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Hardware Implementation of aReal Time Monitoring and Controlling System for Three-Phase Induction Motor Using ZigBee and IOT

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Abstract: ***Analysis, monitoring and controlling of parameters of motors is much essential to find out utilization index of the motor for better performance, and it can help avoid any faults early. Although there are many solutions that are used for real time monitoring and controlling the induction motors in manufacturing process, most of them monitor in local or limited in small area. In this paper, IOT and web applications are used to on-line monitoring and controlling solutions from anywhere around the world have become possible with the developing technology. This utilization of IOT and Web applications increased the efficiency of the monitoring and controlling process.***

Keywords: Real-Time Monitoring, Three Phase Induction Motor, Internet of Things (IoT)

1. Introduction

Choosing Induction Motors as a part of industry process due to their stability, hardness and speed control flexibility. In this manner, the affair of induction motor protection is an active research area attracted by many researchers. The main purpose of this paper is for the protection and monitoring of three phase Induction Motor.

There are many techniques utilized for fault discovering and protection of Induction motor. Some of fault detection using Microcontrollers based protection system, Artificial Neural Network, Programmable Logic Controller (PLC) based protection system and Stator fault checking strategies[1].

In our work, the technique utilized is Microcontroller based protection system and monitoring using internet of things (IOT). The circuit will have the full control of the motor and it will protect the motor from some faults, for example, over/under voltage, over/under current and the circuit will allow the motor switched on under safety conditions.

The proposed system is additionally protecting induction motor from single phasing which is also a major fault. It's completely controlled by the microcontroller which used for consistently monitoring the voltage and the current for the three phases and it will switch the motor off if the voltage or the current goes abnormal until they are returns typical. With the help of the proximity and temperature sensors which monitors the number of rotates and motor temperature, if they exceed some particular levels then the microcontroller will send a wireless signal to main node via ZigBee network to take the right decision for protecting the motor automatically by the high level code or manually by the system administrator.

Nowadays with the evolution of the Internet of Things (IOT), the Monitoring and controlling of machines process have become much easier and can be manipulated from any part around the world. The proposed idea will focus on monitoring and controlling of three phase induction motor using ZigBee and IOT.

Our system is divided to four parts, (Node I, Node II, Main Node and Main PC), Every part has a group of tasks to do.

Every part on our developed system, unless main PC part, uses Arduino Leonardo board, which is based on ATmega32u4 low-power CMOS 8-bit microcontroller depends on the AVR enhanced RISC architecture and XBee module, which is based on ZigBee wireless communication system, as a local main unit.

The protection of the three-phase induction motor with Arduino Leonardo board has adaptability to switch off the motor at required time, monitors the three-phase voltage, current, temperature and number of rotates (RPM) for the motor at each time. furthermore, every motoring activity is shown through Two liquid crystal displays (LCD's) and simultaneously uploading the measured value to our used cloud "which is thingspesk.com".

2. Related works

During the last year's significant efforts have been dedicated to induction motors efficiency monitoring and many techniques have been proposed. Therefore, in this section a brief characterization of the main techniques used presented in the literature, also their advantages and disadvantages are presented.

Monitoring and Control System for Three Phase Induction Motor [2] was designed by M. P. Bodkhe, K. N. Pawar. they used IC ADE7758 for Poly Phase Multifunction Energy Metering and ZigBee Protocol. The ZigBee network topology was point to point topology, which means, the ZigBee network is limited to two nodes only. One ZigBee node for reading all motor parameters (voltage, current, number of rotates RBM and temperature of stator winding) and the other for base station node which used as the system monitoring and controlling. The system designed for work in limited area "for local monitoring only".

Note: there are No buttons used for control choices showed in the GUI.

While, Mehmet FatihIşık, Mustafa ReşitHaboğlu, and BüşraYartaşı[3] proposed Energy Monitoring System for 3 Phase Induction Motors using smart phone. The proposed system used a PLC for controlling the motor.

