DESIGN, CONSTRUCTION AND EXPERIMENTAL ANALYSIS OF FREE FLOATING PIG FOR PIPELINE LEAK DETECTION

Prepared By

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CERTIFICATION OF APPROVAL

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By

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A project dissertation submitted to the
Mechanical Engineering Programme
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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS
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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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NORAIMAN BIN TAJUDDIN

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ABSTRACT

This thesis focuses on the development of a free floating tool called Pig Tool, which is capable of detecting and locating oil and gas pipeline leakages using differential pressure detection method. Leakages can result in significant environmental and financial consequences due to pipeline corrosion during construction, operation and decommission. To ensure its integrity, periodical inspection is vital to assess the significance of pipeline defects. Traditional detection equipment or pig has a risk of blocking a pipeline. This study aims to design free swimming inspection device which can run freely in a pipeline with minimum risk of blocking a pipeline, and to develop a sensitive leak detection system that can detect and locate leaks in oil and gas pipelines. Leakage of pressurized product from a pipe creates a pressure differential across the pipe wall, and this pressure drop can be identified by using a pressure sensor, on board the Pig Tool. Pressure sensor, manufactured by DFRobot is used as the leak detection equipment for identifying leaks in pipeline. The Pig Tool was designed and fabricated in spherical shape and the sensor is programmed using Arduino Integrated Development Environment to the microprocessor, Arduino UNO R3, to allow the sensor to detect the pressure and temperature difference. The product was tested in a pipeline to test the mobility of the Pig Tool, and to validate the functionality of the sensor. Three indirect tests were performed such as Leak test, Sensor test and Pig Tool test due to the unavailability of pipeline facilities for test loop. The experimental results show that Pig Tool is fully sealed, leak proof and has the mobility to navigate inside pipe. Consequently, changes in temperature and pressure of surrounding were continuously detected by the on board sensor. The data obtained from the sensor was successfully processed by the microprocessor and stored in the memory storage using Micro SD Shield. Future development of the Pig Tool with the incorporation of pressure sensor is required to detect differential temperature and pressure to facilitate actual test run using a scaled pipeline.

CONTENTS

List of Figures

List of Tables

CHAPTER 1

INTRODUCTION

1.1 Background of Study

After the commissioning of an oil or gas pipeline, it is vital that it is inspected periodically to maintain its integrity. According to (Werff, 2006), time, deterioration and corrosion of the world‘s ageing pipeline infrastructure increase the overall likelihood of pipeline failures, according to industry trends.

It appears that 65% of all pipeline failures are caused by corrosion. World governments are putting pipeline integrity laws into place that regulate the pipeline business. In the USA, the Pipeline Integrity Bill requires regulated pipelines to be inspected for integrity every five years if transporting liquid, and every seven years if transporting natural gas.

1.2 Problem Statement

For many years, pipelines are frequently used for pipeline commissioning, cleaning, transfer of products and more recently pipeline monitoring. Due to the transmission medium, transport conditions, change of geographical climate, and construction influence and weld cracking will appear in the pipeline (Cosham, 2000). This will eventually generate leaks in the pipeline, causing economic loss and environmental pollution.

The accidental release of crude oil or petroleum products for instance to the environment can cause a number of problems to the environment and to human health, and can gain a very high profile with the public. The environmental risks of pipeline leaks are also associated with a rupture of a pipeline from the result of fatigue and corrosion.

Besides that, it is difficult to know exactly what is going on inside, or even outside a pipeline. Traditional detection equipment which is the pipeline inspection gauges or pigs, is highly costly and has a risk of blocking, even damaging the pipeline.

1.3 Objective

The objectives of this project are:

- To design a free swimming inspection device which can run freely in a pipeline with minimum risk of blocking a pipeline
- To develop a technology that can economically detect and determine location of leaks in pipeline

1.4 Scope of Study

Incorporated with the pipeline system design, this project involves mainly on the designing of the Pig Tool and testing of the pig tool. The pig tool will require to be able to flow freely in a pipeline and able detect anomalies that are present in the pipeline. During the tests, it will involve testing the product in a scaled pipeline and testing out the functionality of the on board sensors of the Pig Tool.

Identification of available leaks is carried out by leak detection methods. As such, a leak is identified by using pressure sensor with combination of memory card, card shield, power supply and microprocessor.

1.5 Outline of the Thesis

The remainder of this thesis is organized as follows; Chapter 2 discusses about the literature review of the project in the area of oil and gas pipeline inspection. Chapter 3 discusses about the methodology that has been adopted into this research. Chapter 4 elaborates on the results and discussions for the project. Finally Chapter 5 discusses on the conclusion and the recommendations for the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this review, several literatures have been selected to be primarily reviewed with some other supporting literatures. This section shall be divided into three points which are history of pigging, Pig Tool design, principle of detection and pressure dependence on leakage.

