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THESIS

SHIPBOARD WIRELESS SENSOR NETWORKS UTILIZING ZIGBEE TECHNOLOGY

by

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September 2006

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13. ABSTRACT (maximum 200 words)

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The expected contribution from the research effort would be a completely wireless sensor network which would result in a net savings in man hours required to maintain and monitor. The sensor network would be reliable, relatively inexpensive and entirely COTS available. With an extended battery life of 18 to 24 months, even the battery replacement could be fit into a standard annual or bi-annual PMS cycle, minimizing the workload to maintain.

Initial feasibility testing completed satisfactorily and the prototype sensor was successfully created and integrated to interface with the existing sensor infrastructure.

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SHIPBOARD WIRELESS SENSOR NETWORKS UTILIZING ZIGBEE TECHNOLOGY

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EXECUTIVE SUMMARY

This thesis represents the application of a new wireless technology to solve a critical problem facing modern naval vessels. In a typical surface combatant, there are almost three thousand hull, mechanical, and electrical (HM&E) sensors which require periodic calibration, the vast majority of which are pressure and temperature sensors, switches, or gages. Of these, the vast majority are either independent visual type sensors or integral parts of shipboard Machinery Control Systems (MCS) which can only be read at system consoles, located far from the original sensor location. All together these sensors represent thousands of man hours spent monitoring, calibrating, and troubleshooting of miles of wires and auxiliary equipment in cases of equipment failure. The number of these sensors is expected to increase as the ships become more modern.

With the emphasis being placed on reducing crew size, a requirement exists for even more sensors and automated systems to replace the available man-hours lost. This represents a paradox of more sensors with fewer available man-hours to maintain them.

A potential solution is a wireless shipboard sensor network, with all sensors capable of being monitored and maintained digitally. This thesis studies the feasibility of utilizing Zigbee standard devices to create a shipboard wireless sensor network. Through a combination of basic feasibility tests such as range, power, and reliability, and also the development of a prototype pressure sensor using the technology, it is demonstrated the technology can work in a shipboard setting.

Supporting software was then generated using LabVIEW 6.0 to assist in the incorporation of existing sensor infrastructure already in place. This program allows a basic workstation and Zigbee gateway to act as a server and allow a remote Integrated Condition Assessment System (ICAS) program workstation to log-in via a TCP/IP connection and monitor sensor data.

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I. INTRODUCTION

A. BACKGROUND

In a modern DDG, there are approximately 2,670 hull, mechanical, and electrical (HM&E) sensors that require periodic calibration, the vast majority of which are pressure and temperature sensors, switches, or gages. Of these, 1,189 are independent visual type sensors and 1,480 are integral parts of shipboard Machinery Control Systems (MCS) which can only be read at system consoles, located far from the original sensor location. All together these sensors represent thousands of man-hours spent monitoring, calibrating, and troubleshooting miles of wires and auxiliary equipment in cases of equipment failure. As an example, a typical engine room watch may spend 25% of his time on watch manually taking readings from the hundreds of sensors at his watch station; a pair of technicians will spend approximately 30 minutes to an hour calibrating a single pressure sensor—provided that the sensor does not need to be removed from the system. The man-hours and system down time increase dramatically as the complexity of the sensor is increased [Ref 1].

With the emphasis being placed on reducing crew size, a requirement exists for even more sensors and automated systems to replace the available man-hours lost. This represents a paradox of more sensors with fewer available man-hours to maintain them [Ref 2].

The current wireless and digital technologies represent a potential stopgap in the man-hour requirement. By utilizing the available commercial off-the shelf (COTS) components, we are able to streamline the calibration process and make digital data from the sensors available for use at multiple remote stations. However, certain support issues remain, such as the need for individual power supplies for sensor and wiring infrastructure. Zigbee standard devices provide a potential solution for this problem. As with most sensor applications, very little bandwidth is actually necessary since sampling rates can be fairly low and still meet the necessary operating requirements. Utilizing

Zigbee, we can fully take advantage of this low bandwidth, low sample rate requirement and extend battery life to months, even years on a standard set of alkaline batteries. This makes the Zigbee standard sensor a true stand-alone unit.

Another potential advantage of the Zigbee standard is the ability to program and define sensor settings. This potentially streamlines the supply issue in that a one universal Zigbee sensor can be utilized to fulfill a multitude of shipboard applications, allowing a total reduction on the sensor parts required.

B. OBJECTIVES

The primary focus of this thesis will be to conduct a feasibility study on the usage of the Zigbee standard sensors into a simulated shipboard environment. This study will include a series of simulations, which will test out the range, reliability, and battery life of the sensor nodes. To accomplish this, a Zigbee sensor will need to be developed and incorporated into a PC oriented operating environment utilizing existing programs such as LabView. Once interfaced, further research will be conducted to incorporate utilities such as smart calibration and programmable sensor settings such as alarm set points and failure modes to increase the functionality of the sensor.

C. PROPOSED CONCEPT OF NEW TECHNOLOGY

This thesis uses current technology to display on a laptop PC, tablet PC or PDA the sensor data from a remote pressure sensor. The remote pressure sensor is connected to an integrated data acquisition (DAQ) card and a wireless Zigbee integrated modem. This modem then transmits the pressure readings via the IEEE 802.15.4 wireless standard, Zigbee, to a Zigbee enabled gateway where the readings are processed and distributed to the necessary operating stations, the PC or PDA. The integrated Zigbee DAQ and modem will also power the sensor enabling a true wireless sensing device. The battery life of the integrated sensor unit should be in excess of 12 to 18 months to allow for the battery replacement to fit into the standard PMS cycle with minimal impact on the ships operational cycle.

D. BENEFIT OF CONCEPT TO THE NAVY

With the increasing complexity of modern naval vessels, it is imperative to have in place an effective wireless sensor network to monitor the many systems onboard and to meet the reduced manning requirements. Implementation of the Zigbee standard and the development of a wireless shipboard sensor network would help in meeting these requirements. With a wireless shipboard sensor network, plant status is easily monitored by all levels of the chain-of-command, regardless of their location onboard. In the event of casualty, this allows the command to make sound decisions based on a greater pool of information. This also allows the information pertaining to the specific onboard equipment to be sent to a shore based maintenance facility for evaluation and maintenance planning.

The plausible benefits from the research efforts would be an overall reduction in required manpower, increased efficiency, and a greater awareness of plant operation and equipment status among not only naval vessels but also shore based facilities that would incorporate the technology. Because the system would be completely wireless, an additional benefit would be the savings in weight, space, and cost from cabling necessary to support a comparable wired sensor network. This is especially crucial onboard naval vessels. The hardware to be used will be relatively inexpensive, reliable, and COTS available.

E. DESCRIPTION OF CHAPTERS IN THESIS

This first chapter is the introduction to the thesis. The second chapter covers the problem statement and proposed approaches to the thesis. The third chapter concentrates on the hardware components of the thesis. It discusses each component's specifications, operating conditions, and use in thesis. The fourth chapter examines the software used and designed in the thesis. Each piece of software has its own section to discuss the role in the thesis, the inputs, outputs and the how it works or how it was utilized. The fifth chapter presents the results that were found and discusses what worked and what failed. The sixth chapter includes the conclusions from the thesis. This describes what was accomplished by this thesis and any future work that may be needed.

II. PROBLEM STATEMENT AND PROPOSED APPROACHES

A. PROBLEM STATEMENT

As discussed in the introduction, the necessity for the development of an effective wireless sensor network exists. Sensors utilizing Zigbee technology may be the critical stopgap between the current-generation wired digital sensors being incorporated into the fleet today, and the next generation smart, wireless sensors.

The goals for this thesis will be twofold. The first will be a feasibility study of the Zigbee technology for use in a shipboard sensor network. If successful, the second portion will be to develop a prototype wireless pressure sensor utilizing the Zigbee technology. The goals will be constrained by the technology currently in use in industry. This will ensure that the hardware used will be readily COTS and relatively inexpensive. The project will also be constrained by the necessity for all developed sensors and networks to be incorporated into the wired sensor networks and maintenance procedures already in place.

Currently the ex-USS Foster is used as a test platform for the wired sensor network. In addition, the USS Howard (DDG-83) and USS Mason (DDG-87) have been built with a number of wireless Network Capable Application Processors (NCAPs) for use in at-sea testing. Figure 1 demonstrates the use of wireless NCAP and Gateway is a shipboard environment such as DDG-83 or DDG-87 [Ref 1].

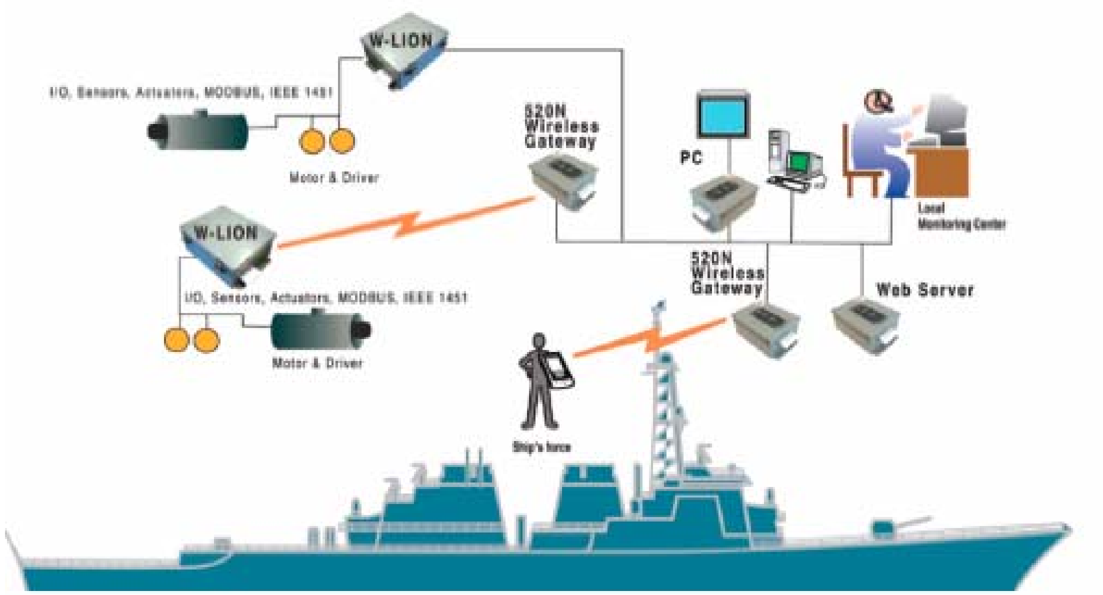

Figure 1. Diagram of Digital Sensor Network in a Shipboard Environment [Ref. 1]

B. PROPOSED APPROACHES

1. Zigbee Feasibility Study

The feasibility study conducted will be a series of range, reliability, and battery life tests.

a. Range

Due to the size and shape of a typical engine room, it is imperative that the sensor have a range well in excess of 10 meters from any aspect. The range test will be conducted at a range of 10 meters. The sensor will be rotated during the test in 45 degree increments while pausing to take measurement readings. The SurgeView program will be used to monitor the mote connectivity and to measure the number of dropped packets.

b. Reliability

For a sensor network to be truly feasible for use on an operational platform, it must demonstrate a level of reliability. For initial reliability testing, a sensor will be placed at 10 meters at the least effective aspect, determined by the testing above.

The power will then be cycled to the sensor and the time to reconnect to the network will be measured. This test will demonstrate that the sensor will not be affected by routine maintenance or intermittent power outages.

c. Battery Life

Finally the battery life will be determined. Utilizing two standard alkaline AA batteries, the overall battery life of a sensor in continuous operation will be determined. This data will then be used to extrapolate the conditions required to extend the battery life to fit into a feasible schedule for routine replacement. A potential method to increase battery life would be to utilize batteries with bigger capacities. Another method would be to utilize a sleep mode.

2. Prototype Wireless Pressure Sensor

Upon the conclusion of the above feasibility study, a prototype wireless pressure sensor will be built utilizing the Zigbee technology. This prototype will be built using the equipment and material listed below:

- Crossbow MICAZ (MPR2400) mote processor and radio module
- Crossbow MICA2 Data Acquisition Module (MDA300CA)
- Honeywell pressure sensor/transducer
- Two-layer printed circuit board for mounting the pressure transducer

The guiding premise for this sensor will be that it will be developed using low-cost commercially available components, it will incorporate the Zigbee technology, thus demonstrating its effectiveness, and finally, the sensor will be of low power consumption as to maximize battery life. Figure 2 below illustrates the proposed sensor configuration.

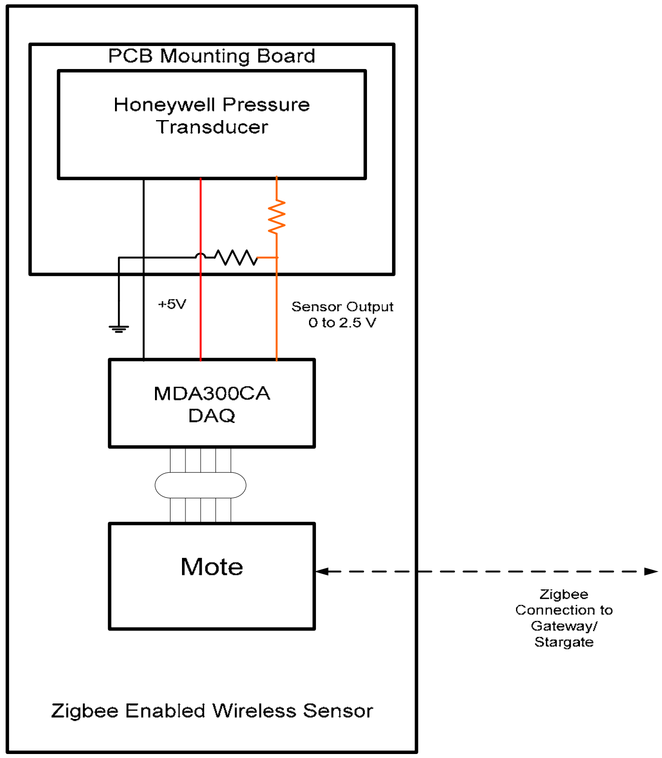

Figure 2. Proposed Zigbee Sensor Configuration

C. PREVIOUS WORK

Previous work on creating a sensor network was conducted by two former students at the Naval Postgraduate School, Steven Joseph Perchalski and Eusébio Pedro da Silva. This work was done in conjunction with guidance and technical support from Mr. Randy Rupnow of NAVSEA Corona, and Professor Xiaoping Yun. The primary focus of their work was the development of a closed loop calibration procedure of a sensor using a wireless tablet PC and an NCAP utilizing a range of LabVIEW programs. The LabVIEW programs allowed the technician to perform a prime standard calibration by inputting a range of test points and automatically computing the new calibration constants using a least squares fitting method. The program then stored the new constants by updating the sensor's RAM or EEPROM. This closed-loop calibration process enabled a significant reduction in time but also the number of personnel required to conduct the maintenance. The concept of operation for the Closed Loop Wireless

Calibration process is illustrated below in Figure 3. Figure 4 shows the primary graphic user interface (GUI) that was developed by Eusébio Pedro da Silva. [Ref. 3 & 4]