The Pc named as CMT-SVR is connected to the plc using Ethernet connection, all the motor parameters collected and processed in the CMT-SVR pc and available for accessing from any IOS/Android based mobile device. The connection between the CMT-SVR and the mobile devices done using wireless communication (Wi-Fi) by connecting them with an access point.

The authors used A frequency converter type A4022EE from speed controller series of Omron 3G3RX for controlling the speed of the motor. The parameters monitored in the developed system were voltage, current, the motor speed and the frequency used to operate the motor. Also, the designed system allows the user to start/stop the motor and control the speed of the motor by changing the frequency of the power applied to the motor.
The system designed for work in limited area "for local monitoring only".

Mahendra P. Bodkhe, K. N. Pawar, [4] introduced a parameter monitoring system for three phase induction motor using ZigBee protocol. The developed system can monitor motor parameters such as voltage, current, wending temperature, the number of revaluations for the motor and start/stop it in emergency case.

The developed system consists of two sections, the first section contains a Pc where the monitoring software is, And the second section called Induction motor control circuit, it's consists of AT Mega microcontroller and sensors, Speed and other parameters of motor controller. The two sections connected to each other via wireless communication link using ZigBee protocol.

The system designed for work in limited area "for local monitoring only".

Geethi.P&V.Saravanan[5] did the same work but using another technology, They used microchip solutions for building their system, the data acquisition system built using PIC microcontroller.

V.S.D Rekha, K.Srinivasa Ravi [6] developed a system for monitoring and controlling a single phase induction motor using IOT. The developed system uses a Raspberry Pi as data collection and gateway to the cloud. The Raspberry Pi connected to the cloud via wired Ethernet link.

All the sensors used in the system are connected directly to the inputs of raspberry Pi.

The sensor used in the developed system was current, voltage, temperature, vibration, moisture and speed sensor.

3. Hardware Implementation

For implementation Like any microcontroller-controlled system, the system must be build using hardware component and software codes for Aiming the hardware to do specific required operations. figure 1 shows the complete designed system.

Figure 1: The complete designed system

“This experiment is done in power electronic lab at Tripoli collage of electronic Technology-Tripoli/Libya” From figure 1 we can divide our system into three parts: main node, node one, node two.

3.1. Main node

This node is responsible for collecting the data comes from the other nodes, connecting the system with the cloud and makes the rightdecisions immediately when any fault accrues within motor operating. figure 2 shows the designed system for main node.

Figure 2: The designed system for main node

It consists of the following sections: XBee Coordinator, Arduino Leonardo board and Personal Computer

a) XBee Coordinator
The XBee coordinator used to initiate the ZigBee network and allowing the other XBee nodes to connect to it for exchanging data between the nodes and the coordinator. An example of XBee module is shown in figure 3.

Figure 3: XBee module

The coordinator handling data comes wirelessly from the other nodes to the Arduino Leonardo board which is connected directly to the PC via serial connection and vice versa. The XBee module can be configured to work as coordinator or End device using X-CTU utility.

b) Arduino Leonardo board

The **Arduino Leonardo** is a microcontroller board based on the ATmega32u4. It has 20 pin as digital input/output (7 pins of them can be used as PWM outputs and 12 pin can be used as analog inputs), it has a 16 MHz crystal oscillator, a micro USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller [7]. An example of Arduino Leonardo board is shown in figure 4.

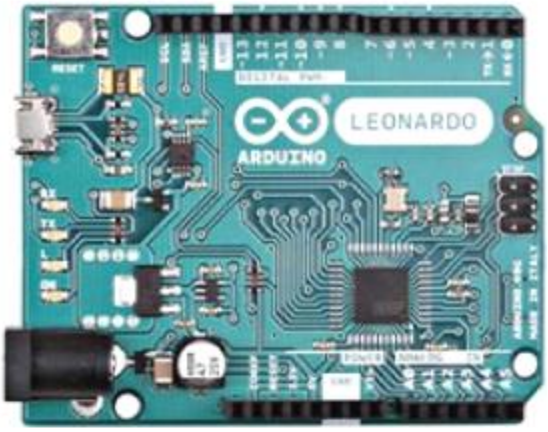

Figure 4: Arduino Leonardo board

This board used as main processing unit in the system, it's programmed with appropriate code for enables it to receive the data comes from the XBee coordinator, extracts it and forms it into useable data form. Also, the code in this board must be used to transfer the commands comes from the user to the XBee coordinator whose transfers it to the destination node.

c) Personal Computer

It's used for real time monitoring and controlling the system, saving the extracted data in database file and as gateway for connecting the system to the cloud to be available over the internet.

