WIRELESS OFFSHORE PLATFORM STRUCTURAL HEALTH MONITORING

By

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FINAL PROJECT REPORT

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CERTIFICATION OF APPROVAL

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Approved:

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TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

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

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Ahmed Mohamed Gamal Eldin

Abstract

Oil platforms are known for their operation in dangerous environments. The most recent technology adapted is the unmanned platform which is a remotely operated platform without any workers on the platform during the operation to lessen the losses occurs in the platforms. To ensure the safety and the reliability of the new platforms a safety monitoring system is required to be developed. In this report, a new structural health and safety monitoring system for unmanned platforms is proposed and developed. The objectives of the project are to develop a system which processes electrical signals to represent structural parameters, develop the proper communication between different parts of the system and test the feasibility of the system. The new system integrates microprocessor technologies and communication technologies to meet the objectives of the proposed system. The project focused on testing the proper connection between the microprocessor and the measuring devices, and studying and simulating the wireless and underwater communication. The system was tested using strain gages to measure strain and half-cell to measure corrosion. The readings obtained were validated against commercial acquisition systems. The results show the efficiency of the system in different applications to measure different structural parameters. The underwater transmission was simulated using OMNET++. The simulation results show low efficiency of acoustic communication which requires further study and investigation.

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CHAPTER 1

INTRODUCTION

Oil platforms are known to be operating in dangerous environments in which it is facing many fatal disasters. Those platforms should be self-sufficient in energy and equipped with solar power panels. Deep-water oil platforms operate in water depth about 3000 meters, as shown in fig. 1. Due to its depth, deep-water platforms are facing more risks; those risks include structural failures and environmental disasters, as shown in fig. 2. In 1980, platform Alexander Kielland collapsed due to a storm in the North Sea causing the death of 123 of the platform's members. Many of the oil and gas companies are trying to apply unmanned oil platforms to reduce the loss in human lives caused due to those accidents. The unmanned platforms are operated remotely and only visited occasionally for maintenance [1]. In order to have better monitoring of the unmanned platforms many monitoring systems had been developed, each monitoring system is responsible of controlling specific factors affecting the platform or the surrounding environment. Those monitoring systems control the safety valves and the shutdown systems placed on the platform in order to shut down the platform in case of emergency.

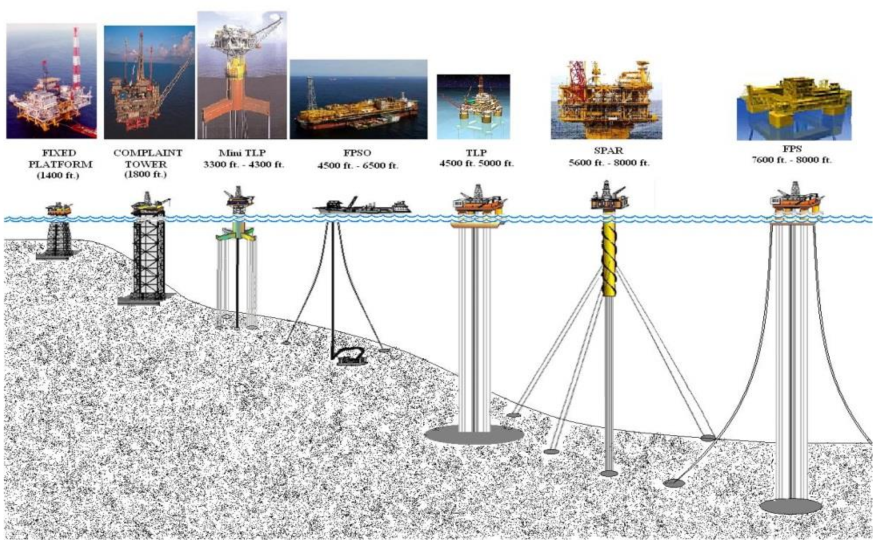


Fig. 1 Oil Platforms [2]

Structural Health monitoring (SHM) is a process of acquisition, processing and analysis of technical data to represent structural parameters to help in management of the structures life cycle [3]. It is important to continuously monitor the structural life cycle in order to reduce the huge amount of money used in enhancement of deficient structures. SHM is able to monitor the behavior under different circumstance and provide potential solutions to ensure the safety of the structures. SHM integrates different engineering fields to enhance the monitoring process. It involves electrical, mechanical, acoustic, information technology and communication technologies to reach structural self-sensing and self-diagnostic [4]. The damage detection patterns can be developed using SHM. A model to predict the structure's response under given conditions can be developed based on the data collected under different circumstances.

Fig. 2 Oil Platform Accident [5]

If the structure is equipped with a monitoring system, the structure is called a "smart structure". A new technology is incorporated in platforms which converts the platforms to SMART platforms. The SMART platforms are equipped with different sensors and measuring devices to measure different factors affecting the platforms with real time data transmission and minimum human intervention. Those platforms use WAN communication like radio transmission or V-Sat for data transmission. In February 2009, British petroleum (BP) installed a monitoring system called DELOS to monitor the environment surrounding the deep-water platforms. The DELOS system was implemented on platforms on depth around 8 kilometers. DELOS system is equipped with onsite memory to store the data gathered and it is visited by ROV for recovery and maintenance every 6 months [6].

A new safety system is proposed to monitor the main parameters affecting the health of oil platforms in general. Equipment and sensors used in this system consist of a combination of off the shelf components and custom designed electronics. Through observing the changes in parameters that are sensitive to affecting factors, an estimate of the overall health of a system can be reached [7]. This system utilizes the advance in the microprocessors and communication technologies.

The study discussed in this paper focuses on processing electrical signals to represent structural parameters and feeding those parameters readings into damage detection algorithm to predict any upcoming disasters. With the help of microprocessor and maritime communication; the measurements are transferred and stored into a web-based database using wireless and cellular network to be accessed remotely. The proposed system should have the following specification: low energy consumption, remote accessing, real time representation, and easier implementation.

1.1 Problem Statement:

Oil platforms are facing many fatal disasters due to the operation in dangerous environments. Those disasters cause many losses in human lives and economical losses. A new type of platforms is used which doesn't include any humans on the operating platforms, those platforms are called Unmanned platforms. The unmanned platforms are remotely operated. To ensure the safety of those platforms, a new safety monitoring system needs to be developed to ensure the absence of any disasters due to structural failure or environmental disasters without any human interference. The system should have the following specifications:

1. Low cost and low energy consumption.
2. Remote accessing.
3. High speed communication.
4. Real time identification of the problems.
5. Simplified representation of the results.
6. Prediction patterns for early identifications of problem.
7. Localization.

1.2 Project Objectives:

The study discussed in this report is predicted to cover the following objectives:

1. Signal Processing: to develop a system capable of processing electrical signals and calculating the equivalent structural parameters for those signals. A prediction algorithm should be developed from those readings for early damage detection.
2. Transmission Systems: to develop and test the communication between different parts of the system. The communication includes radio frequency (RF), cellular and acoustic communication.

1.3 Project Scope:

The mentioned objectives and specifications led to shaping the project scope to fit in the allowed time frame. The project is focusing on three main points to be delivered by the end of the allocated time frame. The three main points of the projects are:

1. Developing a data acquisition system able to monitor strain, corrosion, displacement and temperature.
2. Testing the acquisition system feasibility on structural models.
3. Simulating the data transmission between different parts of the system.

1.4 The Relevancy of the Project:

The safety monitoring system for unmanned platforms is an essential addition to the new technology of unmanned platforms. The project is significant due to the attention given by Malaysian oil and gas companies, in particular PETRONAS, to apply unmanned platforms to reduce risks associated with platforms. One of the key concerns of oil and gas companies on unmanned platforms is real time monitoring of structural failures or environmental disasters.

1.5 Feasibility of the Project:

The project proposed was effectively conducted in the given time frame due to the presence of all the required resources. The hardware needed for this project is present. Microprocessor MSP430G2553 development board is available and will be used. In coordination with civil engineering department, all the structural measuring devices and testing machines can be used to test the new system and validate the results with the comercial measuring systems. The interface between the microprocessor and the measuring devices can be acquired through various datasheets and previous studies. The communication between different parts of the system will be simulated using proper simulation software.

CHAPTER 2

LITERATURE REVIEW

The literature review is conducted based on the project objectives. The literature review is divided into the following sections where each section addresses one of the objectives.

2.1 Structural Health Monitoring:

Researchers have been facing many challenges while developing new structural health monitoring systems. Researchers and developers used different approaches for structural health monitoring. Some used wireless sensors with self-diagnosing and self-calibration capabilities to reduce data transmission in order to reduce power consumption [8]. Others used a similar approach, which is implementing wireless sensors which are capable of actuation, in which the sensor node is able to fix the problems detected without sending the data to the control node so that the power used can be reduced [9]. The advantage of the wireless sensors network is observable in applications where volume and mass is considered a limitation [10].

Most of the researches worked on the field of the SHM reached some common recommendations. The most common recommendations were power consumption and the reduction of this power to the minimum, local damage detection, durable monitoring, and integrating multidisciplinary to reach full self-sensing structures [11] [12]. Researchers used different approaches to improve the performance of SHM systems.

Power consumption is one of the main problems facing structural health monitoring. Many researchers tried different approaches to overcome this problem such as solar and wind energy, self-acquisition of sensors, and sensor actuation. Other improvements to the monitoring systems were recommended such as reducing the size of the system, increasing the read range, increasing the memory, and improving the ruggedness and robustness of the sensor node. Collision of the transmitted signals could be an issue facing wireless transmission with many sensors nodes used; the solution to this issue can be multiplexing or sequence spread spectrum [8].

2.2 Communication:

2.2.1 Wireless communication:

In order to transmit the data between different parts of the system, there are several transmission possibilities. The data can be transmitted through long range RF, through cellular transmission, or through satellite. The other challenge is the network topology; the topology is important for energy consumption. The topology should be developed in a way that ensures the minimum energy consumption. The topology should ensure bottleneck free communication and avoid the dependency of the system failure on one or more components of the system [13]. The advantage of the wireless sensors network is observable in applications where volume and mass is considered a limitation [10]. In order to improve the overall performance of the wireless sensor networks, the hardware of the system should be supported with well-designed software [9].

Wireless sensor networks (WSN) are limited in terms of memory and energy usage. Since WSN are battery operated, once a battery is depleted, the entire sensor node will be dead in some cases [14]. Due to the energy constrains of WSN, most of wireless MAC protocols are developed to address this issue. Two of the most commonly used wireless MAC protocols are IEEE 802.11 and IEEE 802.15.4. IEEE 802.11 is characterized with high data rates, wide range, and supporting TCP/IP which allows to connect to the internet and this means transmitting the data globally. The disadvantages of IEEE 802.11 are the large overhead added to the information sent and this leads to high energy consumption. IEEE 802.11 is not suitable for application with low energy consumption.