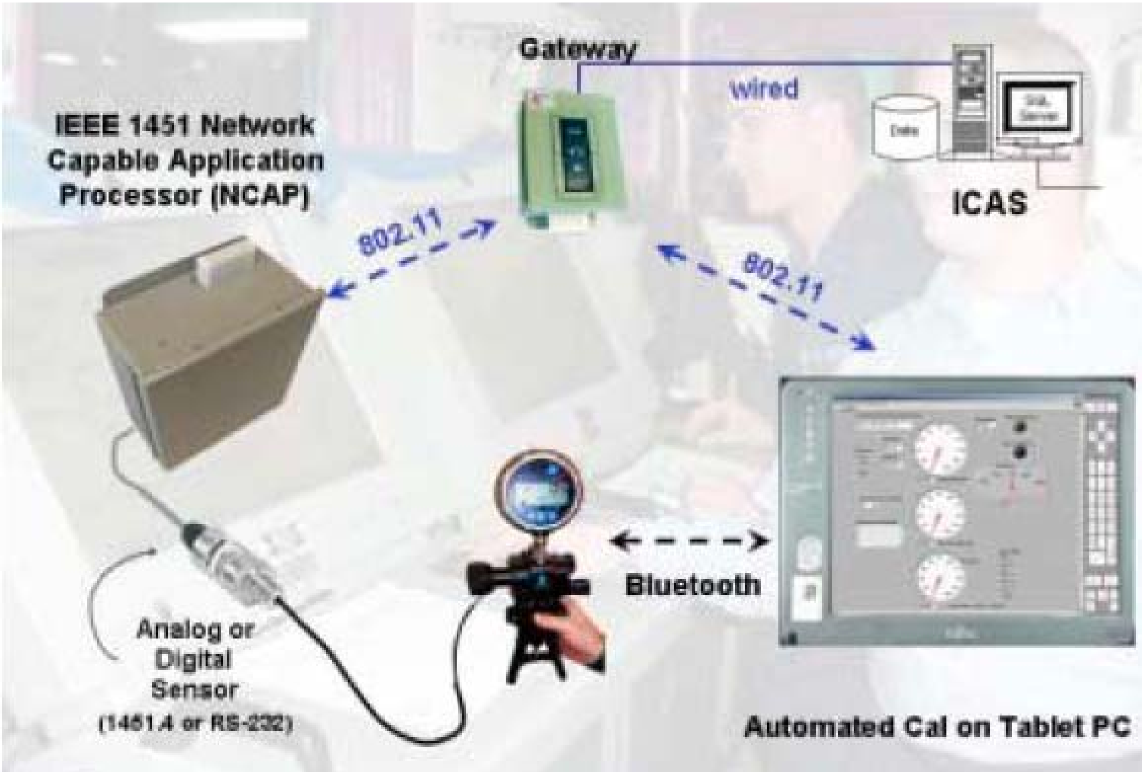

Figure 3. Concept of Operation for Closed Loop Wireless Calibration [from Ref. 3]

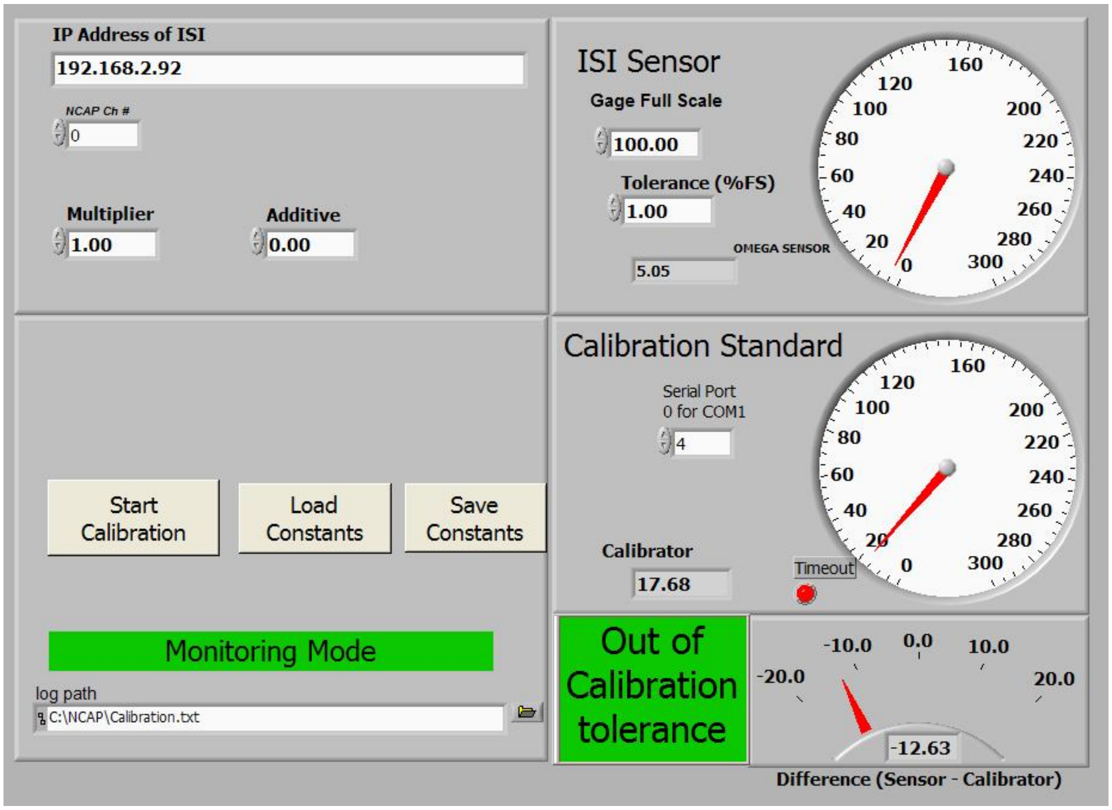

Figure 4. Wireless Calibration Program Graphic User Interface

In a recent test on board the ex-USS FOSTER, conducted in September 2005, Professor Yun, Mr. Rupnow, as well as several student SWALAC project members were able to join the previous work using a LabVIEW program with the installed ICAS system. In addition, a smart ISI pressure sensor as well as a TCP/IP enabled thermocouple was incorporated into the already existing system and full functionalities for both new sensors were demonstrated. This was an important step towards demonstrating the feasibility and the robustness of using a smart shipboard sensor network on navy ships. Figure 4 illustrates the concept of operation for the calibration process.

D. SUMMARY

In summary, the research problem was to determine the feasibility of utilizing the Zigbee technology to develop the next generation wireless sensor network and to develop the technology for incorporation into the current, wired digital sensor network that is in place today. A variety of tests were conducted to ensure feasibility such as battery life, range, as well as the ability to self repair the multi-hop mesh network in cases of individual sensor failure. Once these tests were conducted, a prototype pressure sensor was created by combining a Zigbee standard wireless modem with a low power data acquisition (DAQ) card and a Micro-Electro-Mechanical Systems (MEMs) pressure sensor. This thesis represents a first step in developing a feasible wireless sensor network for use in a shipboard setting. The next chapter will more closely describe the hardware used to accomplish this task.

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III. HARDWARE DESCRIPTION AND DISCUSSION

A. INTRODUCTION TO HARDWARE

This chapter discusses the different types of hardware used in this thesis. The equipment used include the Crossbow MICAZ (MPR2400) mote processor and radio module, Crossbow Serial Gateway (MIB510), Crossbow Stargate Gateway (SPB400), Crossbow MICA2 Data Acquisition Module (MDA300), Honeywell pressure sensor/transducer, laptop PC/tablet PC, and the wireless LAN. Figure 5 shows the generalized schematic to show component interrelations. Also included in this section are alternate Zigbee platforms considered for usage in this thesis.

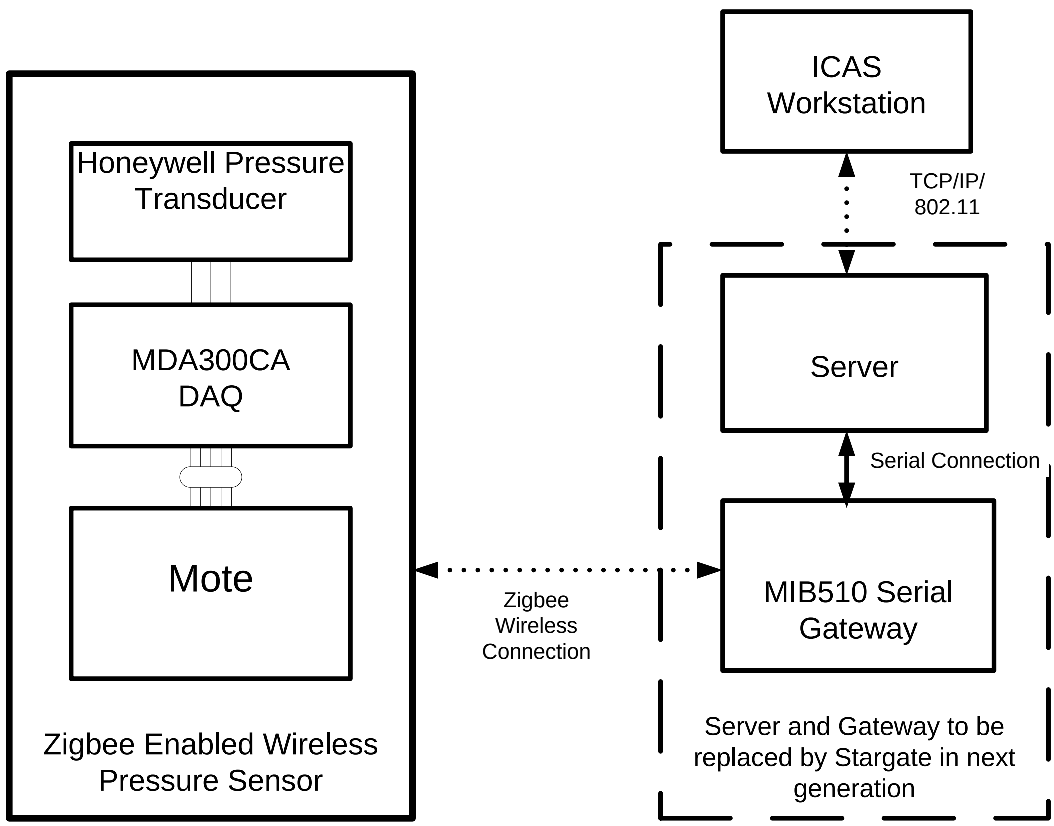


Figure 5. Proposed Hardware Configuration and System Connections

B. CROSSBOW MICAZ (MPR2400) MOTE PROCESSOR AND RADIO MODULE

The MPR2400 (MICAz) is the primary workhorse of the project. The MICAz is latest generation of Motes developed by Crossbow Technology. The MICAz is fully compliant with the IEEE 802.15.4 standard and is capable of establishing and maintaining a multi-hop mesh network. The MICAz is used in this thesis for sensor-to-sensor communications and sensor-to-gateway communication. Figure 6 below shows the general layout of the MICAz.

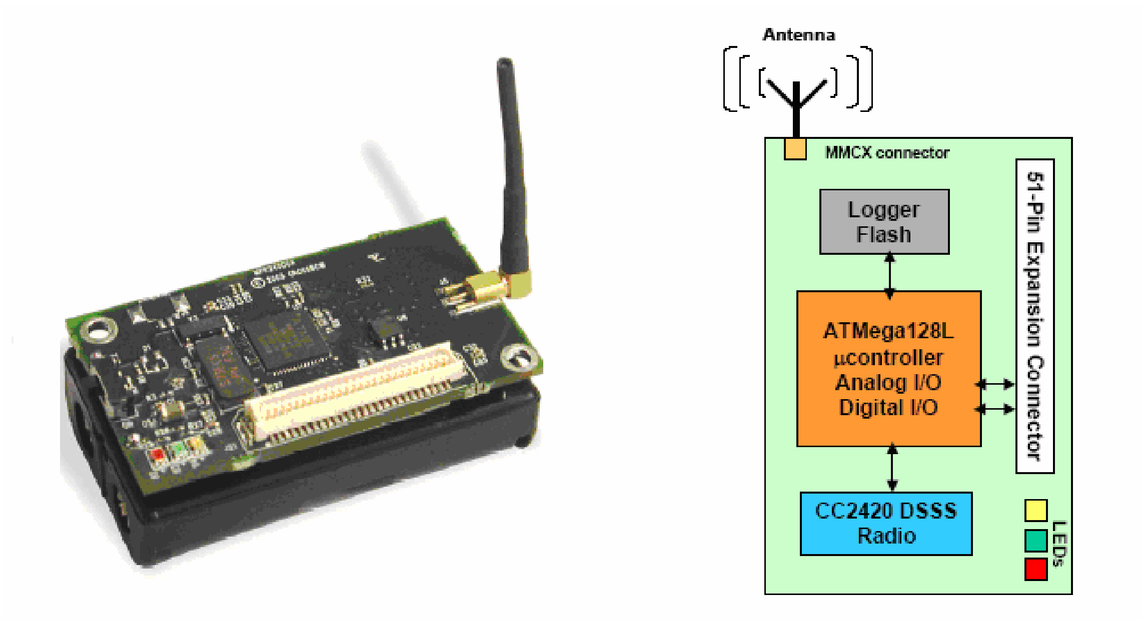


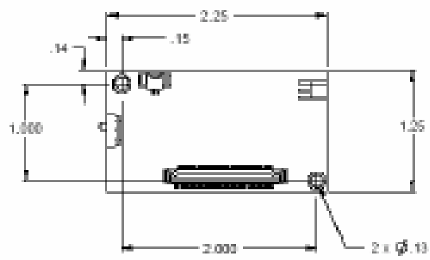
Figure 6. MPR2400-MICAz [Ref 5]

1. Specifications

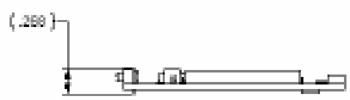
The dimensions of the MICAz is 2.25” x 1.25” x 0.2” without the battery mount. Figure 6 above illustrates the dimensions. Some features of the MICAz, MPR2400 motes are:

- Integrated Atmega128L micro-controller
- Chipcon CC2420 ZigBee ready radio frequency receiver
- 2400 MHz to 2483.5 MHz operating band

- Hirose 51 pin I/O connector,
- 512 kB serial flash memory
- 250 kbits/sec max data rate
- Imbedded TinyOS operating system
- External power supply, 2.7 V to 3.6 V (3.0 V nominal)
- 3 color programmable LED indicators (red, yellow, and green) [Ref 5]



MICAz top view



MICAz side view

Figure 7. MICAz Overall Dimensions [Ref. 5]

2. Use in Thesis

The MICAz mote acts as the wireless modem between the sensors to the gateway. It is connected via the Hirose 51 pin connector to either the gateway or the DAQ unit. If the MICAz mote is connected to the MDA300CA DAQ unit described below, the 3.0V nominal power supply attached to the mote supplies power to the DAQ card and associated sensor. The mote then transmits the output of the sensor via the multi-hop mesh network to neighboring sensors and gateway. If the MICAz mote is connected to a gateway, the mote is powered via the 51 pin connector by the external power supply connected to the gateway.

C. CROSSBOW SERIAL GATEWAY (MIB510)

The Crossbow Serial Interface Board (MIB510) acts as a gateway between the operating station, in this case a laptop PC, via an RS-232 serial connection and the Zigbee enabled mote. As previously described, the MIB510 is connected to the MICAz via the Hirose 51 pin connector.

