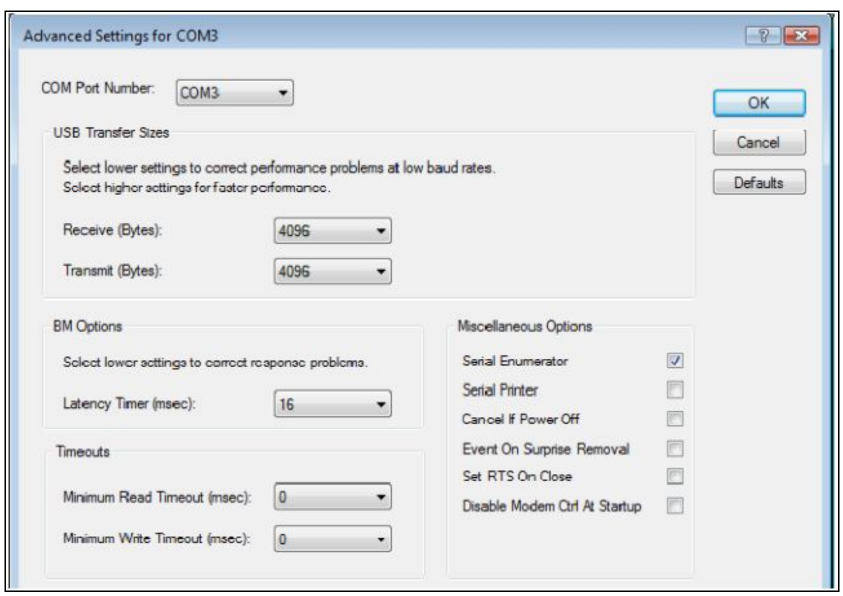

Figure 12: Virtual Serial Port Advanced Settings

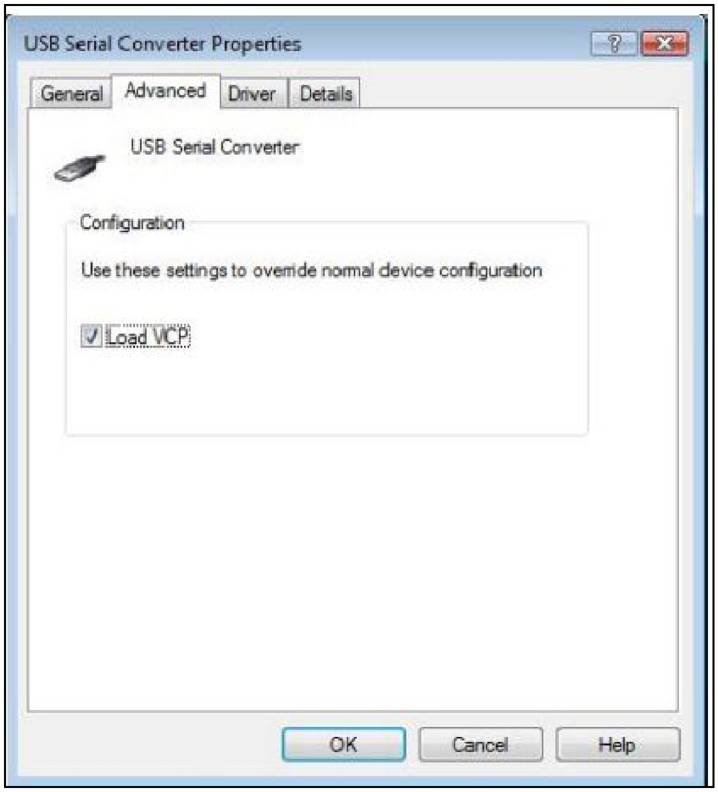

Figure 13: Virtual COM Port Properties Menu

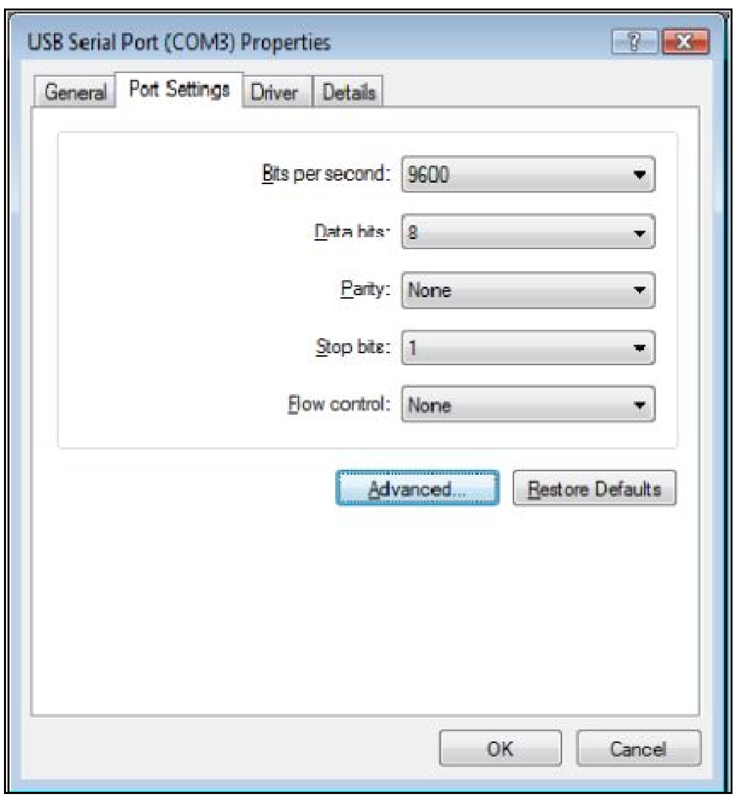

Figure 14: Virtual COM Port Properties Sub-Menu

Figure 15: Connecting X-Bee Module with Laptop Via X-CTU Software

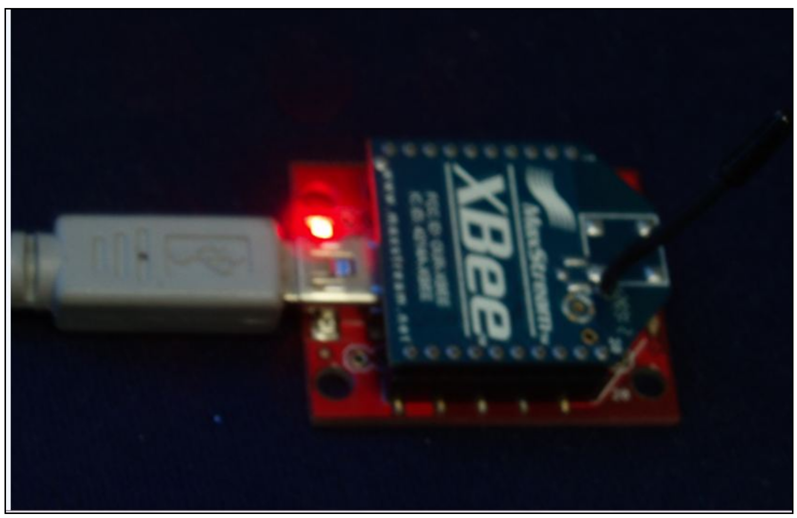

Figure 16: Connection of USB Cable and XBee USB Xplorer

4.8 Discussions

4.8.1 XBee Functionality Check

Another main concern during development using Xbee module is to check the functionality of Xbee Module. Normally, user will need to develop RS232 level shifter for communication to serial port. This requires extra work just to check the functionality of Xbee module.