IEEE 802.15.4 is a MAC protocol for low power consumption, low cost, and low data rate applications. In addition, IEEE 802.15.4 supported hardware is made to be inexpensive. However, the IEEE 802.15.4 has the disadvantage of having a medium to low data rate, and it requires all the nodes to be close to each other to be able to communicate [14]. The relaying transmission is a better transmission technique over the direct transmission in order to reduce the power consumption and reduce the signal interference. The IEEE 802.15.4 had two modes of operation, the beacon mode and the non-beacon mode. The beacon mode is divided to active region and inactive region. The active region is composed of 16 time slots, while during the inactive region; the sensor node is at a low power mode. The non-beacon mode is based on

CSMA/CD, where the sensor node listens for the medium to be idle before sending the frame to prevent collision [14].

2.2.2 Underwater communication:

When considering the communication between the sensor nodes which are located under the sea level, many challenges will be faced. The radio frequency (RF) communication doesn't work under the sea level while optical communication is only used for short distances [13]. Another challenge is connecting the underwater sensors using electrical cables will require expensive and vulnerable cables [15].

There are many types of underwater sensor networks. Those networks differ in the method of storing and retrieving the data. The types of underwater sensor networks are [16]:

a. Sensor retrieval: in this network, the sensor is equipped with a limited storage, when the data storage is done; the sensor is taken back to the surface to collect the data stored.
b. Wired/wireless mix: it is composed of a buoy with a wire to the surface through which the data is sent to the surface. The buoy has a wireless communication for connections with other buoys and with the shore.
c. 2D architecture: sensors at the sea bed communicate wirelessly to an underwater sink; the underwater sink is connected to the surface station.
d. 3D architecture: same as 2D architecture, but the sensors are placed at different locations along the water column with no sink. The sensors are connected to the surface station through multi-hopping.
e. Using autonomous underwater vehicle (AUV): sensors with a limited storage to store the data collected. AUV passes through the network to collect the data from the sensors.

The underwater wireless communication can be achieved using acoustic channels. To increase the network capacity, the distance should be shorter and the path can be deeper. The consistency propagation of signal can be achieved by two techniques: Reliable acoustic path (RAP) and deep sound channel (DSC) [15]. The RAP is achieved when one of the propagation paths like direct path, bottom bounce or surface ducts, is dominant over the other and hence the transmission loss is reduced. The RAP is achieved when the source is deeper than the receiver under the sea level which allows no reflection. The DSC takes place when the velocity of the signal increases due to the hydrostatic pressure increase in the deep-water which forms a DSC axis around which the signal rays are bent by refraction which lower the loss in the signal [15]. The operating frequency of the signal propagation should be thoroughly considered. The frequency should be as low as possible to reduce the signal loss and to have a better acoustic propagation [17].

In acoustic communication networks, the horizontal channels are more varying than the vertical channels [18]. The speed of acoustic waves in the underwater communication is affected by temperature, pressure and salinity. The wave speed increases with the increase in temperature, pressure or salinity [19]. The propagation of acoustic waves is affected by the following factors, ambient noise, temperature and pressure variation, propagation delay, multipath and path loss [18]. The underwater communication has three different propagation modes which are normal mode, ray theory, multipath expansion, fast field, and parabolic equation [19].

2.3 Microprocessors:

When considering the processing of the electrical signals, the microprocessor technologies should be studied. MSP430 microprocessor is a new technology developed by Texas Instruments (TI). TI MSP430 family is an ultra-low power microcontroller family of devices. The microcontrollers are equipped with five low power modes. The architecture is optimized to achieve extended battery life in portable measurement applications. The devices are equipped with a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally controlled oscillator built in inside the microcontrollers allows the microprocessor to wake up from the low power modes in less than 6μs. MSP430 development boards include on board functional blocks which enhances the performance of the entire system. These functional blocks include memory registers, timers, analog to digital convertors (ADC), comparators, universal serial synchronous/asynchronous communication interfaces (USART), and some include radio frequency antenna. Typical applications of this family of microcontrollers include sensor systems that capture analog signals, convert them to digital values, and process and transmit the data to a host system [20].

2.4 Measuring Devices:

The compatibility between the measuring devices and the microprocessor is one of the essential focus points in developing a monitoring system. When considering the strain measurements, the wheat stone bridge connection is considered the best interface circuit for the compatibility of the strain gages and the microprocessor. The strain gages replace one, two or four of the resistors in the bridge based on the type of the connection used. In case of the quarter bridge, one strain gage replaces one resistor while in case of the half bridge, two strain gages placed on opposite side of the structural member replace two resistors in opposite direction of the bridge. The half bridge connection develops a better representation of the strain values. The change in the resistor values of the strain gages due to the strain leads to change in the overall resistance of the bridge; the change in the bridge resistance is recorded and processed to obtain the equivalent change in strain using the corresponding equation [21].

For the corrosion testing, the half-cell testing procedure can be used, in which a half-cell potential is placed on the concrete surface while being connected to the bars inside. The difference in voltage measured through the connection represents the possibility of corrosion occurring in this area. The accepted voltage-corrosion relationship states that [22]:

1. Potentials greater than -200m V indicate generally, 90% or higher probability of no corrosion taking place at the time of measurement.
2. Potentials in the range of -200 to -350m V are inconclusive.
3. Potentials less than -350m V generally indicate, 90% or higher probability of active corrosion in that area at the time of testing.

For displacement measurements, Analog devices ADXL accelerometer is used. The ADXL is a small, thin, ultralow power, 3-axis accelerometer with high resolution. Its output is 16-bit twos complement digital value which can be accessed through SPR or I2C digital interface. Due to its low power consumption and digital interface output, ADXL is easily compatible with the microprocessor [23].

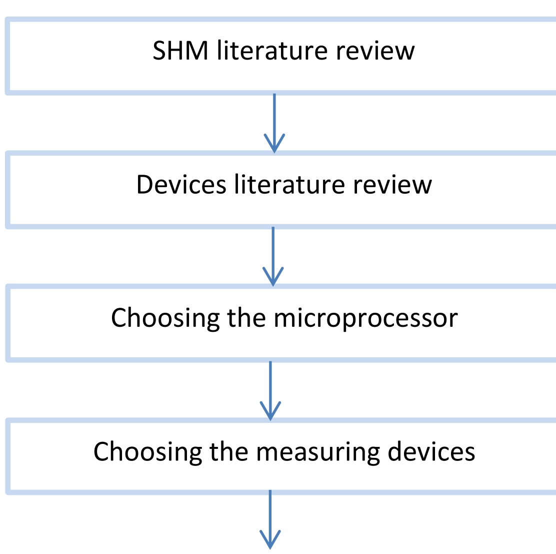
CHAPTER 3

METHODOLOGY

The project is divided into two stages to develop the new safety monitoring system and investigate the efficiency of this system. The project is divided into:

- System assembly and application: The first stage is concerned with utilizing the microprocessor to be compatible with the measuring devices and implementing the sensor nodes along with the onsite control unit on the structure to test its performance to collect and store the data. In this stage, the background of structural health monitoring studies is discussed, the difference between various microprocessors and measuring devices is studied and the connection between microprocessor and measuring devices is studied. After those steps are done, the measuring system is assembled, and data acquisition and processing algorithms are developed and tested.
- System communication: The second stage deals with connecting the different parts of the system. In the second stage, the communication protocol between sensor nodes and platform control unit is developed and the communication protocol between the platform control unit and onshore control unit is developed and tested. A communication network between different parts of the system is simulated using OMNET++ software.

Fig. 3 shows the flow chart for the methodology including every task to be carried out during the project.



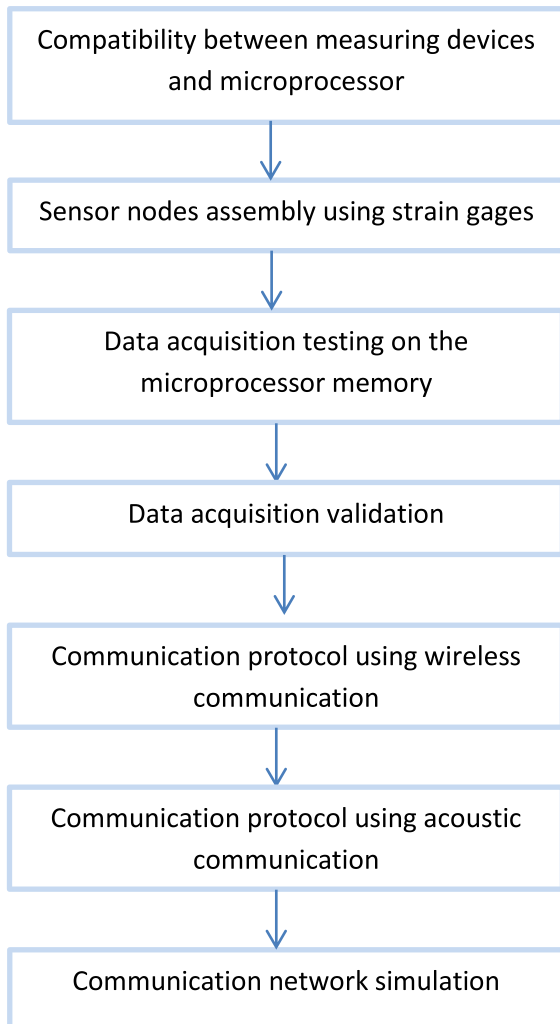


Fig. 3 Methodology flow chart

3.1 Project Gantt Chart:

Activity / Months	**February**		**March**		**April**		**May**		**June**		**July**		**August**	
Literature Review	■	■												
System Assembly		■	■											
Sensor Node Implementation			■	■										
Sensor Node Testing				■	■	■								
Underwater Communication							■	■	■	■				

Long Range Communication														
Communication Simulation														
Paper work														

3.2 Tools Needed:

- Texas Instruments Development Board MSP430: the microprocessor used for data acquisition form the sensors, processing the data, and readings storage.
- Strain gages: a transducer to measure the strain values.
- Code composer studio: code developing software for microprocessor debugging.
- OMNET++: simulation software for communication networks.
- MATLAB: to develop data processing codes.

3.3 Project Activities:

The project started with designing the outline of the entire system and dividing it into subsystems. After the system design was done, the first stage of the system which is the sensor node was studied and constructed. The second stage focused on the communication part of the system. During this stage, the communication protocol was studied and network was simulated to obtain the necessary information about the communication performance.

3.3.1 System Design:

The new system is required to monitor the structural health of oil platforms with optimal power efficiency. The system is powered through the solar panels placed on the platform. The system will focus on the main parameters affecting the structural health of those platforms especially structural shacking and temperature. The senor nodes are placed on different locations along the structure and communicate with the control unit on the structure top through acoustic communication or wireless communication depending on the sensor node location. The data from the sensor nodes are collected and stored on the memory registers available on the control unit. The data will be processed and compared to predefined safety values to check for any irregularities. When all the data are stored on the control unit, the onsite control unit will send the data gathered to the onshore control unit through satellite and/or cellular transmission. The data collected on the onshore control unit will be feed into representation patterns to display the data.