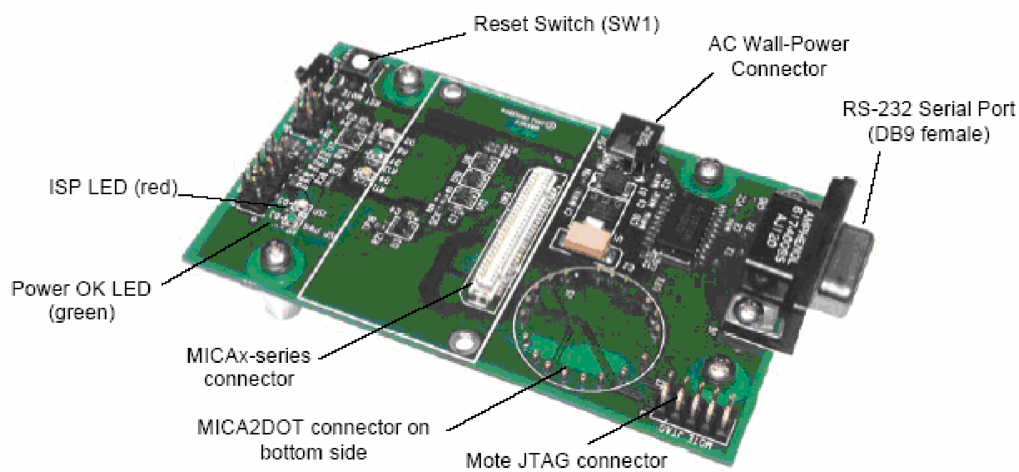


Figure 8. MIB510 Serial Gateway [Ref 6]

1. Specifications

The MIB510 interface board is a multi-purpose interface board used with the MICAz. Power is supplied via an external power adapter. The MIB510 has the following key features:

- RS-232 mote serial port and reprogramming port
- Atmega16L on-board in-system processor (ISP) to program the Motes
- Onboard regulator, will accept 5 – 7 V via external power supply
- Supplies 3 V nominal power to attached mote
- 51 pin Hirose connector for connection to MICAz
- Reset switch for resetting both Mote and MIB510 processors [Ref 6]

2. Use in Thesis

In this thesis, the MIB510 was connected to a laptop, which enabled the sensor data streaming from the MICAz to be converted and made available for usage by the monitoring programs in place. In a shipboard setting, the MIB510 would be connected to a NCAP unit or a local server, which would replace the laptop in this scenario. The usage MIB- 510 represents an intermediate step in that the ultimate goal of this project would be replace both the MIB510 and the laptop with the Crossbow Stargate Gateway (SPB400).

D. CROSSBOW STARGATE GATEWAY (SPB400)

Crossbow's Stargate represents the next generation in wireless sensor network development. It utilizes Intel's latest generation 400 MHz XScale® processor (PXA255) in a single board computer enabling enhanced communications and sensor signal processing capabilities. Utilizing the accessory daughter board, it can be enable to interface with a wired LAN, USB connection, or a RS-232 serial connection. Using the accompanying PCMCIA compact flash card, it can be configured to interface with a standard 820.11a/b wireless LAN. [Ref 7]

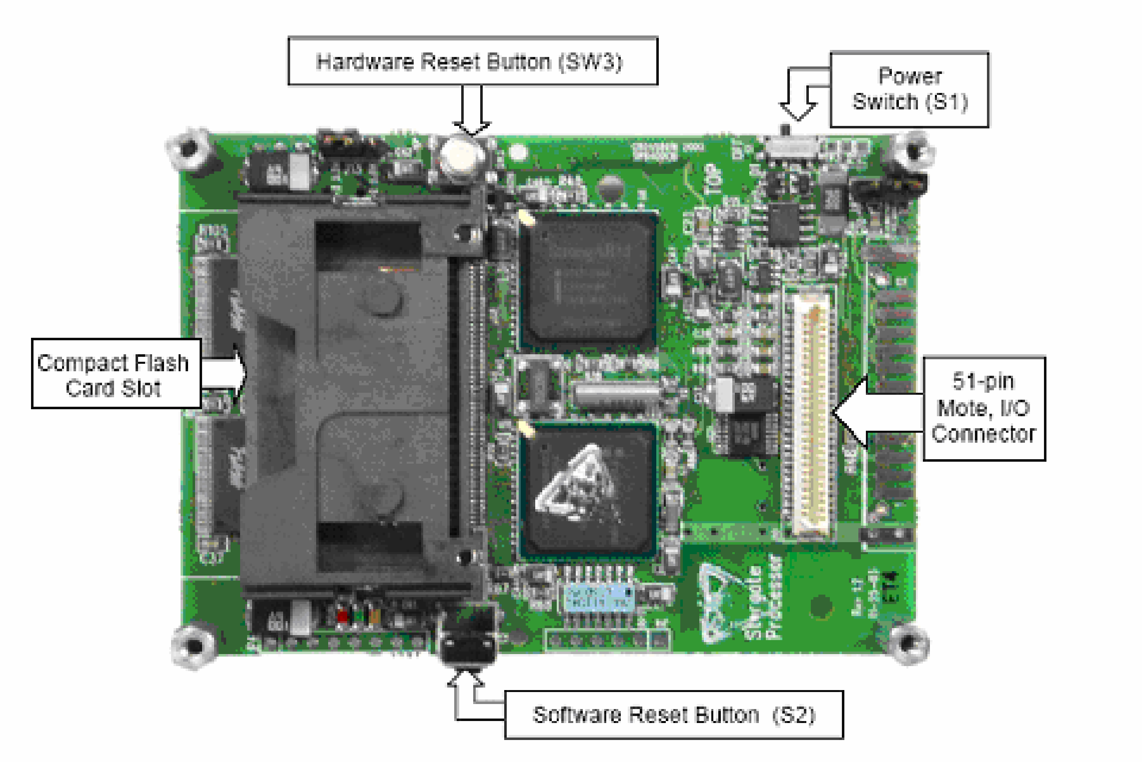


Figure 9. SPB400 Stargate (top view)

Figure 10. SPB400 Stargate (bottom view) [Ref 7]

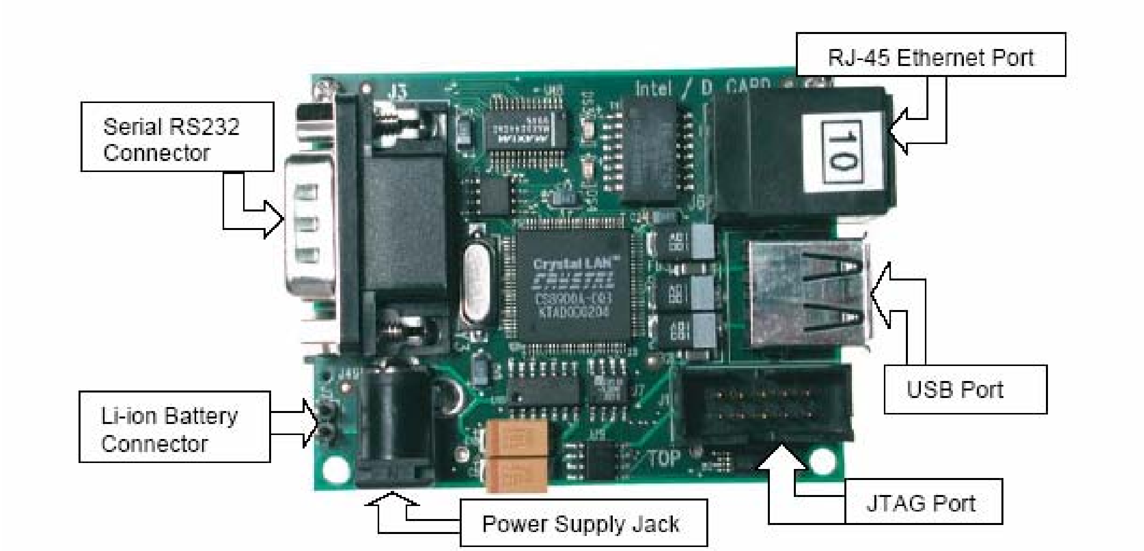


Figure 11. Stargate Daughter Board [Ref 7]

1. Specifications

Dimensions of the Stargate is 3.5” × 2.5”. Some key specifications of the unit are:

- 32-bit, 400 MHz Intel PXA255 XScale RISC processor.
- SA1111 StrongARM companion chip for multiple I/O access.
- 32 MB of Intel StrataFlash.
- 64 MB of SDRAM.
- 1 Type II CompactFlash+ slot.
- 1 PCMCIA lot
- Reset button
- Real time clock
- Lithium ion battery option
- MICA2 and MICAz Mote capability, GPIO/SSP and other signals via 51-pin expansion connector
- I2C connector via an installable header

- 51-pin daughter card interface for:
    - Wired Ethernet via a 10 Base-T Ethernet port
    - Host USB
    - JTAG port
    - External A/C power supply adapter
    - RS-232 serial port via DB-9 connector [Ref 7]

2. Use in Thesis

Though the unit was not received in enough time to incorporate into the thesis, some initial studies were conducted to test the feasibility of using the platform as part of the integrated project. The proposed usage of the Stargate would be to replace the MIB510 gateway and the associated laptop/tablet PC to create a customizable 802.11a/b wireless sensor network gateway capable of performing embedded sensor signal processing. In the current iteration of the project, the signal is received at the MIB510 and sent via a serial connection to the laptop, which processes and converts the data into engineering units. The laptop then prepares the data and makes it available for the monitoring programs such as ICAS via a wired LAN or an 802.11 wireless network. Due to the onboard processing capabilities of the Stargate, the conversion can easily be done using a software code embedded into the onboard memory. The Stargate, utilizing the Zigbee and the 802.11 a/b standards, can then act as a fully wireless gateway for the sensor network allowing a greater flexibility in the placement of the gateway with minimal support infrastructure. Figure 12 illustrates the Stargate in a hardened case for use in a shipboard setting.

Figure 12. SPB400 Stargate in Hardened Case for Use in Shipboard Setting [Ref 7]

E. CROSSBOW MICA2 DATA ACQUISITION MODULE (MDA300CA)

The MICA2 Data Acquisition Module (MDA300CA) acts as the interface for the raw analog data streaming from the standard analog sensor to the MICAz mote. The MDA300CA connects to the mote via the 51 pin connection and draws power for itself and the connected sensor from the parent mote.

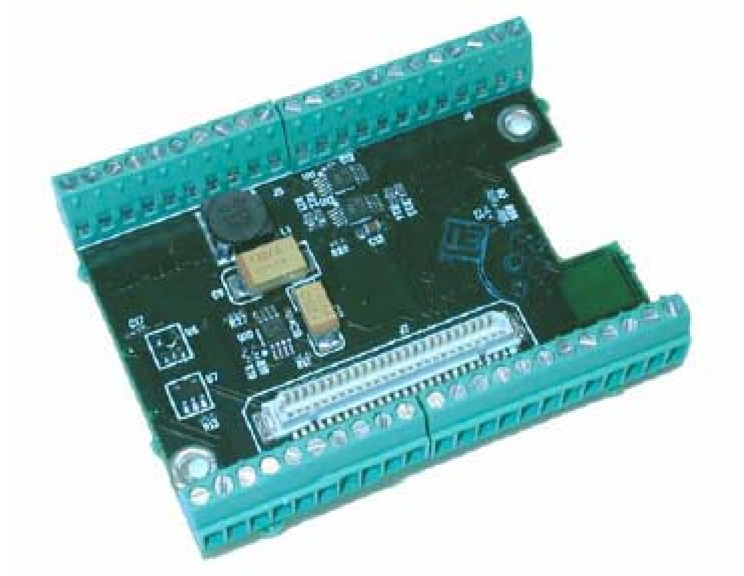


Figure 13. MDA300CA Data Acquisition Module [Ref 5]

1. Specifications

The key specifications for the MDA300CA are:

- +VDD to GND*..............................–0.3V to +5.5V
- 2.5 V, 3.3 V, and 5 V available for powering external sensor

Digital Lines:

- Input voltage range**..…….-0.5 V to VDD+ 0.5 V
- Continuous output low current…..……….50 mA
- Continuous output high current………..…–4 mA

Analog Lines:

- Input voltage range.………-0.2 V to VCC + 0.5 V Typically 0 V to 2.5

Counter Line:

- Input voltage range ………………….0 V to 5.5V

Relays:

- Maximum Contact Voltage……………..….100V
- Maximum Contact Current…..…………..150mA [Ref 5]

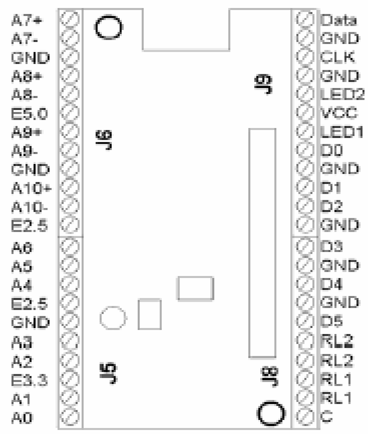


Figure 14. MDA300CA Wiring Schematic [Ref 5]

2. Use in Thesis

The MDA300CA was used as a DAQ module to connect the analog Honeywell pressure sensor to the MICAz mote. The MDA300CA once connected to the MICAz using the standard 51 pin connection outputs 2.5 V, 3.3 V, or a 5.0 V and associated ground for use by the sensor. The pressure output from the sensor, limited from 0 to 2.5 volts, is then read by an analog input channel labeled A0 through A10. Capability for reading a digital input or outputting a digital signal for use in valve actuation also exists using this module.

F. HONEYWELL PRESSURE SENSOR/TRANSDUCER

The Honeywell pressure sensor serves as the primary sensing device in this thesis. This sensor was selected for its small size, relatively low power consumption, and its voltage input and output requirements. It is shown below mounted on a fabricated printed circuit board.

Figure 15. Honeywell Pressure Sensor/Transducer on a PCB Mount

1. Specifications

• Measurement Type	Gage
• Signal Conditioning	Amplified
• Pressure Range	0 psi to 100 psi
• Maximum Overpressure1	50.0 psi
• Supply Voltage	4.75 Vdc min., 5.25 Vdc typ., 6.50 Vdc max.
• Response Time	8.0 ms typ., 11.0 ms max.
• Full Scale Span	4.0 Vdc
• Zero Pressure Offset	0.420 min., 0.500 typ., 0.580 max.
• Total Error (% Full Scale)	± 2.0 % Span
• Shock	50 G for 11 ms
• Vibration	10 g at 20 Hz to 2000 Hz
• Operating Temperature Range	-20 °C to 105 °C [-4 °F to 221 °F]
• Storage Temperature Range	-40 °C to 125 °C [-40 °F to 257 °F] [Ref 8]

2. Use in Thesis

The Honeywell pressure transducer was mounted onto a printed circuit board and connected to the MDA300CA DAQ module. The MDA300CA DAQ module supplied the 5 V input voltage into the sensor and received the measurement voltage output from the sensor. The output of the sensor was reduced to less than 2.5 V by utilizing two 22 kΩ resistors in a voltage divider configuration. The printed circuit board utilized in this thesis was designed by the author with the help of James Calusdian. The plans for the board were then sent off to PBCEX.com where it was fabricated.

G. MAXSTREAM XBEE™/XBEE-PRO™ OEM RF MODULES

A potential alternative to the Crossbow motes and gateway was the Maxtream XBEE RF Modules.