2.2 History of Pigging

For those who may not be familiar with “running a pig”, actually pigging known as any device which travels inside a pipeline driven or propelled by product flow. Typically, the word “Pig” originated in the United States is a free moving piston or defines as Pipeline Inspection Gauge (PIG).

The most commonly accepted explanation of “Pig” or “Pigging” arises from the squealing sounds created as the early pigs run in the line (Hopkins, 2009). In this project, pigging is the term that commonly used and related to inspection that involve pig tool which navigate through the pipeline in order to inspect flaws which has grown in the pipe wall. It is proven that pigging is really significant to access pipeline integrity to central the maintenance of the line.

Pigs were originally developed to perform cleaning tasks inside the pipeline. Smart or instrumented pigs have been introduced for decades, and have become quite sophisticated and capable to perform various other tasks such as gauging, detect metal loss, leaks and many more(Tiratsoo, 1999). However, pigs also have limitations such as pig tools get stuck in unpiggable pipelines due to problematic bends or connections.

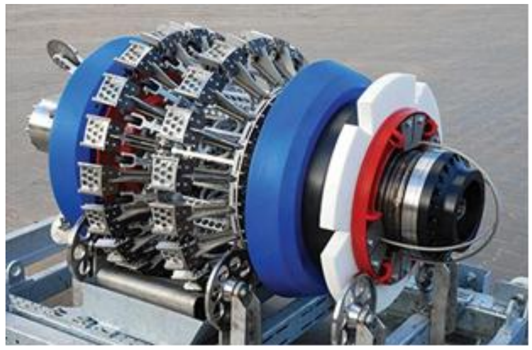


Figure 1: Ultrasound pig tool (source: ROSEN Group)

The pigging equipment has limited applications even though being very crude in nature. Today, pigging are designed to execute specific functions for pipelines due to many reasons i.e. pipeline leak detection.

As pigging developed, at first it measures and records information used to assess pipeline integrity, as well as to perform non-destructive assessment of pipeline defects. Today, pigging has successfully conducted, which covers some functions such as base line surveys, commissioning, maintain efficiency in production, to prepare for intelligent pigging, corrosion mapping, crack and leak detection.

There is one lesson which pigging, for example, should not take away from oil industry as happened in British Petroleum (BP) in Alaska. In global, the vital of pigging operations conducted at costly expensive a year has much proven their significant to the industry (Cosham, 2000). BP has being unfortunate in finding severe loss of material in the 29 year old system as they conducted ultrasonic testing instead of pigging which resulted large spilled with a mixture of crude oil, methanol and water leaking. Hence, pigging plays a major role in pipeline safety in leak detection, corrosion protection, and also corrosion repair which are usually obligatory.

2.2 Smartball Design

According to Mueller (2011), a new approach of in-line inspection (ILI) program used is Smartball, introduced as a free swimming device with high coverage of sensitivity of acoustic leak detection device.

Figure 2: Spherical design of Smartball (source: Pure Technologies)

One of the advantages of the spherical design of the Smartball is it offers much flexibility during deployment and retrieval to a cylindrical tool and also a perfect run in most unpiggable pipelines. Furthermore, the ball is able to negotiate small radius bends, multiple range of bore changes and other connections within the pipeline. Smartball can be used on pipes manufactured of any pipe material including steel, plastic, concrete, etc. On the other hand, Smartball has been experimentally proven to be able to detect leaks as low as 0.028 gallon per minute (gpm) under ideal conditions (Mueller, 2011).

The spherical device is capable of navigating through any pipeline with minimum size of 4" diameter or greater (Oliviera, 2011). Pig launcher and receiver are used to insert and retrieve the Smartball in a pipeline and inspect hundred kilometers of pipeline during single deployment. Besides, the location of Smartball during the inspection is determined by using on board accelerometers or tracked by Global Positioning System (GPS) synchronized surface sensors in the same method as a conventional pig.

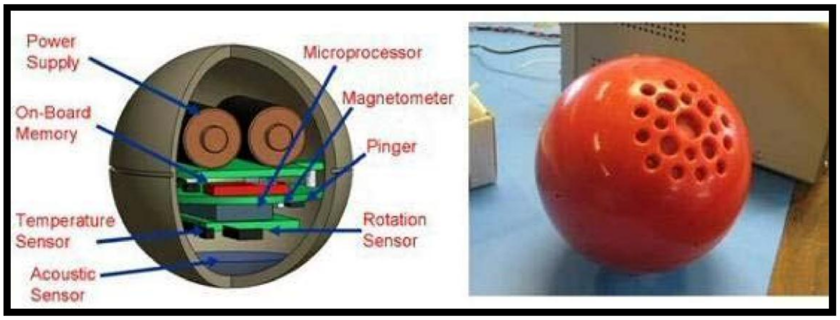


Figure 3: Smartball internal components (L); Outer Shell (R) (source: Pure Technologies)

The inspection tool is composed of aluminum alloy core, pressure tight that consists of power source, acoustic sensor, temperature sensor, magnetometer, accelerometer, GPS synchronized ultrasonic transmitter and temperature sensor. Acoustic sensor is used to detect leaks in the pipeline. Magnetometers are used to identify pipe weld joints, block valves and in-line valves. Temperature and pressure sensors are used to measure the temperature and pressure in the pipeline. The Smartball is equipped with an on-board memory to record the data obtained from the sensors. The pinger acts as a transmitter to facilitate ball tracking.

