Development oF Wireless Sensor Network For Slope Monitoring

by

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CERTIFICATION OF APPROVAL

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

(Dr Micheal Drieberg)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
Sept 2011

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.

(NURUL AMIRAH BINTI ALI)

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First of all, thanks to the Merciful God of Allah to allow me to finish this project. Without His blessing, this project should unable to reach the current progress and accomplish. All the devotion and effort were dedicated to my family, without your support and encouragement; I may fall halfway through this journey.

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ABSTRACT

An increase in the number of landslides in Malaysia, especially during monsoon season, has caused extensive damage to property and lives. The latest tragedy on 21st May 2011, which claimed 16 lives of innocent orphans, has become an indicator that a capable real-time monitoring system is crucial in order to avoid this terrible incident from happening again. This report highlights the deployment of Wireless Sensor Network interfaced with suitable sensors for slope monitoring. The sensors include rain gauge, accelerometer, inclinometer, force sensor and pressure sensor. The system is designed to collect the data from the sensors, transmit it to the base station, present the data with graphical representation and interprets the data so that suitable decision can be made. This decision will determine the level of warning that will be declared. Along with the prototype, a slope model will be built to demonstrate the event of landslide. This project is expected to be able to perform a real-time monitoring on the slope and collects relevant data so that appropriate warning can be raised if necessary.

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CHAPTER 1
INRODUCTION

1.1 Background Study

Wireless Sensor Network (WSN) is originated from Distributed Sensor Networks (DSN) program at the Defence Advanced Research Projects Agency (DARPA) in the eighties [1]. Now, this technology is labelled as the most potential technology in the century. WSN is said to bring new dimension in remote monitoring and data gathering fields. The abilities of WSN to perform local processing and wireless communication are very useful since it can help human in many areas, such as traffic control, agriculture and disaster management. However, certain improvements still need to be done in these aspects of WSN:

1. Ad-hoc deployment
2. Unattended operation (self-operated)
3. Power problem
4. Dynamic changes in environment

This rapidly evolving field has offered scope for a lot of research, including this project.

1.2 Problem Statement

1.2.1 Problem identification

Nowadays, numbers of landslides cases in Malaysia are increasing. The worse that landslides can cause are injuries and fatalities. The National Slope Master Plan 2009-2023 shows an increase in the number of fatalities with an increase in the number of landslides from year 1973 to 2007 [2]. Besides, people affected by the landslides may lose their property. Based on this, the need for early detection for this disaster has increased significantly. Early detection not only can avoid major losses, but also may save one's life. This detection can be realized using WSN. The challenge is to build the working prototype consisting of wireless sensor motes interfaced with various sensors for slope monitoring and the slope model itself.

1.2.2 Significance of the project

Referring to the problem identification, this project will enable wireless real-time monitoring on landslide-prone areas in our country. WSN are currently being employed in a wide variety of applications such as agriculture, disaster management and military. However, commercially available wireless sensor nodes are not equipped with geophysical sensors that are often used for these applications. This project aims to combine sensors and connect them to a single wireless sensor mote. This method is faster and more effective in term of data collection. To be more precise, the objectives of the project are given in the next subsection.

1.3 Objective

1.3.1. To build the working prototype consisting of wireless sensor motes interfaced with various sensors for slope monitoring.

1.3.2. To build a slope model that demonstrates the event of landslide.

1.3.3. To interpret the data collected by the wireless sensor motes, translate the data into graphical representation and decide the level of warning based on the data analysed.

1.4 Scope of study

In this project, a WSN interfaced with soil moisture sensor, pressure sensor and flexibend sensor will be developed for slope monitoring purposes. The sensors that are used to detect physical factors that lead to slope instability will be interfaced to the wireless sensor motes. A physical model of a slope will be built to replicate the phenomenon of slope movement/failure. The wireless sensor motes are used to detect these movements and report them back to the base station. These measurements will enable users to continuously monitor the slope's stability.

To complete this project, studies need to be done in area of wireless sensor network and its implementation, and also landslide characterization. After that suitable sensors will be chosen and interfaced with the MICAz wireless sensor mote. The sensors must be tested before being implemented to the board. Then, the prototype is also tested for its functionality. The data obtained must be interpreted, analysed, and shown through a graphical representation. Based on these, level of warning can be determined.

1.5 The relevancy of the project

Implementation of WSN for early detection of disasters is a very promising new area that yet needs to be explored in Malaysia. This project provides way to monitor landslide-prone areas more effectively and a fast way to warn people that might be affected by the landslide.

1.6 Feasibility of the project

This project will need an experiment in order to complete it. The project could be done within time given provided that everything goes according to the plan. The objective can be achieved if the procedures are closely followed.

CHAPTER 2

LITERATURE REVIEW

2.1 Wireless Sensor Network

Wireless Sensor Network has gain an increasing popularity nowadays because of the rapid development of its application. According to [3], a wireless sensor network is a collection of nodes organized into a cooperative network. Each node consists of processing capability, may contain multiple types of memories, have a RF transceiver, have a power source and accommodate various sensors and actuators.

Figure 1 shows the basic structure of WSN. MICAz motes connected to certain sensors, also known as nodes, are placed in distributive manners to cover certain area. The data connected by the target node will be send to the base station or sink node. If the base station is located outside the transmission range of the node, relay approach will be used where the node will send the data to the nearest node until it reaches base station.

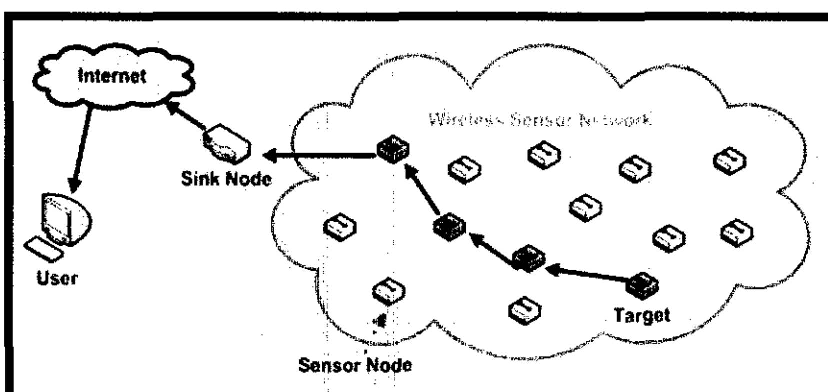


Figure 1: Basic structure of wireless sensor network [4]

Worldwide, WSN has been famously used in many applications such as disaster management and forest fire early detection system. For example, in [5], the author presented a distributed event detection approach in wireless sensor network for disaster management. It was stated that disaster management is one of the important aspects that need to be taken into account in order to provide necessary responses anytime and anywhere whenever a catastrophe occurs to save lives and reduce casualties. In this paper, the approach proposed is light-weight and accurate event detection approach that integrates decision trees for distributed event detection and a novel reputation-based voting method for decision making purpose.

In the meantime, another interesting application of WSN designed in [6] is forest fire early detection system. This design monitors the change of temperature and humidity in the forest for prevention of forest fire using wireless sensor networks. The operation of the design is broken down into three levels which are Field level, Communication Network level and Control level. Each level has been defined discreetly and exclusively to each other, to make sure that the event detection is successful with as minimum a false detection rate as possible. Field level consists of a set of sensors and actuators that interact directly with the environment. Communication Network level determines the way each level communicate while Control level is a control and monitoring center that exploit the data fed by the sensors to specify the actions required. With this systematic network design, the early detection of forest fire is enabled, as it not only allows continuous monitoring, but also energy optimization. Figure 2 illustrates the application of WSN to detect forest fire and in palm oil plantation.

Figure 2: Forest fire [7], palm oil plantation [8]

2.2 Crossbow MICAz Mote

Crossbow MICAz Mote operates within the 2.4 GHz ISM band and is compliant with IEEE 802.15.4.IEEE 802.15.4 specifies the low rate Wireless Personal Area Network (WPAN) standards. It deals with low data rate, long battery life and low complexity. MICAz is designed especially for Deeply Embedded Sensor Network with the capability of 250 kbps data rate with 4kB RAM, 128kB program flash memory and 512kB measurement (serial) flash memory. Its signal ranges between 75-100m outdoor and 20-30m indoor. This mote is supported by MoteWorks wireless sensor network platform. It is based on the Atmel ATmega128L. The ATmega 128L is a low power microcontroller that runs MoteWorks from its internal flash memory [9]. Crossbow MICAz processor board (MPR2400) can be configured to run sensor application and the radio communication simultaneously. The motes can be connected to external peripherals such as sensors and data acquisition boards via 51-pin expansion connector. Hence, it can be used in many applications that vary from monitoring to security purposes.

Figure 3: Crossbow MICAz mote [9]

Every MICAz motes has router capability where it can act as an intermediate router that passes on data from other devices. Besides, it can be programmed as a base station that becomes an interface between the software monitoring tool and the mote. To function as a base station, the mote must be connected to a PC interface board such as MIB520CB Mote Interface Board.

2.3 Landslide

The point of interest in this project is to deploy WSN, interfaced with suitable sensors for slope monitoring. Slope monitoring will serve the purpose of early detection of landslides. As defined in [10], landslide is a range of downhill earth movement, from rapidly moving catastrophic rock avalanche and debris flows in mountainous regions to more slowly moving earth slides, affected by gravity. Not all landslides move abruptly, as some are slow and the effect can be seen gradually. Early detection of this disaster can prevent huge damage to properties and save lives.

The recent tragedy at Hulu Langat, Malaysia, which claimed the lives of 16 people, including 15 orphanages has triggered a massive investigation from authorities [11]. The investigation includes team from the Public Works Department and geologist from a university institute surveying hillside developments in the town, where clusters of traditional ethnic Malay-style houses line the country road next to a river. The main cause for the landslide is believed to be the cutting of the slope that makes the slope unstable. Figure 34shows the slope anatomy and potential slip surfaces.

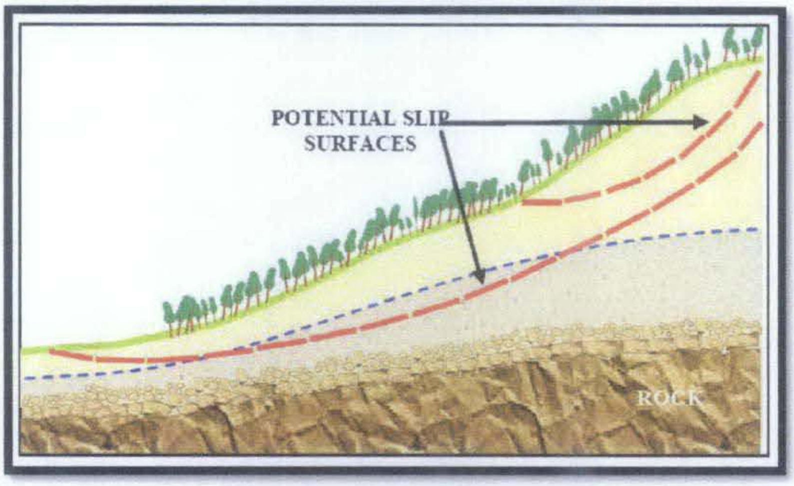


Figure 4: Slope anatomy and potential slip surfaces [12]

Figure 5 illustrate the tragedy of landslide that occurred on 21st May 2011 at Hulu Langat, Selangor.

Figure 5: Landslide tragedy at Hulu Langat, Selangor[13]

Looking back into the statistics, Malaysia shows an increase in number of landslide cases in the past few years. The earliest recorded landslide in Malaysia occurred on 7 December 1919 which took 12 lives [2]. Reported landslides and fatalities from 1973 to 2007 indicate an increase in the number of fatalities with an increase in the number of landslides.

Author of [14] investigated 49 cases of landslides over the last 6 years. Results show that 60% of the slope failures are caused by inadequacy in design alone. In a meantime, 8% of the cases are due to construction errors alone. Aside from that, 20% of the failures are because of the combination of design and construction errors. For landslides in residual soil slope, geological features and lack of maintenance contributed 6% each.

For hill-site developments in Malaysia, normally the Factor of Safety (FOS) against slope failure recommended by the Geotechnical Manual for Slope of Hong Kong is adopted. FOS is determined from the ratio of resisting forces to driving forces. The lowest FOS is the critical stability of a slope. Four possible different stages of landslide stages [14]:

a) Pre-failure stage, when the soil mass is still continuous. This stage is mostly controlled by progressive failure and creep;
b) Onset of failure, characterized by the formation of a continuous shear surface through the entire soil or rock mass;
c) Post-failure stage which includes movement of the soil or rock mass involved in the landslide, from just after failure until it essentially stops;
d) Reactivation stage when the soil or rock mass slides along one or several pre-existing shear surfaces. This reactivation can be occasional or continuous with seasonal variations of the rate of movement.

When dealing with a slope that has high failure potential, there are three main options:

1. Do nothing to the slope and possibly reduce its possible consequences;
2. Do nothing but install a warning system in order to detect any early sign of failure;
3. Improve the safety of the slope above the satisfactory level.

This project focuses more on option number 2, where WSN acts as an detection network, so that an appropriate warning can be summoned to people that might be affected by the slope failure. In [15], the author designs a system to monitor, and detect the landslides in a landslide prone area of Kerala, India. One improvement that has been introduced in the paper is the design of a Deep Earth Probe (DEP) to support the deployment of sensors. This probe will connect all the sensors to a single wireless node. The network is build by combining WSN, Wi-Fi, a satellite network, a broadband network, a GPRS and GSM network. The decision system is developed into three level warning: Early, Intermediate and Imminent. Early warning is triggered by moisture level of the soil, while Intermediate warning depends on the pore pressure. However, when there is soil movement, Imminent warning will be issued. The type of sensors used may differ for different location because it depends on the nature of the soil and underlying bedrock, the configuration of the slope, the geometry of the slope and groundwater conditions.

The main aim in [16] is to develop a system that would change the data sampling rate of the soil moisture sensors based on weather condition. The modification has been made to the program installed in the MICAz transceiver to allow two sets of sampling rate. The basic operation of the system is as the following:

1. The rain gauge detects the rain and sends the data to the gateway.
2. Soil moisture sensor detects the soil moisture level based on the sampling rate that is set by gateway.
3. The data is sent to gateway to be passed to the MoteView software. The data will be stored and displayed here.