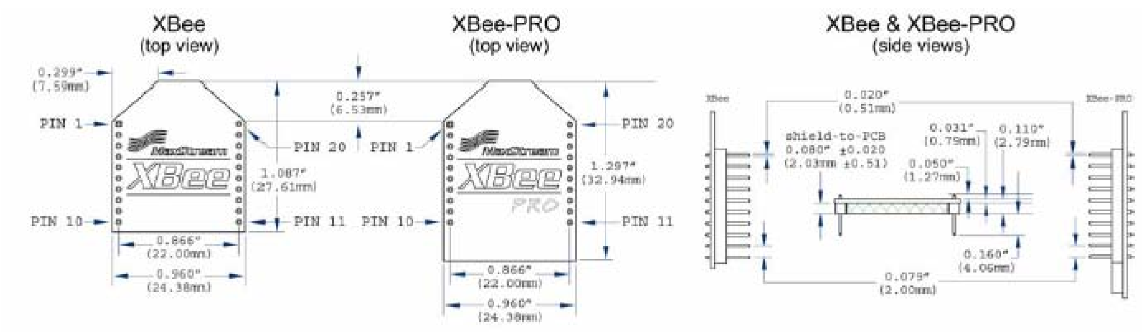


Figure 16. Maxstream XBEE RF Module

1. Specifications

Specification	XBee	XBee-PRO
Performance		
Range: Indoor/Urban (w/ 1.9 dB Whip or 2.1 dB Dipole antenna)	up to 100 ft. (30m)	Up to 300' (100m)
Range: Outdoor RF line-of-sight (w/ 1.9 dB Whip or 2.1 dB Dipole antenna)	up to 300 ft. (100m)	Up to 1 mile (1500m)
Transmit Power Output (software selectable)	1mW (0 dBm)	60 mW (18 dBm) conducted, 100 mW (20 dBm) EIRP*
RF Data Rate	250,000 bps	250,000 bps
Interface Data Rate (software selectable)	1200 - 115200 bps (non-standard baud rates also supported)	1200 - 115200 bps (non-standard baud rates also supported)
Receiver Sensitivity	-92 dBm (1% packet error rate)	-100 dBm (1% packet error rate)
Power Requirements		
Supply Voltage	2.8 – 3.4 V	2.8 – 3.4 V
Transmit Current (typical)	45mA (@ 3.3 V)	If PL=0 (10dBm): 137mA(@3.3V), 139mA(@3.0V) PL=1 (12dBm): 155mA (@3.3V), 153mA(@3.0V) PL=2 (14dBm): 170mA (@3.3V), 171mA(@3.0V) PL=3 (16dBm): 188mA (@3.3V), 195mA(@3.0V) PL=4 (18dBm): 214mA (@3.3V), 227mA(@3.0V)
Idle / Receive Current (typical)	50mA (@ 3.3 V)	55mA (@ 3.3 V)
Power-down Current (@ 3.0 V)	< 10 µA	< 10 µA
General		
Operating Frequency	ISM 2.4 GHz	ISM 2.4 GHz
Dimensions	0.960" x 1.087" (2.438cm x 2.761cm)	0.960" x 1.297" (2.438cm x 3.294cm)
Operating Temperature	-40 to 85° C (industrial)	-40 to 85° C (industrial)
Antenna Options	U.FL Connector, Chip Antenna or Whip Antenna	U.FL Connector, Chip Antenna or Whip Antenna

Table 1. Maxstream XBEE RF Module Specifications [from Ref 9]

2. Use in Thesis

Though not used in this thesis, this platform has demonstrated promise for use as a strictly Zigbee enabled modem and data repeater. This platform would be ideal due to its small size and low power usage for use with an accelerometer or vibration sensor where the signal detection and processing would be done with an external unit. Further research must be conducted to test the connectivity of this platform with the Crossbow motes and gateways currently in use in this project. [Ref 9]

IV. SOFTWARE DESCRIPTION AND DISCUSSION

A. INTRODUCTION TO SOFTWARE

This chapter describes the software used in this thesis. In the first portion, the software provided by the manufacturer for use in programming the motes is described. These programs are MoteView, SurgeView, and Crimson Editor. The second portion of the chapter discusses the programs developed for use in data acquisition and processing. These programs were compiled and processed using LabView version 6.0 and are called ZigbeeSerialRead.exe and Zigbee_to_IP_Sever.exe. These programs and their usage are described in detail later on in this chapter.

B. MOTE-VIEW

1. Mote-View Functionalities

The primary function of the program is to monitor the communications between the individual motes and the gateway. Figure 16 illustrates the data that can be displayed using the Mote-View program. The primary indications of interests are the mote voltage signals which give indication of battery life remaining and the ADC voltage signals which for these motes indicate the raw analog voltage signals output from the sensors, an indication of pressure. The color of the mote icons on the left hand side of the program's graphic user interface (GUI) indicates the overall health of the connection from the mote to the gateway. In this case, the green color indicates the signal is good and the latest signal received from the particular mote is current. Another useful functionality of the Mote-View program is the ability to individually programming the mote that is connected to the gateway. Figure 17 shows the parameters that can be set using the program. This screen can be accessed by selecting the Tools icon on the menu bar and selecting the Program Mote option. [Ref 10]

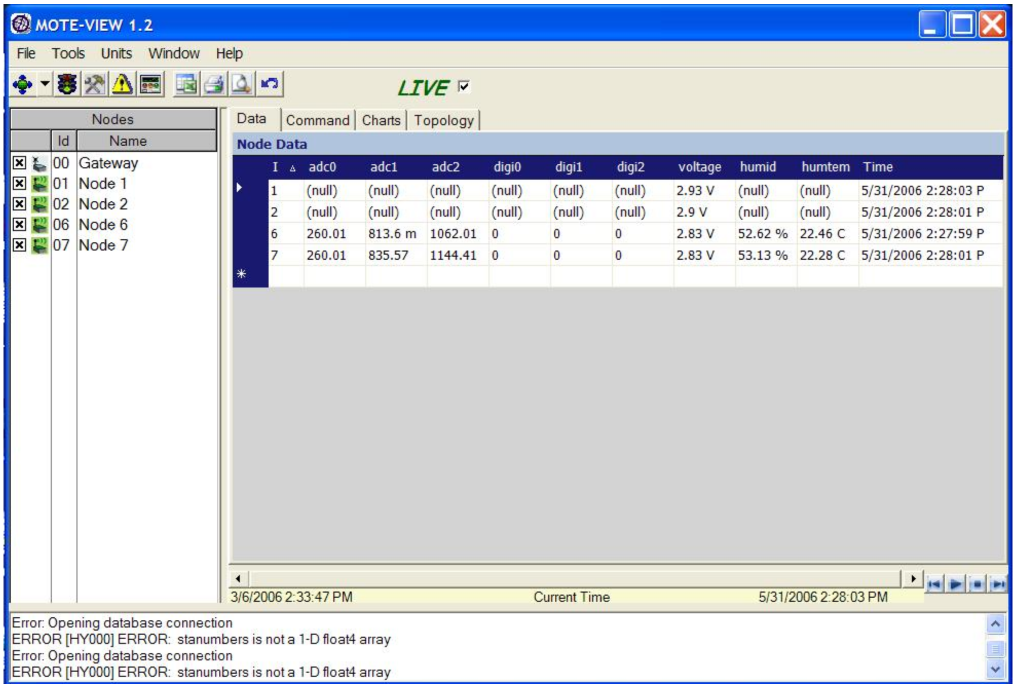


Figure 17. Mote-View 1.2 Primary Display

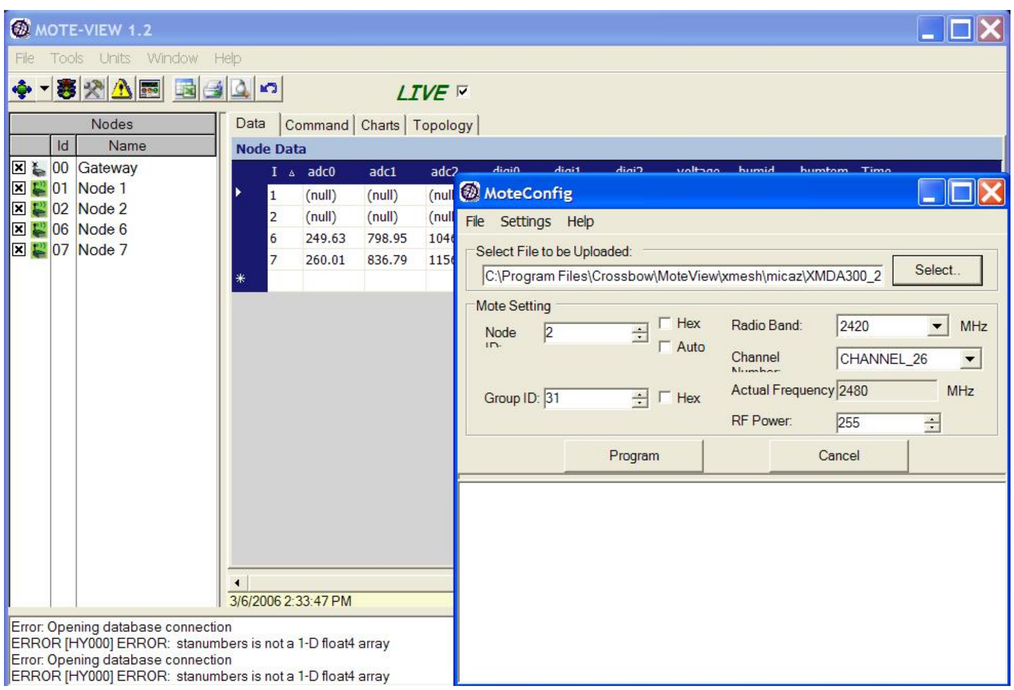


Figure 18. Mote-View 1.2 Uploading Operating File to Mote

2. Usage

The Mote-View program was used in this thesis in two primary ways. First, the program was utilized to program the individual sensor and gateway motes with the compiled executable program. In this case, we loaded the Xmesh MDA300 protocols and set the group and mote ID's as indicated in Figure 17. Channel 26 was selected for the thesis to minimize interference with the 802.11g wireless network already in place.

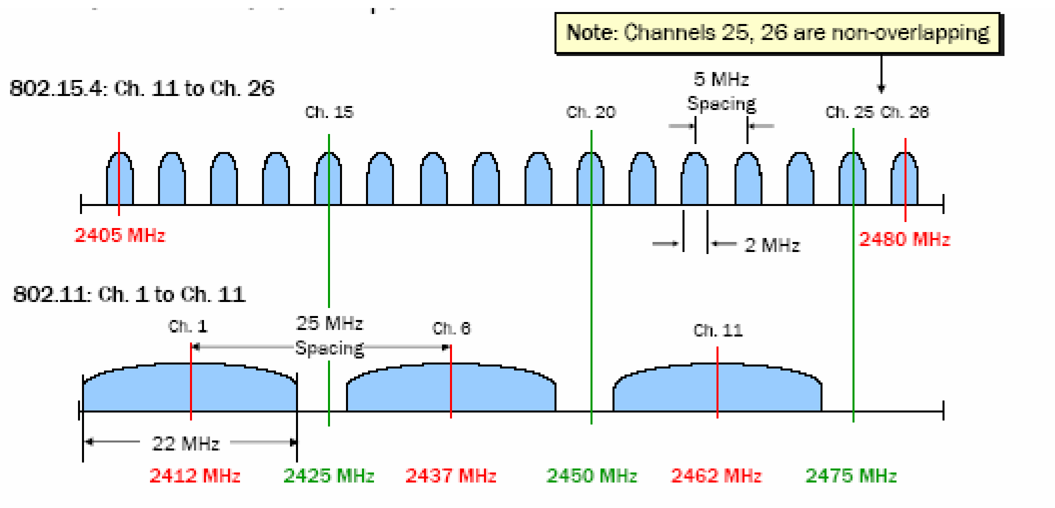


Figure 19. IEEE 802.15.4 and 802.11b Spectrum Relationship [Ref 11]

The program was also utilized to measure the battery voltage of the individual motes. In Figure 18, the chart option was selected to plot the battery voltage over time to determine the power consumption both for the motes with the sensor and DAQ module attached and the motes with no external accessories. A detailed description of the results will be given in Chapter V.

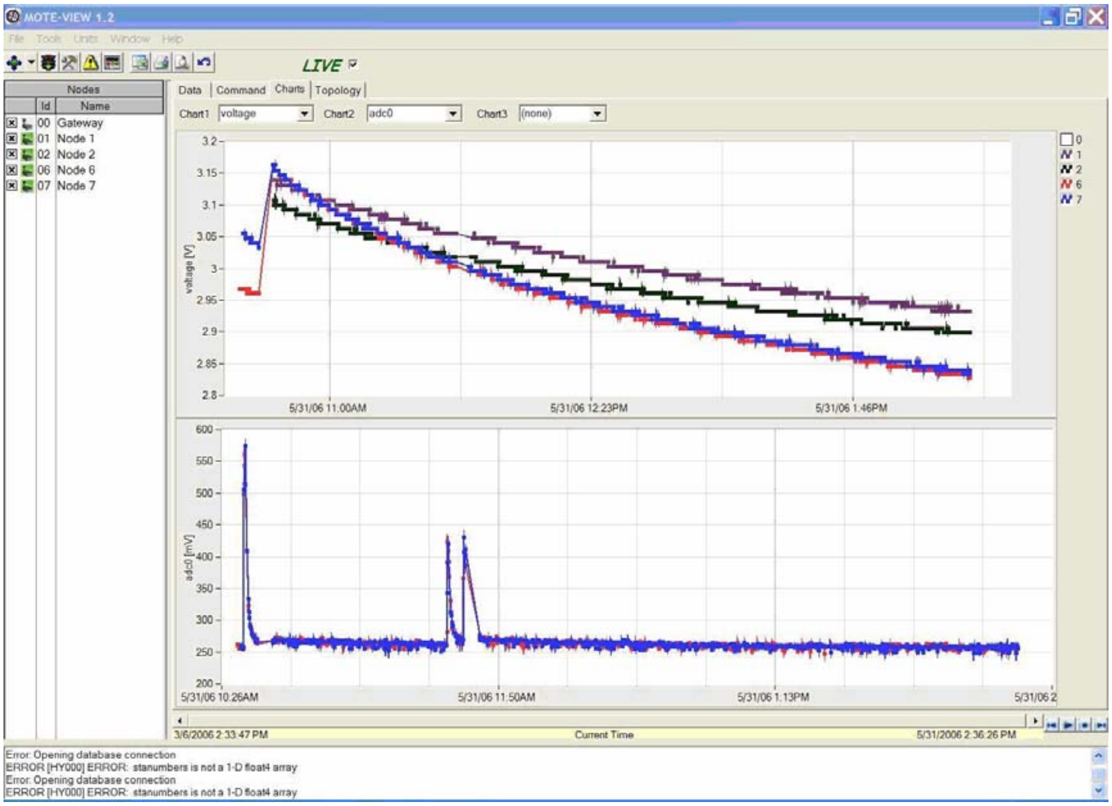


Figure 20. Mote-View 1.2 Utilizing Chart Mode

C. SURGE-VIEW

1. Surge-View Functionalities

Surge-View is supplied by the manufacturer for use in analyzing mote performance. The program once connected to a serial gateway will display incoming packet information. It has two primary displays. The first display shown below in Figure 20 is the network topology of the sensor network. From this screen, the user can see very quickly the link path and quality of the each sensor mote. The functionality of this screen can be increased by replacing the standard white background with a floor plan of an engine room compartment and adjusting mote locations on the display.