Furthermore, laptops and computers nowadays have phased-out the serial port, replacing it with USB port. With this reason, the purchasing of Xbee Explorer has eased the work of checking just the functionality of Xbee modules. It requires USB type B cable to connect with USB port of a computer or laptop. User only has to plug the Xbee Explorer with a Xbee module sits on top of the pin sockets, via a USB type B cable to the desired laptop. Then, installation of driver called Virtual COM Port need to be done in order to create an extra virtual COM port for the Xbee module.

With this, user will have an Xbee USB Dongle. No external power is required since Xbee Explorer will tap 5V from the USB port to power up the Xbee module.

4.8.2 Test Run Result

Installation of software called X-CTU is required prior to test the functionality of the XBee module. X-CTU is a computer based software to communicate with XBee, to change configuration or to transmit data. Steps below were taken to test the module with X-CTU software.

- X-CTU software was launched, "PC Settings" tab was chosen. Baud and parity settings of the COM port were verified to match with the XBee module. The virtual COM port is normally located at the last port, USB serial port.

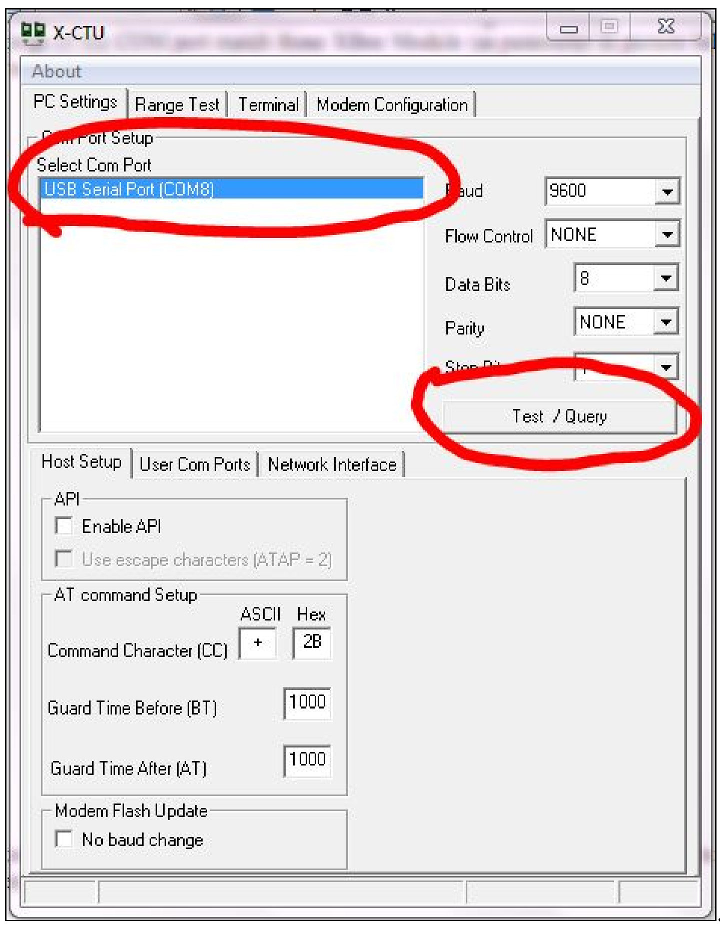

Figure 17: Using X-CTU Software to Test X-Bee's Connectivity

- The COM port was chosen and "Test/Query" tab was clicked. The box below will appear, then "OK".

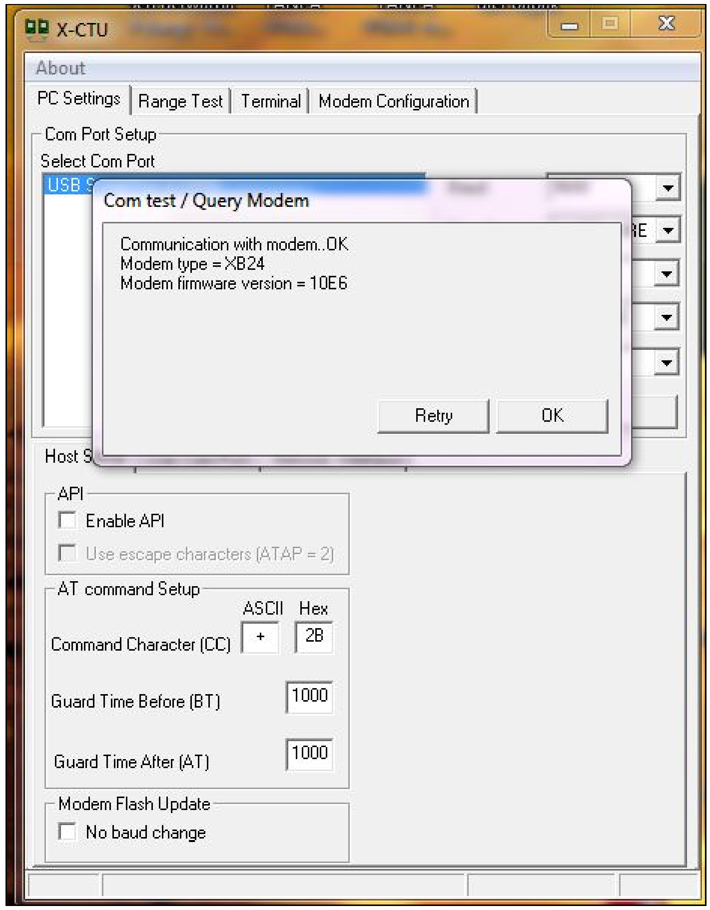

Figure 18: X-CTU Interface Showing XBee Module Availability

The trial runs to check the availability of the XBee modules had succeeded. X-CTU software detected the module type and its firmware version.

4.9 Modifying / Reading XBee Module

To modify or read XBee module parameters, the module must first enter Command Mode; a state in which incoming characters are interpreted as commands. Two commands mode options are supported: AT Command Mode and API Command Mode. But for functionality test, only AT Command Mode was used.

First, "Terminal" tab was selected in X-CTU software. To enter AT Command Mode, 3 character command sequence "+++" and XBee module will response "OK", which means it already enter Command Mode.

However, the failure to enter AT Command Mode is most commonly due to baud rate mismatch. Ensure the "Baud" setting on the "PC Settings" tab matches the interface data rate of the XBee module. By default, the baud rate is 9600 bps.

Syntax shown below is the one used to send AT commands and parameters:

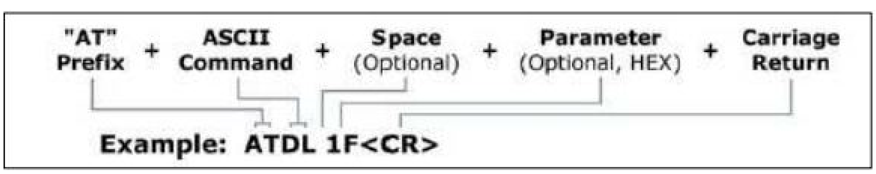

Figure 19: Syntax for AT Commands

4.9.1 Simple Example Done on AT Command Mode

This preceding example would change the XBee module Destination Address (Low) to "0x1F". To store the new non-volatile (long term) memory, subsequently send a "WR" (Write) command.