Based on the data obtained, the right level of warning will be decided.

CHAPTER 3
METHODOLOGY

3.1. Research Methodology

This chapter will discuss the detail explanation of methodology that is applied in order to finish the project. This project is divided into a few steps to make sure it flows smoothly. The steps are:

3.1.1. Planning

The first step necessary to this project after selecting the topic is planning. Planning involves a lot of background work in the general area of the problem. Planning stage helps in the process to understand the theoretical issues related to the project.

3.1.1.1. Preliminary research/ Literature review

In order to gain maximum useful information, the project's resources and requirements, literature reviews and schedule are planned. Related materials are collected from journal, text books, research paper and internet articles. Besides, the information regarding the project are also gained from constant discussion with Supervisor.

Based on the project description provided, there is a need to understand about wireless sensor network and landslide (types, triggering factors and parameters that can be measured) and also software related to the chosen wireless sensor network. After collecting the resources, they were classified into relevant material and irrelevant material. Only relevant material will be focused on.

3.1.1.2. Analysis of scenario and Selection of Geophysical sensors

Scenario in this context is landslide. Landslide detection and slope monitoring depends on the type of the landslide that could occurs in that particular area. This project will be focusing on rain-driven landslide. Based on this decision, the related parameters are volume of rain, soil moisture, pore pressure, and soil movement. The sensors chosen are rain gauge, soil moisture sensor, pore pressure sensor, force sensor, accelerometer and inclinometer.

3.1.2. Design

3.1.2.1. Slope Modelling

A model of a slope needs to be build to demonstrate the event of a landslide. The slope will be build inside an acrylic casing. The drawing of the casing for slope model is attached in the Appendix A.

3.1.3. Implementation

During FYP 1, this project focused on interfacing the sensor to the MICAz motes, establishing communication between the nodes (which consists of MICAz mote, data acquisition board and sensors) and the base station (which consists of MICAz mote connected to an USB interface). The sensor tested during this period of time is the soil moisture sensor.

During FYP 2, the project has broadened its scope by adding a few more sensors such as pressure sensor and flexi bend sensor. Besides, a slope model is built to demonstrate the event of landslide.

3.1.3.1. Interfacing the sensors to MICAz Wireless Sensor Mote

The commercially available wireless sensor nodes do not include implanted geophysical sensors that are needed in this project. These geophysical sensors cannot be connected directly to the data acquisition board, integrated with the wireless sensor node. Interfacing circuit is necessary to make sure all the data are successfully acquired, and transmitted to the centre computer. The steps to interface the sensors and MICAz mote will be discussed in the Results and Discussion Chapter.

3.1.4. Analysis

3.1.4.1. Data interpretation, analysis and graphical representation of the data

The data collected from the geophysical sensors must be interpreted to distinguish between meaningful data and erroneous data. Then, analysis must be made to the meaningful data to produce graphical representation of that data. Finally, level of warning can be decided.

3.2 Gantt Chart

Table 1: Gantt chart

No.	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1.	Sensor Testing															
2.	Pressure Sensor Circuit Integration															
4.	Force Sensor Circuit Integration								MID SEMESTER BREAK							
5.	Submission of Progress Report															
6.	Slope Model Construction															
7.	Electrex															
8.	Submission of Technical Paper															
9.	Submission of Final Report															
10.	Viva															

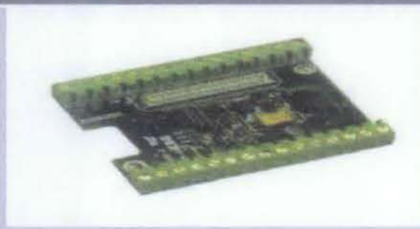
Suggested Milestone   Progress

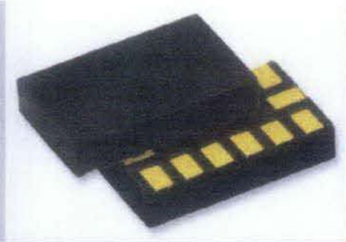
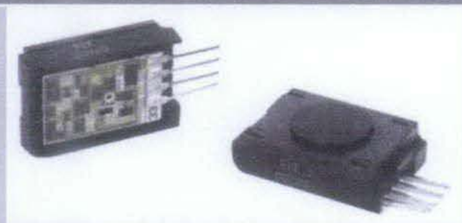
3.3 Tools, Equipments and Materials

The tools, equipments and materials needed for the project are listed as the following.

3.3.1 Slope Monitoring Device

Table 2: List of tools, equipment and materials for the slope monitoring devices

Devices	
MICAz wireless sensor mote	
Data acquisition board (MDA 320)	
Gateway (MIB 520)	
Seba Hydrometric RG 50 (Rain gauge)	
Decagon EC-5 (Soil moisture sensor)	

STMicroelectronics LIS302DL (Accelerometer)	
Analog Device ADIS16209CCCZ (Inclinometer)	
Honeywell S&C FS01 (Force sensor)	
Honeywell S&C 164PC01D37 (Pressure sensor)	

3.3.2 Slope Model

For the slope model, the materials that will be used are acrylic, different type of soils, different type of rocks and water.

CHAPTER 4

RESULTS AND DISCUSSION

The full system is build by:

1. Interfacing the MICAz motes with sensors such as soil moisture sensor, pressure sensor and flexi bend sensor, and connect them with MDA300 data acquisition board to construct a data acquisition device.
2. Interfacing the MICAz mote with MIB520 USB interface board to construct a base station.

The steps taken in the process are discussed in the following sections.

4.1 Hardware and Software Configuration

4.1.1 Hardware

4.1.1.1 MICAz Wireless Mote

MICAz mote works on 2.4 GHz ISM band [9]. This mote is design for Deeply Embedded Sensor Networks. For this project, 3 MICAz motes are used. 2 motes are interfaced with sensors while 1 mote is programmed as a base station. Figure 6 shows the example of MICAz mote that is used in the project.

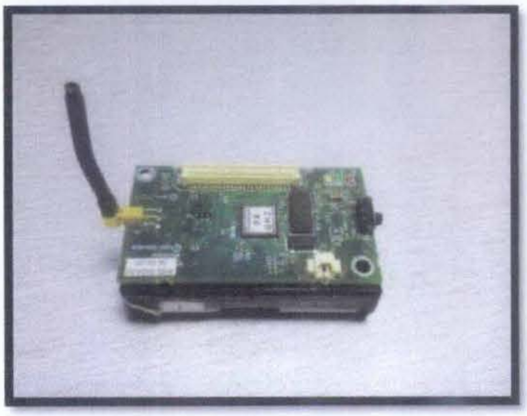


Figure 6: MICAz mote

4.1.1.2 MDA300 Data Acquisition Board

The MDA300 is a data acquisition board that also has onboard temperature and humidity sensors. It can be used to interface with external sensors. This board has 6 digital I/O channels that have event detection interrupt. It can support the maximum of 11 channels of 12-bit analog input. The board can operate with 2.5, 3.3 or 5V sensor excitation voltage [17]. Data logging and display is supported by Crossbow's MoteView user interface [17]. This board is connected to the MICAz wireless mote. Figure 7 is the MDA300 Data Acquisition Board used.

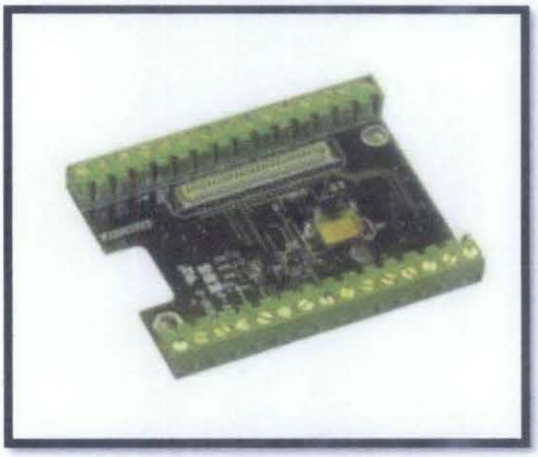


Figure 7: MDA300 Data Acquisition Board [17]

4.1.1.3 MIB520 USB Interface Board

The MIB520CB mote interface board provides USB connectivity to MICAz for communication and programming. It has two ports, one for in-system mote programming and the second port is used for data communication over USB [18]. MIB520 connects to the MICAz mote via a 51-pin expansion connector. This board requires the installation of FTDI FT2232C to use USB port as a virtual COM port. [19]. Figure 8 illustrate the MIB520 USB Interface Board.

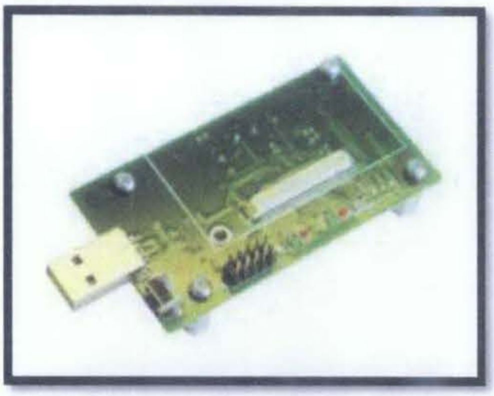


Figure 8: MIB520 USB Interface Board [19]

4.1.1.4 Decagon EC-5 Soil Moisture Sensor

The Decagon EC-5 Soil Moisture Sensor, as shown in Figure 9, determines volumetric water content by measuring the dielectric constant of the media using capacitance/frequency domain technology. Volumetric water content is the ratio of volume of water in the soil to the total volume of the soil [20]. Soil moisture can be very useful in many areas including weather and climate, flood control, soil erosion and slope failure, reservoir management and others.

Figure 9: Decagon EC-5 Soil Moisture Sensor [20]

4.1.1.4.1 Sensor's Calibration

To increase the accuracy of the sensor outputs, the sensor must be calibrated. Decagon EC-5 datasheet provides a few equations that can be chosen, depending on the type of data logger and soil [20]. The equations will be used to calculate the output of the sensor. The calibration of the sensor implies that a suitable equation is chosen. EC-5 requires a 2.5V to 3.6 V excitation voltages. Basically, the output of the EC-5 is in Volt. The output voltage produces by the sensor is determined by the dielectric constant of the medium surrounding the sensor. This output ranges from one tenth to half of the excitation voltage.

Since a non-Decagon data logger is used and the soil tested is mineral soil, excitation voltage from 2.5-3.6 V is applied [20]. For the same reasons, the following equation is chosen. The volumetric water content (VWC) as measured by EC-5 is [20]:

$$VWC = 1.19x - 0.401 \quad (1)$$

where x is equal to the output of the sensor in volt.

4.1.1.5 Honeywell 164PC01D37 Pressure Sensor

The Honeywell 164PC01D37 is a piezoresistive device [21]. Piezoresistive device is a device that converts the stress from the diaphragm deflection at the input ports into an electrical signal by the Piezo Resistors [22]. These Piezo Resistors change their electrical resistance due to the mechanical stress. Typically, there were four Piezo resistors connected in a Wheatstone bridge circuit were used. This circuit configuration was used to provide an output which changes primarily with pressure.

Honeywell 164PC01D37 has two ports: P1 and P2.These ports are shown in Figure 10. P1 is used for dry gases only meanwhile P2 is limited to those media which will not attack polyester, silicon or silicone based adhesive. This sensor is divided into two types which are differential and gage. In differential devices, pressures are applied to both ports. While in gage devices, P1 is vented to atmospheric pressure and the pressure is applied to P2 [23].

The output voltage of the sensor is proportional to the pressure applied. This sensor operates with positive voltage supply tanging from 5.0 to 16.0 VDC. 164PC01D37 is a differential type sensor where the output is equal to the difference in pressure between port P1 and port P2. The complete drawing that shows the structure of the sensor can be viewed in Appendix B.

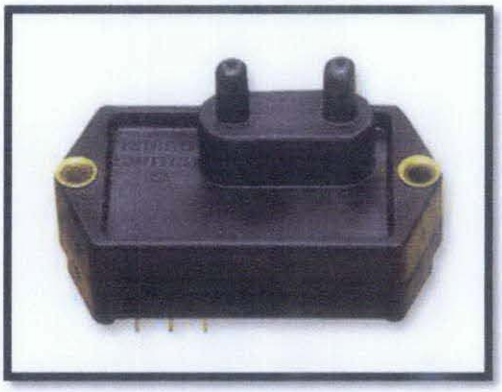


Figure 10: Honeywell 164PC01D37 Pressure Sensor [23]

4.1.1.5.1 Sensor's Calibration

240PC sensors are considered ratio metric since the output signal is proportional to the supply voltage. Standard output characteristics specified by the manufacturer in product literature imply an 8VDC supply voltage (V_s). However, for the simplicity of this project, the supply voltage used is 5VDC. Changing V_s has the following effect [23]:

$$\text{Null offset (V)} = \pm\frac{1}{8}V_S,\ \text{Span (V)} = \pm\frac{5}{8}V_S$$

The general transfer function for 240PC series that relates input pressure to output voltage (V_o) is:

$$V_o = (V_{CC} - V_{SS})(k_o + k_1 P) + V_{SS} \tag{2}$$

Where V_{CC} = Supply voltage to V_s

V_{SS} = Supply return voltage

k_o = null offset factor = $\frac{1}{8}$

k_1 = Sensitivity factor = $\frac{5}{8}$

P = Applied pressure (psi)

4.1.1.6 FlexiBend Sensor

FlexiBend Sensor is based on resistive carbon elements [24]. This type of sensor is also known as a variable printed resistor. When the substrate is bent, the sensor produces a resistance output correlated to the bend radius. The smaller the radius, the higher the resistance value. This sensor has a flat resistance value of ≅1 kΩ and its bend resistance value ranges from 0k – 1 kΩ.

Normally, this sensor can be used with or without an impedance buffer. Low bias current of the op amp reduces error due to source impedance of the flex sensor as a voltage divider. The picture of FlexiBend Sensor is illustrated in Figure 11 as follows.