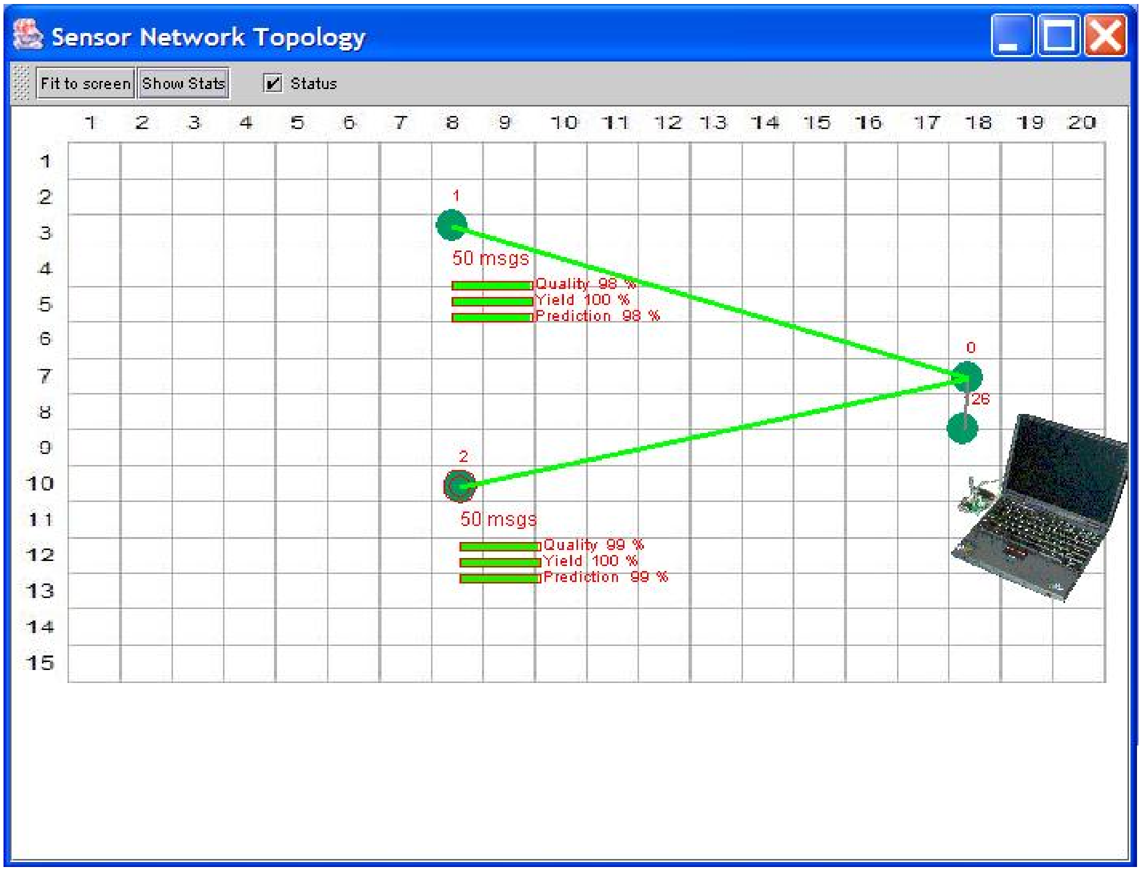
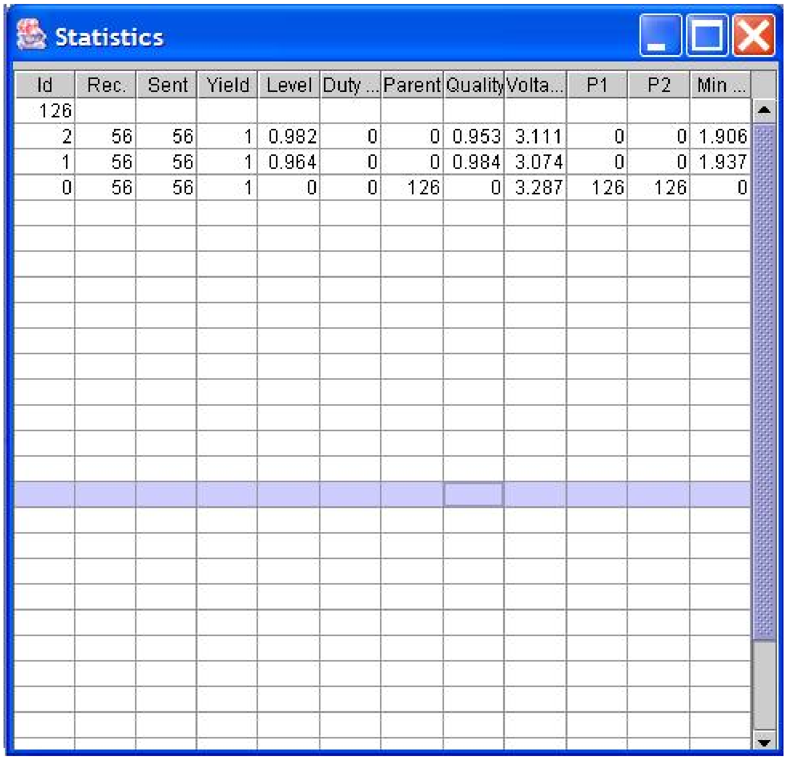


Figure 21. Surge-View Topology Display

The second display is the statistics display shown in Figure 21. This screen provides the user with network information given in the topology display, but in a tabulated form. However, this screen also provides additional mote communications information such as the number of packets received versus sent as well as the battery voltage of the mote, allowing the user to see the overall health and communications efficiency of the mote. This information can be captured in a data file by executing the Surge-View program by typing the following in the command window:

Surge [Group ID] < [Log File Name.txt]

Ex: *Surge 31 < log.txt*



Id	Rec.	Sent	Yield	Level	Duty ...	Parent	Quality	Volta...	P1	P2	Min ...
126											
2	56	56	1	0.982	0	0	0.953	3.111	0	0	1.906
1	56	56	1	0.964	0	0	0.984	3.074	0	0	1.937
0	56	56	1	0	0	126	0	3.287	126	126	0

Figure 22. Surge-View Statistics Display

2. Usage

The program was primarily used in this project during the range testing portion of the feasibility study. As previously stated the test motes were place 10 meters from the gateway and turned on. The program was then used to receive and measure at least 100 packets of data inbound from the test motes. The data file generated by Surge-View was then used to determine the link efficiency by comparing the packets received versus the packets sent and also the average link quality for each packet received.

D. CRIMSON EDITOR

1. Crimson Editor Functionalities

Crimson Editor is a source code editor for the window platform. It serves as a primary interface for the user to customize and program the tiny-OS operating applications onto the mote. It is similar to a notepad editing program but allows a much greater ease of use and functionality. Some of the more helpful functions are *find and replace*, *directory tree window*, *spell checker*, and the ability to use *user tools and macros*. Crimson Editor also enables the user to compile a tiny-OS mote operating program and to upload it to serial connected mote.

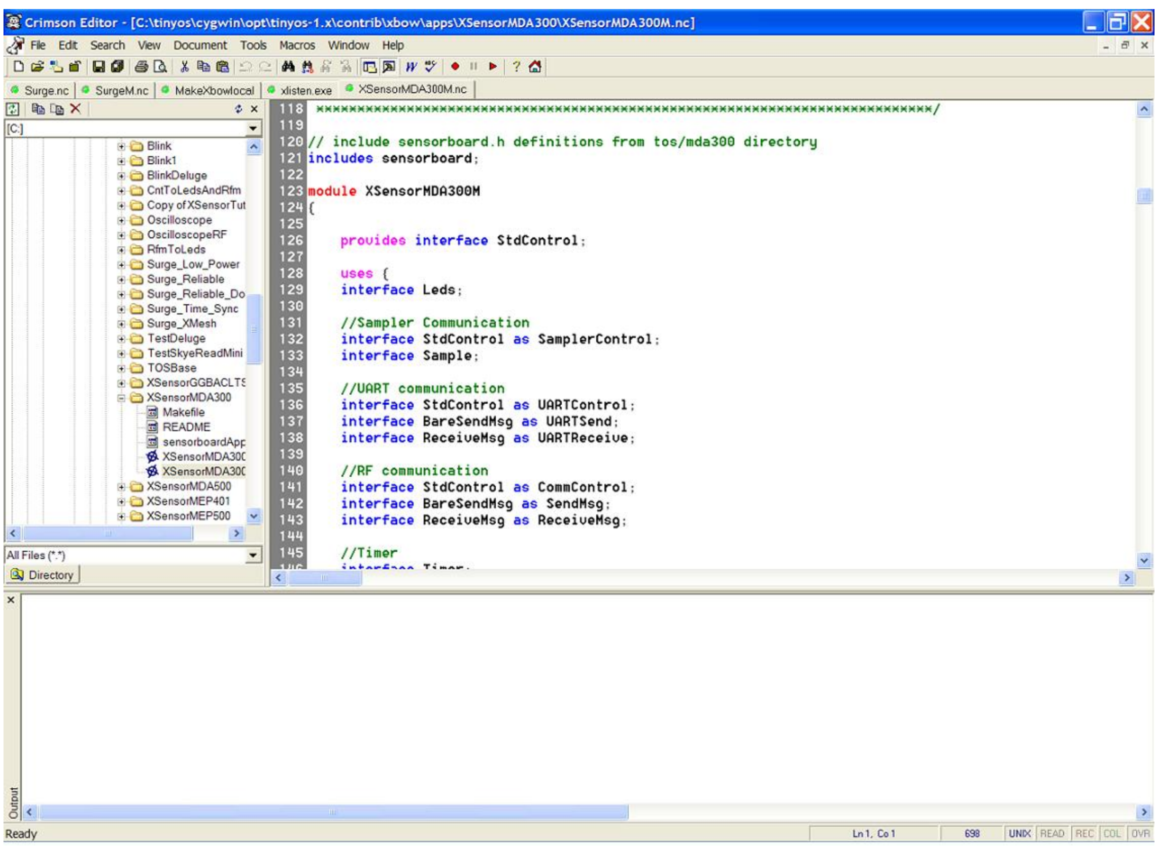


Figure 23. Crimson Editor

2. Usage

The Crimson Editor was used to modify the manufactured provided Xmesh codes for the MICAz motes. Some of the modifications included the adjustment of the sleep time in reduced power mode, reduction in transmission power and transmission rate. The mote LED's were also tested to simulate various alarm modes such as low battery and low or high signal input from the sensor.

E. ZIGBEESERIALREAD.EXE

ZigbeeSerialRead.exe is the first iteration program for analyzing the mote sensor data received at the RS-232 serial port. The program serves as a display interface for the data received at the serial port via the MIB510 serial gateway and the sensor motes via the Zigbee wireless connection. Although the most recent version of LabVIEW available is version 8.0, the program was designed in Labview version 6.0 to ease incorporation into the SWACLC program and minimize version mismatch errors.

LabVIEW is a multiplatform, data flow language. Programming in LabVIEW is designed to be intuitive and relies heavily on logic diagrams and modular programming. The primary program components in LabVIEW are called Virtual Instruments or VI's for short. Each VI is organized into two main components, the front panel or the graphic user interface (GUI) and the block diagram. The GUI is used as the primary user interface and is composed of a combination of inputs called controls and outputs called indicators. The block diagram is where the actual program is assembled. In the block diagram, the programmer links the terminals of the various controls and indicators do develop a logical sequence of processes. It is this intuitive programming combined with a user friendly GUI development that makes LabVIEW an ideal programming tool for interfacing the many different systems that are used in this project.

1. Role in the Thesis

ZigbeeSerialRead.exe receives the data at the RS-232 serial port, in this case the port is ASRL::INSTR or COM1. The system then generates an 80 byte buffer at the port to ensure a full packet. The packets are delineated at both ends by a code 7E, thereby easing the parsing of the data into complete packets. The program then converts the raw data received from the gateway into engineering units and the output is displayed on the graphic user interface (GUI) displayed as Figure 24. The primary indications of interest are the mote identifiers such as mote number and group. These numbers will be used to identify the sensor the incoming is associated with. The other primary indications are the battery voltage and sensor output. The data received for these indications are given in raw integer form to minimize the packet size. The program also displays the date and time stamp of the packet. As the packets transmitted do not indicate a time of transmission, the time displayed is the system time of the server at time of the signal reception. This program has limited functionality since it does not have the capacity to further parse the incoming data to associate it with a specific sensor or sensor group. This program was designed to be an intermediate step to demonstrate the ability to take incoming serial port data from the sensors and parse it into meaningful data for the user.

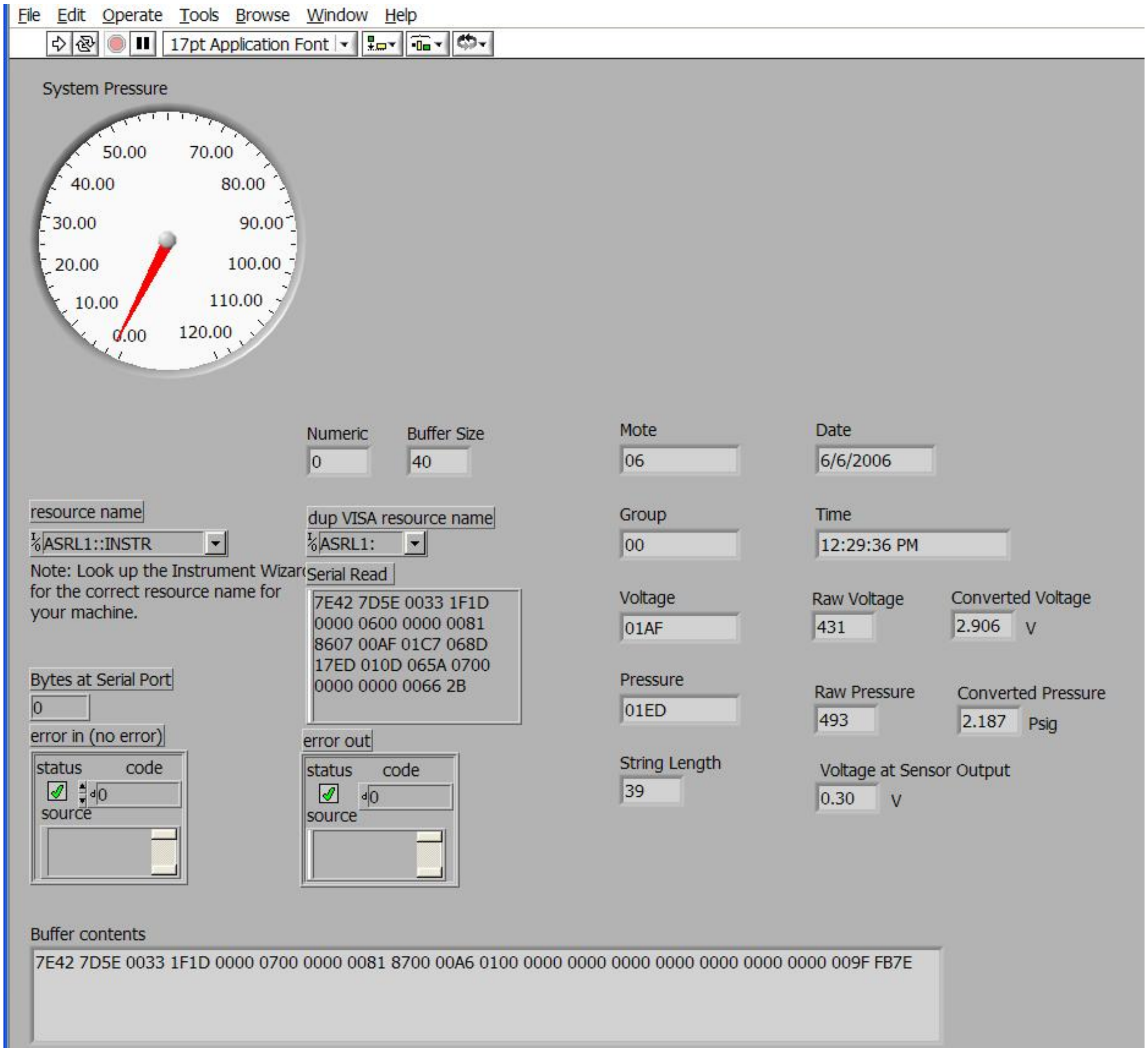


Figure 24. ZigbeeSerialRead.exe Front Panel

2. Block Diagram

The diagram for ZigbeeSerialRead.exe is depicted in Figure 25. The diagram contains three main portions. The first portion establishes a connection to the serial port and defines the connection parameters such as baud rate, flow control, parity, and connection name. The program then passes this connection information to the next portion which generates the 80 byte buffer, once this buffer size has been exceeded the program then passes to the parsing and display portion the oldest full packet, delineated by a ‘7E’ at both the beginning and the end of the packet. The final portion of the program parses the 40 byte packet into useful data. From the packet information such as mote and group ID’s are determined. Also, the raw data for battery voltage and the sensor outputs are also parsed and converted to engineering units. The final two portions of the program, the buffer generation and data parse are combined into a while loop with an incorporated shift register to maintain the buffer.