The system is composed of three subsystems. The first subsystem is represented by the sensor node which is composed of the measuring device (e.g. strain gages, or accelerometer) connected to an acoustic modem for underwater transmission or RF antenna for wireless transmission. The second subsystem represents the onsite control unit, this stage is the backbone of the system, which connects all the subsystems together; it acts as a link between the measuring device and the end user, and also acts as the brain of the entire system. The second subsystem consists of a microprocessor (e.g. MSP430F6137), RF transmission unit, cellular transmission unit and acoustic modem. The onsite control unit is responsible of carrying data from the sensors node to the onshore control unit, as well as carrying commands from and to the sensors node and the onshore control unit. The onsite control unit stays in low power mode until it is activated by the sensor node or the onshore control unit. The last subsystem is the onshore control unit which is responsible for receiving the data from the structure and representing it to the end user. It is responsible for carrying the commands back to the structure as well. The system outline, shown in fig. 4, shows the system different subsystems.

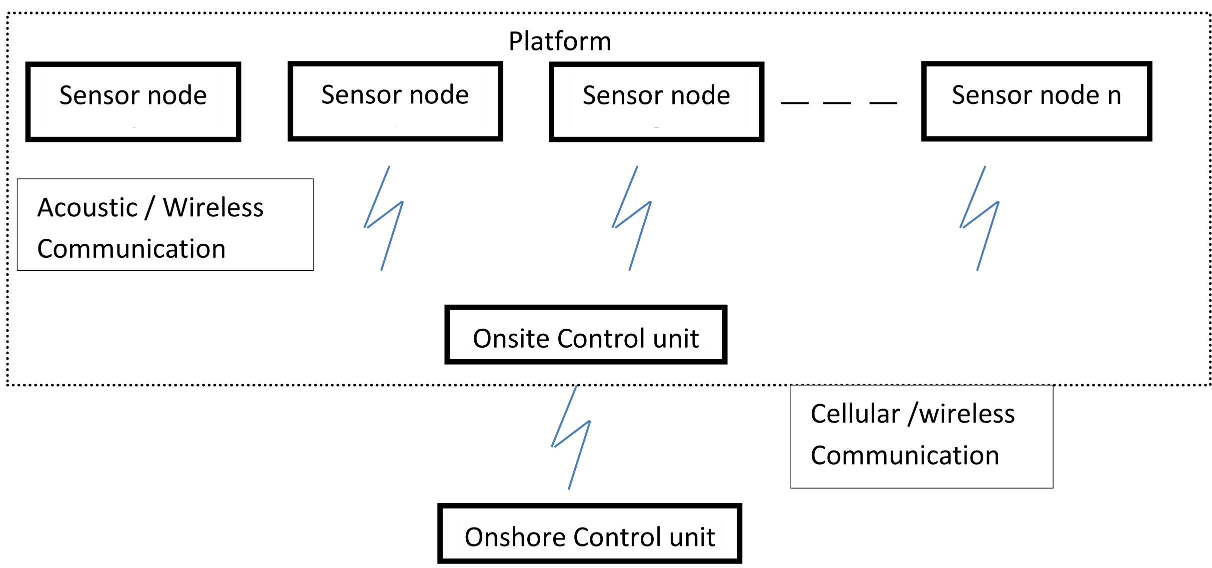


Fig. 4 System Outline

The sensor node is developed to be placed on different locations along the monitored structure. On each sensor node all the required measuring devices are connected to the microprocessor through multiplexer. Each microprocessor collects the data from all the devices connected to it based on the predefined time periods for each one which separates every two consecutive reading. The microprocessor processes those readings and transmits it to the control unit. The control unit receives all the readings from each sensor node simultaneously. When the readings are received, the control unit combines all the related readings and formulates the required comparison through graphs and grids. The comparison graphs and grids show a comparison between different locations of the structure for a better estimation of the structure performance.The system must be accessible at any time, from any location and gives a detailed report about the platform's performance.

System Advantages:

The system is designed as mentioned to achieve the following advantages:

1. Using a microprocessor board (e.g. MSP430) on the sensor node, having its own memory, allows storage of more readings on the sensor node without the need for data transmission and power.

2. The microprocessor facilitates performing necessary processing on the data on the sensor node before sending to the main control unit which allows less data transmission and power.

3. The microprocessor board contains all the necessary blocks for data reading, data processing, data storage, and data transmission mounted on a small board which decreases the size of the sensor node.

4. Connecting all the sensor nodes to the main control unit through wireless transmission reduces the number of wires used for connection, and hence gives more freedom for locations to apply sensor nodes.

5. The presence of the platform control unit helps to collect the data from all the sensor nodes available in order to do the necessary processing and comparison before sending the data to the onshore unit.

6. The cellular transmission allows more mobility for the end user, and the graphical representation of the data gives better interpretation of the data.

7. Dividing the system into a number of small sized sensor nodes connected to one control unit permits the implantation of the system in any location on the structure in addition to comparing the different readings collected to develop an overall estimation of the structure performance.

3.3.2 Sensor Node Setup:

In this report, the first stage of the system which is discussed and constructed is the sensor node. Three measuring devices were studied for the measurement of strain, corrosion and displacement. The output from each device goes through an interface circuit to make the readings compatible with the microprocessor before feeding into the input of the microprocessor, as shown fig. 5.

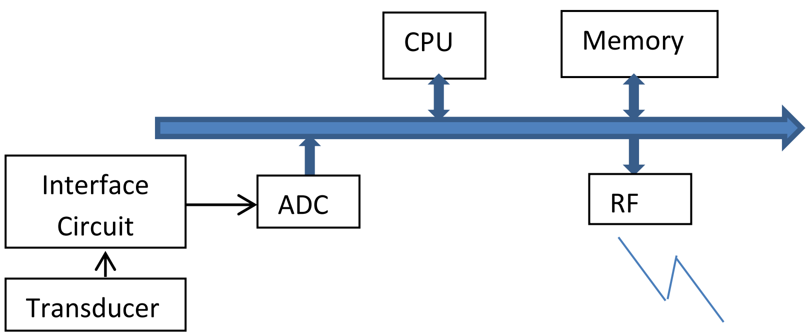


Fig. 5 Sensor Node Diagram

The digital readings stored on the microprocessor are handled with other software such as MATLB to perform the necessary conversions. The digital data is converted back to its equivalent analog readings through the following equation:

$$N = \frac{2^{12} * V_{in}}{2.5}$$

Where N is the digital value, and V_{in} is the output voltage.

The analog readings are represented by their equivalent structural parameters readings. The parameters readings are grouped together to represent the overall performance of each member. The readings are represented in graphical forms to the end user.

Strain Readings:

For the strain measurements, the wheatstone bridge technique is used to measure the change in strain due to the change of the resistance of the strain gages, as shown in fig. 6. The half bridge setup is used where two resistors in the wheat stone bridge are replaced by two metallic strain gages. The two strain gages are placed on two opposite sides of the member of the structure to measure the average change in strain of this member. The change in the resistance of the strain gages due to the change in the strain of the member causes a change in the overall resistance of the bridge. The change in the bridge's resistance goes through an interface circuit composed of op-amps and resistors to amplify this value, as shown in fig. 7 and fig. 8. The output from the interface circuit is fed into the ADC of the microprocessor where the data is converted into digital readings and stored on the memory registers.

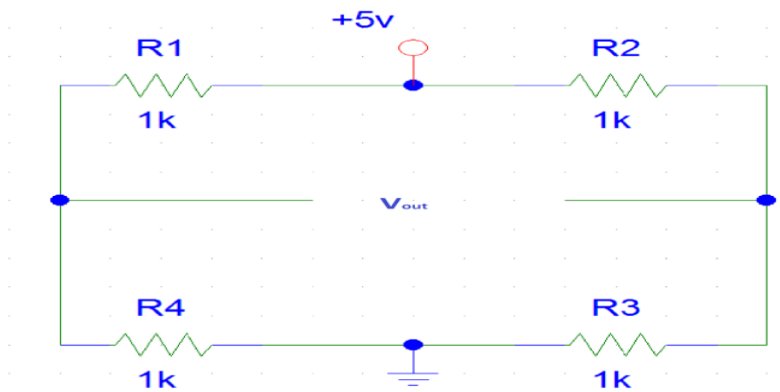


Fig. 6 Wheatstone Bridge

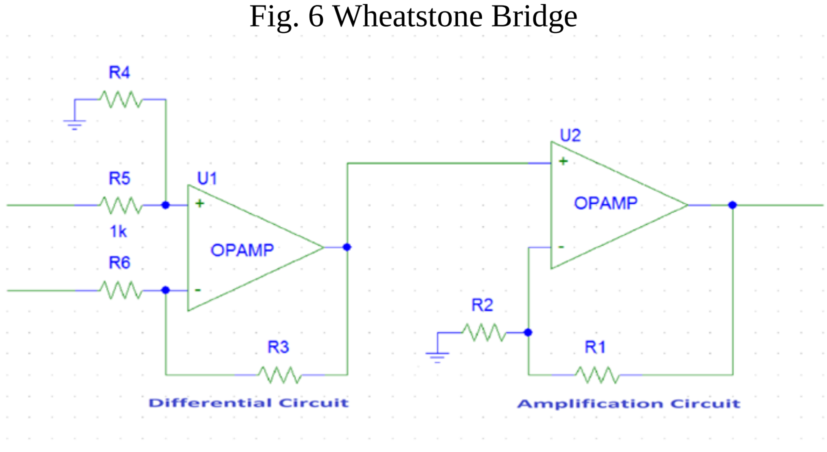


Fig. 7 Interface Circuit Schematic

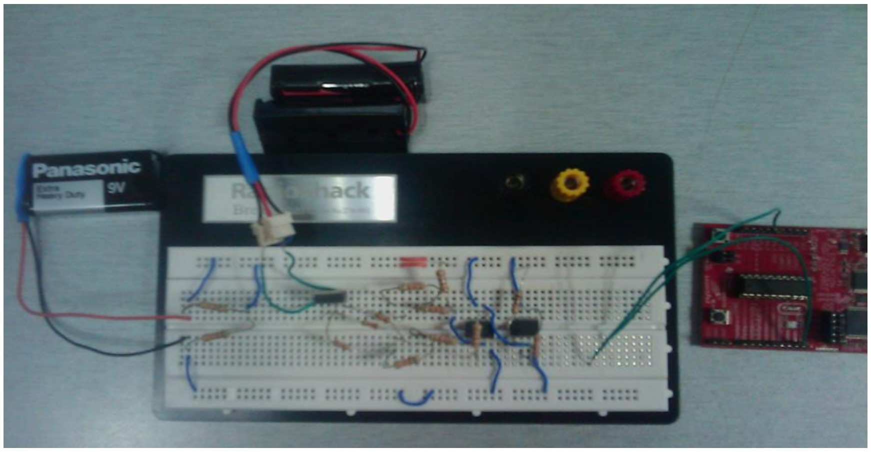


Fig. 8 System Hardware

The stored data is converted back to its analog equivalent values and then used to compute the equivalent strain value for each reading using the following equation [22]:

$$\varepsilon = \frac{V_{out} * 2}{G.F. * V_{ex}}$$

Where Ɛ is strain, V_{ex} is the supply voltage to the Wheatstone bridge, and G.F is gage factor. In case of metal strain gages, G.F. is equal to 2.019.