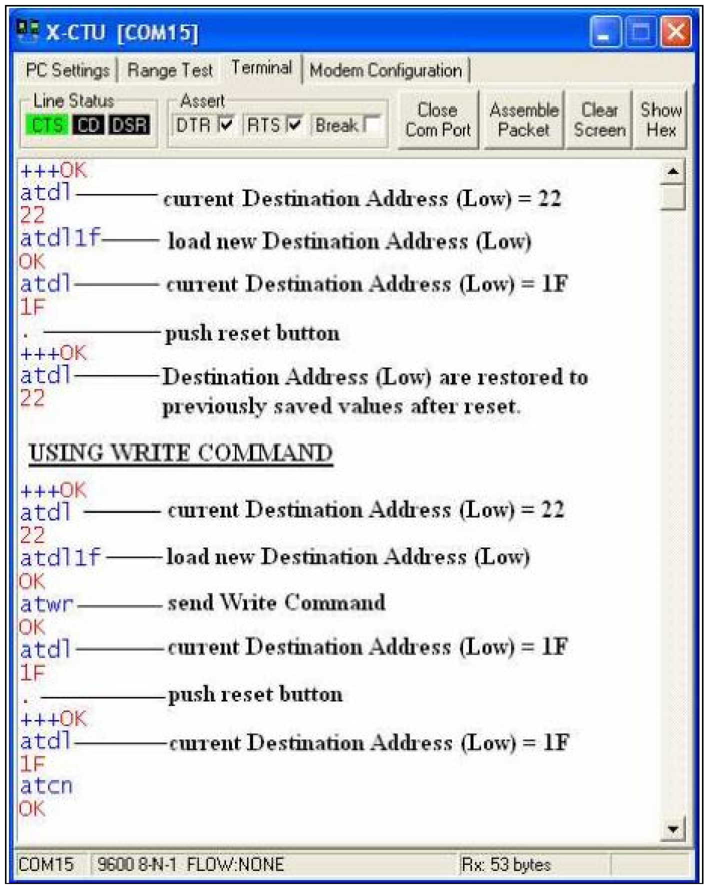

Figure 20: Changing XBee Module Destination Address

For modified parameter values to persist in the module's registry after a reset , changes must be saved to non-volatile memory using the "WR" (Write) command. Otherwise, parameters will be restored to previously saved values after reset.

When a command is send to a module, the module will parse and execute the command. Upon successful execution of a command, the module returns an “OK” message. If execution of a command results in an error, module will return “ERROR” message.

To exit AT Command Mode, send ATCN commands are received within the time specified by CT (Command Mode Timeout) Command, the XBee module automatically returns to Idle Mode. So, if another command need to send, “+++” should be entered so that the module will enter into AT Command Mode again.

4.10 Communications between Two XBee Modules

Using to XBee modules, alongside with two XBee Xplorer enables us to connect those two XBee as modems. Several set-ups needed to be done before they can be communicating with each other. Below are the steps involved in communicating between two XBee modules, given names of SKXBee1 and SKXBee2 respectively.

To communicate between two of those SKXBee's, Source Address (MY) of SKXBee1 must be match to Destination Address (DL) of SKXBee2 and Destination Address (DL) of SKXBee1 must be match to Source Address (MY) of SKXBee2.

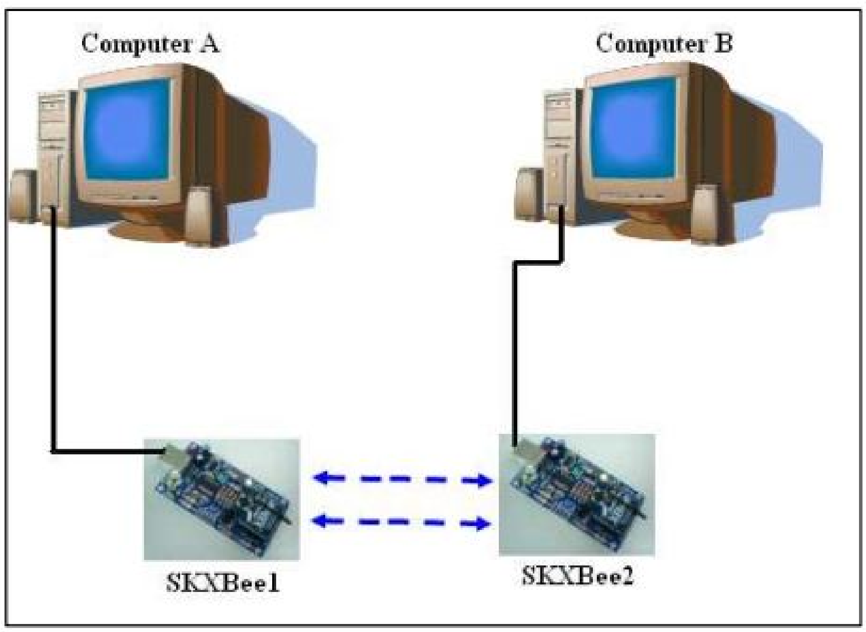

Figure 21: Connecting Between Two XBee Modules; SKXBee1 and SKXBee2

The addresses for each of the module were set as shown below:

SKXbee1:

MY = 1111

DL = 2222

SKXbee2:

MY = 2222

DL = 1111

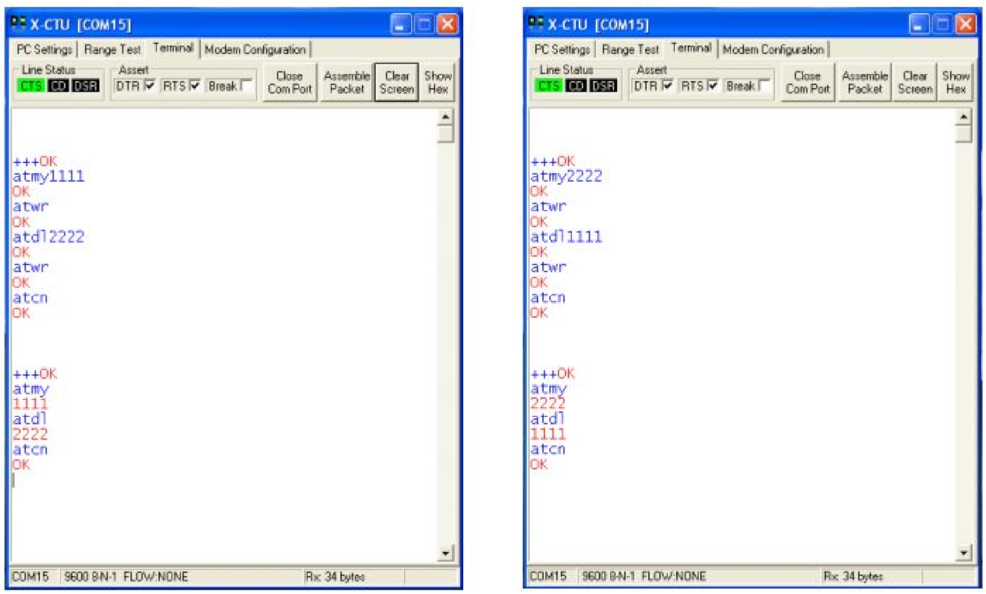

Figure 22: Matching of Destination Address and Source Address for both SKXBee1 and SKXBee2

After connection was built between these two SKXBee's, they can communicate among each other. Data sent by SKXBee1 will be received by SKXBee2, while data sent by SKXBee2 will be received by SKXBee1.