A polyurethane coating or a protective outer foam foam shell is encapsulated inside the core. The protective shell or coating gives additional surface area to propel the device while reducing the ambient noises present in the pipeline (Li, 2012).

In order to ensure no electronic components are exposed to the environment, the Smartball is ready with fully sealed. This to confirm that the Smartball is essentially safe for use in flammable products such as oil and gas, and to achieve optimum reliability in many applications and hostile conditions (Martini, 2011).

2.3 Principle of Detection

All non-destructive technologies have unique capabilities and limitations that affect the accuracy and efficacy of the technology. The pressure activity associated with a leak is derived from the pressure differential across the pipe wall (Ariaratnam, 2012). With little to no pressure differential, the device will not detect leakage as there will be no associated pressure activity.

In general, the pressure sensor inside the ball always passes within one pipe diameter of a leak and therefore it can be used to identify very small leaks. For example, on a 150 psi pipeline, it was confirmed that a leak of 0.028 gpm could be detected. Other experiences have confirmed this ability; for pipes with significant pressure of 50 psi or more, under ideal conditions, Pig Tool may detect leaks as small as 0.028 gpm. For pipelines that operate at pressure less than 10 psi, small leaks in this range may not be identified. Continued testing is necessary to confirm minimum detection standards.

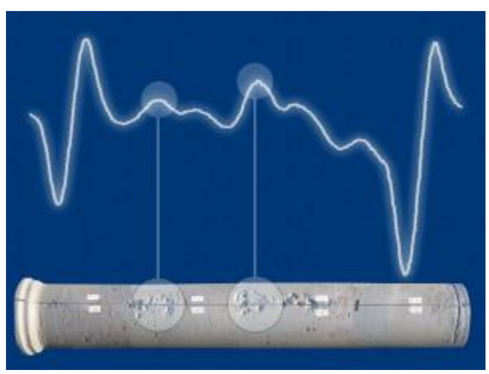


Figure 4: Pressure differential associated with leaks in pipe (Carlson, 1993)

Pig Tool detects and report anomalies that have different pressure profile on pressurized pipeline. However, other forms of ambient pressure may be identified during the data analysis. For medium and large leaks there is significant pressure dropped as compared to operating pressure and therefore, these events are almost certainly leaks (Carlson, 1993). However, for small leaks, there may be other forms of ambient pressure that are difficult to evaluate. Detailed data analysis is required upon completion of pigging inspection to avoid common ambient pressure that should not be reported as leaks as they contain different pressure signatures such as pumps and valves.

2.4 Pressure Dependence on Leakage

When a leak is present in a pipeline, the high differential pressure between the inner and outer pipeline will cause the release of the elastic energy (Wei, 2013). This process makes the gas inject into the outer space with a high speed, and produces the sound vibration along the pipeline at the same time. When the gas pipeline leaks, the gas flows under the differential pressure and export condition, and this can be considered as one of the free turbulent injection situation.

In a pipeline leakage, there will be a turbulent jet in the leak (Yang, 2008). When the jet hits the wall of the pipe, it will carry significant turbulent pressure fluctuations which will impact on the pipe wall. In addition, as water passes through the leak hole, its velocity increases. If the velocity is high enough, the pressure at the leak point can drop below the vapor pressure of the liquid and form vapor bubbles. The downstream static pressure is normally higher than the vapor pressure of the liquid. Therefore, the bubbles of vapor implode. When a bubble implodes, all the energy is concentrated into a very small area. This creates an enormous pressure in the small area, generating minute shock waves. These shock waves impacting on the solid portions of the pipe wall.

One of the case studies is conducted for first exploration and illustration of behavior of pressure by leakage simulation in water distribution network in Barcelona as shown in Figure 5 below (Landeros, 2009). In the experiment, the difference of pressure depending on the distance of the leakage was studied. Multiple sensors are placed at upstream and downstream of network. Pressure decreases as leakage increases. The method is by comparing sensitivities of sensors to any leakage with normalisation on the maximum pressure difference in each sensor.