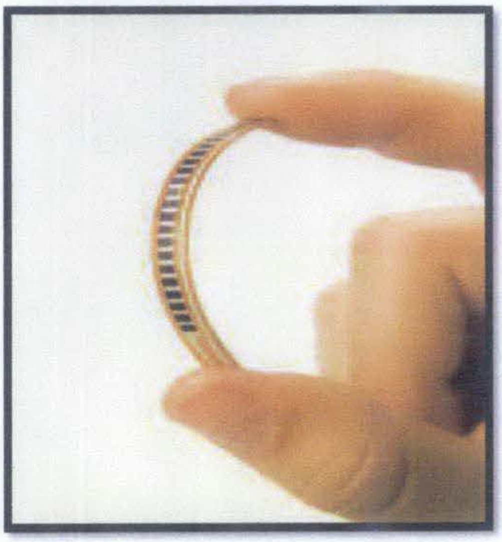


Figure 11: FlexiBend Sensor [24]

4.1.1.7 Hardware Configuration

The hardware configuration of the project is divided into two parts:

1. Data Acquisition Device

   It consists of sensors, MDA300 Data Acquisition board and MICAz motes, as shown in Figure 12. In a meanwhile, Figure 13 and Figure 14 both show the connections made at Node 1 and Node 2.

Figure 12: Data Acquisition Device

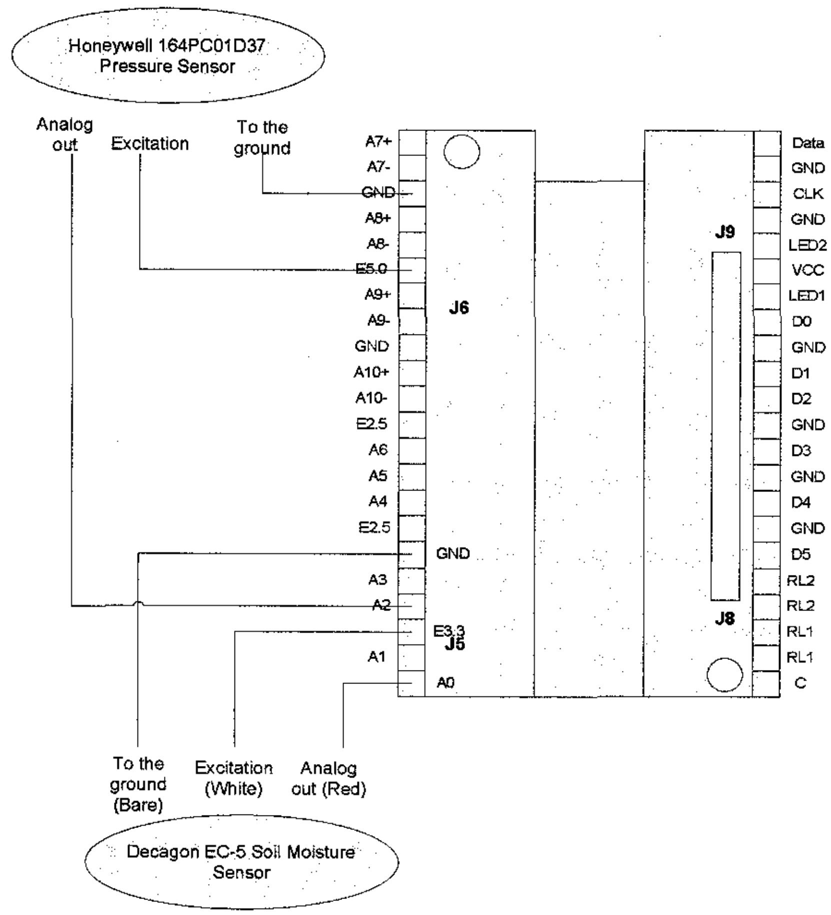


Figure 13: Connections at Node 1

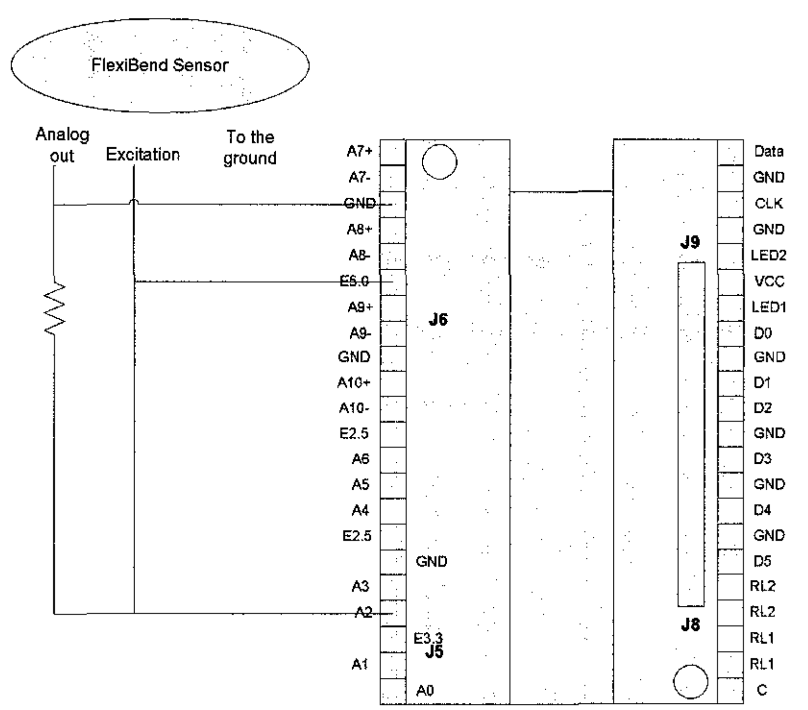


Figure 14: Connections at Node 2

2. Data Monitoring Device

It consists of MIB520 USB Interface board, MICAz mote and a laptop/PC, as shown in Figure 15 below.

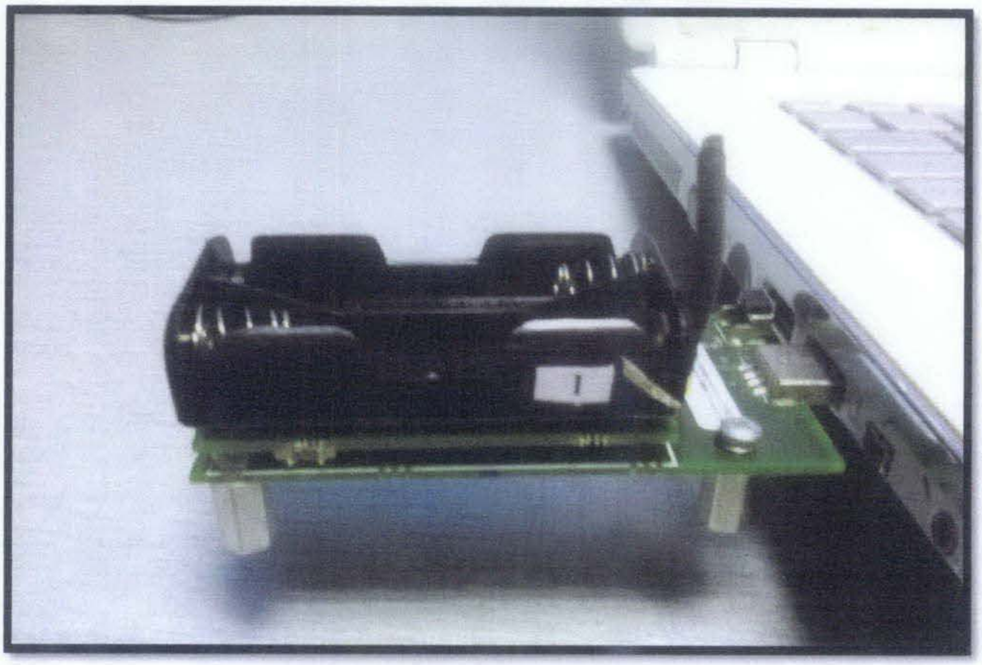


Figure 15: Data Monitoring Device

4.1.2 Software

4.1.2.1 MoteWorks

This software is the end-to-end enabling platform for the creation of wireless sensor networks [25]. MoteWorks network landscape is comprises as the following:

1. The Mote tier

   The software that runs on the cloud of sensor nodes forming a mesh network called *XMesh* resides under this tier. *XMesh* provides the networking algorithms required to form a reliable communication backbone that connects all the nodes within the mesh cloud to the server.

2. The Server tier

   This tier is an always-on facility that handles translation and buffering of data coming from the wireless network and provides the bridge between the wireless Motes and the internet clients. *XServe* and *XOtap* are server tier applications that can run on a PC or Stargate.

3. The Client tier

   It provides the user visualization software and graphical interface for managing the network. MoteView is an example of the client software. However, *XMesh* also can be interfaced to custom client software.
   The summary of MoteWorks architecture can be viewed in Figure 16.

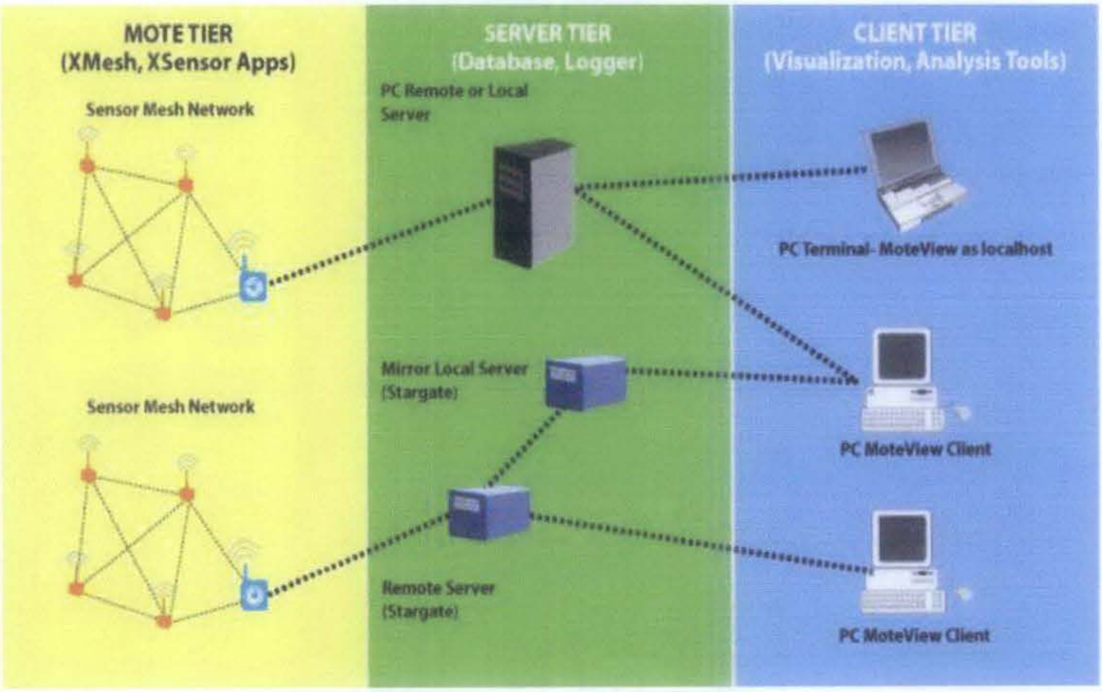


Figure 16: MoteWorks Architecture [25]

4.1.2.2 MoteConfig

MoteConfig is a Windows-based GUI utility for programming Motes [26]. This utility provides an interface for configuring and downloading precompiled *XMesh/TinyOS* firmware applications onto Motes. It allows the user to configure the Mote ID, Group ID, RF channel and RF power.

4.1.2.3 MoteView

MoteView is designed to be an interface ("client tier") between a user and a deployed network of wireless sensors [27]. It provides the tools to simplify deployment and monitoring of WSN. It also makes it easy to connect to a database, to analyse, and to graph sensor readings.

MoteView supports all of Crossbow's sensor and data acquisition boards as well as the MICA2, MICA2DOT, and MICAz processor/radio platforms. It has four main user interface sections: Toolbar/ Menus, Node List, Visualization Tabs and Server/ Error Messages.

4.1.2.4 Uploading the Firmware into the Mote

In order to upload the firmware onto the motes, the gateway must be used. This project requirement specifies that the gateway used is MIB520. Before starting, the assigned COM port number must be noted. The steps to check the COM port number assignment can be viewed in [26]. In this project study, COM port numbers assigned are COM4 and COM5. Bear in mind that lower number COM port is for Mote programming while the higher number is for Mote communication (COM4 is for Mote programming and COM5 will be use when transmitting the data between the Motes).

MIB520 must be powered and attached to the PC via the USB port. At the same time, turn off and connect the mote to the gateway. Make sure the connection is tight. The rest of the steps can be viewed in [26]. Uploading the firmware onto the mote requires choosing a suitable pre-compile X-Mesh application. X-mesh is one of the MoteWorks components. MoteWorks installation steps can be viewed in [25]. The suitable application depends on the type of motes used, radio frequency and data acquisition board [26]. For this project, since the type of mote used is MICAz with radio frequency of 2.420 GHz and the type of data acquisition board is

MDA300, *'C:\ProgramFiles\Crossbow\MoteView\xmesh\MICAz\MDA300\XMDA30 0_2420_hp.exe'* is executed.

This is the application for XMesh high power mode. In high power, all the nodes or motes are always on. This project utilized Xmesh high power mote because it offers the highest message rate. There is also application for low power mode. For low power mode, the power consumption is reduced by putting the processor to sleep once the task queue is empty [26]. However, this results longer delay in data transmission compared to high power mode.

The difference between normal node and base station is their *NODE ID*. For base station, the *NODE ID* must be equal to 0. For normal node, the *NODE ID* must be bigger than 0. However, for both normal node and base station, the *GROUP ID* must be equal.

4.1.2.5 Viewing the Sensor's Reading

To collect the data from the sensor, MoteView software is used. To install this software, the steps in [27] can be followed. This software is an important tool in monitoring and data analyzing purposes. It can convert the data into a meaningful graphical representation.

When the nodes are up and running, MoteView will show the following, as in Figure 9. If the nodes are in grey color, which means that either the nodes are still not configured by MoteView or the process of transmitting the data between them has failed. The setting needs to be rechecked to rectify this problem.

Figure 17: Active node and gateway

Ensure that the *LIVE* box is checked and the LIVE icon is green.From Figure 9, we notice that MoteView shows several sensor readings. Keep in mind that MDA300 data acquisition board has embedded temperature and humidity sensors. The node data shown is based on the configuration made in MoteView. Table 3 shows the node list icon and its state. This state depends on the duration the mote being connected or disconnected from the software.