3.2. Node I

This node is responsible for monitoring the three-phase voltage, the current applied to the motor and switching the motor ON or OFF depending on commands comes wirelessly from the main node. figure 5 shows the designed system for Node I.

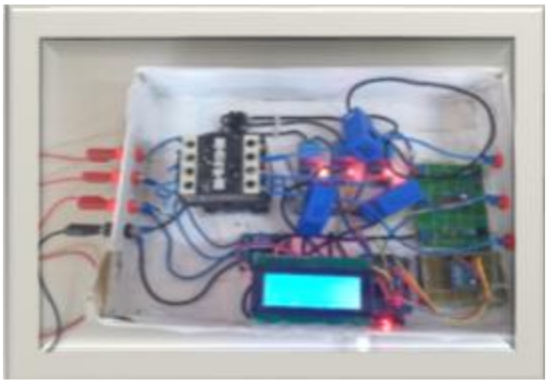

Figure 5: The designed system for Node I

This node is consisting of the following sections:

a) SCT013-000 Spilt-Core Current Transformer

This transformer is used for current measurement, current monitor and current protection for AC motors, lighting equipment, air compressor… etc. an example of SCT013-00 Current Sensor is shown in figure 6.

Figure 6: SCT013-00 Current Sensor

This sensor can be clamped onto the mains lines without interrupting power into the circuit breaker. The output of the current transducer is an AC voltage proportional to the AC current enclosed by the sensor's ring as result of voltage output type built-in sampling resistor.

It can measure AC current from 0 to 100A with output AC voltage for representing the input current from 0 "at 0A" to 50mv AC "at 100A".

We used three current sensors; each sensor is clamped onto each "hot" wire going into the circuit breaker.

b) Interfacing the current sensor with Arduino Leonardo board

To connect a current sensor to an Arduino, the output signal from the current sensor needs to be conditioned so it meets the input requirements of the Arduino analog inputs, i.e. a positive voltage between 0V and the ADC reference voltage. As known the output signal type of the current sensor is a current output, so its needs to be converted to a voltage signal using a resistor called "burden resistor" connected in parallel with the two output lines of the current sensor. The value of this resister can be found from the following formulas:

Maximum output value of the current sensor at 100A will results 50mA RMS [8].

We can calculate The Peak-to-peak current value from RMS current value, we use the following formula:

$$I_{ptop} = I_{RMS} * 2\sqrt{2} = 50 * 2\sqrt{2} = 141.42\, mA \qquad (1)$$

We know that the maximum voltage of the Arduino board is 5v so we can calculate the burden resistor from ohm's low:

$$R = \frac{V}{I}\frac{5}{141.42 * 10^{-3}} = 35.35\Omega \qquad (2)$$

35 Ω is not a common resistor value. The nearest values either side of 35 Ω are 39 and 33 Ω. Always choose the smaller value, we recommend a 33 Ω ±1% burden.

This can be achieved with the following circuit (figure7) which consists of two main parts:
1) The CT sensor and burden resistor which is 33 Ω
2) The biasing voltage divider (*R1 & R2*) which are R1=R2=10k Ω

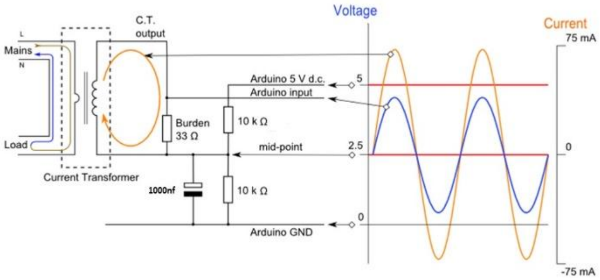

Figure 7: Current sensor condition circuit for Arduino

We used three current sensors with three condition circuits. The output reading of the three sensors connected to Arduino Leonardo analog ports A0 to A2.