<u>Corrosion Readings:</u>

For corrosion measurements, half-cell technique is used in which a half-cell potential is placed on the concrete surface and the other end is connected to the bar located inside the member. The voltage difference between the two ends of the half-cell is recorded. The voltage readings are passed through an interface circuit before reaching the microprocessor for amplification. The ADC on the microprocessor converts the values into digital values and stores them in the memory registers.

<u>Displacement Readings:</u>

For the displacement measurements, Analog devices ADXL345 accelerometer is used. ADXL345 is a 3-axis digital output accelerometer. The accelerometer is placed in different location on the structure to measure the displacement at each location. The accelerometer is connected directly to the input of the microprocessor through SPI interface to store the digital output data in the memory registers, as shown in fig. 9.

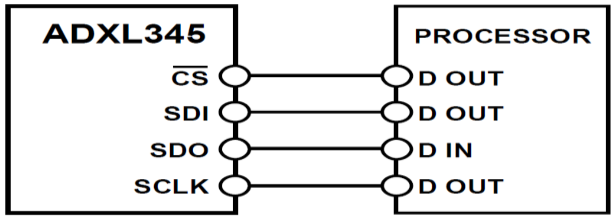


Fig. 9 ADXL and Microprocessor connection [23]

Temperature Readings:

For the temperature measurements, the temperature sensor placed on the microprocessor board is used to ensure the temperature of the sensor node is safe within the allowed limits.

3.3.3 Communication Simulation:

In order to choose the best communication protocol that can serve the purpose of the system and ensure the proper communication between its parts, different communication protocols was tested using a communication simulator with the same parameters as the surrounding environment where the system is to be implemented. OMNET ++ software is used to simulate the communication process. OMNET ++ is an open source component based C++ simulation library and framework which provides a graphical and command line execution of simulation and visualization of the results [24]. The simulation is done using a framework MIXIM. MIXIM is a framework for wireless and mobile networks developed by OMNET ++ [25]. For the acoustic communication simulation, due to the lack of the underwater simulation software, the simulation is done using the MIXIM framework for air transmission frames with modifying the necessary environment parameters and attenuation changes to resemble the underwater environment.

To resemble the underwater environment, the thermal noise affecting the transmission is adjusted to have the same effect on the transmission. The thermal noise is calculated using the following formula [18]:

$$N_{thermal} = \left(rx_{temp} + bkg_{temp}\right) * rx_{bw} * BOLTZMANN's\ constant$$

$N_{thermal}$ is the thermal noise, rx_{temp} is the device temperature, bkg_{temp} is the water temperature, and rx_{bw} is the receiver bandwidth.

For the simulation of attenuation changes, the impairments affecting the signal propagation in an underwater environment were discussed. In order to calculate the path loss for signal propagation, the following formula is used [18]:

$$A(l,f) = \left(\frac{l}{l_r}\right)^k a(f)^{l-l_r}$$

f is frequency, l is transmission distance with reference to a reference distance l_r , k is spreading loss, and a(f) is absorption coefficient.

For signal to noise ratio calculation, the following formula is used [18]:

$$SNR(l,f) = \frac{S_l(f)}{A(l,f)\,N(f)}$$

$S_l(f)$ is power spectral density of transmitted signal, and N(f) is the noise power.

In order to evaluate the performance of different protocols, the evaluation parameters are chosen as follows:

- Transmission power
- Bit error ratio (BER)
- Path loss
- Distance

3.3.4 Communication setup:

After reviewing and discussing the communication requirements, the proposed protocol was developed to be implemented for the communication between different parts. The proposed protocol will be useful in identifying the requirements of this protocol and hence identify the most suitable protocol for the process and the modifications required on this protocol. Fig. 10 shows the proposed communication protocol.

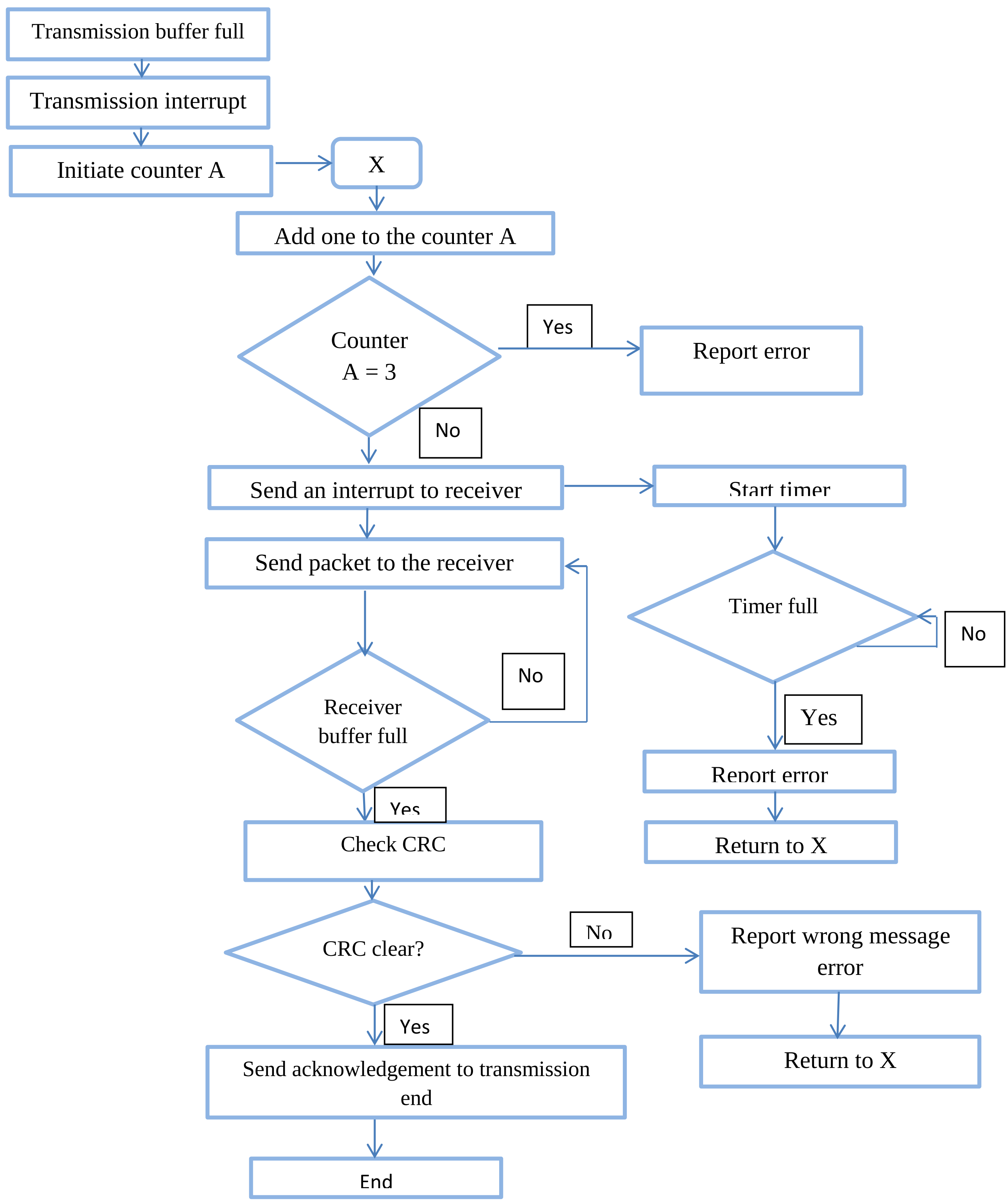


Fig. 10 Communication Protocol

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Sensor Node Testing:

The first system's testing was conducted on the sensor nodes constructed for strain measurements using strain gages and corrosion measurements using half-cell device. The first stage is focused on using offline data from previously conducted similar experiment to test the data processing algorithm. In this experiment, MSP430F6137 was used as the microprocessor, strain gages used in half bridge wheatstone bridge setup, half-cell device is used and a bridge model with a static and dynamic loads. Three different sets of data were collected for each sensor. The strain data were collected during different loads on the bridge and the digital equivalent readings were stored on the microprocessor memory. The half-cell device was placed on different locations and in each location several readings were collected and stored by the microprocessor.

To test those readings, the digital readings are fed into a conversion algorithm where the original analog readings are retrieved and the equivalent parameter values are calculated and represented in graphical form. The parameter values go through modeling algorithm to group the values based on the location of the sensor node and develop an overall estimation graphical representation of each member performance. The collected values are used in a prediction algorithm to predict the future performance of the structure and detect any coming irregularities.

Table 1 (a) shows some examples of the data set collected from first strain gage while table 1 (a) shows the readings collected from the second strain sensor. Table 2 (a) and 2 (b) shows the data collected from the first and second corrosion sensors respectively.