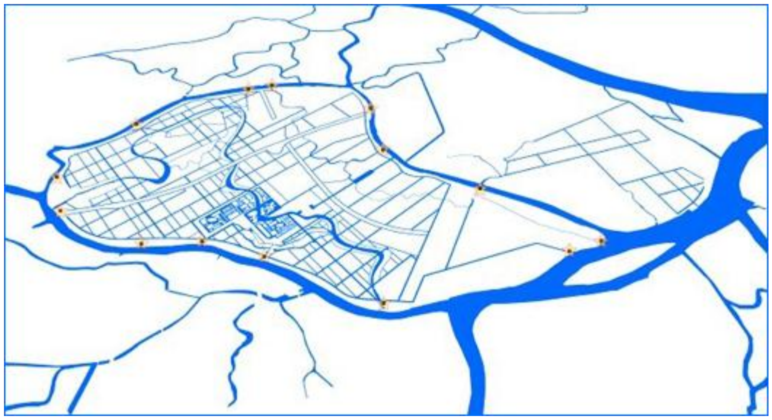


Figure 5: Water Distribution Network in Barcelona (Landeros, 2009)

As the leakage increased, the difference on pressure is more dependent on the distance. Thus, the normalized difference decreases in all sensors and shows the pressure dropped with approximate leakage localization. The results show that this technique manages to solve the leakage detection problem by introduction a number of sensor in the water network.

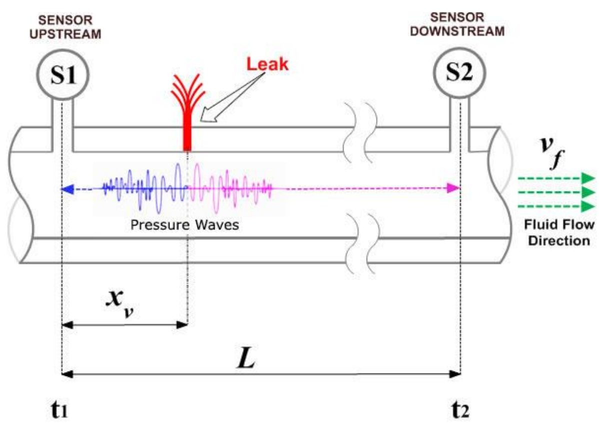


Figure 6: Negative Pressure Acoustic Leak Detection System
(Pipeline Technologies, n.d.)

In different case study, operating principles of negative pressure acoustic leak detection system (Pipeline Technologies, n.d.) as shown in Figure 6 describes when a leak occurs, the sudden drop in pressure at the leak location causes oscillations in the fluid pressure that propagate in both directions, upstream and downstream, at the speed of sound.

Guided by the pipeline wall, high performance pressure sensors (S1 and S2) are installed at opposite ends of the protected pipeline segment will detect the drop in pressure and transmit the oscillating pressure signals for data acquisition, signal conditioning, noise filtering, data processing and communication. Conditioning and filtering functions applied to separate leak signals from the background noise, and then applies advanced detection algorithms to determine if a leak "event" took place.

The location of the leak is computed based on the pressure wave propagation velocity in the fluid, by examining the difference between wave arrival times (t_1 - t_2) at the two opposing sensors (S1 and S2), and the length of the pipeline segment, as shown in the Equation 1 below:

$$X_v = \frac{L_{pipe} + (t_1 - t_2)v}{2}$$

Equation 1: Distance from segment end to leak detection (Source: Pipeline Technologies.com)

Where,

X_v = Distance from segment end to leak location

L_{pipe} = Length of this pipe segment

v = sonic velocity in the fluid

t_1 = detection time at sensor S1

t_2 = detection time at sensor S2

2.5 Arduino: A Multipurpose Microcontroller Equipment

Every experiment running uses several types of equipment and software, in most cases, to execute events (behavioral or physiological) and generate signals (control different machines). Such tasks, require high accuracy, specific hardware and software, real-time operating system with expensive boards and software packages (Ausilio, 2011). While the objective of this project is to ensure the inspection tool is cost effective with applicable systems, cheap and simple microcontroller board may achieve even many of experiment tasks and use to control different physical outputs such as lights, motors and sensors.

Introducing Arduino board, which offers the open source library of both software and hardware. This low-cost has the ability to load the experiment task on board's memory and let it run without interfacing with external software or computers. Besides, the microcontroller is completely portability, independence, accuracy with thousands of projects around the globe using Arduino which can be modified and used according to particular experiment needs (Ausilio, 2011).

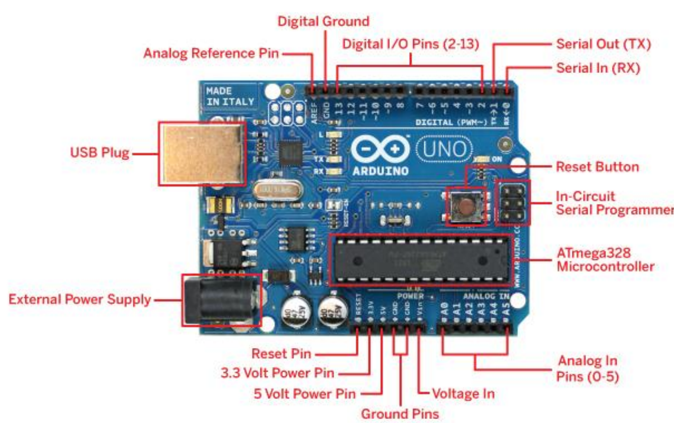


Figure 7: Arduino board and external appearance (source: arduino.cc)