c) ZMPT101B AC single phase voltage sensor module

ZMPT101B Single Phase Voltage Sensor Module is designed to be easily used with Arduino microcontroller boards. The Product features for this module[9]:
1) Built in micro precision voltage transformer.
2) Built in operational amplifier circuit with high precision, precise sampling and appropriate compensation function of signal.
3) It can be used to measure within 250V AC voltage, the corresponding output analog quantity can be adjusted.
4) PCB board size: 49.5 (mm) x19.4 (mm).

The ZMPT101B AC single phase voltage sensor module is illustrated in figure 8.

Figure 8: ZMPT101B AC single phase voltage sensor module

We used one voltage sensor for every phase for measuring the voltage source fed to the motor. The output reading of the three sensors connected to Arduino Leonardo analog ports A3 to A5.

d) Contactor

A contactor is an electrically controlled switch used for switching an electrical power circuit, Similar to relay except with higher current rating. A contactor is controlled by a circuit which has a much lower power level than the switched circuit. It's used to be directly connected to high-current load devices and controls them. These devices may be motors, lighting, heating, air-compressors, heating, thermal evaporators and other electrical loads.

Contactors typically have multiple contacts, and those contacts are usually (but not always) normally-open, so that power to the load is shut off when the coil is de-energized.
In our design we used external relay for energize/de-energize the contactor which connected with A1 and A2 contactor plugs. A 3-Phase Contactor is shown in figure 9.

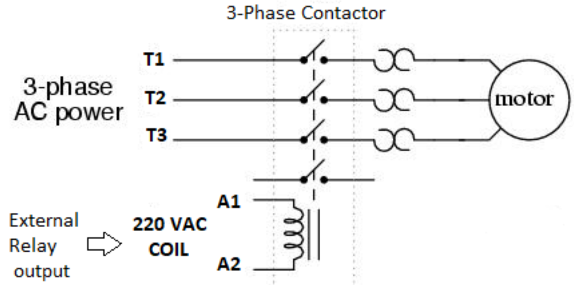

Figure 9: 3-Phase Contactor

e) Relays

A relay is an electrically operated switch that can be turned on or off, letting the current go through or not, and can be controlled with low voltages, like the 5V provided by the Arduino pins. An example of Relay module is shown in figure 10.

Figure 10: Relay module

This relay module has two channels and should be powered with 5V, which is appropriate to use with an Arduino.

We used this relay for activate/deactivate the contactor by applying 200VAC on it's A1 and A2 plugs when the relay is activated by sending logic 1 from pin D5 on Arduino Leonardo board.

f) Arduino Leonardo board

This board is programed with code for reading the data comes from the analog ports A0 to A5, makes the necessary logic sequences and calibrations to be in familiar form before transfers it to the main node via XBee Node I. Also, the code includes the necessary procedures for making sure of the connectivity between the XBee Node I with the XBee coordinator and responsible for handling data goes/comes through them.

g) XBee end device

This device is responsible for sending/receiving data which transferred from/to the Arduino Leonardo board wirelessly from/to the main node.

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h) 20x4 LCD

We used this element for local monitoring of the voltage and the current measured by the sensors.

Figure 11 shows an output sample of node I local monitoring. It shows L1, L2 and L3 voltage and current values applied to the motor.

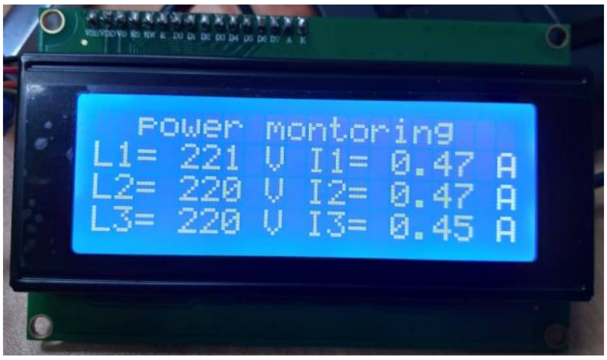

Figure 11: Node I local monitoring

This LCD is connected to the Arduino Leonardo board on pin 2 and pin3.