Data which was sent is in blue colour and data which was received is in red colour. Below is example of data sent and received of SKXBee1 and SKXBee2 in X-CTU terminal.

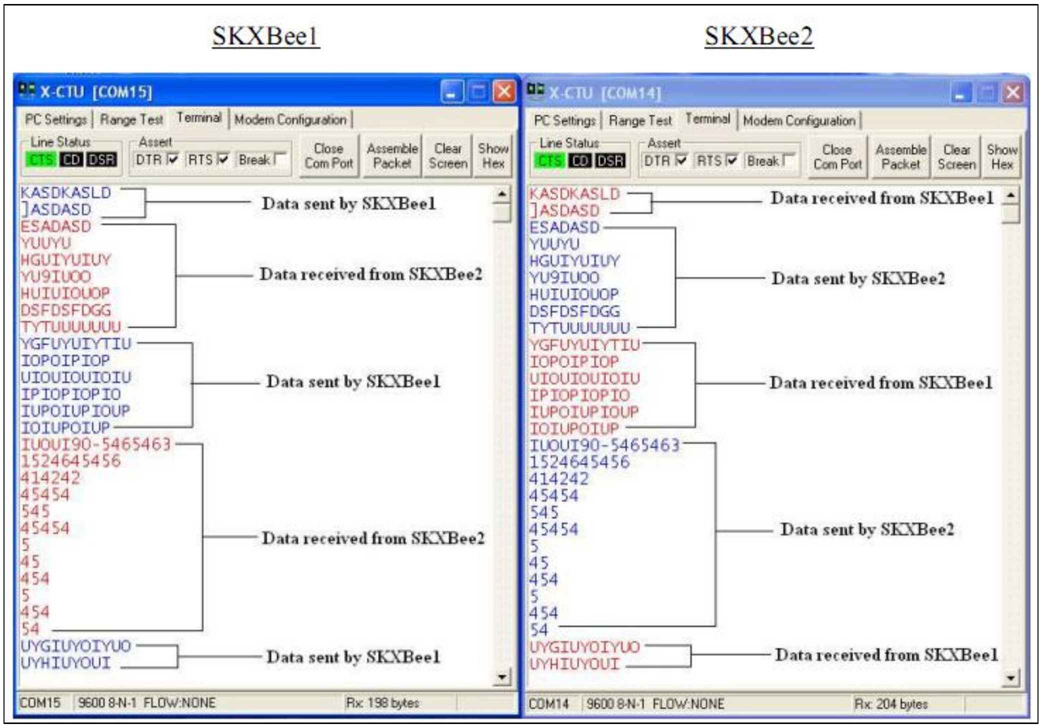

Figure 23: Data Sent & Received by SKXBee1 and SKXBee2

4.11 Working on Zigbee API Mode Interface

The X-Bee module connected with the USB Xplorer was configured to behave as a coordinator within a point-to-point topology. The Xplorer can be plugged directly into the USB port of a PC and doesn't require batteries or power adapter since it is USB powered.

An X-Bee module has three communication modes:

- Transparent mode,
- Command mode
- API mode.

At startup, an X-Bee module is in transparent mode. In this mode, the module acts as a serial line replacement. All data received from the DIN pin is transmitted, and when RF data is being received, it is sent out on the DOUT pin. A pair of X-Bee modules can act as invisible cables in this mode.

Command mode is we can change a large amount of settings of the X-Bee module. To enter Command mode we must send the characters "+++" and wait a second. Once the X-Bee enters command mode, it will answer with OK. While in command mode we can change baud rate, destination address, and various other settings that suit our need. Leaving command mode can be accomplished by executing the ATCN command.

API mode is the best mode to choose if we intended to send messages constantly to changing targets, which are other X-Bee modules. It is the most powerful but also the most complicated mode to use. Besides, it consumes more power from the battery. API (Application Programming Interface) mode is a frame-based method for sending and receiving data to and from an X-Bee.

API mode has some special abilities:

- Changing parameters without entering command mode;
- RSSI and source address information;
- Receive packet delivery confirmation on every transmitted packet

The first command author started with was the Node Discovery command, which will let every device on the network respond with basic information about that device. These responses are received by the Xplorer, the address information of the responding X-Bee devices is stored and the next step is to send a request to all of the responding devices to request information about their hardware version.

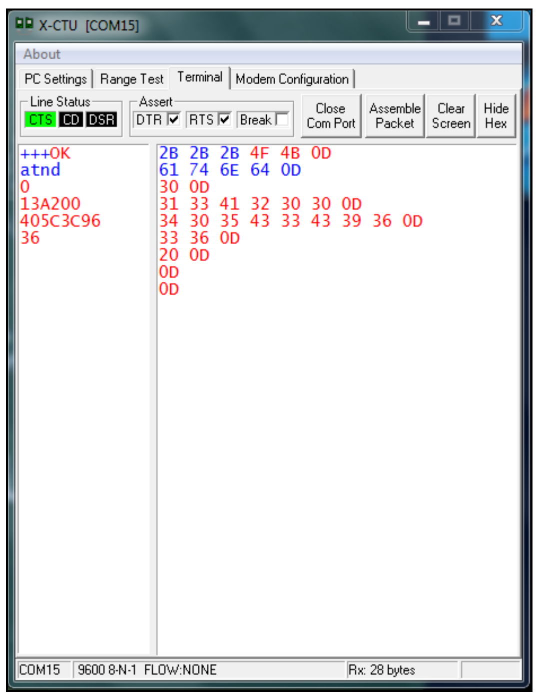

Figure 24: Single X-Bee Node Discovery

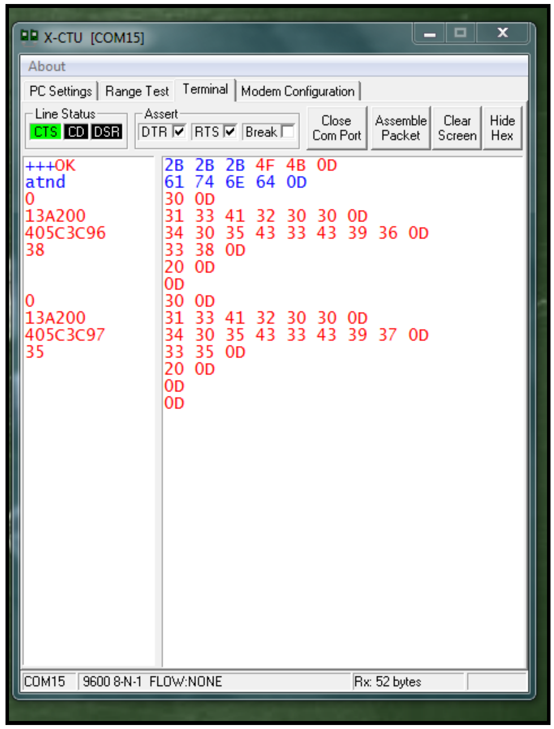

Figure 25: Two Nodes Discovery and Transmitting

4.12 Sensor Selection

In this project, the transmitter part will receive input from a sensor attached directly to the motor. The sensor will give required information that needed to be transmitted to the end side of the receiver, in order for personnel to monitor the condition of the motor. After considering a few options, the first parameter chosen to be monitored is temperature. LM35 was chosen as the sensor to give reading of motor's temperature.