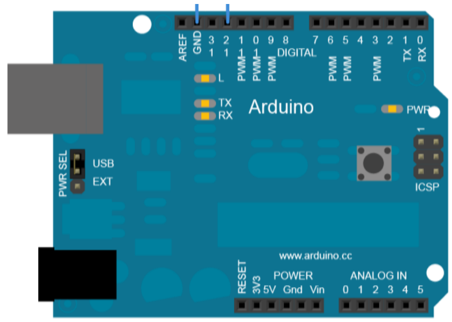


Figure 8: A simplified schematic of digital and analog input/output ports (source: arduino.cc)

Based on Figure 7 and 8, Arduino UNO, the most popular board, has 14 digital input/output pins, 6 analog pins, a USB connection, a power jack and other circuits. Furthermore, six tests were conducted to verify timing accuracy with increasingly complex tasks. Test 1 was conducted using a channel to verify basic timing capability which the board had to generate signals 900 ms long with 100 ms interval as shown in Figure 9.

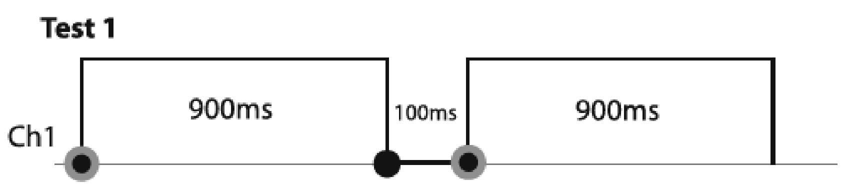


Figure 9: The figure shows the durations and delays in Test 1. The analyses measured the durations as well as the delay between black and gray dots (source: Ausilio, 2013)

Test 1 showed a mean length of 0.9004 s (reference value: 900 m) and a delay between onsets of 1.0006 s (reference value: 1000 ms). Standard deviations were, respectively, 0.000048 and 0.000048, thus showing a negligible error and extremely small variability.

Hence, Arduino UNO is an accurate platform for a series of lab settings with proved robust enough to be accurate even with poor programming. However, wrong programming style would give error during uploading work to the board, thus the script must be correct and improve. Arduino is the only viable solution especially when running multiple events at the same time with the same set-up.

In addition, Arduino board can perform by using standard 9V battery which impossible with standard boards. This is important for a pig tool as it's navigate inside the pipeline that requires wireless application. The critical advantage of Arduino concept is indeed feasible to perform multipurpose tool in all conditions with modest programming and electronic features.

In summary, the findings of these literature reviews such as Smartball design, principle of detection, pressure dependence on leakage and Arduino microcontroller define the objectives of the project to proceed with Project Methodology in Chapter 3 and Result and Discussion in Chapter 4.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

In the process of completing this project, various methods and sources were referred to facilitate this project. The working flow diagram was identified and used in the design and construction of the Pig Tool.

3.2 Work Flow

Figure 10 shows the flow chart to achieve the objectives of project. Based on the flow chart, the methodology for this project were conducted as followed:

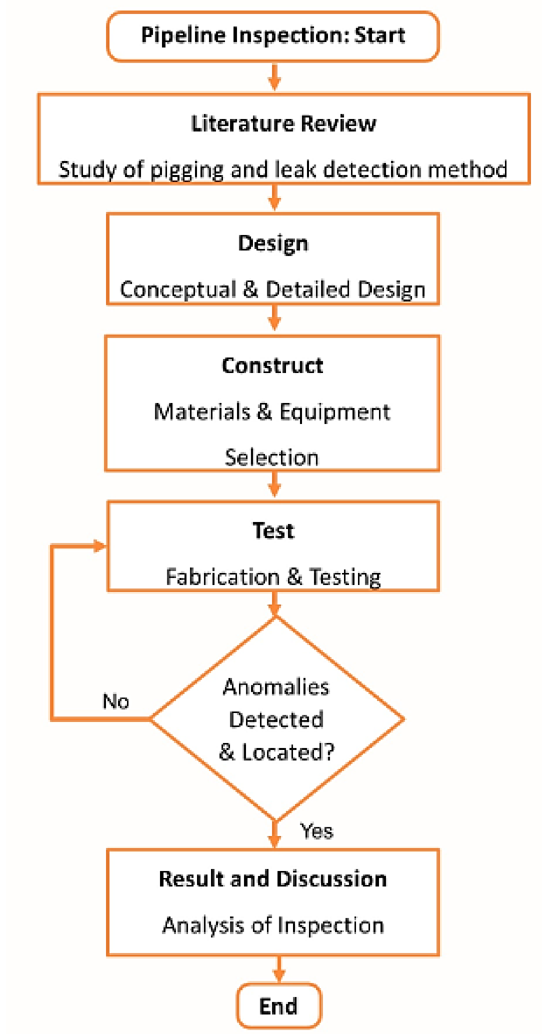


Figure 10: Flow Chart

3.2.1 Design

The design process of the project was done in two phases: conceptual design and detailed design. Conceptual design was done by drawing multiple hand sketches and the best design concept was selected. The best conceptual design was used to create a detailed design using CATIA.