Table 3: Node Colour and Its State [27]

Node List Icon	State
 (Gray Mote Icon)	No results received
 (Green Mote Icon)	Fresh results within last 20 minutes

 (Light Green Mote Icon)	Results stale by >20 minutes
 (Yellow Mote Icon)	Results stale by >40 minutes
 (Orange Mote Icon)	Results stale by >60 minutes
 (Red Mote Icon)	Results stale by more than a day

4.2 Results

The results obtained from the experiment are shown in the Table 4:

Table 4: Readings obtained from MoteView

A

Duration	Pressure Sensor	Pressure Sensor	FlexiBend Sensor
1	0.5505	0.6390	0.0006
2	0.5505	0.6384	0.0012
3	0.5512	0.6421	0.0012
4	0.5524	0.6397	0.0006
5	0.5512	0.6415	0.0012
6	0.5518	0.6372	0.0006
7	0.5524	0.6403	0.0006
8	0.5512	0.6384	0.0006
9	0.5542	0.6390	0.0012
10	0.5524	0.6366	0.0012
11	0.5524	0.6390	0.0006
12	0.5487	0.6384	0.0006
13	0.5524	0.6415	0.0012
14	0.5524	0.6415	0.0006
15	0.5518	0.6390	0.0012
16	0.5530	0.6397	0.0006
17	0.5524	0.6384	0.0006
18	0.5518	0.6390	0.0012
19	0.5530	0.6421	0.0006
20	0.5524	0.6421	0.0012
21	0.5524	0.6384	0.0006
22	0.5530	0.6403	0.0006
23	0.5524	0.6409	0.0006
24	0.5524	0.6409	0.0006
25	0.5524	0.6427	0.0012
26	0.5524	0.6397	0.0012
27	0.5524	0.6433	0.0006
28	0.5524	0.6403	0.0006
29	0.5542	0.6397	0.0079
30	0.5530	0.6421	0.0287
31	0.5518	0.6439	0.0089
32	0.5524	0.6366	0.0021
33	0.5530	0.6390	0.0088
34	0.5530	0.6427	0.0012
35	0.5505	0.6427	0.0162
36	0.5518	0.6409	0.0094
37	0.5548	0.6427	0.0100
38	0.5499	0.6397	0.0149
39	0.5524	0.6445	0.0023
40	0.5487	0.6427	0.0061
41	0.5493	0.6421	0.0015
42	0.5469	0.6433	0.0074

43	0.5493	0.6421	0.0024
44	0.5450	0.6439	0.0020
45	0.5499	0.6421	0.0095
46	0.5518	0.6415	0.0015
47	0.5505	0.6439	0.0059
48	0.5493	0.6409	0.0089
49	0.5499	0.6433	0.0186
50	0.5499	0.6415	0.0021
B			
51	0.5499	0.6403	0.0100
52	0.5499	0.6439	0.0076
53	0.5530	0.6451	0.0161
54	0.5524	0.6421	0.0222
55	0.5524	0.6415	0.0229
56	0.5524	0.6421	0.0186
57	0.5524	0.6421	0.0125
58	0.5518	0.6403	0.0277
59	0.5524	0.6421	0.0180
60	0.5518	0.6390	0.0314
61	0.5518	0.6403	0.0241
62	0.5518	0.6403	0.0100
63	0.5524	0.6390	0.0302
64	0.5548	0.6384	0.0253
65	0.5518	0.6397	0.0314
66	0.5518	0.6415	0.0296
67	0.5512	0.6397	0.0131
68	0.5518	0.6403	0.0308
69	0.5512	0.6366	0.0363
70	0.5512	0.7433	0.0515
71	0.5518	0.7397	0.0351
72	0.5524	0.8427	0.0387
73	0.5481	0.8409	0.0229
74	0.5512	0.8403	0.0174
75	0.5505	0.8409	0.0247
76	0.5505	0.9439	0.0247
77	0.5505	0.9721	0.0113
78	0.5518	0.8397	0.0229
79	0.5512	0.7331	0.0326
80	0.5512	1.6397	0.0424
81	0.5505	1.6378	0.0601
82	0.5512	1.6409	0.0607
83	0.5512	1.6415	0.0595
84	0.5505	1.6445	0.0668
85	0.5487	1.6451	0.0686
86	0.5512	0.6403	0.0564
87	0.5512	0.6433	0.0860
88	0.5512	0.6421	0.0638
89	0.5493	0.6397	0.0613
90	0.5493	0.6403	0.0344
91	0.5505	0.6439	0.0735
92	0.5512	0.6409	0.0595
93	0.5512	0.6403	0.0760
94	0.5524	0.6384	0.0735
95	0.5512	0.6397	0.0515
96	0.5487	0.6421	0.1089
97	0.5512	0.6421	0.1581
98	0.5505	0.6403	0.1666
99	0.5530	0.6409	0.1526
100	0.6118	0.6409	0.2602
101	0.7108	0.6415	0.2766
102	0.7360	0.6397	0.2840
103	0.7618	0.6421	0.3830
C			
104	0.7696	0.6433	0.6104
105	0.7871	0.6415	0.6128
106	0.7696	0.6397	0.6165
107	0.7924	0.6433	0.6268
108	0.8039	0.6409	0.6183
109	0.7696	0.6421	0.6189
110	0.7780	1.6397	0.6226
111	0.7696	0.9433	0.7831
112	0.7702	0.9415	0.7947
113	0.7696	0.7445	0.7959
114	0.7787	0.8390	0.7947
115	0.7174	1.6397	0.6311
116	0.7223	1.6397	0.7843
117	0.7198	0.9409	0.7916
118	0.7192	0.8445	0.7959
119	0.6688	0.6397	0.7837
120	0.5686	0.6439	0.7959
121	0.6268	0.6433	0.7690
122	0.6352	0.6427	0.7642
123	0.6352	0.6421	0.7690
124	0.6346	0.6409	0.7703
125	0.6340	0.6409	0.7678
126	0.6274	0.6403	0.7660
127	0.6364	0.6439	0.7819
128	0.6358	0.6415	0.7745
129	0.6352	0.6397	0.7776
130	0.6358	0.6433	0.7855

131	0.6352	0.6421	0.7880
132	0.6364	0.6397	0.7959
133	0.6352	0.6439	0.7910
134	0.6165	0.6433	0.7892
135	0.6395	0.6464	0.7886
136	0.6488	0.6702	0.7782
137	0.8203	0.6799	0.7703
138	0.9216	0.6860	0.7752
139	0.9332	0.6860	0.7806
140	0.9357	0.6732	0.7947
141	0.9357	0.6549	0.7935
142	0.9381	0.6415	0.8057
143	0.9271	0.6329	0.7977
144	0.9222	0.6348	0.7935
145	0.9216	0.6323	0.8032
146	0.9174	0.6274	0.7929
147	0.8862	0.6439	0.7947
148	0.8801	0.6421	0.8002
149	0.8777	0.6421	0.7959
150	0.8752	0.6397	0.7568
151	0.8734	0.6409	0.7935
152	0.8710	0.6451	0.7983
153	0.8661	0.6415	0.7886
154	0.8545	0.6421	0.7929
155	0.8533	0.6421	0.7965
156	0.8514	0.6397	0.7990
157	0.8496	0.6421	0.7831
158	0.8453	0.6390	0.8002
159	0.8313	0.6415	0.8093
160	0.8240	0.6439	0.8075
161	0.8209	0.6421	0.7996
162	0.8173	0.6421	0.7996
163	0.8160	0.6464	0.8087
164	0.8136	0.6397	0.8221
165	0.8106	0.6427	0.8209
166	0.8081	0.6421	0.8136
167	0.8081	0.6415	0.8240
168	0.8075	0.6415	0.8209
169	0.8051	0.6421	0.8191
170	0.8038	0.6427	0.7882
171	0.8026	0.6421	0.8173
172	0.8014	0.6433	0.7965
173	0.8044	0.6409	0.7567
174	0.7996	0.6421	0.6143
175	0.7971	0.6433	0.6510
176	0.7965	0.6433	0.6452
177	0.7977	0.6427	0.6480
178	0.7953	0.6397	0.5783
179	0.7947	0.6415	0.5813
180	0.7953	0.6421	0.5838
181	0.7916	0.6403	0.4579
182	0.7892	0.6421	0.4530
183	0.7904	0.6409	0.4646
184	0.7898	0.6415	0.4646
185	0.7892	0.6390	0.4652
186	0.7886	0.6415	0.4157
187	0.7880	0.6378	0.4093
188	0.7874	0.6421	0.4069
189	0.7874	0.6458	0.4075
190	0.7855	0.6433	0.2305
191	0.7837	0.6470	0.2348
192	0.7861	0.6427	0.2354
193	0.7849	0.6433	0.2373
194	0.7831	0.6458	0.2324
195	0.7849	0.6366	0.2281
196	0.7819	0.6439	0.2330
197	0.7849	0.6415	0.0078
198	0.7819	0.6415	0.2379
199	0.7819	0.6421	0.2409
200	0.7806	0.6403	0.2385
201	0.7806	0.6409	0.2360
202	0.7794	0.6439	0.2330

The graph in Figure 18 below illustrates the findings:

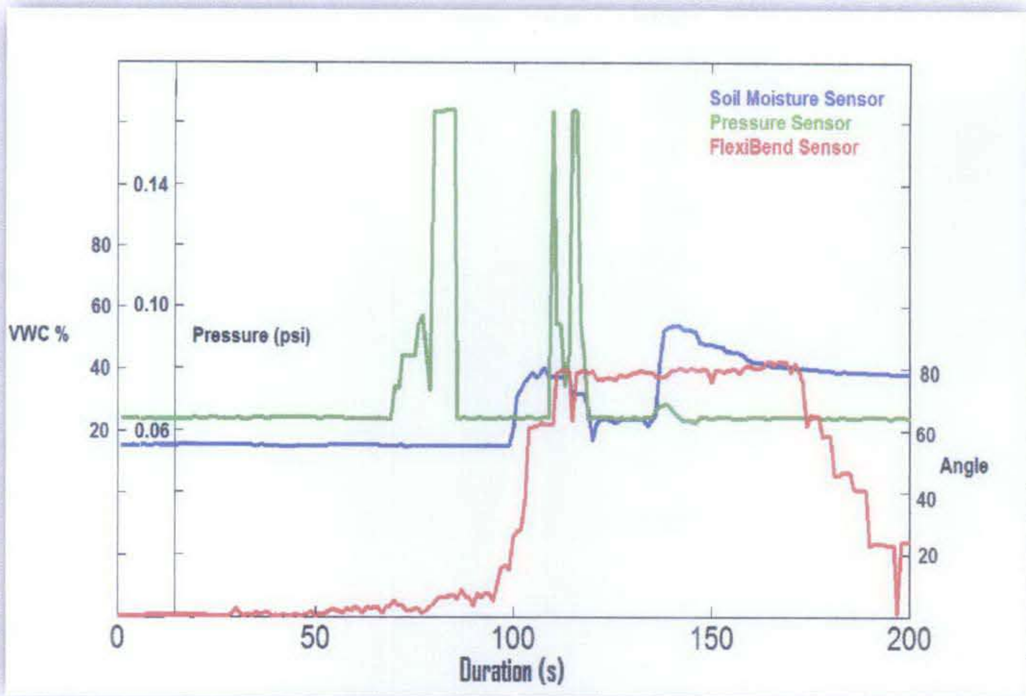


Figure 18: Readings for the sensors

To simplify discussions, the results are categorized into three periods: Period A, Period B, and Period C. Period A started when water was poured onto the slope model at 1st second. During this period, the reading of soil moisture sensor are at normal for wet soil (refer sensor characterization sections). Flexi bend sensor didn't show any changes in its readings. The readings for pressure sensor were increasing at 60th second until it falls back. This is because the water was flowing downward. When the water flow was interrupted, the pressure sensor reading started to increase, thus entered Period B. However, the readings of soil moisture sensor still the same as previous. Flexi bend sensor shows a slight increase in its reading.

Period C started when Flexi bend sensor's reading suddenly goes up drastically. This shows that the flexibend sensor has some angle displacement. At the same time, pressure sensor's reading also increase from its previous stable state. Soil moisture sensor's readings show that it started to saturated. This is because the water is stagnant.

Period A represents an event of heavy rain. Period B shows that after the heavy rain, soil moisture and pore pressure started to increase. However, during this period, there is still no major earth movement that suggest a landslide. Period C demonstrates the event of landslide where there was a massive earth movement, depicted by fluctuations in flexi bend sensor's reading.

Different level of warning can be issued on different periods, as shown in the Table 5 below.

Table 5: Level of Warning

Period	Level of Warning	Description
A	1	Early warning. Normally triggered by a continuos heavy rain. The warning issued just to inform people that live in a landslide-prone area.
B	2	Second level warning. The warning issued to alarmed people that landslide may occurred if the current condition continued.
C	3	Emergency warning. When this level of warning is issued, there was already earth movement in a certain part of the slope.

4.3 Sensor's Characterization

The current sensors output are in Voltage. To obtain more meaningful data, these output voltages must be characterized.

4.3.1 Decagon EC-5 Soil Moisture Sensor

The reading of the sensor is taken under two extreme conditions, that is in air and soaked completely in pure water, and also two normal conditions which are in dry soil and wet soil to determine the values of the output. The corresponding

VWC percentage (%VWC) can be observed in MoteView. Table 6 below summarizes the finding.

Table 6: Soil Moisture Sensor Reading

Reading / Conditions	Voltage (V)	Volumetric Water Content, VWC (%)
Air	0.29	-5.59
Water	0.9	67.00
Dry Soil	0.38	5.68
Wet Soil	0.73	46.81

The reading of the soil moisture sensor is not accurate in the air because the value is negative. Decagon EC-5 output is influenced by the dielectric constant of the media around it. This sensor is calibrated to read VWC of the mineral soil (which has value of dielectric approaching 5). If the sensor is left on the ground and taking the reading from the air (which has value of dielectric approaching 1), the output value will become negative.

In a meanwhile, in pure water, the VWC will reach its maximum value around 60% [20]. The maximum VWC % can be more than 60% if the water used is tap water, which is not pure water [29]. Usually, tap water contains chlorine, various types of salts and nitrates [28]. Thus, its dielectric constant is slightly different from pure water.