4.12.1 LM35 Descriptions

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celcius (Centigrade) temperature. The LM35 has an advantage over linear temperature sensors in °Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±1/4 °C at room temperature and ±3/4 °C over a full -55 to +150 °C temperature range. Low cost is assured by trimming and calibration at the wafer level.

The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supply, or with plus and minus supplies. As it draws only 60µA from its supply, it has very low self-heating, less than 0.1°C in still air. The LM35 is rated to operate over a -55 to +150 °C temperature range.

4.12.2 LM35 Application

The LM35 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface with thermal paste and its temperature will be within about 0.01°C of the surface temperature.

This presumes that the air temperature is almost the same as the surface temperature; if the air temperature is much higher or lower than the surface temperature, the actual temperature of the LM35 die would be at an intermediate temperature between the surface temperature and the air temperature.

To minimize this problem, the wiring to the LM35 was assured when leaving the device, is held at the same temperature as the surface of interest. The easiest way to do this is to cover up these wires with a bead of epoxy which will insure that the leads and wires are all at the same temperature as the surface, and that LM35's die temperature will not be affected by the air temperature.

These devices are sometimes soldered to a small light-weight heat fin, to decrease thermal time constant and speed up the response in slowly-moving air. On the other hand, a small thermal mass may be added to the sensor, to give the steadiest reading despite small deviations in the air temperature.

4.12.3 Typical Applications

Basically, there are two types of setups available for the application of LM35 as centigrade temperature. There are few other setups, but in this project our main focus are these two setups:

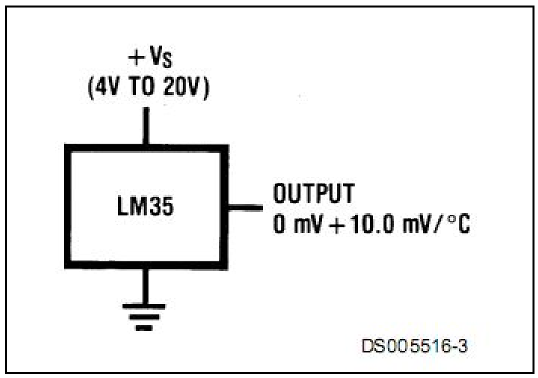

Figure 26: Basic Centigrade Temperature Sensor (+2°C to +150°C)

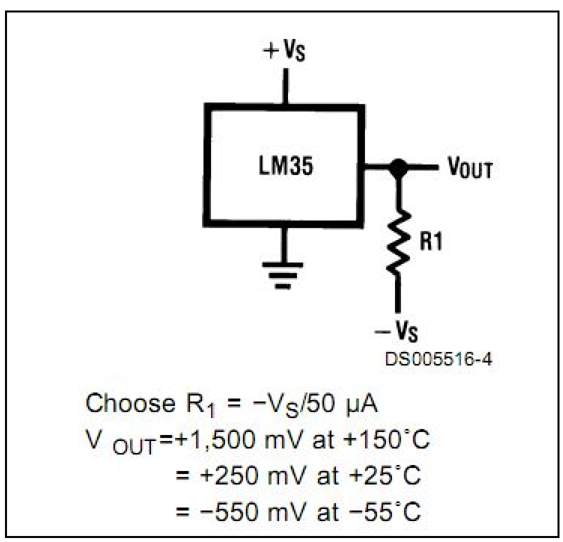

Figure 27: Full-range Centigrade Temperature

4.13 Temperature Reading on Different Motor Parts Without Zigbee

Below here is the plotted graph for AC Motor 230V's temperature reading, using the temperature gun traditionally, without any connection with the Zigbee modules. The motor was left running for an hour, and temperatures from various parts of the motor were taken.

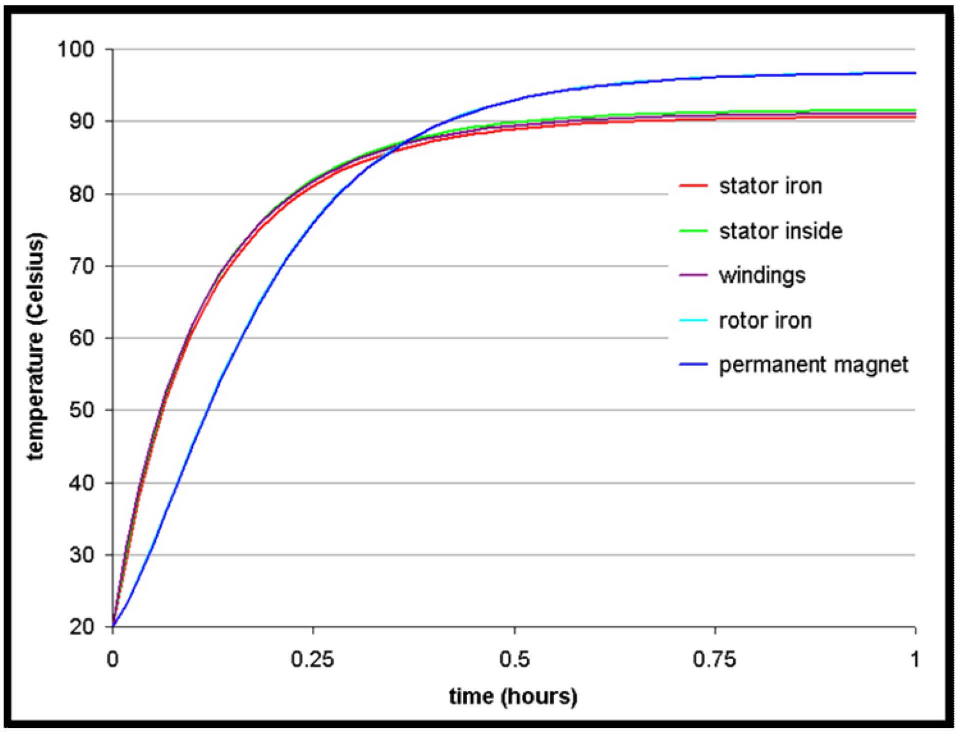

Figure 28: AC Motor Temperature Graph

4.14 Circuit Diagram

Below is the circuit diagram for the circuit constructed for the transmitter side. Voltage source came from a 9V alkaline battery, regulated into 5V by the voltage regulator (7805). The regulated 5V then was used by the temperature sensor as its main voltage source. Zigbee, using its internal voltage regulator dropped down the 5V into 3.3V for its self power up. The Vref pin on the Zigbee was later shorted with VCC pin, so that we have a 3.3V value of reference voltage. The reference voltage is used by the built-in ADC to compare the actual and relative voltage sensed by the DI/O pin, which received analog voltage signal from the temperature sensor.