Table 1: Strain-Digital Equivalent values

Reading	Digital Value	Strain Value
[1]	1618	-1630.400
[2]	1344	-1354.300
[3]	1524	-1535.700
[4]	1398	-1408.700
[5]	1364	-1374.500
[6]	1432	-1443.000

[7]	1344	-1354.300
[8]	1584	-1596.200
[9]	1014	-1021.800
[10]	1786	-1799.700

(a)

Reading	Digital Value	Strain Value
[1]	1884	-3037.5
[2]	1894	-3053.7
[3]	1844	-2973.1
[4]	1882	-3034.3
[5]	1904	-3069.8
[6]	1876	-3024.7
[7]	1875	-3023
[8]	1907	-3074.6
[9]	1896	-3056.9
[10]	1893	-3052.1

(b)

Table 2: Corrosion-Digital Equivalent values

Reading	Digital Value	Corrosion Value
[1]	2419	-295.29
[2]	2418	-295.17
[3]	2413	-294.56
[4]	2496	-304.69
[5]	2416	-294.92
[6]	2430	-296.63
[7]	2431	-296.75
[8]	2416	-294.92
[9]	2431	-296.75
[10]	2422	-295.65

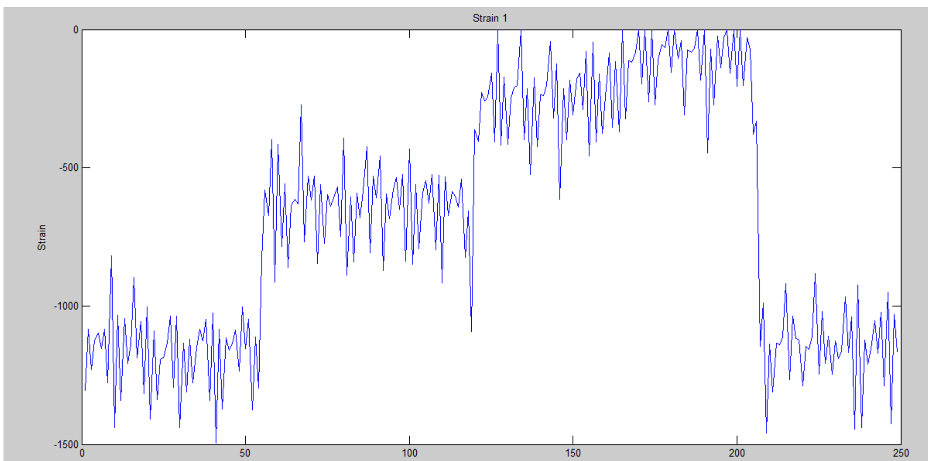
(a)

Reading	Digital Value	Corrosion Value
[1]	3334	-406.98
[2]	3318	-405.03
[3]	3333	-406.86
[4]	3334	-406.98
[5]	3336	-407.23
[6]	3333	-406.86
[7]	3340	-407.71
[8]	3331	-406.62
[9]	3337	-407.35
[10]	3332	-406.74

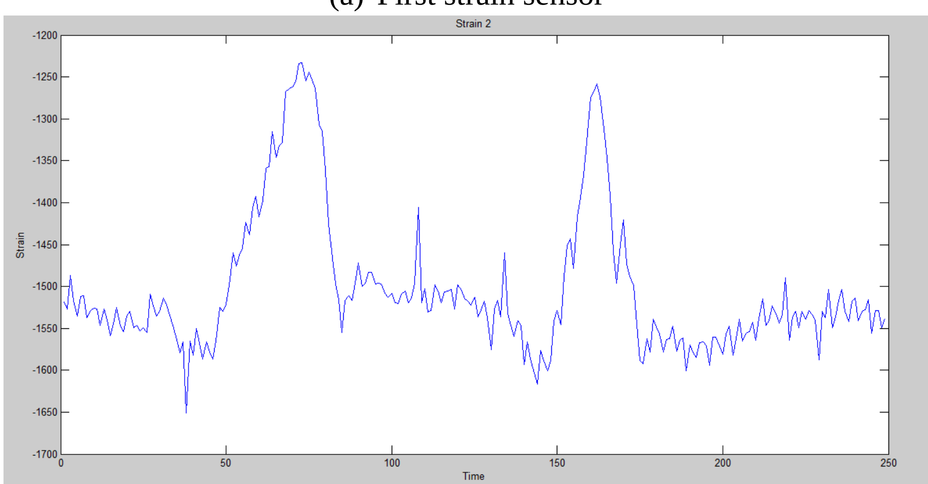
(b)

In fig. 11, the strain values equivalent to the digital values recorded from each sensor are calculated and represented by graphs. In the graphs the difference in strain due to the different loads applied can be detected. The strain increases gradually when increasing the loads added to the member, while it increases instantly when a dynamic load passes over the member.

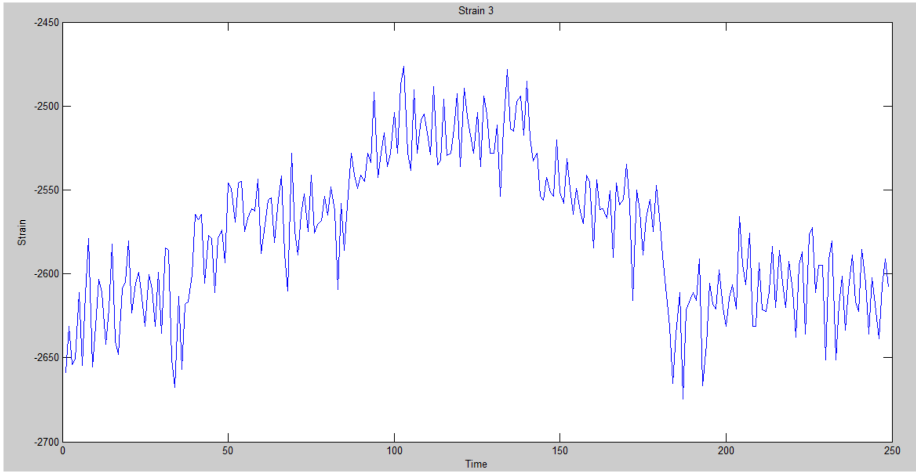
In fig. 12, the corrosion values are interpreted from the voltage readings and represented by graphical representations. From the graphs, it can be seen that the values are vibrating in a small range where the average of this range shows the voltage value at this member which represents the corrosion level at this member. The graphs shows the values within the accepted limits indicated in the literature review section. These readings show the efficiency of the used system in measuring the corrosion values.



(a) First strain sensor

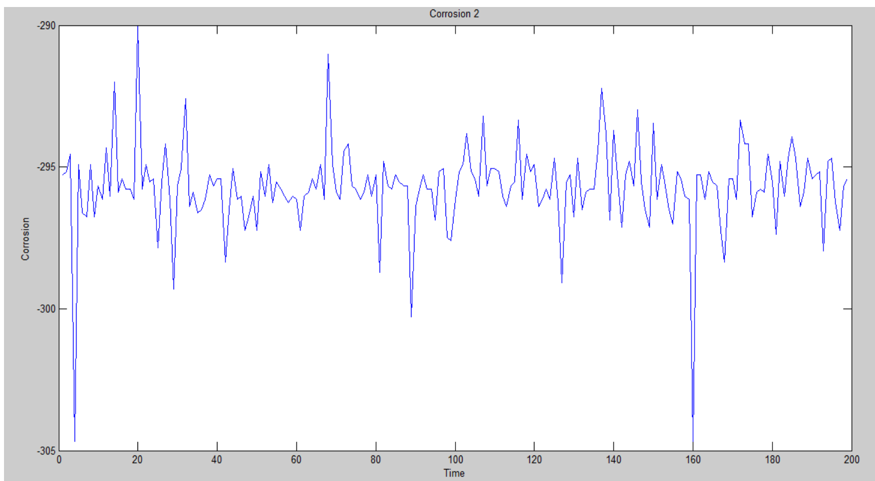


(b) Second Strain Sensor

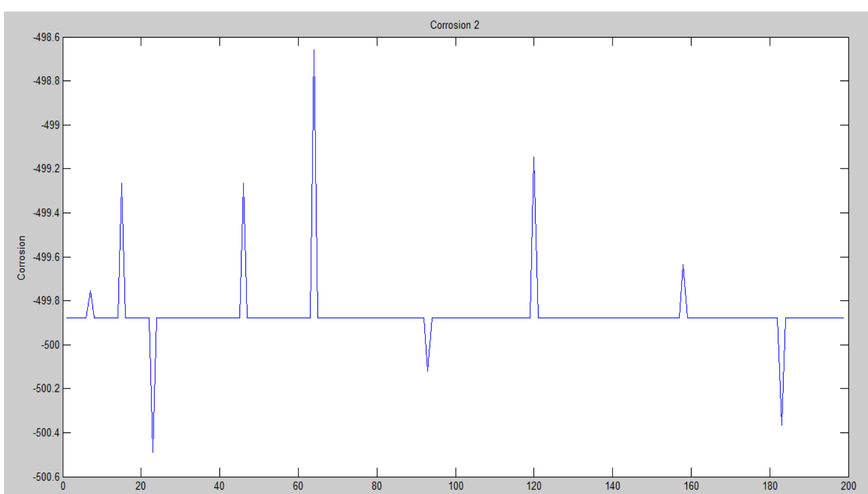


(c) Third Strain Sensor

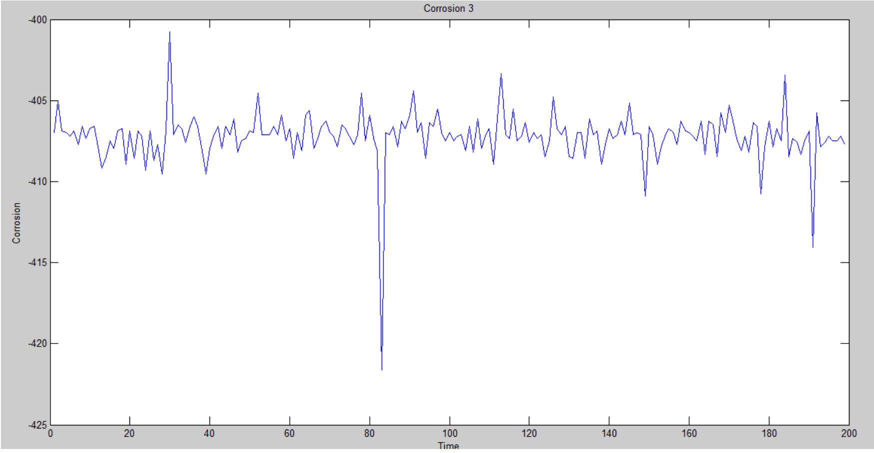
Fig. 11 Strain Graphs



(a) First Corrosion Sensor



(b) Second Corrosion Sensor



(c) Third corrosion Sensor

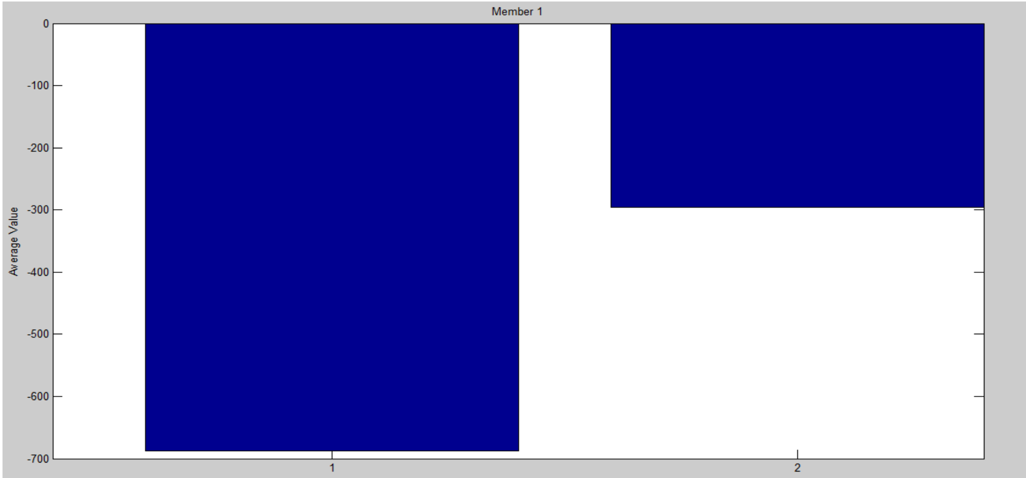
Fig. 12 Corrosion Graphs

The readings from each member are grouped together and the average of those readings is calculated and an average of the overall performance of the structural member is developed. Table 3 shows the average values of each of the three members tested.