EC-5 output can be around 10-40% of its excitation voltage and the range of measurement is from 0% to saturation. Normally mineral soil saturates at 40-50% VWC in normal condition [20]. From the characterization table, the VWC% in dry soil is around 5% while in wet soil is 46%. The VWC (%) of the data obtained by the system is showed in the Figure 19.

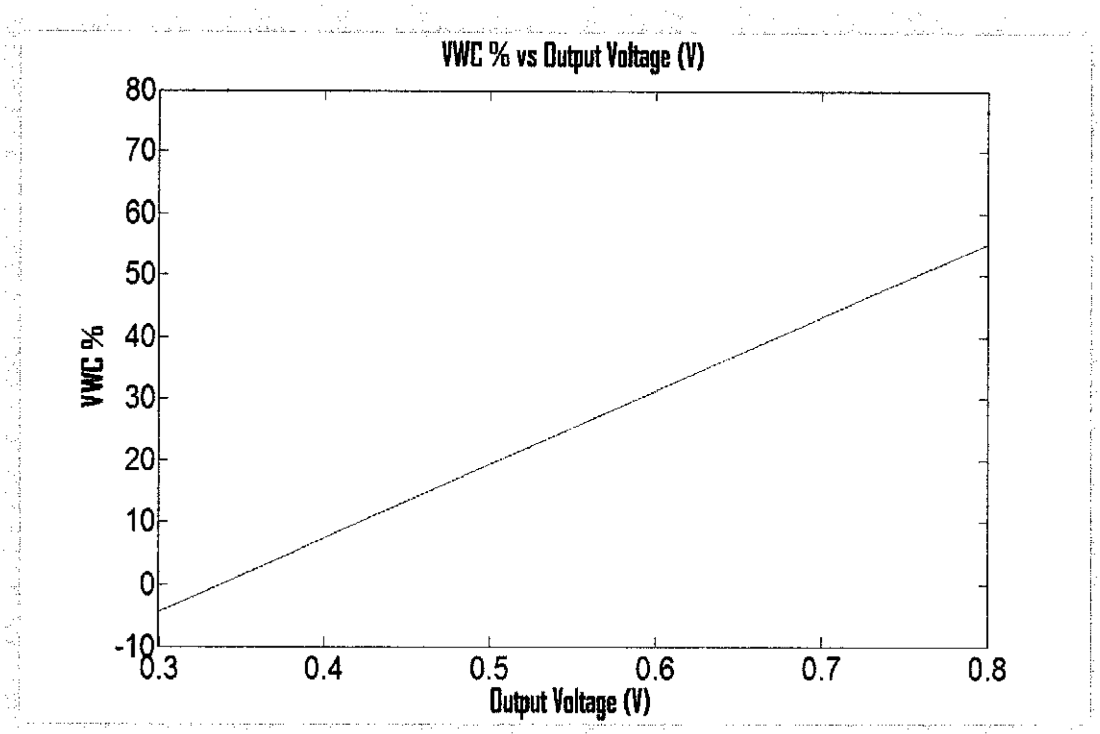


Figure 19: VWC (%)

4.3.2 Honeywell 164PC01D37 Pressure Sensor

Pressure is defined as the continuous physical force exerted on or against an object by something in contact with it. The pressure sensor works as the following:

To characterize the pressure sensor, a series of experiment was conducted to obtain the data needed. From the data, the pressure applied to the sensor is found by altering (2). For span of 0-10 VDC, set $V_{CC} = 14\ \mathrm{V}, V_{SS} = -2\ \mathrm{V}$. Hence, the equation to find the pressure is:

$$P = 0.1V_o \tag{3}$$

First, find the minimum and maximum value the sensor can read.

Minimum output voltage (Null-offset) $= \pm\frac{1}{8}V_S = \pm\frac{1}{8}(5) = \pm 0.625\ \mathrm{V}$

Maximum output voltage (span) = $\pm\frac{5}{8}V_S = \pm\frac{5}{8}(5) = \pm 3.125$ V

The pressure sensor's characterization is summarized in the Table 7 below:

Table 7: Pressure Sensor Reading

Location of P2		P1-P2	
	[illegible]	[illegible]	[illegible]
Water	1	1.13	0.035571
	[illegible]	[illegible]	[illegible]
	3	1.19	0.10671
	[illegible]	[illegible]	[illegible]
	5	1.71	0.17785
	[illegible]	[illegible]	[illegible]
	7	2.19	0.24899
	[illegible]	[illegible]	[illegible]
Air		0.65	0.065

The values of the pressure measured by the sensor are converted into pounds per square inch (psi). The pressure can be converted into any other units by referring to the conversion table shown below [30].

Table 8: Conversion Table

	Pascal	Bar	Technical Atmosphere	Standard Atmosphere	Torr	Pound per Square Inch
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Pa	1 N/m^2	10^{-5}	1.0197×10^{-5}	9.8692×10^{-6}	7.5006×10^{-3}	145.04×10^{-6}
bar	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
at	0.980665×10^5	0.980665	1 kp/cm^2	0.96784	735.56	14.223
atm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1 Torr	133.322	1.3332×10^{-3}	1.3595×10^{-3}	1.3158×10^{-3}	1 mmHg	19.337×10^{-3}
psi	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The pressure of the slope (in psi) is illustrated in the Figure 20.

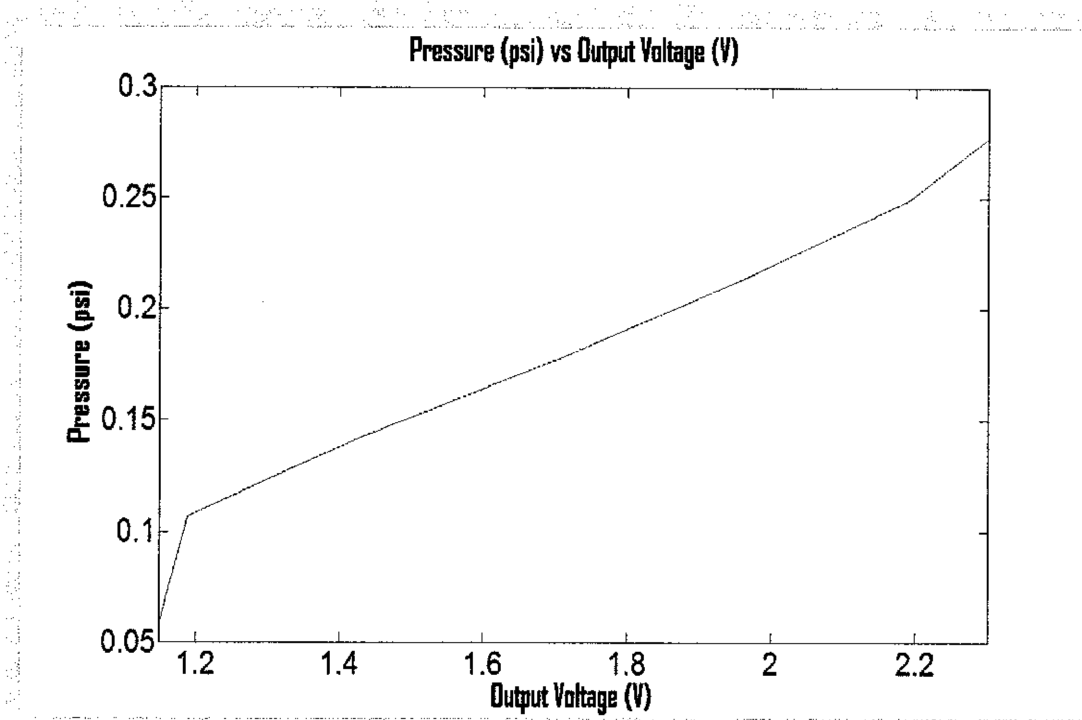


Figure 20: Pressure (psi)

4.3.3 FlexiBend Sensor

As discussed previously, the flex sensor is based on angle displacement measurement [24]. Hence, the characterization of this sensor depends on its bending or angle displacement, shown in Figure 21.

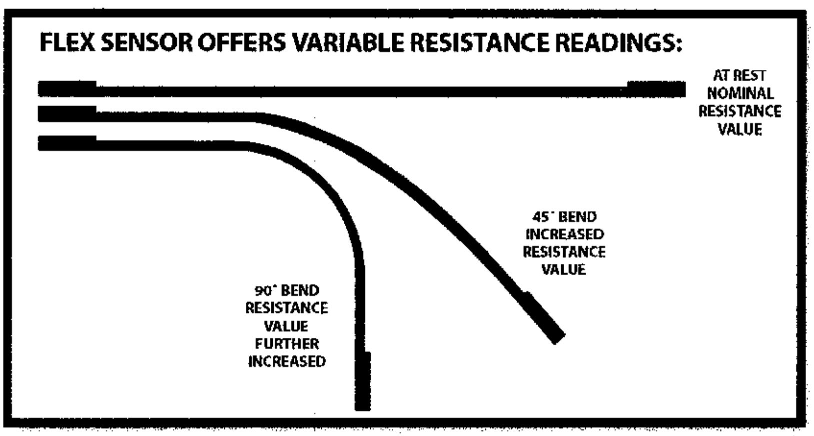


Figure 21: Angle Displacement of the bend sensor [24]

Since flex sensor acts as a voltage divider, the relationship between output voltage, input voltage, R_1(flex sensor) and R_2(2.93kΩ) is [24]:

$$V_o = V_{in}\left(\frac{R_1}{R_1+R_2}\right) \qquad (4)$$

The maximum value of flexi bend sensor is stated as 1.0 kΩ, so the expected maximum output can be calculated as:

$$= 5\left(\frac{1.0\ \text{k}}{[1.0\ \text{k} + 2.93\ \text{k}]}\right) = 1.27\ \text{V}$$

Table 9 below summarize the flex sensor's characterization.

Table 9: FlexiBend Sensor Reading

Angle	Output Voltage (V_o)	Resistance R_1(kΩ)
0	[illegible]	[illegible]
45	0.43	0.277
90	[illegible]	[illegible]

Graph in Figure 22 is plotted to obtain the Linear Regression formula for FlexiBend Sensor.

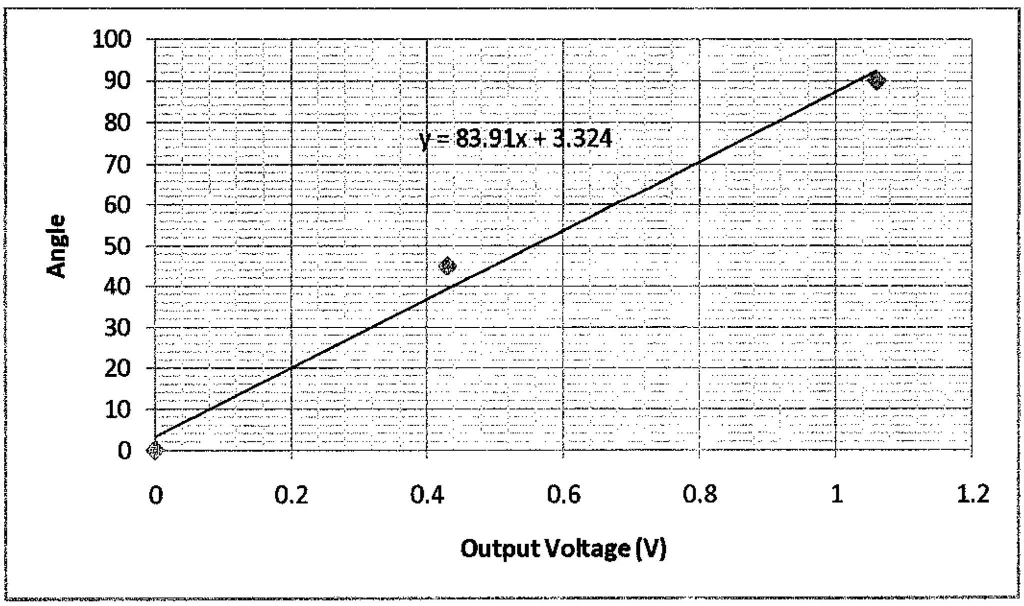


Figure 22: Angle Displacement (Degree) vs Output Voltage (V)

The equation obtained for FlexiBend Sensor is:

$$\text{Angle (Degree)} = 83.91x + 3.324 \quad (5)$$

The angle of displacement of the flexibend sensor is shown in Figure 23:

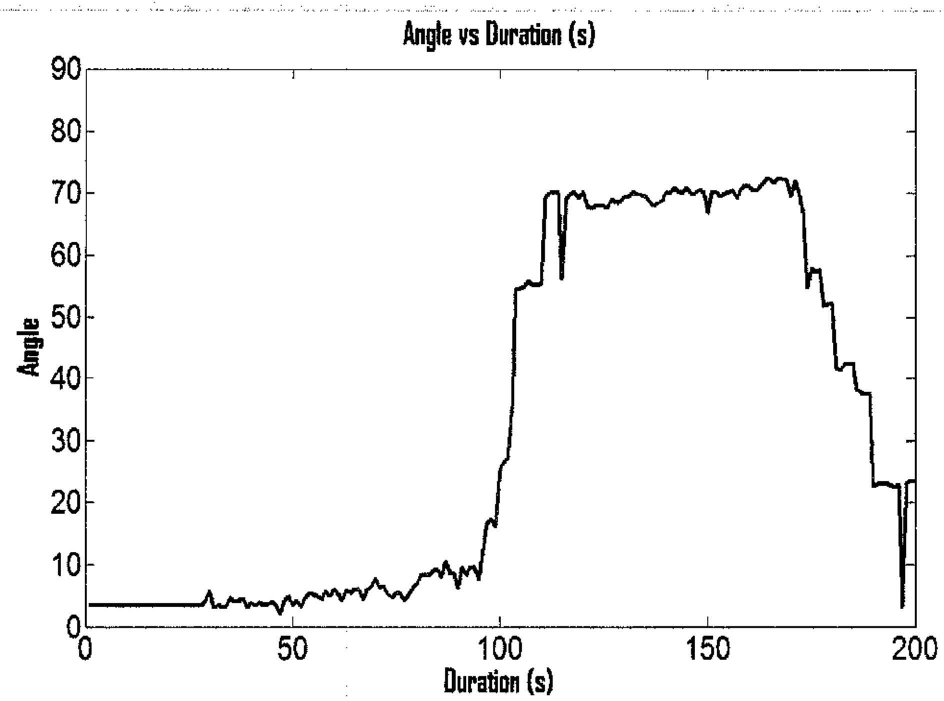


Figure 23: Angular Displacement (Degree)

The Flexi bend sensor was buried halfway into the ground. The sensor started to show an increase reading after the 50th second. On the 110th second, the first earth movement occurred, causing the flexi bend sensor to bend 70 degrees. On the 150th second, the second earth movement occurred, causing the flexi bend sensor to bend 80 degrees. These two earth movement demonstrate the event of landslide.