3.3. Node II

This node is used only for monitoring the temperature and the speed of the motor. figure 12 shows the designed system for Node II.

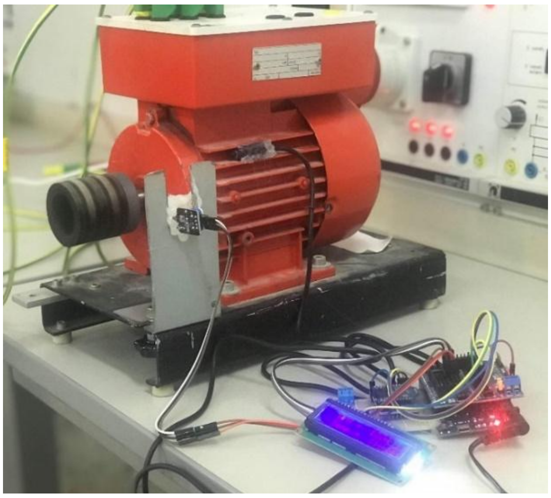

Figure 12: The designed system for Node II

It's consists of the following sections:

a) Infrared obstacle avoidance sensor

Infrared Obstacle Sensor Module has built-in IR transmitter and IR receiver that sends out IR energy and looks for reflected IR energy to detect presence of any obstacle in front of the sensor module. The module has on board potentiometer that lets user adjust detection range. The sensor has very good and stable response even in ambient light or in complete darkness. The Infrared obstacle avoidance sensors is shown in figure 13.

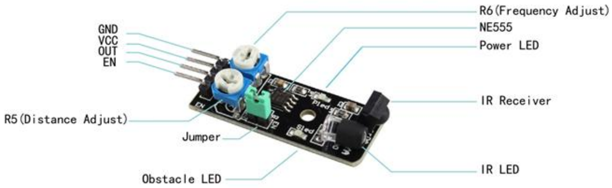

Figure 13: Infrared obstacle avoidance sensors

As shown in figure 13, The Infrared Obstacle Avoidance Sensor has Power, Ground, Signal, and Enable pins. there are also 2 potentiometers, and one jumper on the board.

The potentiometer R5 on the figure is used to adjust how sensitive the sensor is. And it can be adjusted to use it to adjust the distance from the object at which the sensor detects it.

This sensor is used for measure the velocity of the motor by calculating the RPM "Rotates Per Minute" of the motor.

Figure 14 shows how this sensor installed in the design for sensing the number of rotates.

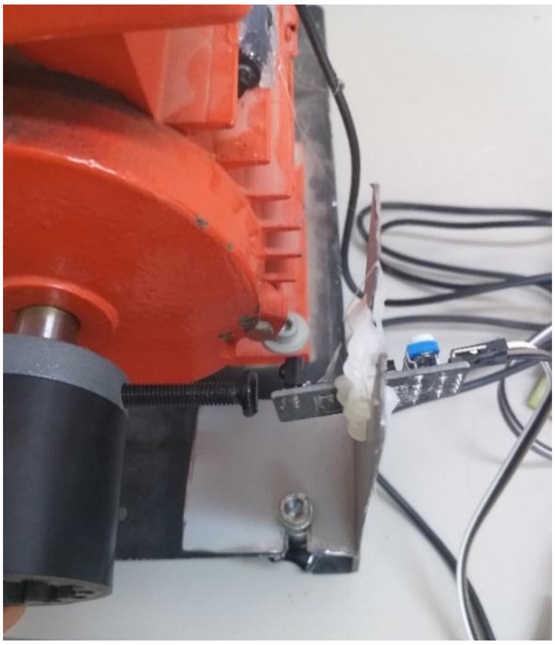

Figure 14: Infrared obstacle avoidance sensor installation

The code programed in the Arduino Leonardo board is responsible for measuring motor number of rotates by calculating the number of zero signals generated by the sensor per minute.