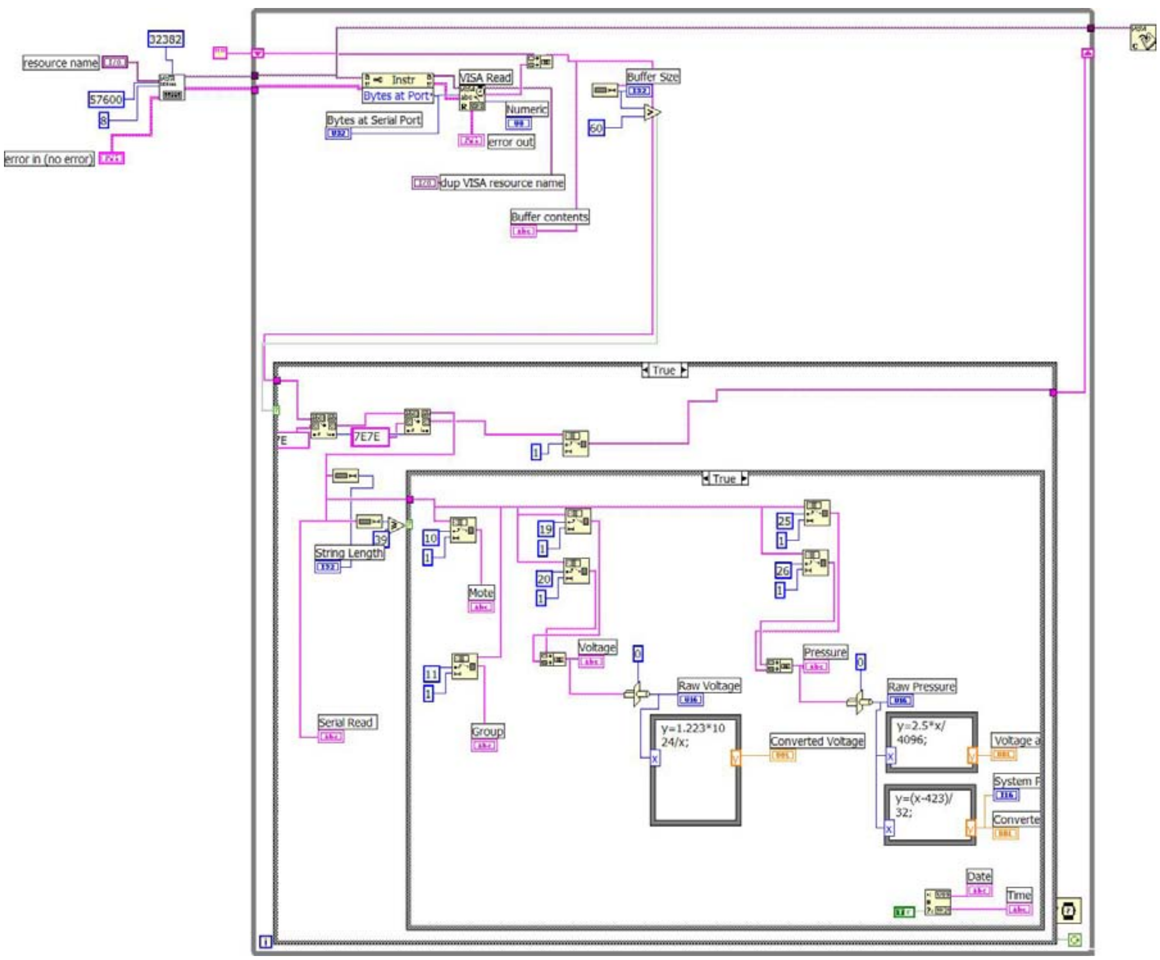


Figure 25. Diagram of ZigbeeSerialRead.exe

F. ZIGBEE_TO_IP_SERVER.EXE AND ZIGBEE_CLIENT.EXE

Zigbee_to_IP_Server.exe is the next generation of software development and retains all of the functionalities of the previous program. Also, programmed using LabVIEW 6.0, the structure of the block diagram is similar to the ZigbeeSerialRead.exe. Similarly, the program also receives the sensor data at serial port and generates a buffer to parse out the sensor packets. Once a completed packet is received, the program then further parses the data to determine the mote number and group in order to associate the sensor data to a specific sensor. The sensor data is then saved in the associated data block reserved for the specific sensor. Another major improvement incorporated into this program is the ability to interface with remote workstations over a standard ships LAN, therefore acting as a server for the distributing the data from the sensor network. The program incorporates a listening subroutine in the block diagram which upon receiving a request from a client workstation will initiate a connection to pass the sensor data to the requesting monitoring station.. The associated program, Zigbee_Client.exe, acts a client program which runs on a remote work station. This program was designed to mimic the Integrated Condition Assessment System (ICAS) program which currently being used in the fleet to monitor ship conditions. The Zigbee_Client.exe program first establishes the TCP/IP connection to the server. Once the connection is established, the program sends a request for data and passes the originating NCAP ID and message. The server then responds by transmitting a 68 byte packet containing the NCAP ID, and 8 sets of 8 byte double precision numbers for each channel of data input into the server.

1. Role in the Thesis

As described in the previous section, the Zigbee_to_IP_Server.exe allows a workstation to act as a server for the entire Zigbee sensor network. The MIB510 Serial Gateway is connected to this workstation and streams data packets received from the sensor motes via the serial connection to the server computer. The server then parses each individual packet and correlates the data to a specific sensor and prepares it for distribution to remote monitoring stations by performing the conversion into engineering units and restructuring the outbound packets into a form ready for use by an ICAS monitoring station. The system then waits for a client to log in via the TCP/IP connection via the ship's LAN. In this case this was achieved using a remote station connected to the server via the LAN using the Zigbee_client.exe program. The front panels for the Zigbee_to_IP_Server.exe and the Zigbee_client.exe programs are shown below as Figure 26 and Figure 27.

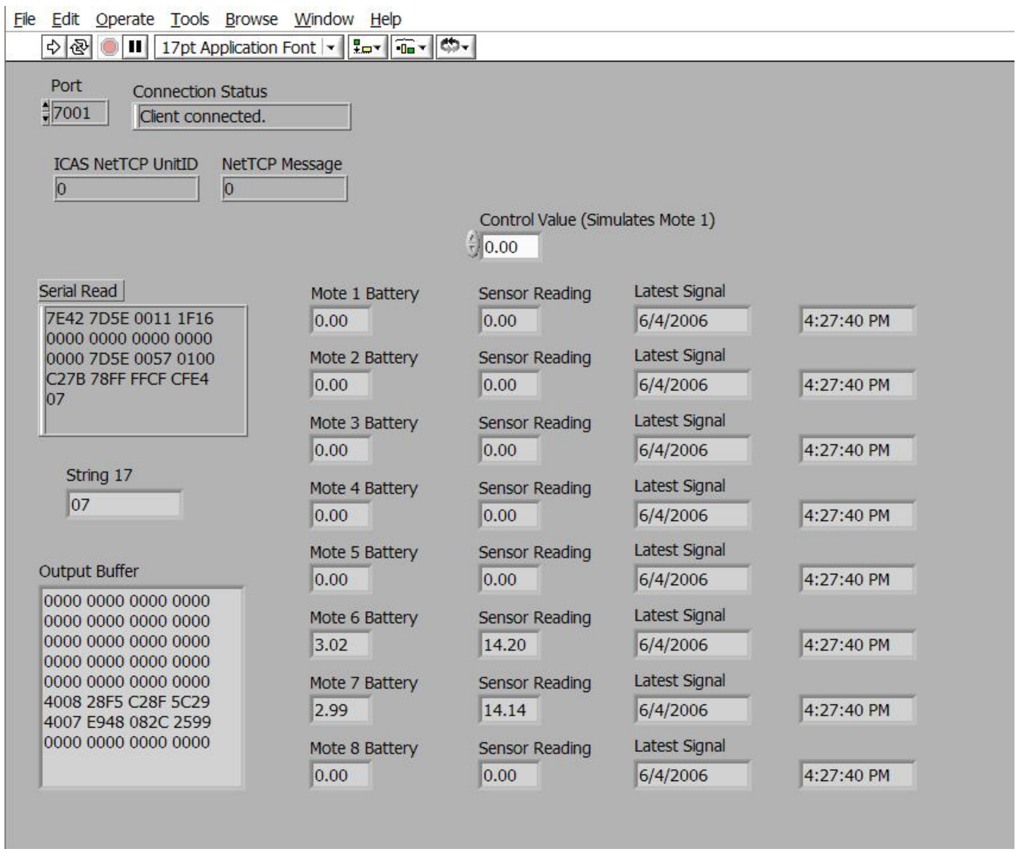


Figure 26. Zigbee_to_IP_Server.exe Front Panel

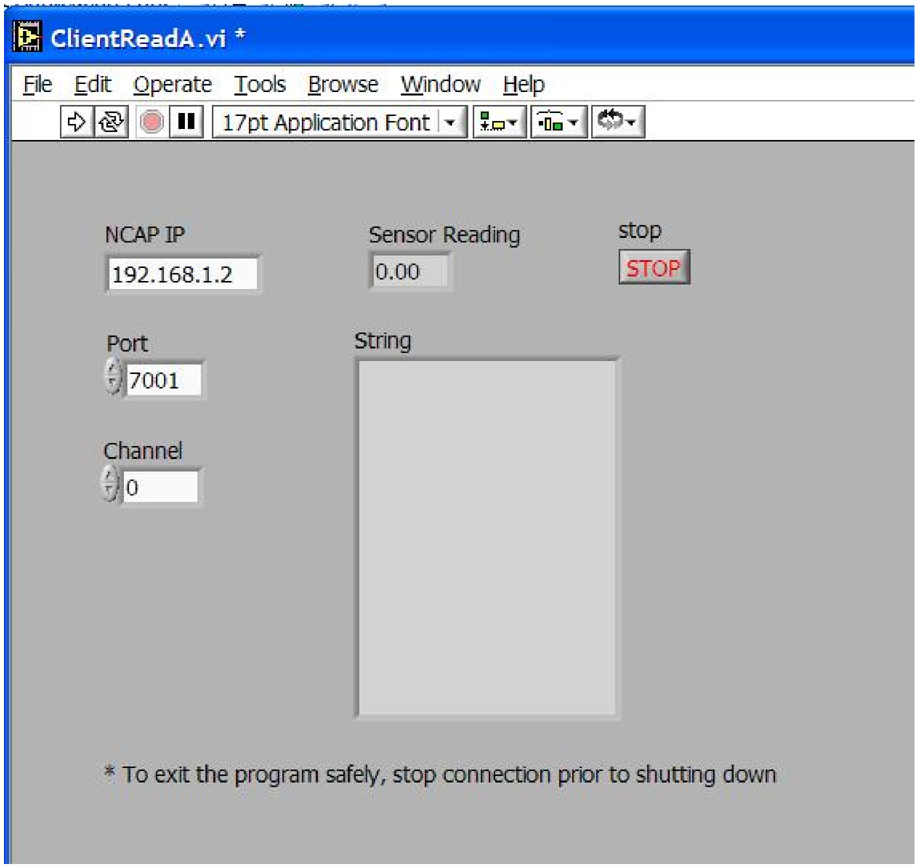


Figure 27. Zigbee_TCP_IP_Client.exe Front Panel

2. Block Diagram

The diagram for Zigbee_to_IP_Server.exe is depicted below in Figure 28 below. Similar to the ZigbeeSerialRead.exe program, this program utilizes the same subroutine to establish a connection to the serial port. However, in this program, the first portion of the program also utilizes the parallel processing capability of LabView to listen for a TCP/IP client to request a connection to the server. Once this connection has been established, the connection data such as port and IP addresses are passed to the next portion of the program. The second portion of the program establishes a continuous loop which will establish the buffer, similar to the ZigbeeSerialRead.exe program, and pass each incoming packet to the next portion of the program. The third portion of the program processes the incoming packet. Each packet is analyzed for the group and mote identifiers and the resultant data is converted to engineering units and stored in an appropriate local variable. This data is then compiled and transmitted to the ICAS client.

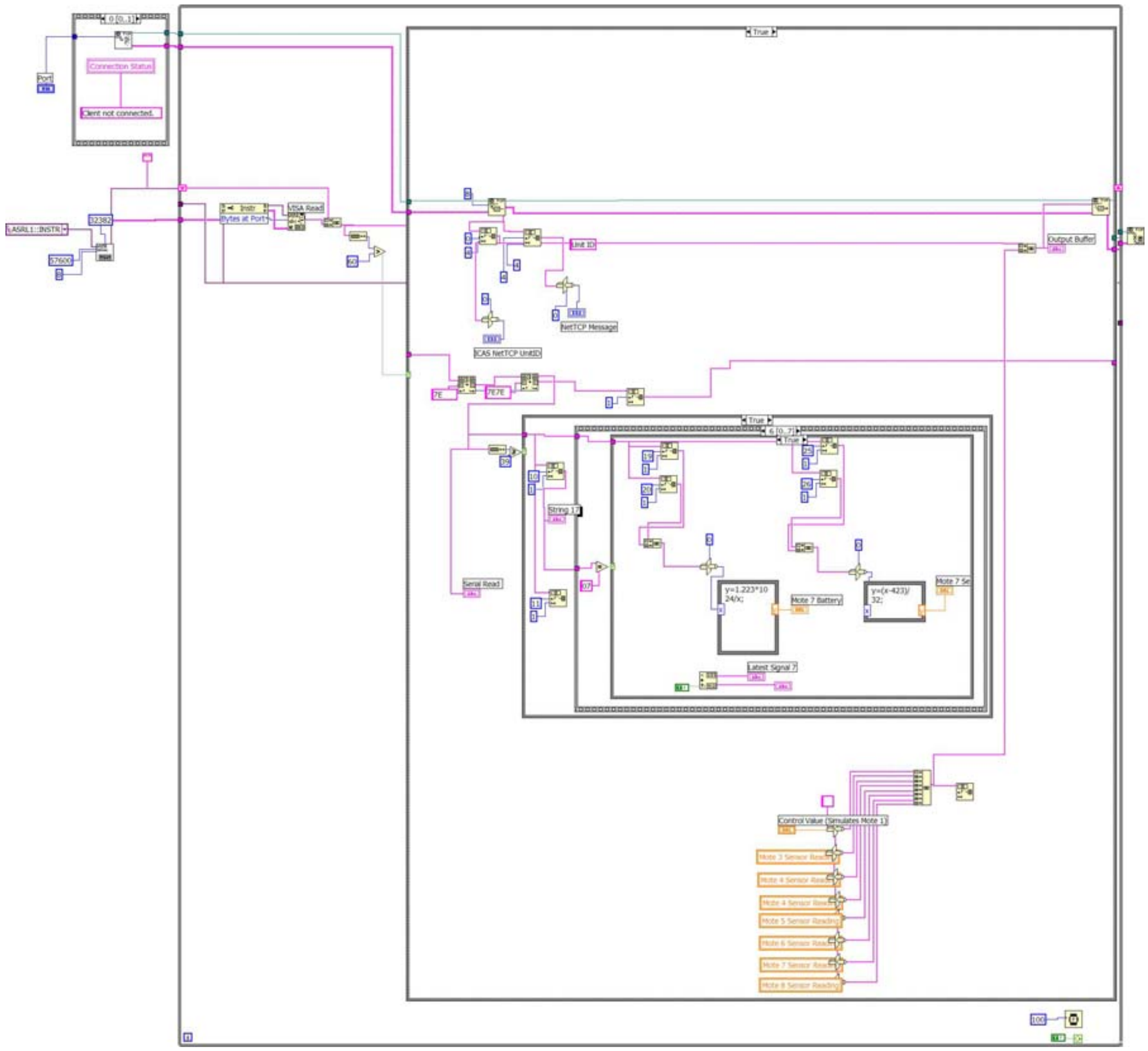


Figure 28. Zigbee_to_IP_Server.exe Diagram

The block diagram for the Zigbee_to_IP_Client.exe program is shown below in Figure 29. This is a simple program whose functionality is to mimic the ICAS client to test the Zigbee_to_IP_Server.exe program. In the first portion of the program the connection to the server is acquired. Once the connection is established, the data from the server streams into the client program where it parses each channel input and readies it for display.