4.4. Sensor Characterization in MoteView

The output display by MoteView can be changed into the characterized output (VWC%, psi and degree) instead of voltage. MoteView provide a special MDA support tools that allows users to define their own calibration parameters to convert from raw output voltage into desired unit.

To create a new external configuration, users must input the corresponding polynomial equation into the Sensor Calibration tool in MoteView. The following steps show how to configure the external sensor in MoteView.

1. MDA Configuration dialog window is started by clicking the MDA Configuration icon as shown in Figure 24.

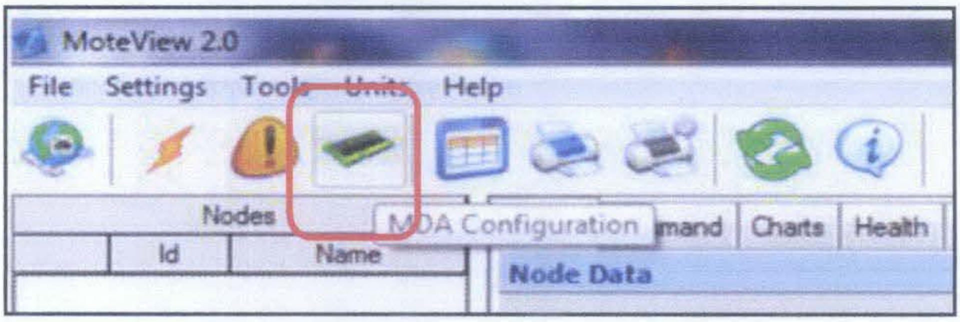


Figure 24: MDA Configuration Icon

2. Select MDA300 and click modify foar ADC0, ADC1 and ADC2. Figure 25 shows the MDA Configuration dialog window.

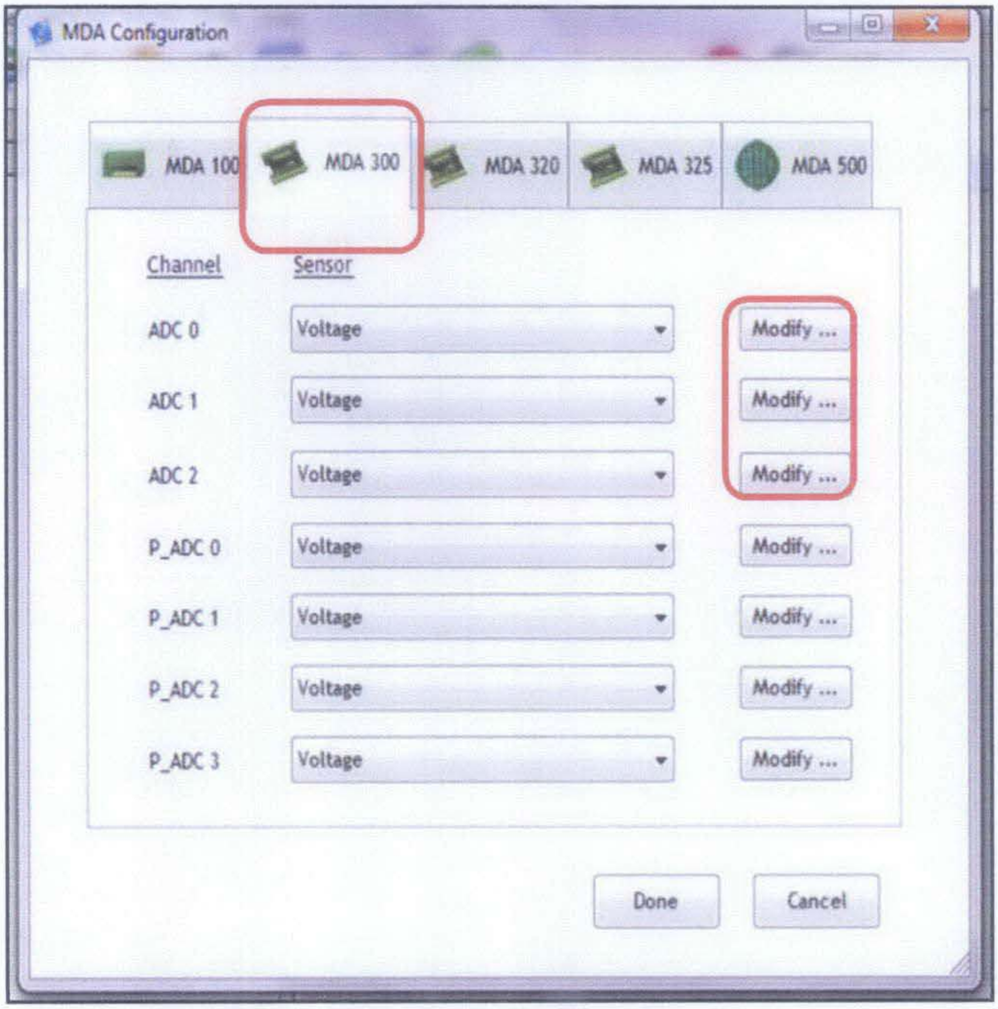


Figure 25: MDA Configuration Dialog Window

3. In Sensor Configuration dialog window (shown in Figure 26), add the corresponding sensor. The calibration type used for the sensors in this project is Polynomial. All the Coefficient values are specified to convert from raw voltage (x) into required units.

Soil Moisture Sensor:	VWC (%)	= (1.19x - 0.401)100
Pressure Sensor:	P(psi)	= 0.1x - 0.4
FlexiBend Sensor	Degree	= 83.91x + 3.324

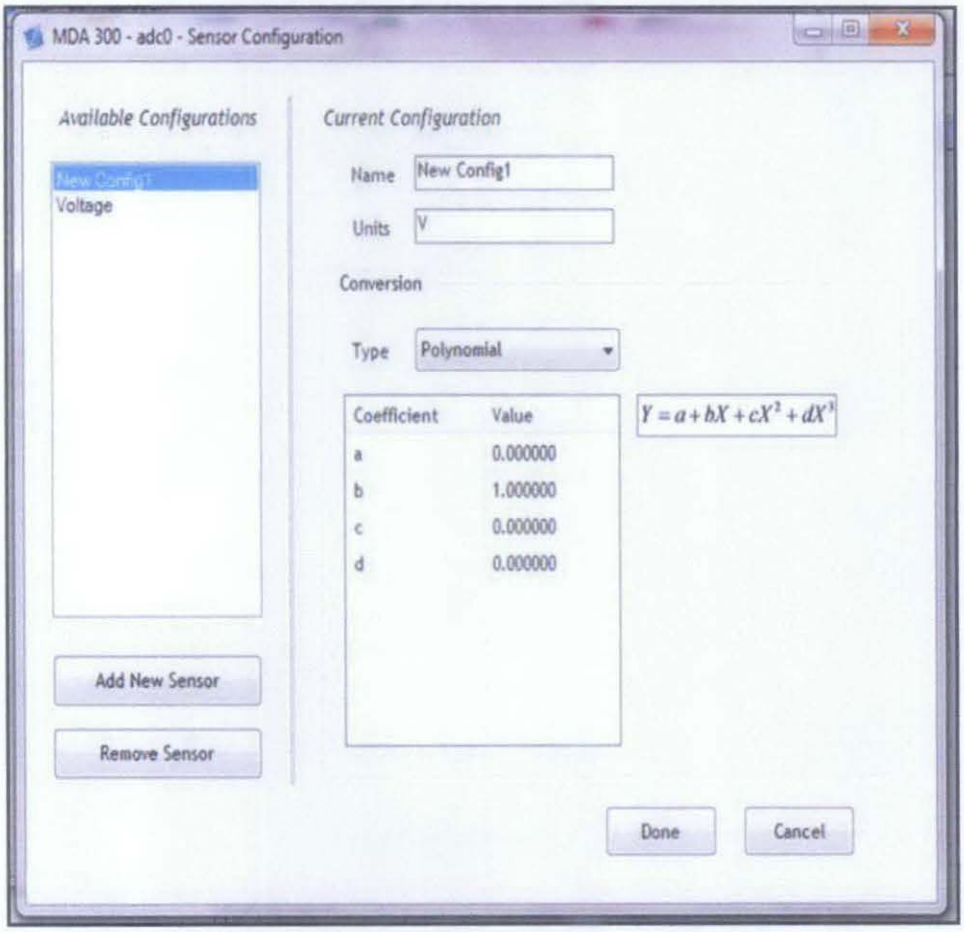


Figure 26: Sensor Configuration Dialog Window

The results were computed in Table 10.

Table 10: Characterized Sensor Reading

Duration(s)	Pressure Sensor (V)	VWC %	Pressure Sensor(V)	Pressure (psi)	FlexiBend Sensor (V)	Angle
1	0.55054	25.41426	0.63904	0.063904	0.00061	3.375214
2	0.55054	25.41426	0.63843	0.063843	0.001221	3.426429
3	0.55115	25.48685	0.64209	0.064209	0.001221	3.426429
4	0.55237	25.63203	0.63965	0.063965	0.00061	3.375214
5	0.55115	25.48685	0.64148	0.064148	0.001221	3.426429
6	0.55176	25.55944	0.63721	0.063721	0.00061	3.375214
7	0.55237	25.63203	0.64026	0.064026	0.00061	3.375214
8	0.55115	25.48685	0.63843	0.063843	0.00061	3.375214
9	0.5542	25.8498	0.63904	0.063904	0.001221	3.426429
10	0.55237	25.63203	0.6366	0.06366	0.001221	3.426429
11	0.55237	25.63203	0.63904	0.063904	0.00061	3.375214
12	0.54871	25.19649	0.63843	0.063843	0.00061	3.375214
13	0.55237	25.63203	0.64148	0.064148	0.001221	3.426429
14	0.55237	25.63203	0.64148	0.064148	0.00061	3.375214
15	0.55176	25.55944	0.63904	0.063904	0.001221	3.426429
16	0.55298	25.70462	0.63965	0.063965	0.00061	3.375214
17	0.55237	25.63203	0.63843	0.063843	0.00061	3.375214
18	0.55176	25.55944	0.63904	0.063904	0.001221	3.426429
19	0.55298	25.70462	0.64209	0.064209	0.00061	3.375214
20	0.55237	25.63203	0.64209	0.064209	0.001221	3.426429
21	0.55237	25.63203	0.63843	0.063843	0.00061	3.375214
22	0.55298	25.70462	0.64026	0.064026	0.00061	3.375214
23	0.55237	25.63203	0.64087	0.064087	0.00061	3.375214
24	0.55237	25.63203	0.64087	0.064087	0.00061	3.375214
25	0.55237	25.63203	0.6427	0.06427	0.001221	3.426429
26	0.55237	25.63203	0.63965	0.063965	0.001221	3.426429
27	0.55237	25.63203	0.64331	0.064331	0.00061	3.375214
28	0.55237	25.63203	0.64026	0.064026	0.00061	3.375214
29	0.5542	25.8498	0.63965	0.063965	0.007884	3.985522
30	0.55298	25.70462	0.64209	0.064209	0.028669	5.729597
31	0.55176	25.55944	0.64392	0.064392	0.008881	4.069235
32	0.55237	25.63203	0.6366	0.06366	0.002136	3.503257
33	0.55298	25.70462	0.63904	0.063904	0.008846	4.066293
34	0.55298	25.70462	0.6427	0.06427	0.001209	3.425428
35	0.55054	25.41426	0.6427	0.06427	0.016201	4.683457
36	0.55176	25.55944	0.64087	0.064087	0.009431	4.115376
37	0.55481	25.92239	0.6427	0.06427	0.010041	4.166561
38	0.54993	25.34167	0.63965	0.063965	0.014886	4.573099
39	0.55237	25.63203	0.64453	0.064453	0.002348	3.521001
40	0.54871	25.19649	0.6427	0.06427	0.006121	3.837592
41	0.54932	25.26908	0.64209	0.064209	0.001533	3.452653

42	0.54688	24.97872	0.64331	0.064331	0.007351	3.940802
43	0.54932	25.26908	0.64209	0.064209	0.002436	3.528379
44	0.54504	24.75976	0.64392	0.064392	0.001981	3.490225
45	0.54993	25.34167	0.64209	0.064209	0.009463	4.118059
46	0.55176	25.55944	0.64148	0.064148	0.001533	3.452653
47	0.55054	25.41426	0.64392	0.064392	0.005888	3.818059
48	0.54932	25.26908	0.64087	0.064087	0.008853	4.066874
49	0.54993	25.34167	0.64331	0.064331	0.018623	4.886674
50	0.54993	25.34167	0.64148	0.064148	0.002108	3.500896
51	0.54993	25.34167	0.64026	0.064026	0.010048	4.167141
52	0.54993	25.34167	0.64392	0.064392	0.00763	3.964199
53	0.55298	25.70462	0.64514	0.064514	0.016148	4.678992
54	0.55237	25.63203	0.64209	0.064209	0.022248	5.190843
55	0.55237	25.63203	0.64148	0.064148	0.022868	5.242867
56	0.55237	25.63203	0.64209	0.064209	0.018588	4.883732
57	0.55237	25.63203	0.64209	0.064209	0.012488	4.371881
58	0.55176	25.55944	0.64026	0.064026	0.027748	5.652348
59	0.55237	25.63203	0.64209	0.064209	0.017978	4.832547
60	0.55176	25.55944	0.63904	0.063904	0.031408	5.959459
61	0.55176	25.55944	0.64026	0.064026	0.024088	5.345237
62	0.55176	25.55944	0.64026	0.064026	0.010013	4.164199
63	0.55237	25.63203	0.63904	0.063904	0.030188	5.857088
64	0.55481	25.92239	0.63843	0.063843	0.025308	5.447608
65	0.55176	25.55944	0.63965	0.063965	0.031408	5.959459
66	0.55176	25.55944	0.64148	0.064148	0.029578	5.805903
67	0.55115	25.48685	0.63965	0.063965	0.013098	4.423067
68	0.55176	25.55944	0.64026	0.064026	0.030798	5.908274
69	0.55115	25.48685	0.6366	0.06366	0.036288	6.368939
70	0.55115	25.48685	0.74331	0.074331	0.051548	7.649406
71	0.55176	25.55944	0.73965	0.073965	0.035068	6.266569
72	0.55237	25.63203	0.8427	0.08427	0.038728	6.57368
73	0.5481	25.1239	0.84087	0.084087	0.022868	5.242867
74	0.55115	25.48685	0.84026	0.084026	0.017368	4.781362
75	0.55054	25.41426	0.84087	0.084087	0.024698	5.396423
76	0.55054	25.41426	0.94392	0.094392	0.024698	5.396423
77	0.55054	25.41426	0.97209	0.097209	0.011268	4.269511
78	0.55176	25.55944	0.83965	0.083965	0.022868	5.242867
79	0.55115	25.48685	0.7331	0.07331	0.032628	6.061829
80	0.55115	25.48685	1.63965	0.163965	0.042398	6.88163
81	0.55054	25.41426	1.63782	0.163782	0.060098	8.366837
82	0.55115	25.48685	1.64087	0.164087	0.060708	8.418022
83	0.55115	25.48685	1.64148	0.164148	0.059488	8.315651
84	0.55054	25.41426	1.64453	0.164453	0.066808	8.929873
85	0.54871	25.19649	1.64514	0.164514	0.068638	9.083428