The output reading of the sensor is connected in pin 7 of the Arduino Leonardo.

b) LM35 Temperature sensor

This sensor is used to monitor the temperature of the motor, the output reading of the sensor is connected to A0 of the Arduino Leonardo board.

Figure 15 shows how this sensor installed in the design for sensing the motor temperature.

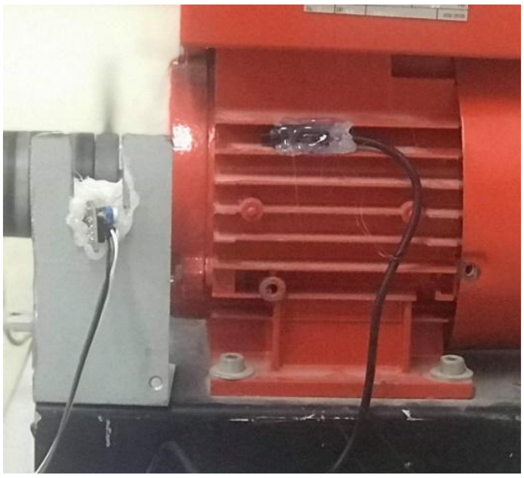

Figure 15: LM35 Temperature sensor installation

c) Arduino Leonardo board

This board is programed with code for reading the data comes from the analog port pin A0 and the digital port pin 7. The code makes the necessary logic sequences for the different data comes from the two ports and calibrates it to be in familiar form before transfers it to the main node via XBee node II.

Also, the code includes the procedures for making sure of the connectivity between the XBee node II with the XBee coordinator and responsible for handling data goes/comes through them.

d) XBee End device

This device is responsible for sending/receiving data which transferred from/to the Arduino Leonardo board wirelessly from/to the main node.

e) 16x2 LCD

We used this element for local monitoring of the temperature and the motor RPM measured by the sensors.
It connected to the Arduino Leonardo board on pin 2 and pin3.

Figure 16 shows an output sample of node II local monitoring. It shows RPM and motor temperature.

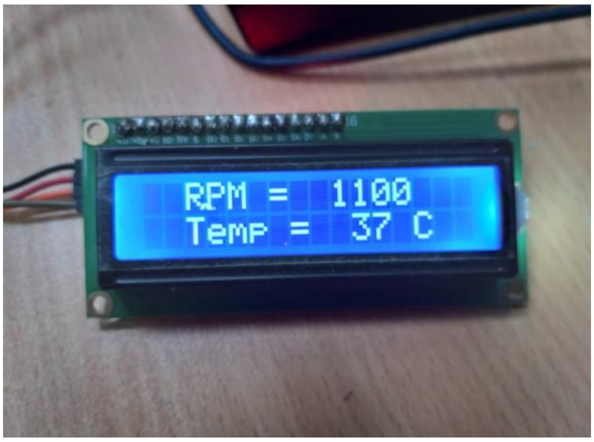

Figure 16: Node II local monitoring

f) Configuring the XBee modules

In this section we'll present the configuration parameters and steps used to configure the XBee's modules to work in ZigBee network.

We used Digi X-CTU software utility "Version 6.4.0 " provided from Digi international company for configuring the XBees parameters, this software is a free utility.

X-CTU is a free multi-platform application that enables developers to manage Digi radio frequency (RF) modules through a simple-to-use graphical interface. The application includes embedded tools that make it easy to set up, configure, and test Digi RF modules[10]. The X-CTU program shortcut is shown in figure 17.

Figure 17: X-CTU program shortcut

g) Steps done for configuring the XBee devices in network

Before we can program XBee using X-CTU, we need XBee explorer card. This card is used to configure XBee parameters and supports XBee settings format. Also, can be used as USB-TTL adapter. An example of XBee explorer card is shown in figure 18.

Figure 18: XBee explorer card

All XBee modules can be installed and can be attached to this card.