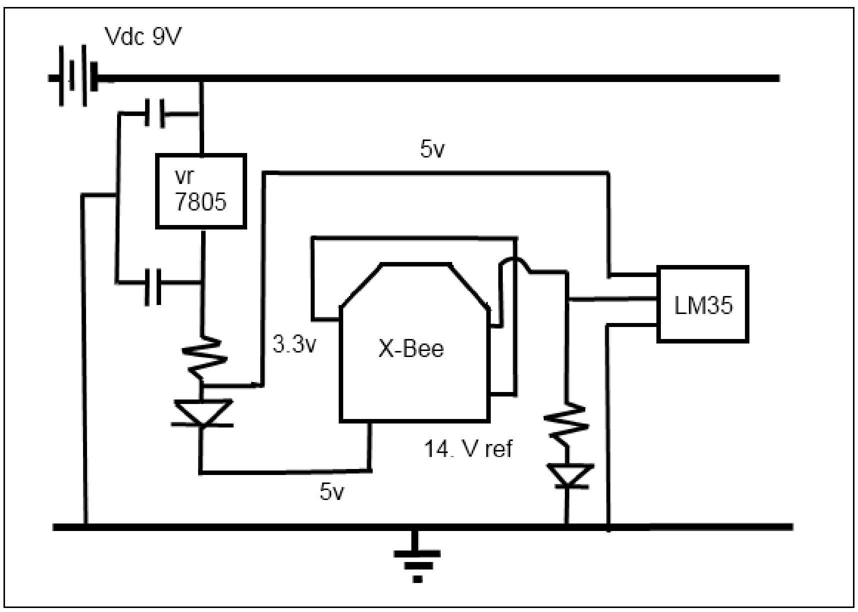

Figure 29: Transmitter Circuit Diagram

4.15 Hex Output

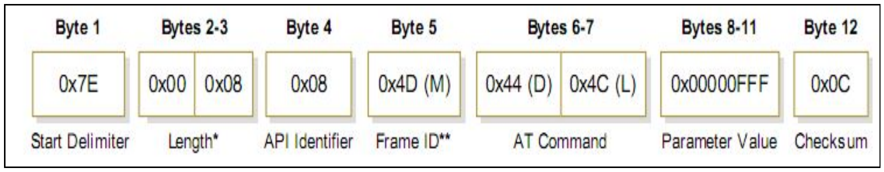

Figure 30: UART Data Frame Structure

Whenever a data is transmitted from a transmitting to a receiving unit of Zigbee, it will be send in the format of packets. A packet of RF data sent, will be sent along its frame as the picture above, ended with a checksum. Other than that, the other parameters sent along are start delimiter, data length (bit), received signal strength indicator (RSSI), data value, and checksum. The length of data (bit) depends on our setting of the transmitter, and may vary depending on how many data we want the transmitter to send to the receiver.

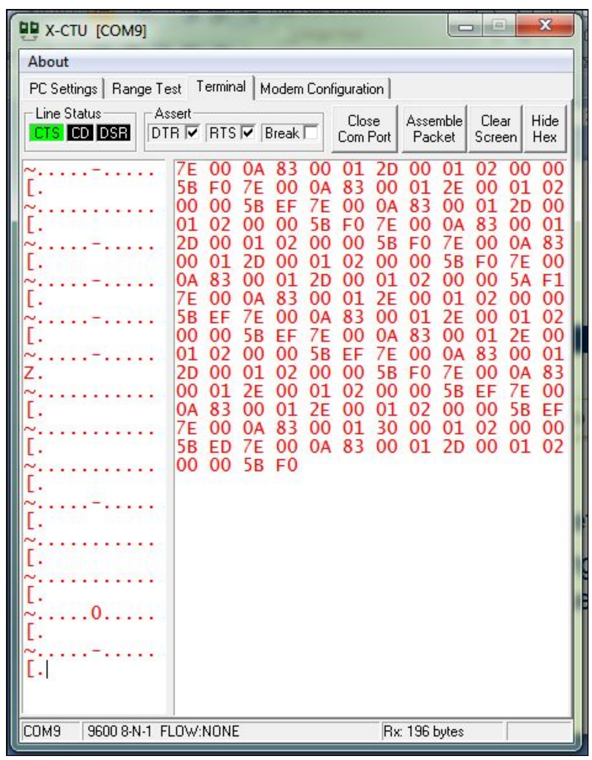

Figure 31: Example of Data Format Received at Receiver Side

4.16 Transmitter Configuration

Below are the main settings configured at the Zigbee transmitter side. Note that the numbers represented in most of the configuration are represented in hex-base, except for PAN ID. Sample rate was set at 60 seconds interval due to the fact that temperature of motor will not change rapidly, and to preserve battery life since more power will be consumed if Zigbee is transmitting data more often.

- PAN ID = 3456
- Destination Address Low DL = 2
- 16-bit source Address = 1
- Power Level = 4 (Highest)
- Time Before Sleep = 1388
- Sample Rate = 3E8 (60 s)

4.17 Receiver Configuration

Below are the main settings configure at the Zigbee receiver side, the Zigbee that was connected to the laptop via USB Xplorer Regulated. Note that the Destination Address Low DL and 16-bit source address of neither the receiver nor the transmitter were matched to each other.

- PAN ID = 3456
- Destination Address Low DL = 1
- 16-bit source Address = 2
- Power Level = 4 (Highest)
- Time Before Sleep (1388)
- Sample Rate = 0

4.18 Sensor's Field Test

Later, the assembled prototype was tested in an air-conditioned lab, using an AC induction motor as benchmark. Two different runs were carried out with different setup of voltages. Here are the specifications of the AC motor used:

- **Manufacturer and Serial** : Electron SRL (A4220S)
- **Motor Type** : 3 Phase Squirrel Cage Motor
- **Speed** : 2700 RPM, 50 Hz

Figure 32: 3 Phase Squirrel Cage Motor

4.18.1 1st Run, 100 V, No-load

Table 5: 1st Field Test Run Results

Minute	Hex	Decimal	Temperature (°C)
0	46	70	22.58
1	44	68	21.94
2	43	67	21.61
3	44	68	21.94
4	44	68	21.94
5	43	67	21.61
6	44	68	21.94
7	44	68	21.94
8	43	67	21.61
9	44	68	21.94
10	44	68	21.94
11	44	68	21.94
12	44	68	21.94
13	44	68	21.94
14	44	68	21.94
15	44	68	21.94

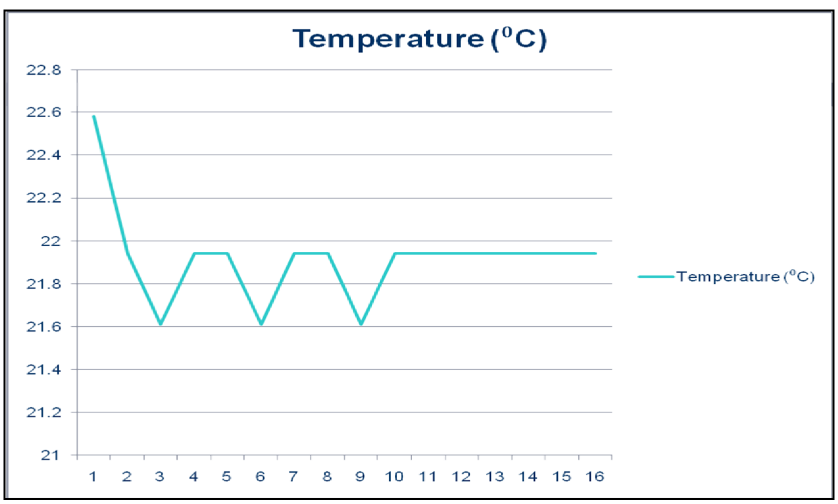

Figure 33: 1st Field Test Run Tabulated Graph

4.18.2 2nd Run, 415 V, Locked Rotor

Table 6: 2nd Field Test Results

Minute	Hex	Decimal	Temperature (^{0}C)
0	46	70	22.58
1	4F	79	25.48
2	4F	79	25.48
3	56	86	27.74
4	57	87	28.06
5	56	86	27.74
6	56	86	27.74
7	57	87	28.06
8	57	87	28.06
9	57	87	28.06
10	57	87	28.06
11	57	87	28.06
12	57	87	28.06
13	57	87	28.06
14	57	87	28.06
15	57	87	28.06