86	0.55115	25.48685	0.64026	0.064026	0.056428	8.058887
87	0.55115	25.48685	0.64331	0.064331	0.086046	10.54409
88	0.55115	25.48685	0.64209	0.064209	0.063758	8.673947
89	0.54932	25.26908	0.63965	0.063965	0.061318	8.469207
90	0.54932	25.26908	0.64026	0.064026	0.034433	6.213281
91	0.55054	25.41426	0.64392	0.064392	0.073518	9.492909
92	0.55115	25.48685	0.64087	0.064087	0.059488	8.315651
93	0.55115	25.48685	0.64026	0.064026	0.075968	9.698488
94	0.55237	25.63203	0.63843	0.063843	0.073518	9.492909
95	0.55115	25.48685	0.63965	0.063965	0.051548	7.649406
96	0.54871	25.19649	0.64209	0.064209	0.108851	12.4577
97	0.55115	25.48685	0.64209	0.064209	0.158069	16.58755
98	0.55054	25.41426	0.64026	0.064026	0.166609	17.30414
99	0.55298	25.70462	0.64087	0.064087	0.152569	16.12605
100	0.611804	32.70462	0.64087	0.064087	0.260154	25.15353
101	0.710814	44.48685	0.64148	0.064148	0.276634	26.53637
102	0.736024	47.48685	0.63965	0.063965	0.283954	27.15059
103	0.761844	50.55944	0.64209	0.064209	0.382989	35.46064
104	0.769637	51.48685	0.64331	0.064331	0.61035	54.53847
105	0.787054	53.55944	0.64148	0.064148	0.61279	54.74321
106	0.769637	51.48685	0.63965	0.063965	0.61646	55.05116
107	0.792407	54.19649	0.64331	0.064331	0.62683	55.92131
108	0.803861	55.55944	0.64087	0.064087	0.61829	55.20471
109	0.769637	51.48685	0.64209	0.064209	0.6189	55.2559
110	0.778041	52.48685	1.63965	0.163965	0.62256	55.56301
111	0.769637	51.48685	0.94331	0.094331	0.78308	69.03224
112	0.770247	51.55944	0.94148	0.094148	0.79468	70.0056
113	0.769637	51.48685	0.74453	0.074453	0.7959	70.10797
114	0.778651	52.55944	0.83904	0.083904	0.79468	70.0056
115	0.717387	45.26908	1.63965	0.163965	0.6311	56.2796
116	0.722267	45.8498	1.63965	0.163965	0.7843	69.13461
117	0.719827	45.55944	0.94087	0.094087	0.79163	69.74967
118	0.719217	45.48685	0.84453	0.084453	0.7959	70.10797
119	0.668797	39.48685	0.63965	0.063965	0.78369	69.08343
120	0.568567	27.55944	0.64392	0.064392	0.7959	70.10797
121	0.62678	34.48685	0.64331	0.064331	0.76904	67.85415
122	0.635184	35.48685	0.6427	0.06427	0.76416	67.44467
123	0.635184	35.48685	0.64209	0.064209	0.76904	67.85415
124	0.634574	35.41426	0.64087	0.064087	0.77026	67.95652
125	0.633964	35.34167	0.64087	0.064087	0.76782	67.75178
126	0.62739	34.55944	0.64026	0.064026	0.76599	67.59822
127	0.636404	35.63203	0.64392	0.064392	0.78186	68.92987
128	0.635794	35.55944	0.64148	0.064148	0.77454	68.31565
129	0.635184	35.48685	0.63965	0.063965	0.77759	68.57158

130	0.635794	35.55944	0.64331	0.064331	0.78552	69.23698
131	0.635184	35.48685	0.64209	0.064209	0.78796	69.44172
132	0.636404	35.63203	0.63965	0.063965	0.7959	70.10797
133	0.635184	35.48685	0.64392	0.064392	0.79102	69.69849
134	0.616547	33.26908	0.64331	0.064331	0.78918	69.54409
135	0.639454	35.99498	0.64636	0.064636	0.78857	69.49291
136	0.6488	37.1072	0.67017	0.067017	0.7782	68.62276
137	0.82031	57.51689	0.67993	0.067993	0.77026	67.95652
138	0.92163	69.57397	0.68604	0.068604	0.77515	68.36684
139	0.93323	70.95437	0.68604	0.068604	0.78064	68.8275
140	0.93567	71.24473	0.67322	0.067322	0.79468	70.0056
141	0.93567	71.24473	0.65491	0.065491	0.79346	69.90323
142	0.93811	71.53509	0.64148	0.064148	0.80566	70.92693
143	0.92712	70.22728	0.63293	0.063293	0.79773	70.26152
144	0.92224	69.64656	0.63477	0.063477	0.79346	69.90323
145	0.92163	69.57397	0.63232	0.063232	0.80322	70.72219
146	0.91736	69.06584	0.62744	0.062744	0.79285	69.85204
147	0.88623	65.36137	0.64392	0.064392	0.79468	70.0056
148	0.88013	64.63547	0.64209	0.064209	0.80017	70.46626
149	0.87769	64.34511	0.64209	0.064209	0.7959	70.10797
150	0.87524	64.05356	0.63965	0.063965	0.75684	66.83044
151	0.87341	63.83579	0.64087	0.064087	0.79346	69.90323
152	0.87097	63.54543	0.64514	0.064514	0.79834	70.31271
153	0.86609	62.96471	0.64148	0.064148	0.78857	69.49291
154	0.85449	61.58431	0.64209	0.064209	0.79285	69.85204
155	0.85327	61.43913	0.64209	0.064209	0.79651	70.15915
156	0.85144	61.22136	0.63965	0.063965	0.79895	70.36389
157	0.84961	61.00359	0.64209	0.064209	0.78308	69.03224
158	0.84534	60.49546	0.63904	0.063904	0.80017	70.46626
159	0.8313	58.8247	0.64148	0.064148	0.80933	71.23488
160	0.82397	57.95243	0.64392	0.064392	0.8075	71.08133
161	0.82092	57.58948	0.64209	0.064209	0.79956	70.41508
162	0.81726	57.15394	0.64209	0.064209	0.79956	70.41508
163	0.81604	57.00876	0.64636	0.064636	0.80872	71.1837
164	0.8136	56.7184	0.63965	0.063965	0.82214	72.30977
165	0.81055	56.35545	0.6427	0.06427	0.82092	72.2074
166	0.80811	56.06509	0.64209	0.064209	0.8136	71.59318
167	0.80811	56.06509	0.64148	0.064148	0.82397	72.46332
168	0.8075	55.9925	0.64148	0.064148	0.82092	72.2074
169	0.80505	55.70095	0.64209	0.064209	0.81909	72.05384
170	0.80383	55.55577	0.6427	0.06427	0.788217	69.46332
171	0.80261	55.41059	0.64209	0.064209	0.81726	71.90029
172	0.80139	55.26541	0.64331	0.064331	0.796475	70.15621
173	0.80444	55.62836	0.64087	0.064087	0.756745	66.82246

174	0.79956	55.04764	0.64209	0.064209	0.614344	54.87364
175	0.79712	54.75728	0.64331	0.064331	0.651025	57.95147
176	0.79651	54.68469	0.64331	0.064331	0.645207	57.46332
177	0.79773	54.82987	0.6427	0.06427	0.647975	57.69555
178	0.79529	54.53951	0.63965	0.063965	0.578299	51.8491
179	0.79468	54.46692	0.64148	0.064148	0.581349	52.10503
180	0.79529	54.53951	0.64209	0.064209	0.583789	52.30977
181	0.79163	54.10397	0.64026	0.064026	0.457904	41.74673
182	0.78918	53.81242	0.64209	0.064209	0.453024	41.33725
183	0.79041	53.95879	0.64087	0.064087	0.464614	42.30977
184	0.78979	53.88501	0.64148	0.064148	0.464614	42.30977
185	0.78918	53.81242	0.63904	0.063904	0.465224	42.36095
186	0.78857	53.73983	0.64148	0.064148	0.415724	38.2074
187	0.78796	53.66724	0.63782	0.063782	0.409306	37.6689
188	0.78735	53.59465	0.64209	0.064209	0.406856	37.46332
189	0.78735	53.59465	0.64575	0.064575	0.407466	37.51451
190	0.78552	53.37688	0.64331	0.064331	0.230543	22.6689
191	0.78369	53.15911	0.64697	0.064697	0.234813	23.0272
192	0.78613	53.44947	0.6427	0.06427	0.235423	23.07838
193	0.78491	53.30429	0.64331	0.064331	0.237253	23.23194
194	0.78308	53.08652	0.64575	0.064575	0.232373	22.82246
195	0.78491	53.30429	0.6366	0.06366	0.228093	22.46332
196	0.78186	52.94134	0.64392	0.064392	0.232983	22.87364
197	0.78491	53.30429	0.64148	0.064148	0.00777	3.976013
198	0.78186	52.94134	0.64148	0.064148	0.237863	23.28312
199	0.78186	52.94134	0.64209	0.064209	0.240913	23.53905
200	0.78064	52.79616	0.64026	0.064026	0.238473	23.33431
201	0.78064	52.79616	0.64087	0.064087	0.236033	23.12957
202	0.77942	52.65098	0.64392	0.064392	0.232983	22.87364

While constructing the WSN using MICAz motes, it is important to note a few things such as:

1. This network consists of one node and one base station. The node is built by interfacing Decagon EC-5 soil moisture sensor and Honeywell 164PC01D37 pressure sensor to the MDA300 data acquisition board and MICAz mote. Furthermore, the base station is constructed by mounting one MICAz mote to the MIB520 mote interface board. The base station is connected to the PC via USB port.
2. During the process of uploading the firmware onto the motes, choosing a correct pre-compile X-Mesh application is crucial because different data acquisition board requires different application. The test case uses MDA300 data acquisition board. So the application must be chosen from the MDA300 folder. The folder contains both high power and low power applications. The chosen application is dependent on the system requirement.
3. Before the data can be viewed, MoteView 2.0 is set up according to [26]. Every nodes and base station that appear in MoteView has to be configured individually.
4. The output of the sensor can be manipulated by inputting certain polynomial during the MoteView configuration. With this, MoteView will display the new value instead of the original output of the sensor. For the report, the original value displayed in the MoteView is the voltage output of the Decagon EC-5 soil moisture sensor. After the configuration, it shows the VWC% of the soil. The value for pressure sensor is in Volt (V).
5. To get accurate soil moisture sensor reading, the sensor must be buried completely in the ground, including its black overmolding. This is because there is measurement sensitivity placed behind this black overmolding. So, if the sensor is not buried completely, it wills pick-up the reading for moisture content in the air, causing an accurate reading for VMC of the soil.
6. The output of the pressure sensor is not perfectly ratiometric. To determine the degree of error, refer to the Accuracy specifications.
7. The pressure sensor must be connected properly because the reversal of supply and ground connections may cause damage to the sensor.

8. FlexiBend sensor cannot be bent more than -90^0 and 90^0 to obtain the best results.
9. To avoid short circuit, the flexi bend sensor must be wrapped inside a plastic cover.

CHAPTER 5

CONCLUSIONS

All in all, WSN is an interesting new technology. The applications of WSN as a monitoring and data gathering tools have turned it into one of the fastest growing technology. WSN is implemented in many fields such as agriculture, disaster management and military. The ability of WSN motes to communicate within a certain range of distance wirelessly in real time enable human to gather the data from the place that they thought as impossible previously. Hence, WSN trigger a major improvement in many aspects of human life.

There are many wireless motes available in the market. The most popular wireless mote is Crossbow MICAz wireless mote. This device is easy to implement and compatible with many data acquisition boards and sensors. MICAz mote can be programmed as node or base station. These nodes and base station must be able to communicate with other, creating a mesh of network. The data read by the sensors will be send by MICAz mote (node) to the PC via a base station.

WSN and MICAz is used in many applications worldwide. It can provide reliable readings and allows us make decision based on the data received. One of the possible applications of WSN is in slope monitoring. Slope monitoring is important to detect landslides in the landslide prone area. Soil moisture sensor, pressure sensor and force sensor is connected to the MICAz mote via the MDA300 data acquisition board to realize this application.