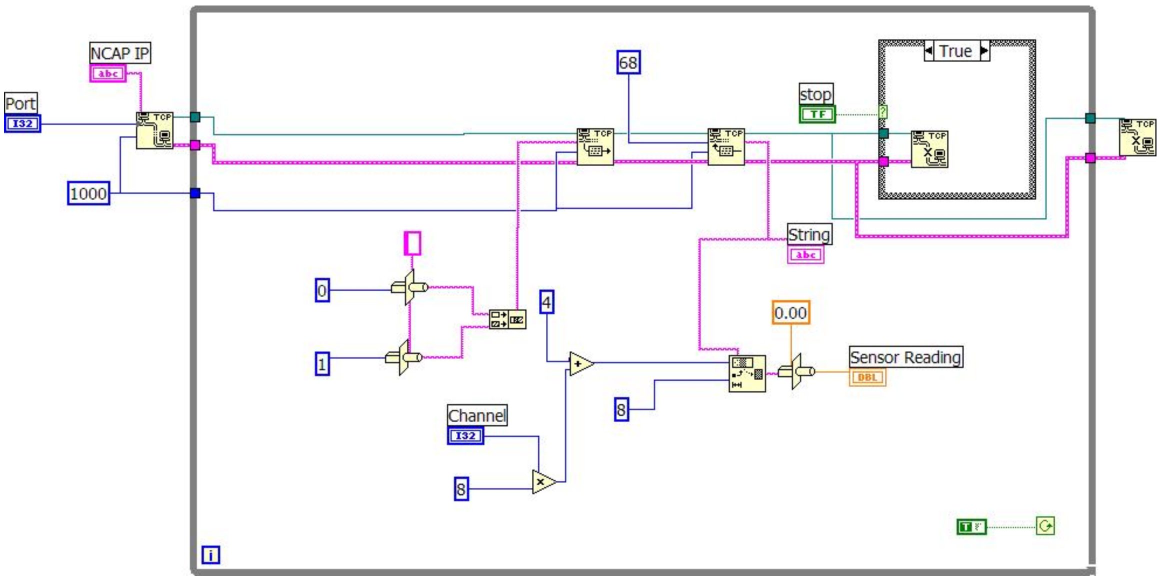


Figure 29. Zigbee_TCP_IP_Client.exe Diagram

V. RESULTS AND LESSONS LEARNED

A. INTRODUCTION

This chapter discusses the results of this thesis, covering the results of the initial feasibility testing conducted in the lab. It describes the prototype pressure sensor that was built according to the specifications defined in the previous chapters. This section also describes how the sensor interfaces with the ICAS monitoring program and the calibration program described in Chapter II. Finally, the chapter discusses the various lesson learned throughout the thesis.

B. FEASIBILITY STUDY RESULTS

As a sensor platform designed to operate in a shipboard environment, it is critical that the sensors developed during this project meet with some basic parameters. Perhaps the most important question to answer is simply, "Will this work"? To answer this, initial range and reliability tests must be conducted to ensure that the sensor, once implemented, will communicate reliably with a gateway and server at ranges comparable to what would be expected aboard a naval vessel. The other significant question is the feasibility of the platform. Currently there are many robust wireless communications platforms in existence such as Bluetooth, 802.11b, and a plethora of other radio communications devices. However, many of these other platforms were considered impractical due to the amount of power required to power these devices, and consequently the expected battery life. To answer this question of practicality, a battery life test will be conducted both on the independent mote and the integrated sensor once developed. This test will occur in high power transmit and receive mode, as well as continuous operation by the microprocessor. Once the battery life in this mode of operation has been established, the total expected battery life can be extrapolated utilizing reduced power sleep modes, lower data rates, and a low power transmit mode tailored to a reduced transmission range.

1. Range and Reliability Tests

In a shipboard, engine room environment, it is expected that the maximum distance between any sensors be between 5 to 8 meters, assuming more than one Zigbee sensor is deployed within the space. As the number of sensors deployed in the space increases, the maximum expected distance between sensors decreases exponentially. For the purposes of this experiment, a distance of 10 meters with no obstacles was selected to conduct the tests. This is well with in the published range of 100 feet for the motes selected. The tests were conducted with the gateway at various aspects to the motes to account for any sensor orientation issues that might arise. Each test was run for 1 hour in an environment with existing 802.11b communications infrastructure to ensure interference would not be an issue. The SurgeView program used to collect the data. In each of the cases it was discovered that the gateway was able to capture 100 percent of the packets transmitted by the motes. The normalized mean signal strength and standard deviation of each of the received is shown below in Table 1 to give an indication of the worst aspect for communications. From the data below, it is evident that for short data ranges, all aspects perform similarly well.

		Mote Orientation						
		0°	45°	90°	135°	180°	TOP	BOTTOM
Mote 1	Mean	0.93	0.94	0.92	0.92	0.93	0.91	0.93
	STD	0.13	0.07	0.12	0.07	0.08	0.08	0.09
Mote 2	Mean	0.85	0.93	0.94	0.92	0.90	0.94	0.94
	STD	0.16	0.07	0.08	0.08	0.08	0.06	0.08

Table 2. Mean Received Signal Strength

Once completed, an extended range and reliability testing was conducted at 10 meters for a period of 24 hours to determine if there would be a signal degradation associated with a longer run time. The extended time period resulted in a 99.99% success rate for communication with a 12921 packets received out of 12924 packets transmitted.

Finally, to test the reliability of mesh topology to maintain itself and reroute communications, multi-hop communications was established with the mote 1 and gateway and with mote 2 acting as a parent for mote 1 by forwarding the data received from mote 1 to the gateway. Power was secured to mote 2, and time was measured to determine how before direct communications between mote 1 and the gateway was established. Once this was done, power was restored to mote 2 and time measure for mote 2 to be acquired by the gateway. The test was conducted successfully conducted 50 times and in each case, both mote 1 and mote 2 were acquired by the gateway. The mean time for acquisition for mote 1 was 35.2 seconds, mote 2, 40.5seconds.

2. Battery Life

The primary purpose of the utilizing Zigbee technology to develop a wireless sensor is to improve efficiency and reduce the workload on the end user, the sailors. Also, because the sensor is required to be truly wireless, it is impractical to remove the wire required for communications and maintain the wire used to power the sensor. Therefore, it is desired to achieve the longest possible battery life to prevent an increase in workload for the engineering technicians caused by having to replace several hundred sets of batteries for these wireless sensors. Ideally, a battery life extending out to two years would allow the greatest operational flexibility by allowing a mass battery replacement as part of a ships pre or post-deployment maintenance, or as part of annual or biannual Preventative Maintenance System (PMS) plan.

As was described earlier, the battery life test was conducted with the motes operating in continuous high power operating mode. Motes 1 and 2 are operating independently with no external devices attached. Motes 3 and 4 are fully integrated pressure sensors with the DAQ unit and pressure transducer attached. The results are plotted below in Figure 30.

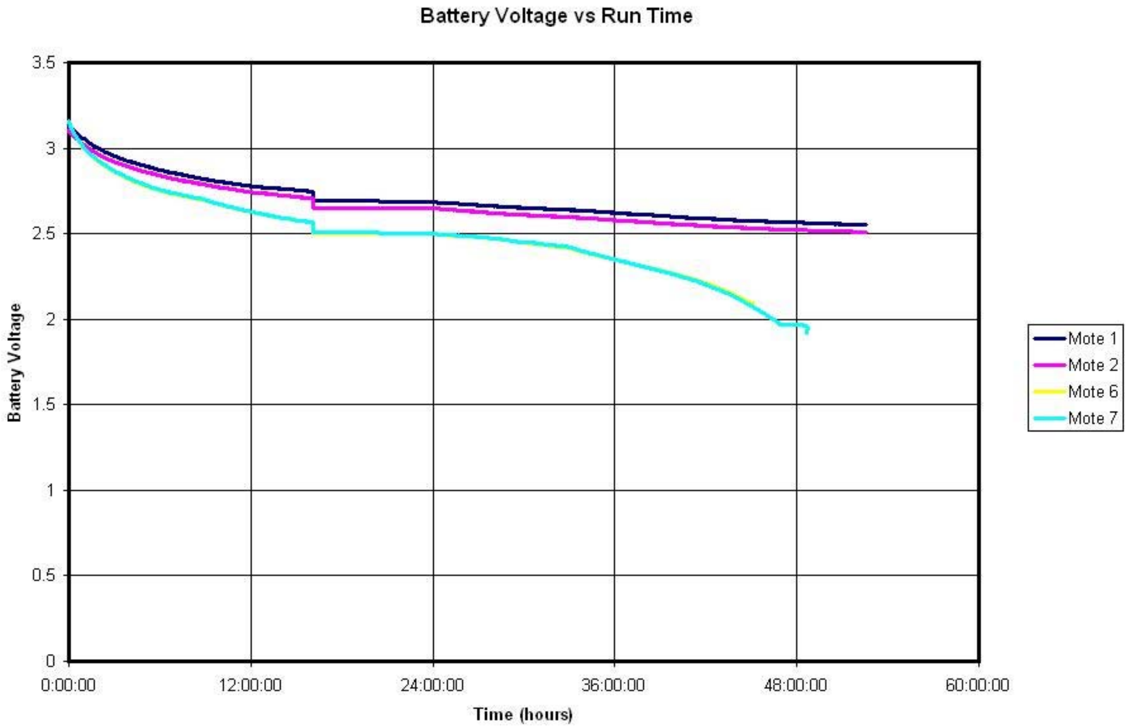


Figure 30. Battery Voltage Over Operating Time at Full Power

The sensor data and battery voltage for the integrated sensor are plotted over time in Figure 31 below to illustrate sensor behavior near end of life. It is evident from the figure below that the sensor behaves erratically once the input voltage from the batteries fall below approximately 2.2 VDC. For two standard AA alkaline batteries, with approximately 3000 mAh of total charge, this occurs at approximately 44-hour mark. From this, a nominal battery life of 40 hours was decided to ensure sufficient margin for battery replacement before sensor failure. In addition, this battery test shows that the integrated sensor draws a mean approximate current of 70 mA.

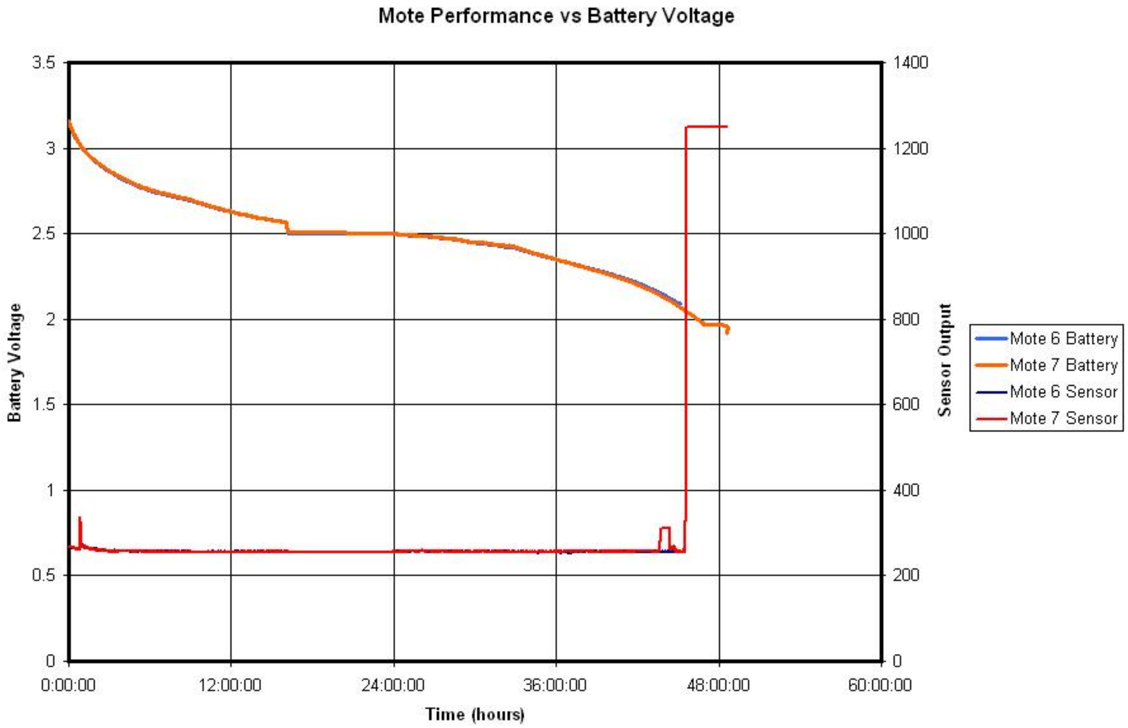


Figure 31. Sensor Reliability at End of Life

This mean current of 70 mA shows definite potential for an extended battery life of greater than two years utilizing a combination of reduced power sleep modes, lower data rates, and larger capacity batteries. Assuming a two standard D cell batteries have 80,000 mAh of total charge, the breakdown of total estimated battery life is with respect to percentage of time spent in sleep mode is shown below in Table 2 below. The battery life is listed below in total months of effective life. It is estimated at that utilizing a low power sleep mode for approximately 95% of the time would allow sensor operation beyond the desired 24-month threshold.