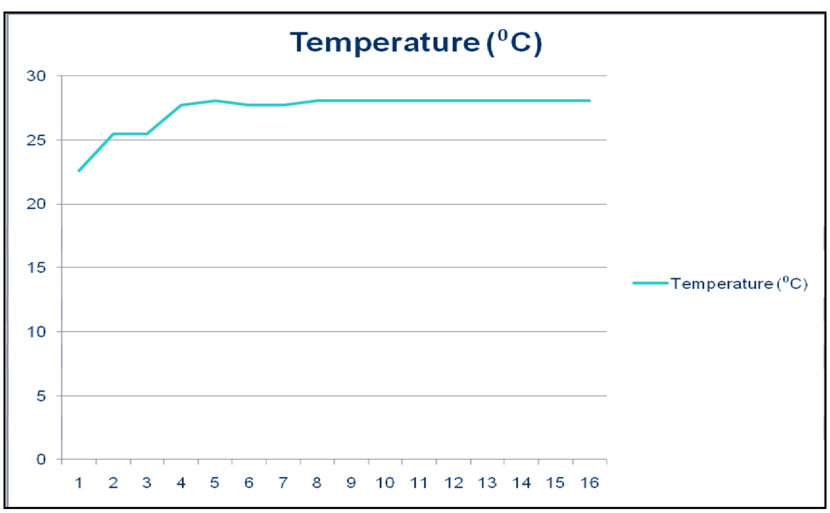

Figure 34: 1st Field Test Run Tabulated Graph

4.19 Calculations

4.19.1 Temperature Conversion from Hex into Decimal

For example, if reading shows 5D (hex), so in decimal the value would be 93 after conversion. Conversion can be done simply using calculator according to base system.

From the manual, maximum value of reading a DI/O pin can handle is 3FF, which is 1023 from the manual.So,

Ratio = Reading / Value = 93 / 1023 = 0.09
Current Temperature = Ratio * V ref = 0.09 * 3.3v = 0.297V → 29.7 ^{0}C

0.297V later converted into its correct degree Celsius according to conversion rate in the LM35 temperature sensor that states 1mV = 1^{0}C. That is how data collected from the table were later converted into hex, and into its respective value of temperature.

4.19.2 Battery Life Estimation

Claims from external resources said that Zigbee's battery life may reach up to 2 years (under certain conditions and circumstances). So, in this project we used alkaline battery 9V (500mAh), as the source for transmitter side.

Zigbee uses around 40mA when transmitting signal. Lower than that when not transmitting and in sleep mode.

So, 500/40 = 12.5 hours of battery life if the transmitter is transmitting non-stop at 1 second data transfer interval, using maximum power level continuously.

4.19.3 Sampling Rate Calculations

The command to configure sampling rate for the Zigbee is ATIR, according to AT Command Mode.

Maximum sampling rate, which is the rate Zigbee may transmit data in a certain interval is based on the calculations below:

Max sampling rate = 1kHz → ATIR = 1
Sampling Rate = 1 * 1 kHz = 1 * (1/1000)s = 0.001s → S_{max}

So, the fastest interval a Zigbee can transmit a data is 0.001s, before it will transmit the next data.

The minimum sampling rate, or the slowest rate of Zigbee transmitting the data will be:

Slowest, FFFF = 65534 = 65534 * 0.001 = 6.534s → S_{min}

In the X-CTU, rate was set at EA60 which is 60 seconds interval, considering that motor temperature does not changes rapidly, and to preserve battery life by lessening the Zigbee's transmitting interval.

4.20 Problems Encountered

In several stages of accomplishing the project, a few problems encountered. However, most of it were managed to be solved, thus the prototype succeeded to be built in time.

4.20.1 Reference Voltage, V ref

Reference voltage acts s a scale to compare actual value before converting analog voltage into digital, mainly by the ADC. At first, it was unsure whether to connect V ref or not, since there's some ambiguities of reference voltage relevancy.

However, it is found that if there is no Vref input, value for ADC input will always be constant at 3FF (1023),the maximum value of DI/O pin can handle, causing the reading to be inaccurate

The solution decided is to take Vref from Vcc pin by shorting both pins together to obtain Vref of 3.3V.

4.20.2 LM35

From the manual, basic centigrade setting does not require resistor to operate. However, problem occurred where readings obtained were too small.

Problem solved by putting a small resistor at the temperature sensor to create a small potential difference, to ensure analog input (voltage) moves from LM35 to Zigbee, not the other way around.

4.20.3 Baud Rate

At some point, Zigbee modules failed to communicate towards each other due to differences in baud rate. Data was failed to be transmitted and received.

The solution is by setting the baud rate at 9600kbps, both the transmitter and the receiver.

4.20.4 Integration with PIC

PIC16F877P was selected as candidate to integrate the Zigbee system with PIC. However, to use it with PIC, it requires many different parts such as oscillator, UART, PIC Programmer, and software which make it hassle and complex.

Later on, PIC integration part was stripped apart, considering project's condition monitoring does not require any hardware control & interaction. So, project proceeded with simplicity and functionality as its main priority.

4.21 Left-out Part of Project

During the development phase of this project, some ideas were developed based on experiences and consultation with related personnel. However, these ideas were later on stripped due to irrelevancy and other logical reasoning.

4.21.1 PIC

In the earlier part of this project, another type of approach was used to arrange the setup to be used in accomplishing this project, which is to use PIC as one of the part in this project. From past experiences with PIC, PIC 16F877A is the best choice. It has 40 I/O pins, serial communications capabilities, relatively high speed processing, and most importantly, it possesses analog-to-digital converter (ADC) function. Since we will be using LM35 as thermal sensor that emits analog voltage as its output, it is necessary to convert the analog output into digital before transmitting them to the receiver. Thus, ADC is one of the main criteria that we looked in a PIC.

4.21.2 Networking

Since we were planning on using PIC, the most suitable method of communication for this project is by using Universal Synchronous Receive Transmit (UART). UART is used to communicate from microcontroller to various other devices. In this case, we were planning to communicate the XBee module to PC via RS232 Serial Port. USART is one form of serial communication. It is called asynchronous in the sense that a common clock signal is not required at both the transmitter and the receiver in order to synchronize the data detection. It uses a start bit and a stop bit added to the data byte to allow the receiver to determine the timing of each bit. In order to uses UART, baud rate need to be set up, which is at 9600 kbps.