1) Run the X-CTU after installing XBee in XBee explorer card and connecting the card to the USB port of the PC.
2) Choose discover device tab to add the XBee connected to the card. The XCTU software utility is shown in figure 19.

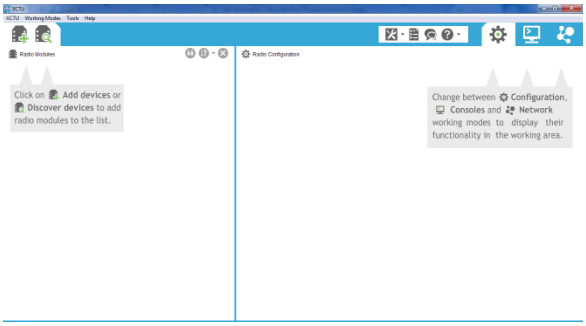

Figure 19: XCTU software utility

3) Choose the serial port where the card connected and Set the serial port parameters as shown in figure 20.

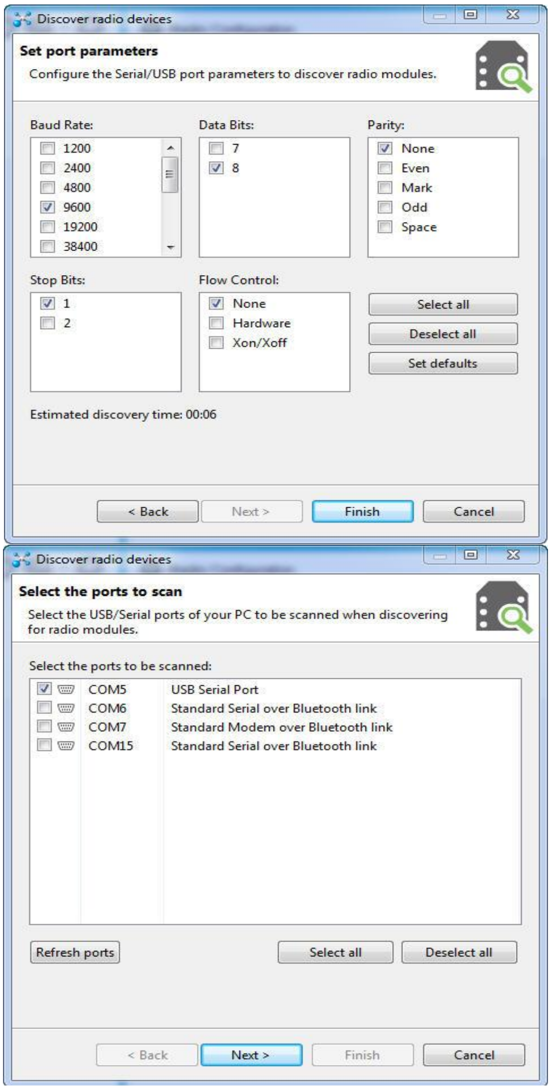

Figure 20: Choosing & selecting serial port

4) The X-CTU will search for XBee until finding it. Add the founded XBee device by pressing add selected devices button. As shown in figure 21.

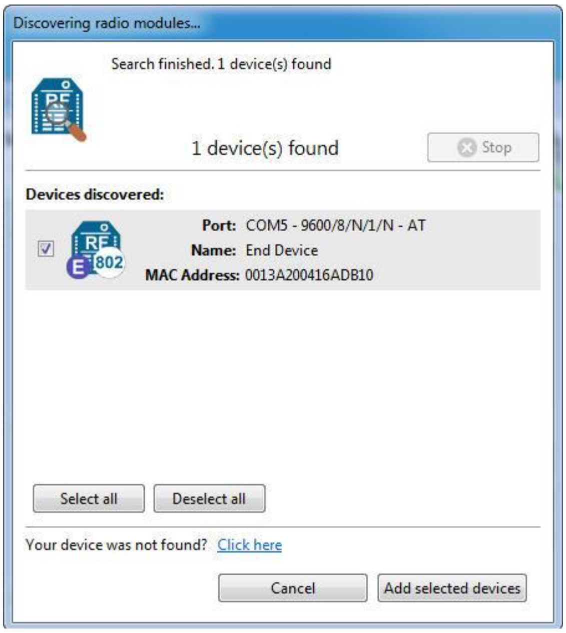

Figure 21: Adding founded XBee

5) The X-CTU is illustrated in figure 22.