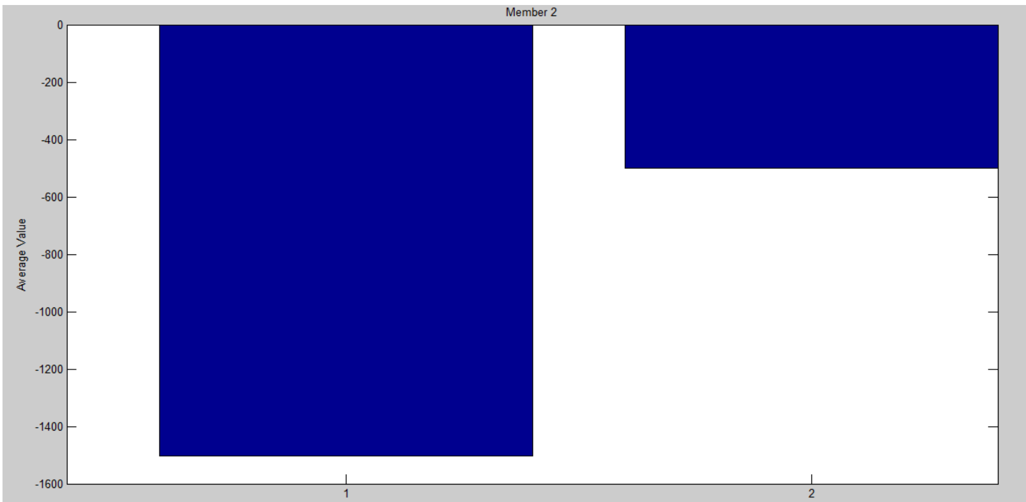
Table 3: Members Average Values

Structural Members	Average Strain	Average Corrosion
Member 1	-687.86	-295.72
Member 2	-1502.57	-499.88
Member 3	-2575.56	-407.21

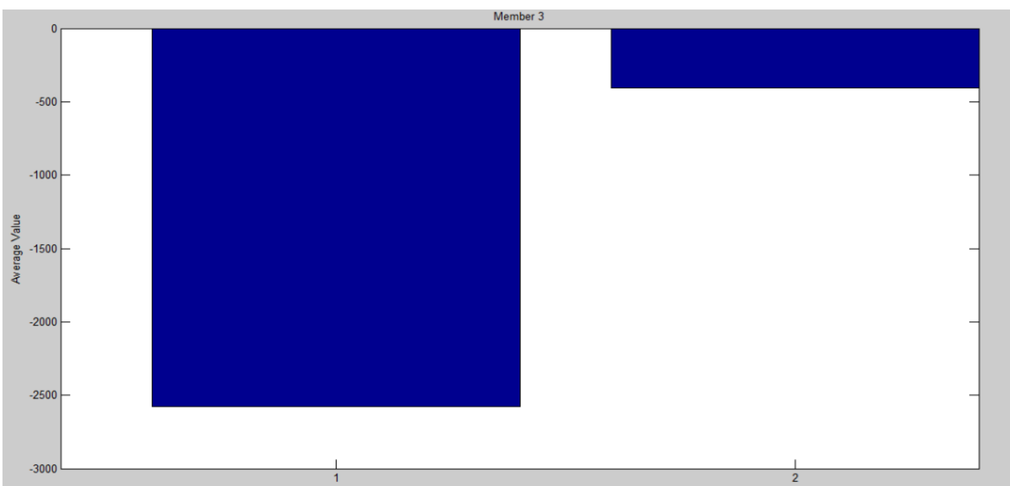
One of the proposed graphical representations of the obtained readings is a bar graph for each member. This graph represents the average values for the strain readings and the corrosion readings. The bar graph can have different colors to show the category in which each average reading lies to show the safety of the member. Fig. 13 shows a sample of the bar graph for each member. In each graph, the first bar represents the average strain value of this member while the second bar represents the average corrosion value of this member.



(a) First Member Average



(b) Second Member Average



(c) Third Member Average

Fig. 13 Member Overall Performance Graphs

The results are fed into the prediction algorithm using neural network to predict the upcoming readings based on the captured readings. The prediction algorithm was tested on the first strain sensor values and the first corrosion sensor values. Fig. 14 shows the predicted values for the coming 24 readings of strain while fig. 15 shows the predicted values for the coming 24 readings of corrosion.

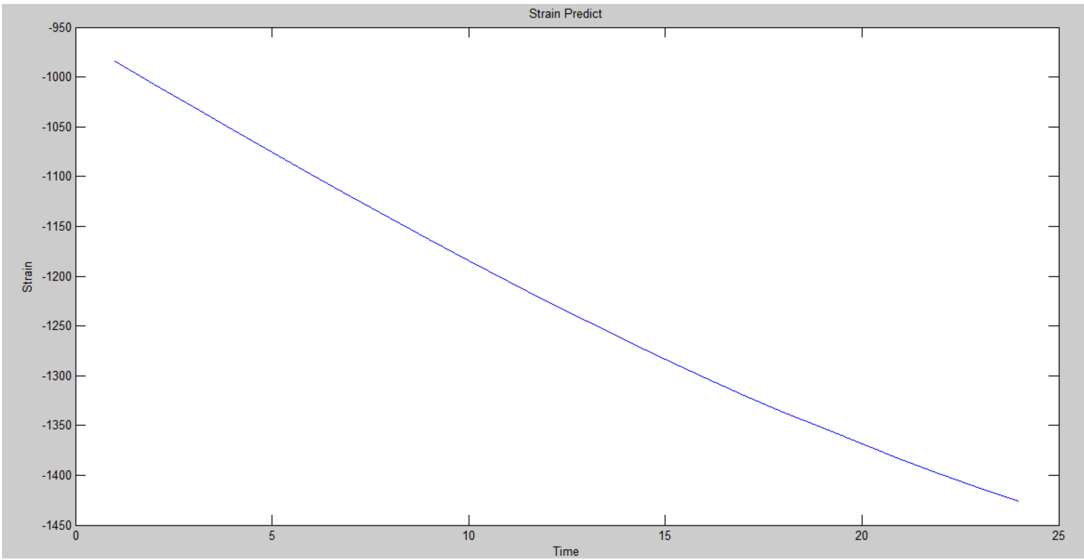


Fig. 14 Strain Predicted Values

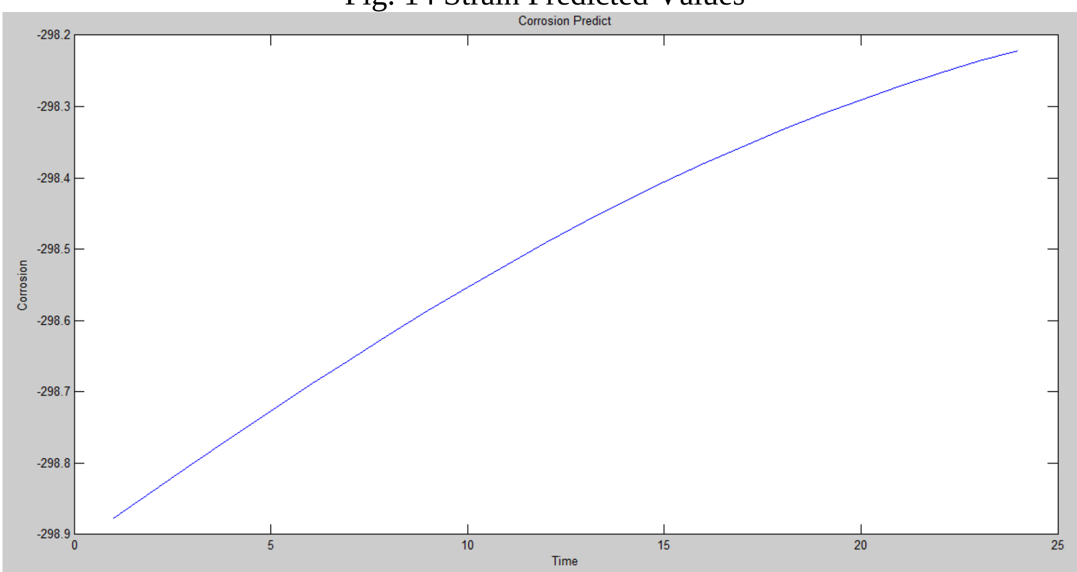
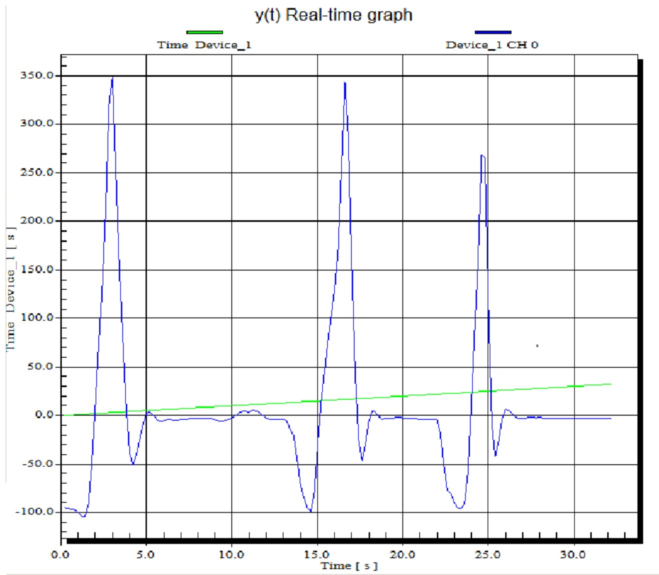
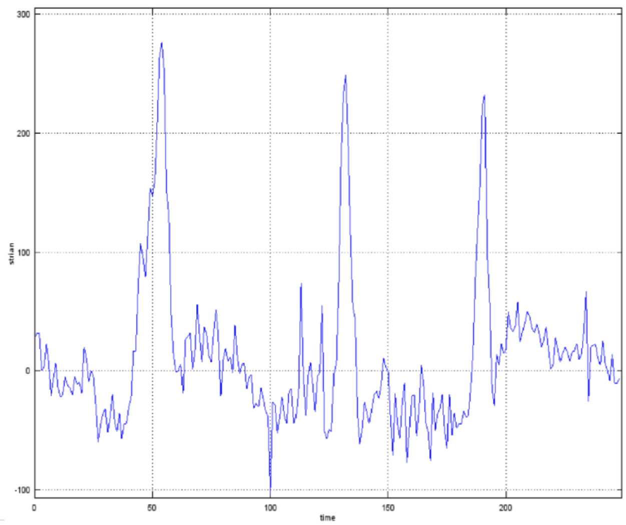