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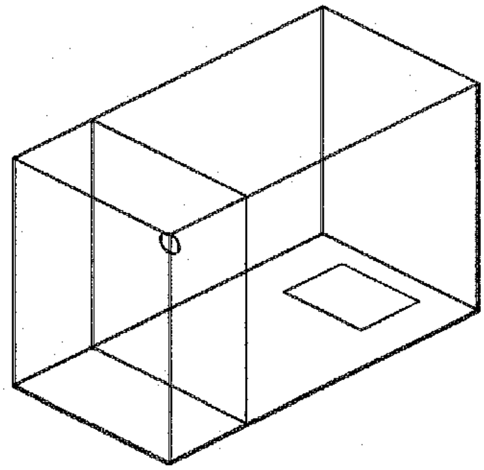
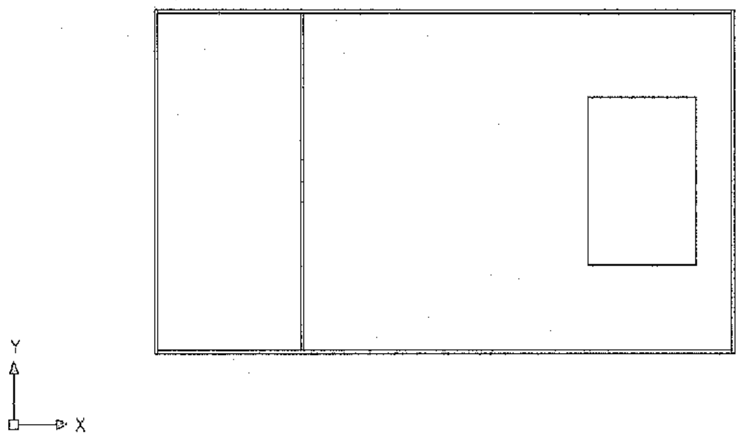
APPENDIX A SLOPE MODEL CASING DRAWING

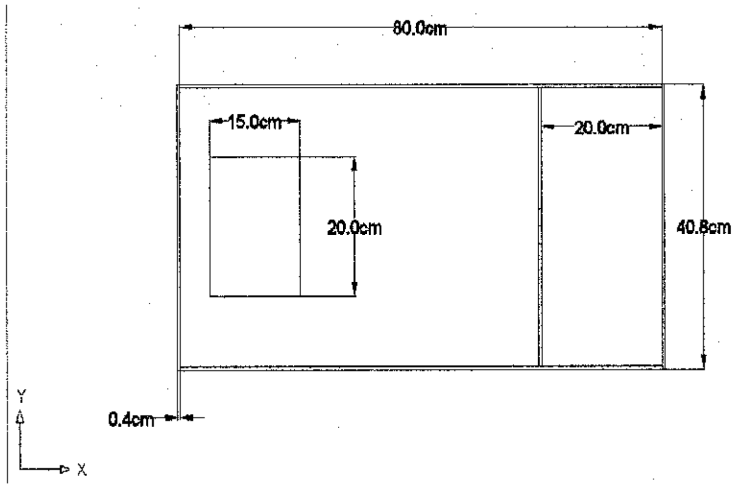
a) Drawing wire frame.



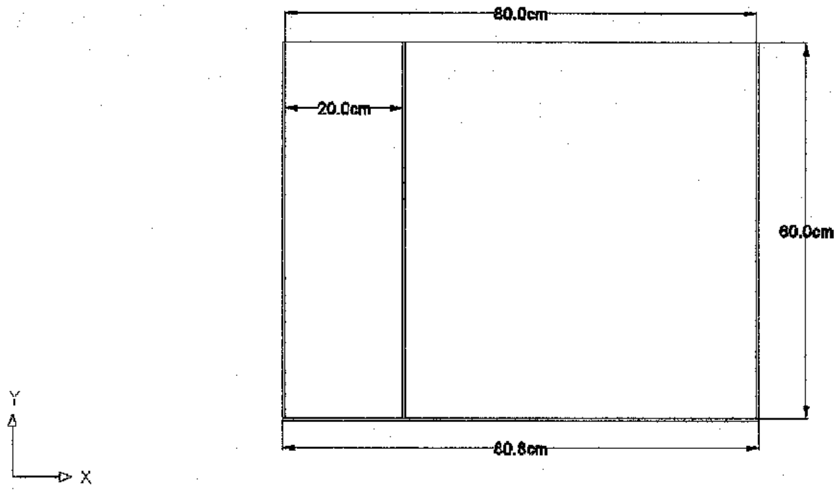
b) Drawing wire frame (top)



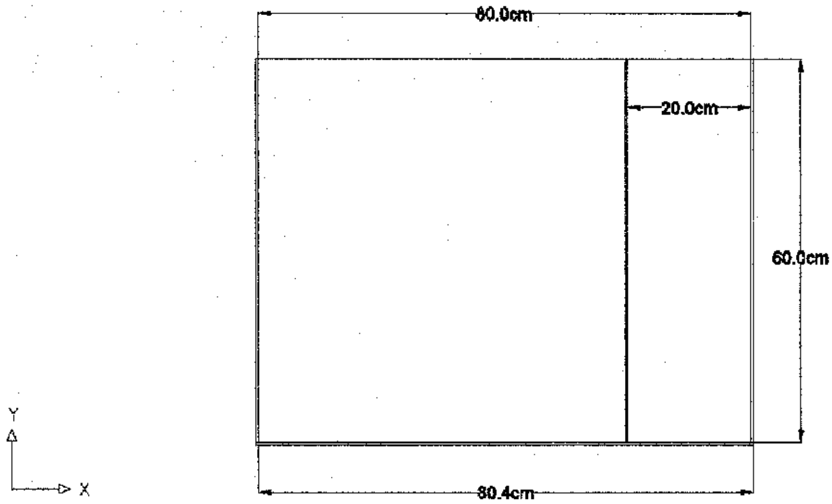
c) Drawing wire frame (bottom)



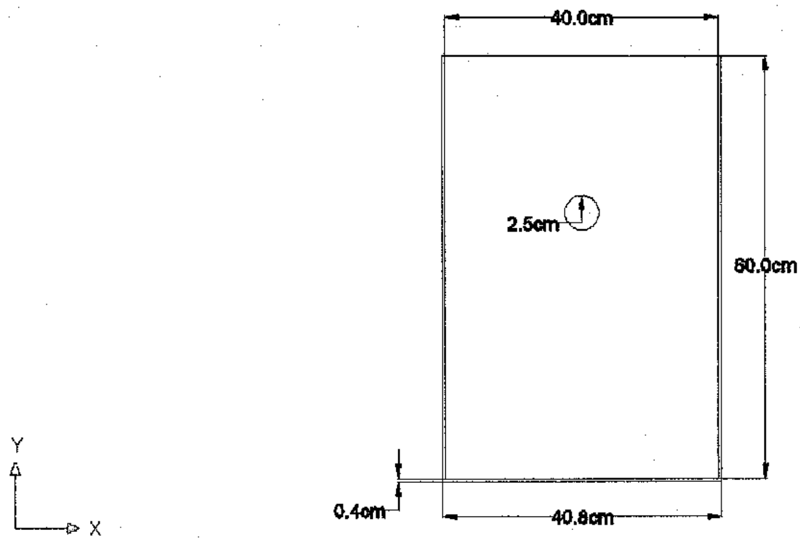
d) Drawing wire frame (front)



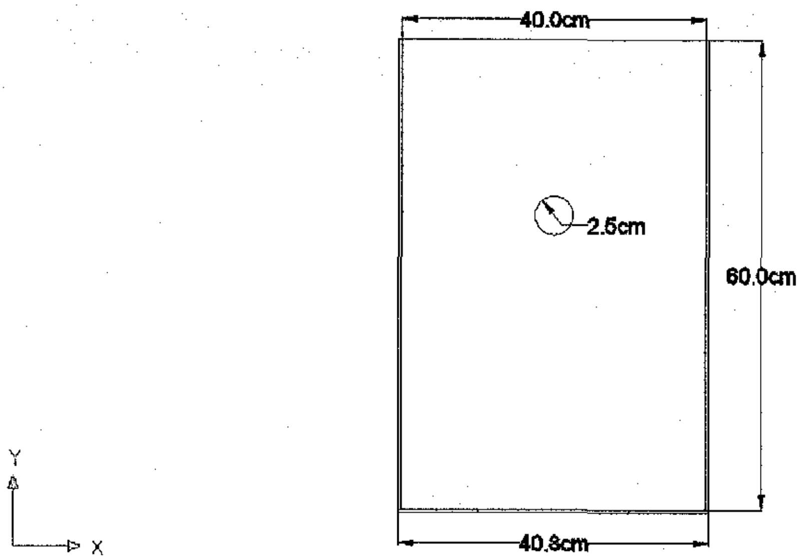
e) Drawing wire frame (back)



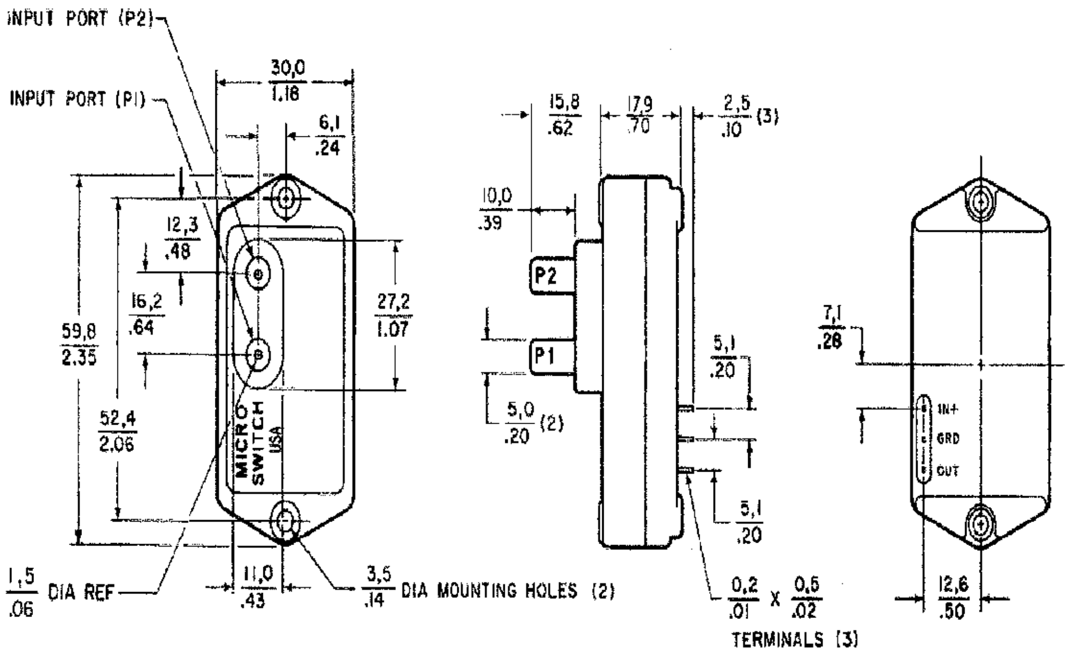
f) Drawing wire frame (left)

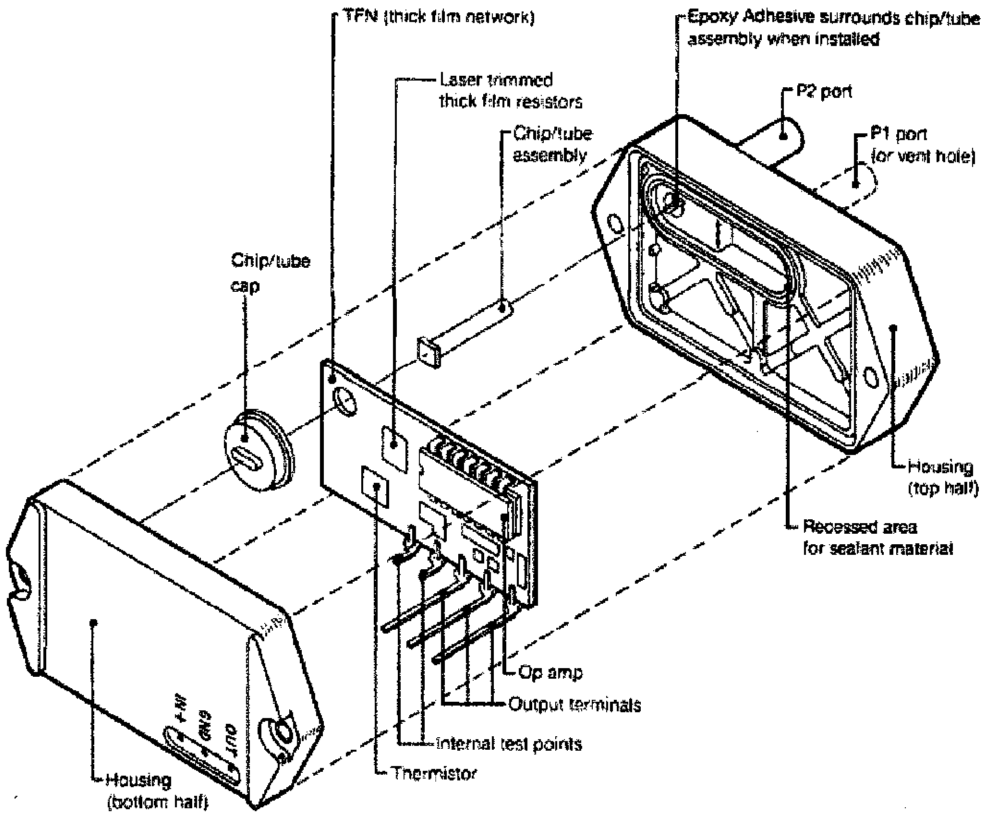


g) Drawing wire frame (right)



APPENDIX B STRUCTURE OF HONEYWELL 164pc01d37 PRESSURE SENSOR





APPENDIX C PIN ASSIGNMENT OF MDA300 DATA ACQUISITION BOARD

A0 or A11+	Single-ended analog channel 0 or differential analog channel 11 positive side
A1 or A11-	Single-ended analog channel 1 or differential analog channel 11 negative side
A2 or A12+	Single-ended analog channel 2 or differential analog channel 12 positive side
A3 or A12-	Single-ended analog channel 3 or differential analog channel 12 negative side
A4 or A13+	Single-ended analog channel 4 or differential analog channel 13 positive side
A5 or A13-	Single-ended analog channel 5 or differential analog channel 13 negative side
A6	Single-ended analog channel 6
A7+ A7-	Differential analog channels 7
A8+ A8-	Differential analog channels 8
A9+ A9-	Differential analog channels 9
A10+ A10-	Differential analog channels 10
DATA	I2C Data
CLK	I2C Clock
D0 - D6	Digital Lines D0 to D6
C	Counter Channel
LED1	RED LED
LED2	GREEN LED
E5.0	5.0 V excitation
E3.3	3.3 V excitation
E2.5	2.5 V excitation
Vcc	Vcc of the Mote
RL1	Relay one sides (Normally-Open)
RL2	Relay two sides (Normally-Closed)