3.2.1.1 Conceptual Design

The conceptual design was done before proceeding with the detailed design. Figure 11 shows the conceptual design of the Pig Tool.

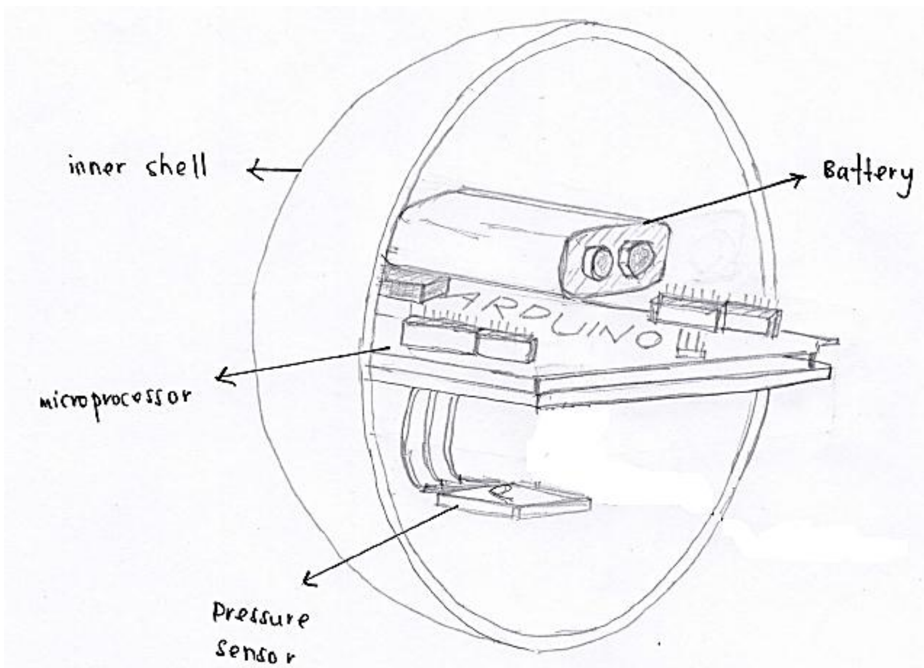


Figure 11 : Conceptual Design of Pig Tool

3.2.1.2 Detailed Design

The detailed drawing of Pig Tool was done by using CATIA software. Section 4.1 discussed the detailed drawing based on the conceptual design of Pig Tool.

3.2.2 Materials and Equipment Selection

Experimental planning was done to identify the required materials and the sensor to fabricate the Pig Tool. Methods such as morphology chart was used to assist the material selection and sensor identification for the Pig Tool.

3.2.3 Fabrication and Testing

The fabrication was done after obtaining the design and identifying all the necessary materials and sensors. After fabrication, the product was tested by performing a test run of the Pig Tool inside a scaled pipeline in mechanical laboratory.

The fabrication of the pig tool was divided into two parts: fabrication of the inner and outer core, and fabrication of the inner components.

3.2.3.1 Fabrication of the cores

The required materials for the cores were identified and will be discussed further in section 4.2.1, along with their functions and specifications. The Pig Tool was design in CATIA and fabricated by using 3D Printer.

Figure 12: Cube 3D Printer

The design of Pig Tool have the following criteria:

- ✓ diameter of 4 inch or smaller
- ✓ easy to fasten and unfasten
- ✓ light
- ✓ fully sealed
- ✓ pressure tight

3.2.3.2 Fabrication of the inner components

The fabrication of the inner components was done by installing and configuring all the required components in the interior of the Pig Tool. The materials and components for the inner structure of the Pig Tool were identified and discussed further in section 4.1.2. The specification of the sensor required, which is the pressure sensor was discussed in section 4.2.

Figure 13 show circuit configuration.