4.21.3 Graphical User Interface (GUI)

Going into graphical user interface part (GUI) part, after doing some literature review on several languages, at first we decided to use JAVA. The book we use to refer is "JAVA programming for Beginner". From the study that we have done, we know that JAVA runs on virtual machine and thus makes it capable of running on any operating systems. This is quite an advantage if we manage to build our GUI using JAVA. However, JAVA compiler does not offer a complete set of method and class especially on serial communication. User needs to download the additional classes in order to use it. To make things worse, after downloading, user also need to go through difficult instructions and processes to makes sure the compiler read the downloaded files, it is not automatic.

Realizing the difficulty that we are facing with JAVA, we search for other alternative. Thus, we choose to study on VISUAL STUDIO 2005 instead. The book that we used to refer on VISUAL STUDIO 2005 is "Advance Programming using VISUAL BASIC 2005". VISUAL STUDIO 2005 offers almost the same functionality as JAVA and it is also easier to be used. The disadvantage of VISUAL STUDIO 2005 compare to JAVA is that it cannot runs on all operating systems. Only computer with WINDOW OS support VISUAL STUDIO 2005. However, considering that most computers in UTP are using WINDOW as their operating system, we finally choose to use VISUAL STUDIO 2005 to build the GUI.

4.21.4 Software

Listed below is the list of software that were suggested in the development period, to comply with the usage of PIC:

- MPLAB
- PICC Lite
- PIC Kit 2

Most of the software are freeware, so to obtain them is not a difficult task. However, familiarization of them might consume time, thus affecting the project’s timeline.

These parts of developments, were later on stripped from the project due irrelevancy since we are using XBee modules, alongside with XBee Xplorer which offers great functionality. It allows us to do direct communication without the hassle of PIC settings. Plus, it also was built in with ADC, easing the process of converting analog signal from the sensor into digital signal. More explanations can be read at 4.9.1 why these parts of project were phased out.

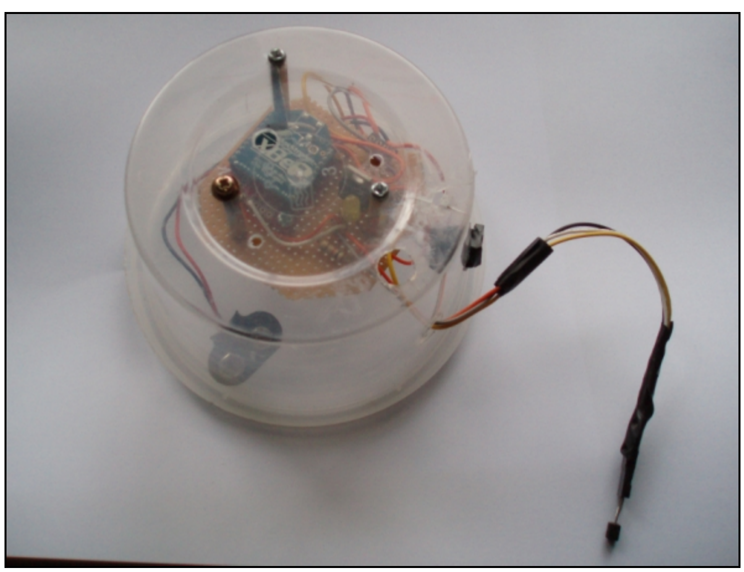

Figure 35: The Prototype Inside Recycled Plastic Enclosure and Add-on 5V Adapter Port

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The overall objective of the project is to establish a monitoring system of motor conditions, using wireless technology to enhance mobility. The wireless system will consists of co-existence between WSN with current cables and wires system. This project contributes in promoting the application of WSN technology in motor condition monitoring to assist in maintenance and plant process. This project also demonstrated the functionality of prototype wireless sensors in motor condition monitoring. Several other recommendations can be further improved in order to enhance the system.

5.2 Recommendation

Several improvements can be made to improve the prototype system. Adding functionality to be integrated into the system will maximize the usage of the Xbee transmitter and receiver. Integration with other system such as wired system to establish co-existence can further increase reliability especially for crucial process monitoring. Further troubleshooting and familiarization are needed in order to establish the condition monitoring system successfully. Personally, the Zigbee module is simple, has lots of functions and great future potential. However, it requires deep understanding of the architecture and algorhythm. It can best be considered as enthusiasts' level equipment, and not suitable for beginners. Test runs and data collecting are required for analysis to improve current system.

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APPENDICES

APPENDIX A:

X-Bee Specifications

Specification	XBee
Performance	
Indoor / Urban Range	Up to 100ft. (30m)
Outdoor RF line-of-sight Range	Up to 300ft (100m)
Transmit Power Output (software selectable)	1mW (0 dBm)
RF Data Rate	250,000 bps (non-standard baud rates also supported)
Receiver Sensitivity	-92 dBm (1% packet error rate)
Power Requirements	
Supply Voltage	2.8 – 3.4 V
Transmit Current (typical)	45mA (@ 3.3 V)
Idle / Received Current (typical)	50mA (@3.3 V)
Power-down Current	<10µA
General	
Operating Frequency	ISM 2.4 GHz
Dimensions	0.960” x 1.087” (2.438cm x 2.761cm)
Operating Temperature	-40 to 85℃ (industrial)
Antenna Options	Integrated Whip, Chip or U.FL Connector
Networking & Security	
Supported Network Topologies	Point-to-Point, Point-to-Multipoint & Peer-to-Peer
Number of Channels (software selectable)	16 Direct Sequence Channels
Addressing Options	PAN ID, Channel, and addresses
Agency Approvals	
United States (FCC Part 15.247)	OUR-XBEE
Industry Canada (IC)	42124A XBEE
Europe (CE)	ETSI
Japan	n/a

APPENDIX B:

Node Discovery Command Line (API mode)

Execute Node Discovery

Sending frame:7E 00 04 08 01 4E 44 64

Serialport.RxCount:33

RxBuffer:7E 00 1D 88 01 4E 44 00 86 23 00 13 A2 00 40 31 B9 04 45 44 41 54 32 00 00 00 02 00 C1 05 10 1E 12

*** Processing frame ***

ApiID = 88

Checksum Ok=True

ATCommandResponse, 29 bytes:

FrameID=1

Command=ND

Status=0

MY **8623**

SH,SL 5526146518202628 (0013A2004031B904)

NI [EDAT2]

PARENT 00 00

DEVICE_TYPE 02

STATUS 00

PROFILE_ID C1 05

MANUFACTURER_ID 10 1E

Request Hardware Version for Node **8623**

Sending frame:7E 00 0F 17 01 00 13 A2 00 40 31 B9 04 86 23 00 48 56 BD

Serialport.RxCount:21

RxBuffer:7E 00 11 97 01 00 13 A2 00 40 31 B9 04 86 23 48 56 00 19 44 E0

*** Processing frame ***

ApiID = 97

Checksum Ok=True

RemoteATCommandResponse, 17 bytes:

FrameID=1

Command=HV

Status=0

Response=19 44 **//so product id is 1944**

Appendix A: Work Done for FYP 2

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Continuation of FYP1	■													
2	Troubleshooting of arising issues		■	■											
	-Data Gathering		■	■											
	-Development phase		■	■											
3	Sensor building and auxiliary works		■	■	■										
4	Submission of Progress Report 1					■									
5	Project Work						■	■				■	■		
	- Compatibility testing and extensive research on coding						■	■				■	■		
6	Submission of Progress Report 2								■						
7	Pre EDX and Poster Presentation													■	
8	Submission of Draft Report													■	
9	Submission of Final Report and Technical Report														■

■	Work Done