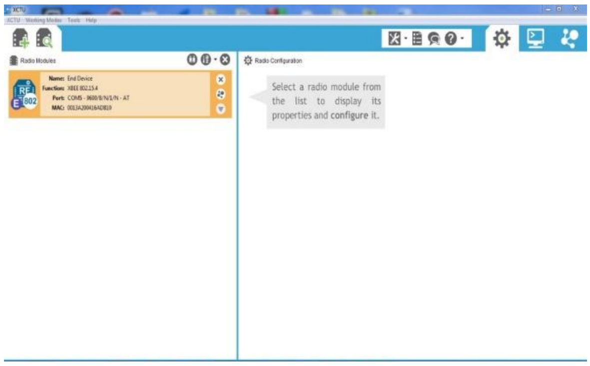

Figure 22: XBee working on it

6) By clicking founded XBee device on the program will show the parameters of the XBee which can be changed to desired values and then clicking on write button to write the new parameters to XBee as shown in figure 23.

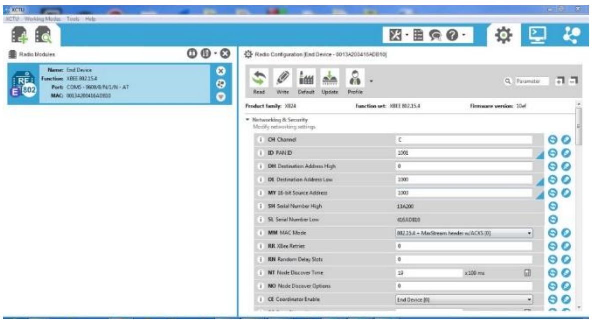

Figure 23.: XBee parameters

Parameters used to configure the nodes in our network is shown in table 1.

Table 1: Parameters used to configure the nodes in our network

parameter	Coordinator	Node I	Node II
Channel used	C	C	C
PAN ID	1001	1001	1001
Destination Address High (HD)	0	0	0
Destination Address Low (LD)	FFFF	1000	1000
Device Type	Coordinator	End Device	End Device
16-bit Address	1000	1002	1003
Mode	AT	AT	AT

A. Parameters Discussion

Channel used: All the nodes must have the same channel and PAN ID to connect to each other. The PAN ID is a 16-bit (4 hex numbers) address which represents Personal Area Network Identification number, it's unique for every network.

Destination address high (HD): it represents the higher 24bit of 48bit XBee module long Address of the destination node, "high portion of the address".

Destination address low (LD): it's represents the lower 24bit of 48bit XBee module long Address of the destination node, "lower portion of the address".

The node's destination low address must be the 16-bit address of the coordinator, because the nodes contacts only with the coordinator in unicast transmission mode, while the destination address of the coordinator is FFFF which means contacting with all nodes in the network using multicast mode.

Device type: means how the XBee device works in the network "End device or Coordinator".
Note: Every XBee network must has only one PAN coordinator and at least one End device up to 216 End devices.

16-bit Address: it's the short address of XBee module represented by 4 hexadecimal numbers and must be unique in the Personal Area Network.

4. Conclusion

The main functions of this system are monitoring data about load voltage, load current, speed and temperature of the motor and the system has the capability of controlling the motor and shutdown of motor at abnormal conditions. The capability of this system is receiving and storing the real time data acquisition on database for future use. The proposed project greatly helps the Industrial Automation and Home automation applications which uses induction motor as the actuator. The requirements to implement the proposed system includes group of sensors like (speed sensor and temperature sensor) for reading motor temperature and it's velocity, current and power transformers for current and voltage measurement and control, and contactors and relays for turns the motor on and off.

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