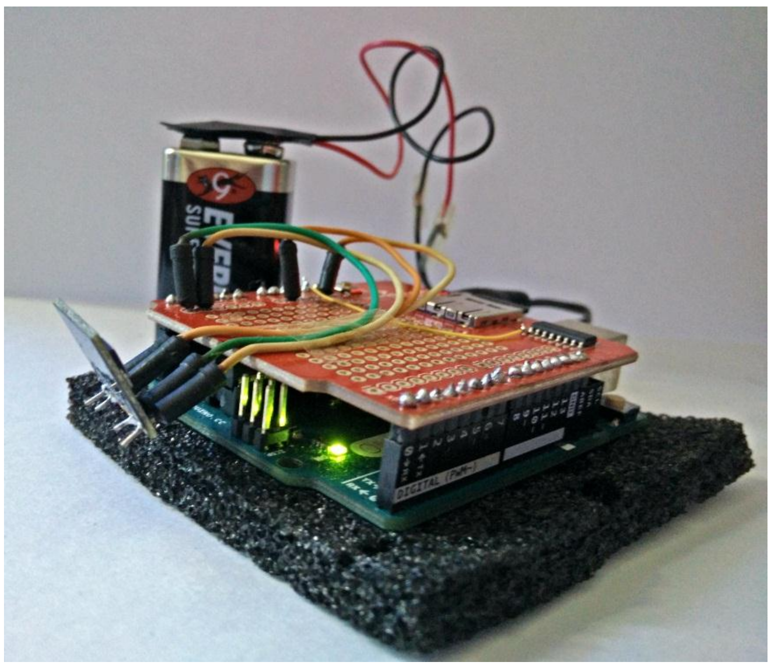


Figure 13: Circuit Configuration

After fabrication, the sensor was programmed to the microprocessor to capture the data obtained by the sensors. The programming of the sensor to the microprocessor was done by using the Arduino Integrated Development Environment (IDE). Figure 14 shows a part of coding for the pressure sensor in the Arduino IDE. Complete coding of sensor is further shown in Appendix 1.

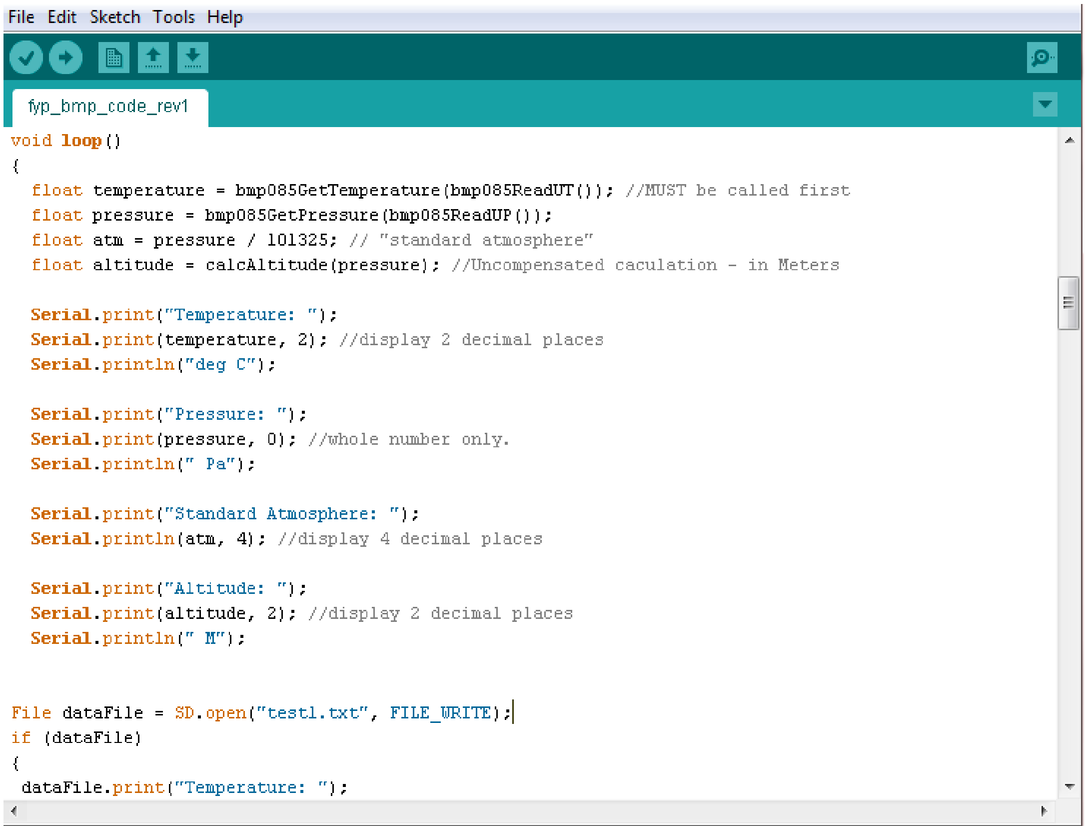


Figure 14: Coding for the pressure sensor in the Arduino IDE

3.2.3.3 Testing

After the completion of the fabrication of the Pig Tool, the product was tested in a pipeline. Few holes were introduced to the pipeline to simulate leak and to see whether the product is able to capture and record the leak present. If the Pig Tool fails to obtain the required result, the product will be repaired and the test will be repeated.