Fig. 15 Corrosion Predicted Values

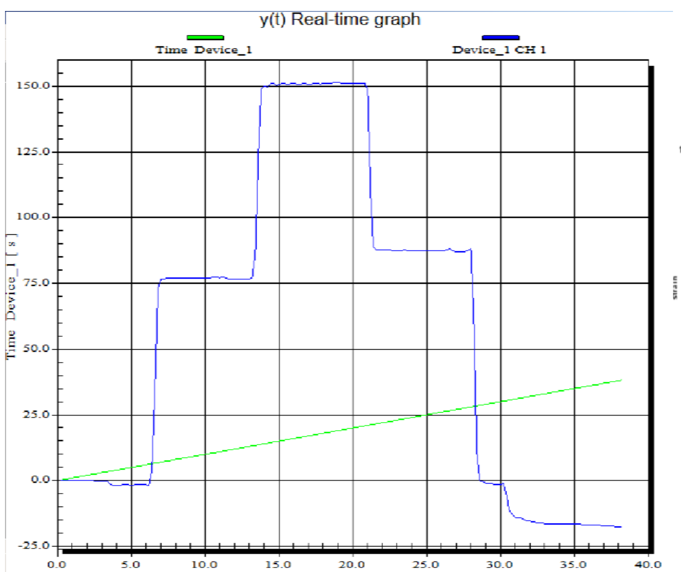
In order to validate the readings of the new system, the same experiment was conducted using the same structural members, the same applied force, and the same environmental conditions. In this stage, a commercial acquisitions system for strain is used to capture the readings. Spider 8 is used to measure the strain values. Fig. 16 (a-e) shows the comparison between the readings collecting using the new system and the Spider 8 readings. The graphs show resemblance in the change in the value of the strain due to applying the same amount of force. This shows the efficiency of the new system in calculating the strain values.



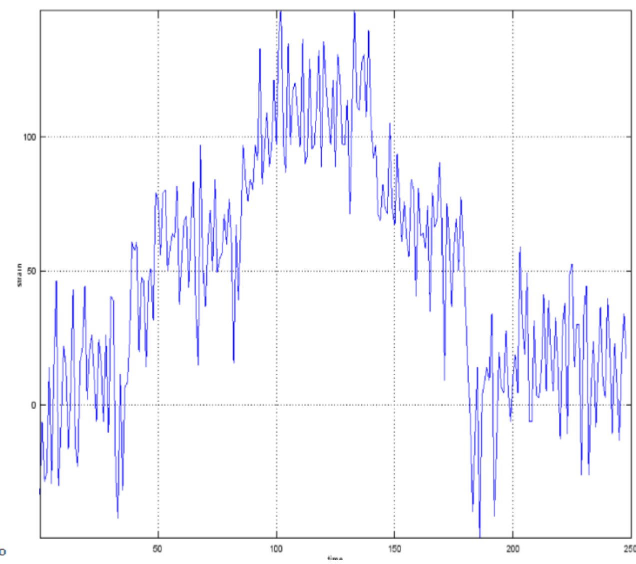
(a) Spider 8 Reading



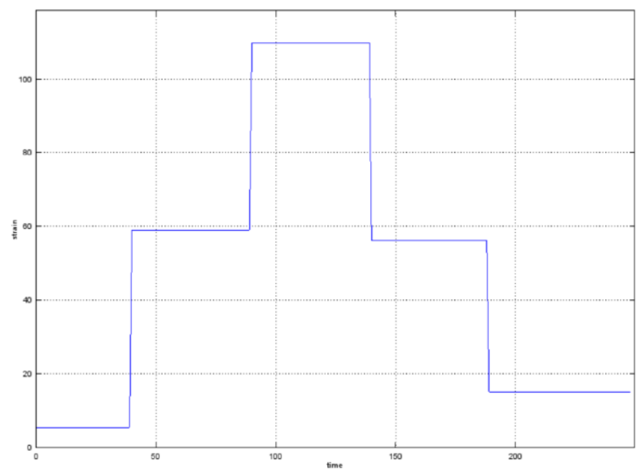
(b) New System Readings



(c) Spider 8 Readings



(d) New System Readings



(e) New System Filtered Readings

Fig. 16 Comparison between New system and Spider 8

4.2 Communication simulation:

The second stage of testing was focused on the communication network simulation. Different protocols were tested for long range wireless communication between the platform and the onshore control unit. Due to the long distance between the transmitter and the receiver, IEEE802.14.5 showed the best performance due to its ability to operate on long range communications, and the ability to operate on low power.

For the acoustic communication testing, it started with specifying the parameters for the underwater network simulation. The environmental parameter for the underwater network simulation was set as follows:

- Range: 10 – 4000 m
- Number of Packets sent: 10 – 200 Packets
- Power: 100- 1000 W
- Bandwidth: 10 KHz
- Frequency: 10KHz to 20 KHz
- Antenna gain: 10 dB
- Thermal noise: 100 dB

Different distances, different number of packets, and different transmission power were applied to those parameters and in each case the simulation was run for significant number of times to evaluate the performance of the protocol based on the evaluation parameters mentioned before. The most suitable MAC protocol for the nature of operation of the system was chosen.

The simulation results shows change in the BER and the path loss when increasing the distance. The BER increase when increasing the distance or the number of packets sent, as shown in fig.

17, 18, but the change is limited within small range. The path loss shows big decrease when increasing the distance, as shown in fig. 19.

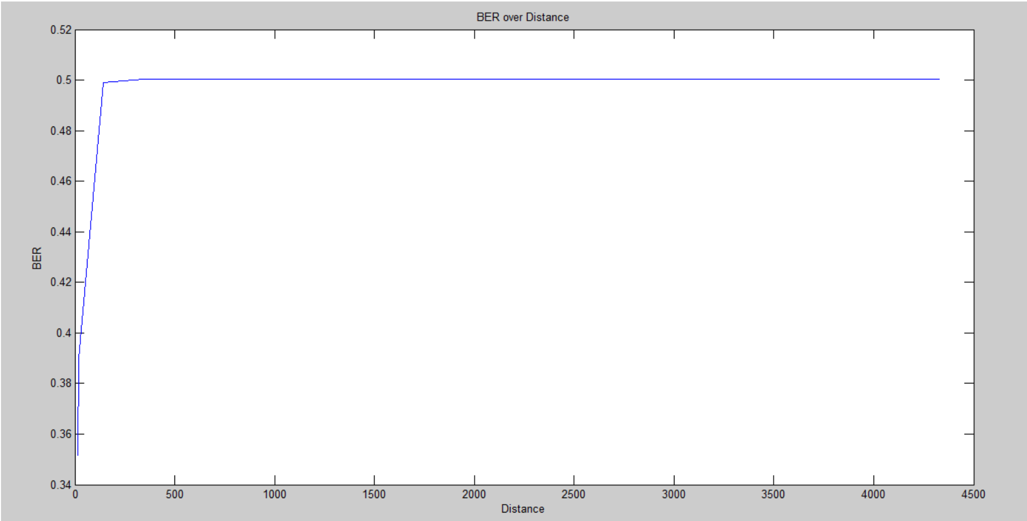


Fig. 17 BER over Distance

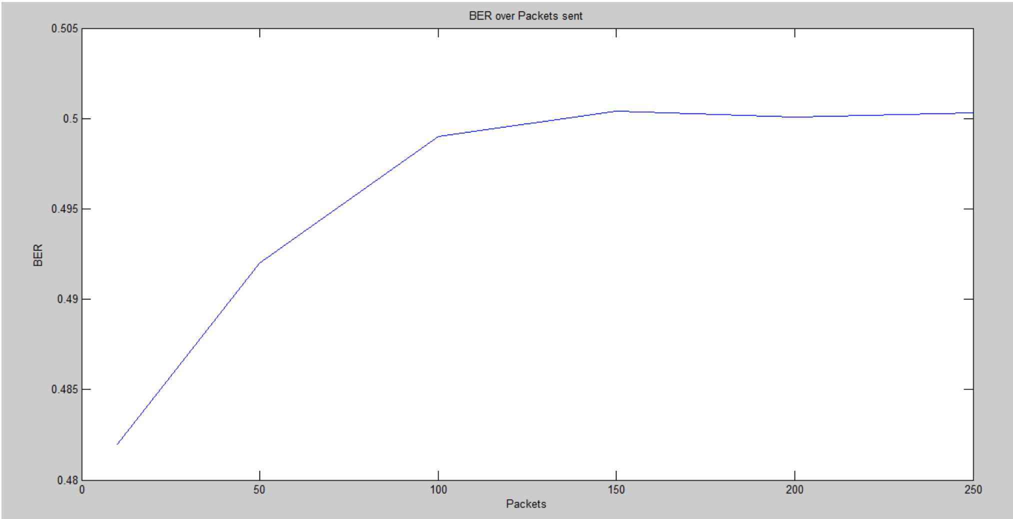


Fig. 18 BER over Packet Sent

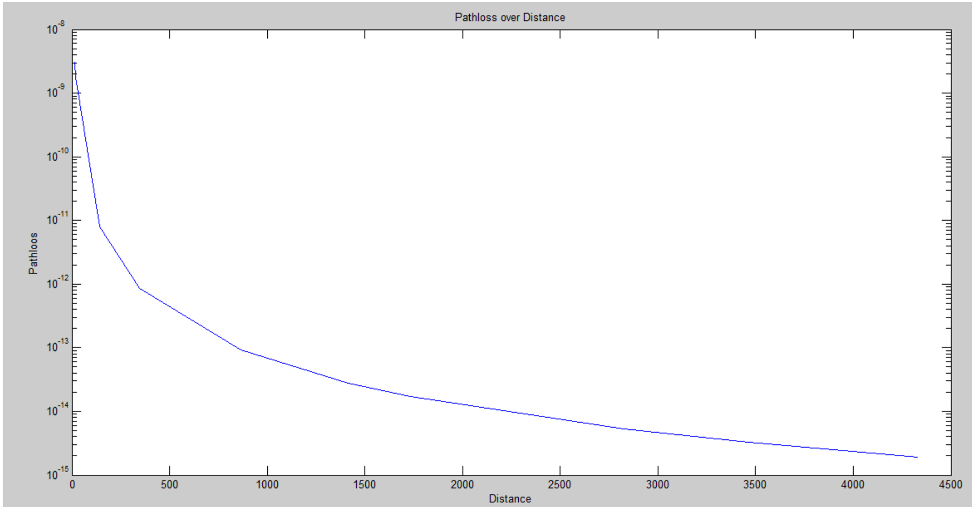


Fig. 19 Pathloss over Disntace

The graphs show that the BER values are averaged around 0.5 when the distance exceeds 1000 m which shows a big value of BER. The values obtained show that the error rate is big compared to the number of bits sent, this shows inaccurate transmission of data. The high BER values shows less efficiency of acoustic communication when used in the given environment. During the simulation, different transmission power was used to improve the BER value. The simulation shows that the increase in the transmission power will not improve the value of BER. Due to the constancy of the BER value with increasing the distance, error coding techniques can be used to improve the BER value.