Time in Sleep Mode	0	50%	75%	90%	95%	98%
Battery Life (Months)	1.54	3.07	6.14	15.36	30.72	76.80

Table 3. Estimated Battery Life

C. PROTOTYPE PRESSURE SENSOR

The prototype pressure sensor was developed utilizing the methodology described in Chapter II. The basic structure of the sensor is shown again in Figure 32 below for illustration purposes. The sensor was developed utilizing the Crossbow MICAZ (MPR2400) mote processor and radio module serving as the communications backbone of the integrated sensor assembly. The mote was then connected via the 51 pin connection to the MDA300CA DAQ module. The DAQ module then supplied a 5 VDC source as well as an associated ground to power the pressure transducer. To ease the assembly of the integrated sensor, a printed circuit board was designed and the plans shipped to PCBEX.com for fabrication. The incorporation of a printed circuit board design allowed an ease of mounting for the pressure transducer as well as allowing the use of two 20 kΩ resistors to step down the 0.5 V to 4.5V output of the pressure transducer to below 2.5V allowed by the DAQ module. The overall power supply for the entire sensor assembly (not shown) is two alkaline AA batteries connected via a factory installed mount installed on the mote.

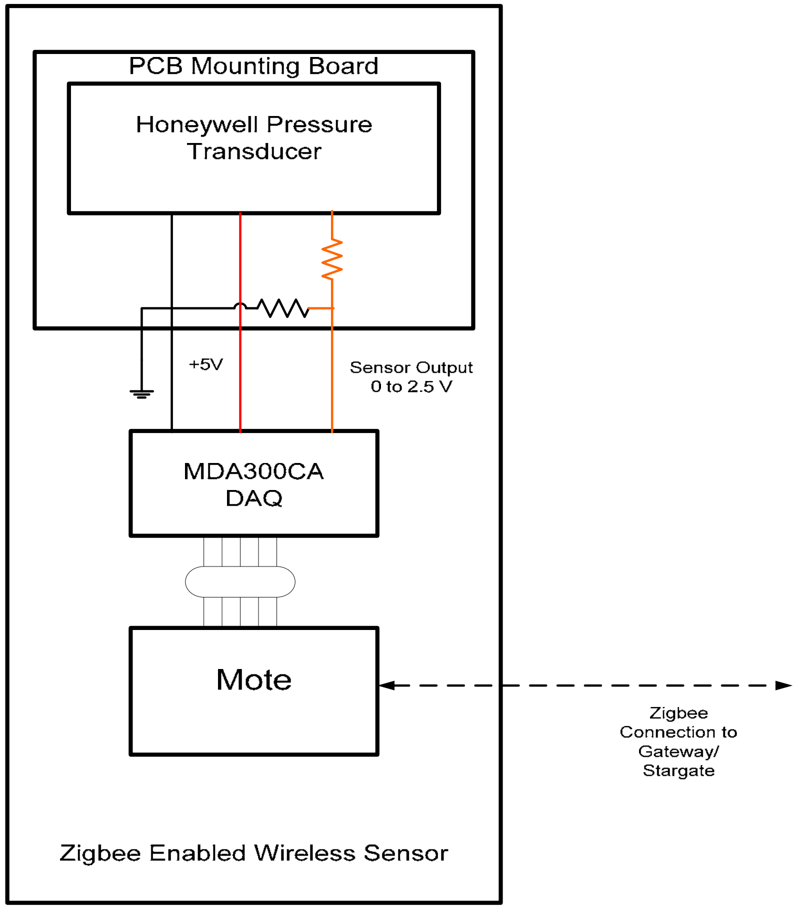


Figure 32. Generalized Diagram of Integrated Sensor Assembly

The completed sensor assembly is shown below in Figure 33, pictured without the battery mount. The completed sensor measures 2.5”x 1.75” x 0.8” and weighs approximately 85 grams. The input port of the pressure sensor is a standard 1/16” and the sensor is accurate to within 0.1 psig over a range of 0 to 100 psig.

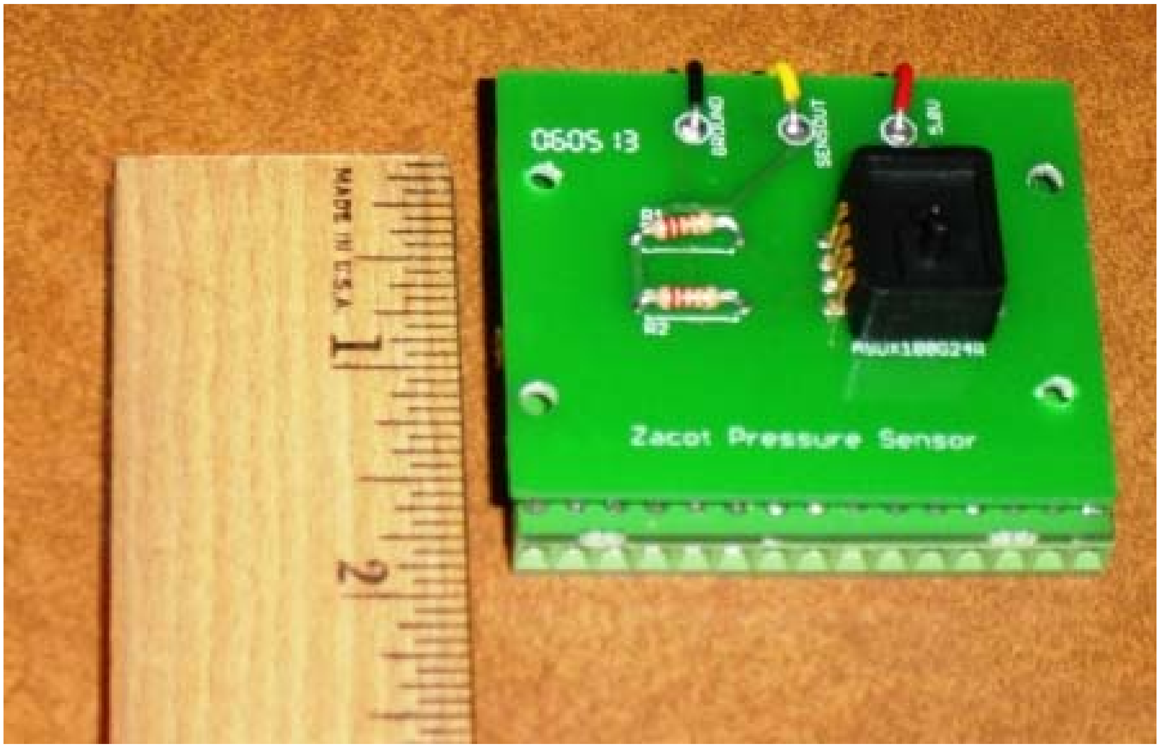


Figure 33. Prototype Sensor

Once assembled, the sensor was then interfaced to the existing ICAS infrastructure using the Zigbee_to_IP_Server.exe. As described, the sensor data, in the form of analog voltage ranging from 0.25 V to 2.25 V is transmitted from the sensor mote to the MIB 510 gateway in a 40 byte packet. The gateway is connected via a serial port connection to a server computer running the Zigbee_to_IP_Server.exe program. The program interprets the incoming data packet, converts the analog voltage output from the pressure transducer into a calibrated pressure data and disseminates the data to all necessary ICAS workstations. A sample of the ICAS workstation output is shown below in Figure 34 below.

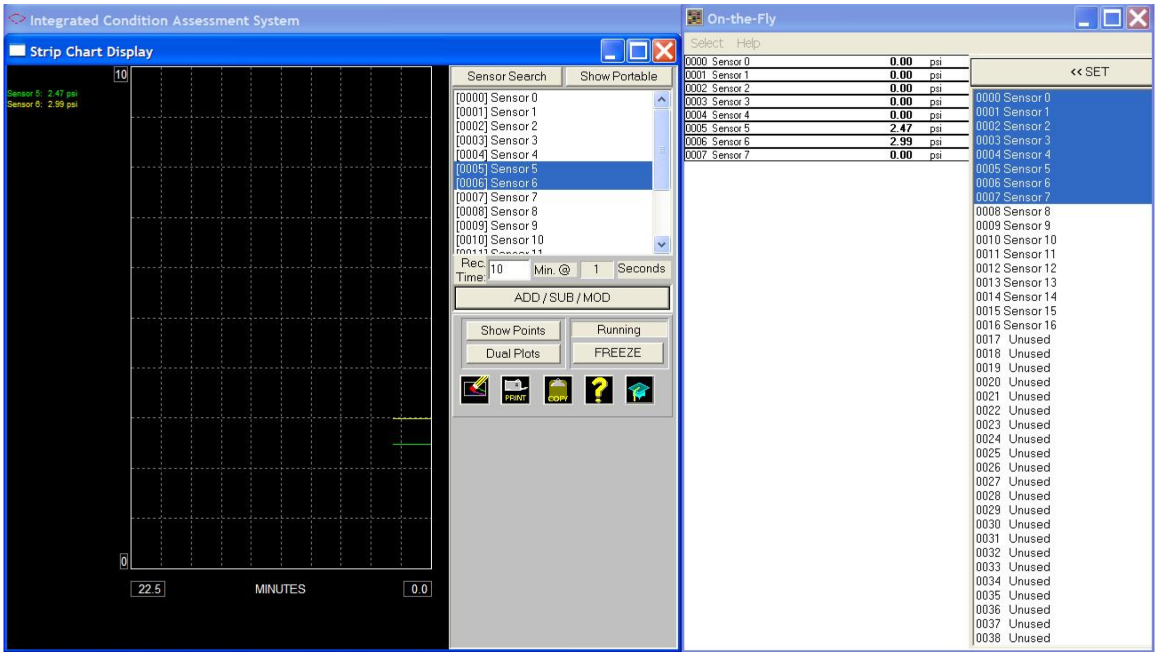


Figure 34. ICAS Display of Prototype Sensor

D. LESSONS LEARNED

There were five primary lessons learned from this project.

- It is important to be aware of the format of the data output from the Zigbee motes.
- Allowing the LabView program to control the buffer size can cause incomplete packets to be sent to the subsequent programs.
- It is easier to program the motes utilizing the Crossbow supplied MoteView program
- Motes should be powered down prior to connection to the gateway for programming
- Under no circumstances should the motes be programmed when the battery voltage is less that 2.5 VDC

1. Data Format

The data format coming from the Zigbee motes are hexadecimal code. For example, the battery voltage is an integer value, however when the Labview program interprets the data from the serial port, this data is converted to a string constant representing the ASCII equivalent. If an integer value of 15 or 0F is received at the port, this value is converted to an ASCII equivalent of 0 46 or “0” “F” is output at the buffer, leading to erroneous data if not caught. This requires careful bookkeeping to convert the data into an appropriate form.

2. Buffer Management

The LabView program allows an automatic management of the buffer generated at the serial port. However, if this feature is used, the user has no access to the data waiting in the buffer. This can allow partial packets or erroneously parsed packets to be sent to the server program causing errors down stream. By disabling the automatic buffer generation and utilizing a series of while loops and shift registers, a buffer can be generated while allowing the user full access to the contents of the buffer.

3. Mote Programming

Although the Crimson Editor allows the user to interface directly with the mote that is connected to the gateway, it was discovered that this method is cumbersome and prone to error. It was determined that using Crimson Editor to program in TinyOS and compiling the program, and using the mote programming GUI of the MoteView program to upload the file simplified process and reduced final number of errors in programming.

4. Mote Power Down Prior to Connection to Gateway

Although the motes themselves are fairly robust, it is recommended that the motes be powered down prior to connection to gateway. Although infrequent, not powering down the motes prior to connection can cause memory errors within the mote programming and make the system difficult to recover.

5. Mote Programming at Greater than 2.5 VDC

Similar to the previous lesson learned, under no circumstance should the motes be programmed wirelessly while the mote battery voltage is less than 2.5 VDC. At lower operating voltages, the programming feature of the mote behaves erratically and often introduces errors into the programming. Some errors are not recoverable. Programming of the mote while it is connected directly to the gateway is permissible at any battery voltage.

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VI. CONCLUSIONS

A. SUMMARY

This thesis conducted a feasibility study of utilizing Zigbee technology into a wireless shipboard sensor network. The hardware selected was developed by Crossbow due to the maturity of the hardware and software interfaces. Lab testing was conducted to demonstrate initial feasibility and a prototype pressure sensor was developed. LabVIEW 6.0 was used for interfacing the sensor to the existing sensor infrastructure such as ICAS and the closed loop calibration program that was developed by the SWACLC program. The sensor was able to successfully connect via wireless Zigbee standard both to the gateway and other sensor motes. The LabVIEW programs that were developed then successfully read the serial data from the gateway and readied it for use by the ICAS and calibration programs.

B. CONCLUSIONS

It was determined through initial testing that the Zigbee technology is feasible for use in a shipboard wireless sensor setting. The simplicity of components, sensor range, and the ability to reliably establish and maintain a multi-hop mesh network make this platform nearly ideal in this application. Battery life, though insufficient in continuous high power operation, can be extended to months, even years, utilizing a combination of standard high capacity batteries such as D-cells and power save sleep modes and reduced transmission power.

C. RECOMMENDATIONS FOR FUTURE WORK

The work conducted in this thesis is considered an initial feasibility test and demonstrate that the system has the ability to work in a shipboard setting. Further testing is necessary to demonstrate that the system will operate reliably over an extended period of time in a shipboard setting. Also further software development and hardware integration is required to extend battery life to sufficient levels to prevent additional workload on ships force from battery replacement while the ship is operational. Integration of Crossbow Stargate to replace the MIB510 and the NCAP unit would represent significant savings in power, cost, and allow greater flexibility in gateway placement. Further development to integrate other sensors such as temperature, vibration monitoring and valve/switch position indication would illustrate the robustness of the platform. Finally, interfacing with other Zigbee platforms such as MaxStream and Cirronet units would provide more manufacturing options.

1. Extended Design and Operational Testing

Further testing must be conducted to demonstrate full product feasibility. This testing should include a greater number of Zigbee enabled devices and include other wireless communications devices to test for effects of potential RF interference and the effect of increased data flow on the gateway. This testing should include the presence of an IEEE 802.11a/b/g standard device due to the overlap of 2.4 GHz operating frequency. Testing should also incorporate an extended time testing with low refresh and update rates. Finally, operational testing must be conducted on board test ship to study environmental effects of the Zigbee while operating in a high noise, high humidity environment.

2. Extending Battery Life

For a wireless sensor to be truly effective, the battery life of the sensor should last be a minimum of 18 to 24 months. If shorter, the burden on ship's force due to additional workload requirements of replacing the sensor batteries would negate any potential savings. Strategies for extending the battery life, as discussed previously, would include a modification of the TinyOS executable program installed on the MICAz mote to include a sleep mode and an optimization of the transmit power to reduce power used while maintaining effective transmit range. Utilization of larger capacity batteries would also increase effective battery life.

3. Developing Stargate as a Combination Gateway and Server

As described in Chapter III, the Stargate has the capability of serving as a Zigbee enabled gateway as well as acting as a server platform to convert the sensor data into engineering units and interface with the LAN via TCP/IP or wirelessly through the IEEE 802.11 standard. Combining the functionality of the gateway and server into one platform would result in a simplification of the overall system, savings in cost, and a greater flexibility in platform placement in an engine room environment.

4. Developing Other Types of Sensors

Pressure sensors represent only a fraction of the overall HM&E sensors onboard a modern naval vessel. Utilizing the Zigbee technology into other types of sensors such as temperature, vibration, and position indication would simplify the overall sensor network. This would lead to a simpler, more cost effective system, and lead to overall reduction in cost and training in order to repair and maintain the system.

5. Integrating Other Zigbee Compliant Devices

Integration of other Zigbee compliant devices would enable to Nave to have more manufacturing options. It would also allow a greater lever of competition between vendors, thereby driving down costs.

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