The path loss obtained graphs show the decrease of the path loss values when increasing the distance. The results obtained show the inefficiency of the acoustic communication in delivering the complete message when used in underwater communication which decreases the reliability of the message delivered. Increasing the transmission power did not affect the value of the path loss.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions:

The safety monitoring system of the oil platform is every essential to ensure the safety of the platforms and reduce the disasters happening to those platforms. The new technology adapted by oil companies is the unmanned platform which operates remotely with no man on the platform. The new technology requires a monitoring system which can operate remotely, have a real time monitoring representation and consumes low power. The system design was developed to meet the requirements of the new system. Using the microprocessor with its on board functional blocks enabled the sensor node to store and process data, this reduces the transmission between different parts and reduces the power consumed by the system. The cellular transmission allows instant access to the data from any location.

Using the developed simplified electrical circuits to replace the commercially used data acquisition systems will reduce the overall cost. The use of simple electrical circuits connected to the small sized microprocessor board reduces the overall size of the system and facilitate the application of the system in any location. The new system testing showed the efficiency of the system, its reliability in different applications, and its ability to replace the traditional data acquisition systems. This system can be expanded to include more measuring devices with minor modifications. Acoustic communication can be used to allow the presence of underwater sensor nodes which allows the monitoring of the essential members of the platform. The prediction algorithm allows early identification of irregularities and reduces upcoming disasters. The developed system in this study meets all the requirements of lower cost, less power, reduced size, flexibility and easier implementation, remote accessing, early detection of problems, simplified representation of the results, and overall estimation of the structure performance through the readings comparisons.

The communication simulations show less efficiency of the acoustic communication when used in underwater communication. The underwater communication shows high error rate and high path loss when increasing the distance and the packets sent. The inefficiency of the communication will results in unreliable message transmission and hence unreliable readings of the sensor nodes at the control unit. The underwater communication needs further studying and improvements.

5.2 Recommendations and Future works:

Different approaches have been used to overcome the challenges faced during the project. Those challenges are considered complications which lessens the efficiency of the proposed system performance. The challenges faced and approaches followed are recommendations that can be followed to improve the performance of the system. The faced challenges and the approaches followed are:

1. System components: the system testing showed that all the system components should be perfectly functioning to improve the system performance. Any malfunction in any component, the interface circuit in particular, will lead to false data representation. It is recommended that a regular check on the system components is conducted. All the system components should be well connected and perfectly protected.
2. Noise associated: the results developed showed that some noise is associated with the readings. The noise was developed due to component connection, supplied voltage, and the measuring devices performance. It is recommended using noise filters on the output of the system to reduce the associated noise and have better representations of the findings.
3. Operating voltage: through the system testing, it was proven that any change in the supplied voltage will affect the output of the system. This leads to increase in the noise associating the output voltage and hence affects the readings. The output values will lead to wrong interpretation about the structure performance. Tests were conducted to test the effect of the operating voltage on the output change when a constant parameter is supplied to the system. The tests showed that the effect of the operating voltage on the output is noticeable but not significant. It is recommended that a fixed supplied voltage is used to enhance the performance of the system.
4. Acoustic communication: the acoustic communication simulation results showed high error rate and high path loss, which shows low efficiency of using acoustic transmission in underwater communication. The increase in the transmission power was one of the proposed solutions but it did not show a great effect on the results. The recommended

solution is using error coding techniques to retrieve the error bits on the receiving end of the system. Since the acoustic communication is still a developing technology, a more detailed study and investigation of this technology need to be conducted to improve its performance.

The entire system needs to be tested using the proper communication techniques, and proper protection and isolation for the system components, in particular the underwater components. The system's efficiency in collecting the correct readings from the sensor node and sending it correctly to the control units needs to be tested on a real platform. The system's energy consumption and durability should be tested.

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APPENDIX

APPENDIX A

MATLAB CODE

MATLAB code which includes the conversion algorithm, modeling algorithm, and prediction algorithm.

```
%member 1 sensors
x= xlsread('sensor1.xlsx','b1:b249');
%load the first member strain digital readings
y= (x*2.5)/(2^12);
z= y/150;
% retrieve the original analog readings
e1= (-(z*2)/(2.019*5))*(10^6);
% compute the strain equivalent values
save ('strain1.mat', 'e1')
%save the strain values for member one
t1=  xlsread('sensor1.xlsx','a1:a249');
figure (1)
plot (t1,e1)
xlabel('Time');
ylabel('Strain');
title('Strain 1');
ea1= sum(e1)/249;
fprintf('average strain 1 %0.2f%%\n',...
    ea1)
%calculate the average strain value and plot the values

x= xlsread('sensor2.xlsx','b1:b199');
%load the first member corrosion digital readings
y= (x*2.5)/(2^12);
z= y/5;
% retrieve the original analog readings
c1= -z*10^3;
save ('corrosion1.mat', 'c1')
%save the corrosion values for member one
t2= xlsread('sensor2.xlsx','a1:a199');
figure (2)
plot (t2,c1)
xlabel('Time');
ylabel('Corrosion');
title('Corrosion 2');
ca1 = sum(c1)/199;
fprintf('average corrosion 1 %0.2f%%\n',...
    ca1)
%calculate the average strain value and plot the values

sensor = [ea1 ca1];
figure (3)
bar (sensor);
ylabel('Average Value');
title('Member 1');
%plot member one average value bar graph
```

```
pause (10);

%member 2 sensors
x= xlsread('sensor3.xlsx','b1:b419');
y= (x*2.5)/(2^12);
z= y/150;
e2= (-(z*2)/(2.019*5))*(10^6);
save ('strain2.mat', 'e2')
figure (4)
plot (t1,e2)
xlabel('Time');
ylabel('Strain');
title('Strain 2');
ea2= sum(e2)/249;
fprintf('average strain 2 %0.2f%%\n',...
    ea2)
x= xlsread('sensor4.xlsx','b1:b419');
y= (x*2.5)/(2^12);
z= y/5;
c2= -z*10^3;
save ('corrosion2.mat', 'c2')
figure (5)
plot (t2,c2)
xlabel('Time');
ylabel('Corrosion');
title('Corrosion 2');
ca2 = sum(c2)/199;
fprintf('average corrosion 2 %0.2f%%\n',...
    ca2)
sensor = [ea2 ca2];
figure (6)
bar (sensor);
ylabel('Average Value');
title('Member 2');

pause (10);

%member 3 sensors
x= xlsread('sensor5.xlsx','b1:b419');
y= (x*2.5)/(2^12);
z= y/150;
e3= (-(z*2)/(2.019*5))*(10^6);
save ('strain3.mat', 'e3')
figure (7)
plot (t1,e3)
xlabel('Time');
ylabel('Strain');
title('Strain 3');
ea3= sum(e3)/249;
fprintf('average strain 3 %0.2f%%\n',...
    ea3)
x= xlsread('sensor6.xlsx','b1:b419');
y= (x*2.5)/(2^12);
z= y/5;
c3= -z*10^3;
```

```
save ('corrosion3.mat', 'c3')
figure (8)
plot (t2,c3)
xlabel('Time');
ylabel('Corrosion');
title('Corrosion 3');
ca3 = sum(c3)/199;
fprintf('average corrosion 3 %0.2f%%\n',...
    ca3)
sensor = [ea3 ca3];
figure (9)
bar (sensor);
ylabel('Average Value');
title('Member 3');

%prediction algorithm for strain 1
l= [1:24];
n= l(:);
net = newfit(t1', e1', 3);
% Construct the neural network architecture
%net = train(net, t1', e1');
% Training of neural network.
forecastLoad = sim(net, n')';
figure (10)
plot (n, forecastLoad);
xlabel('Time');
ylabel('Strain');
title('Strain Predict');
%prediction algorithm for corrosion 1
net = newfit(t2', c1', 3);
% Construct the neural network architecture
%net = train(net, t2', c1');
% Training of neural network.
forecastLoad = sim(net, n')';
figure (11)
plot (n, forecastLoad);
xlabel('Time');
ylabel('Corrosion');
title('Corrosion Predict');
```

APPENDIX B

CCS CODE

Code Composer Studio (CCS) code which collects the readings from the interface circuits, feed the readings into the ADC to convert it into digital readings and save the digital readings in the memory registers.

```
//****************************************************************************
//   Description: Input voltage is applied to P2.0, the input voltage is converted
from analog to digital input,
//   and stored in ADC memeory.
//
//                 CC430F6137
//              -----------------
//          /|\|                 |
//           | |                 |
//           --|RST          P1.0|--> LED1
//             |                 |
//      Vin -->|P2.0/A0          |
//
//****************************************************************************
#include "cc430x613x.h"

#define   Num_of_Results   200

volatile unsigned int results[Num_of_Results];

void main(void)
{
  WDTCTL = WDTPW+WDTHOLD;                   // Stop watchdog timer
  P1DIR |= 0x01;                            // P1.0 output
  P2SEL |= 0x01;                            // Enable A/D channel A0
  /* Initialize REF module */
  // Enable 2.5V shared reference, disable temperature sensor to save power
  REFCTL0 |= REFMSTR+REFVSEL_2+REFON+REFTCOFF;
  /* Initialize ADC12_A */
  ADC12CTL0 = ADC12ON+ADC12SHT0_14+ADC12MSC; // Turn on ADC12, set sampling time
  ADC12CTL1 = ADC12SHP+ADC12CONSEQ_2;       // set mode
   ADC12IE = 0x01;                           // Enable ADC12IFG.0
   ADC12MCTL0 = ADC12SREF_1;                 // Vr+=Vref+ and Vr-=AVss
   __delay_cycles(75);                       // 75 us delay @ ~1MHz
   ADC12CTL0 |= ADC12ENC;                    // Enable conversions

while (1)
  {
        static unsigned char index = 0;

        ADC12CTL0 |= ADC12SC;                      // Start conversion
    results[index] = ADC12MEM0;             // Move results
    index++;                                // Increment results index
```

```
        P1OUT |= 0x01;
        __delay_cycles(500000);
        if (index == 200)
        { P1OUT = 0x00;
     index = 0;                                  // Reset the index; Set Breakpoint here
        }
     __no_operation();                                   // For debugger
   }
}
```