However, due to difficulty in obtaining the pipeline facilities in terms of time for manufacturing, the product cannot be tested in a pressurized pipeline. Therefore, 3 indirect test were conducted as shown below, which means that the product will be tested without inserting it into a scaled pipeline.

i. Leak Test

<u>Objective</u>

To test whether the Pig Tool is fully sealed and the circuit is not affected by any leaking

<u>Method</u>

Submerge tool into a bucket of water for 24 hours without sensor and placed tissues inside

<u>Equipment</u>

Pig Tool (without sensor), Bucket, Stopwatch, PTFE tape, Insulating tape, tissues

<u>Procedure</u>

1. Tissues were put inside the tool
2. Pig tool was fully sealed by using PTFE tape and Insulating tape as shown in Figure 15

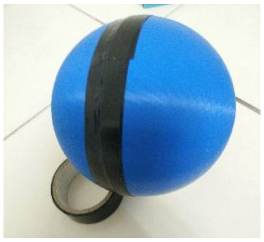


Figure 15: Pig Tool sealed with tape

3. A bucket of ½ filled water was set up as shown in Figure 16

Figure 16: Bucket filled with water

4. Inserted and submerged Pig tool with heavy object to avoid from floating.
5. Submerged tool for 24 hours and time is taken by using stopwatch.
6. Took out tool from water after 24 hours for analysis.

ii. Sensor Test

Objective

To test capability of sensor to detect changes in surrounding temperature and pressure as well for the whole circuit.

Method

Submerge tool (with sensor) for 10 minutes into a bucket of water using hot and cold water.

Equipment

Pig tool (with sensor), 10 liter of water, Stopwatch, PVC Adapter, Bucket.

Procedure

1. Bucket filled in with 10 liter of water (cold and hot water)
2. Circuit was connected to Arduino software and code verified as shown in Figure 17

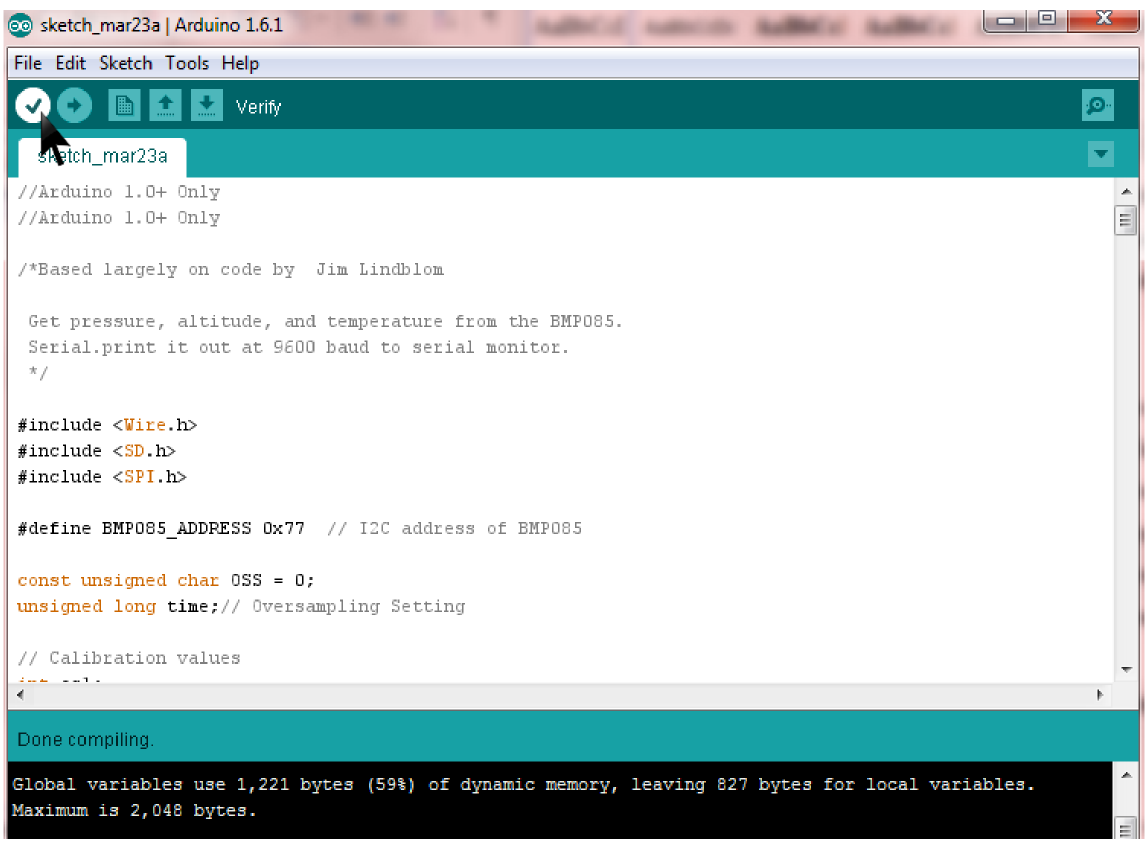


Figure 17: Verify and Compile Code

3. Set time to 30 seconds in programming for each pressure reading
4. Code uploaded to Arduino board as shown in Figure 18

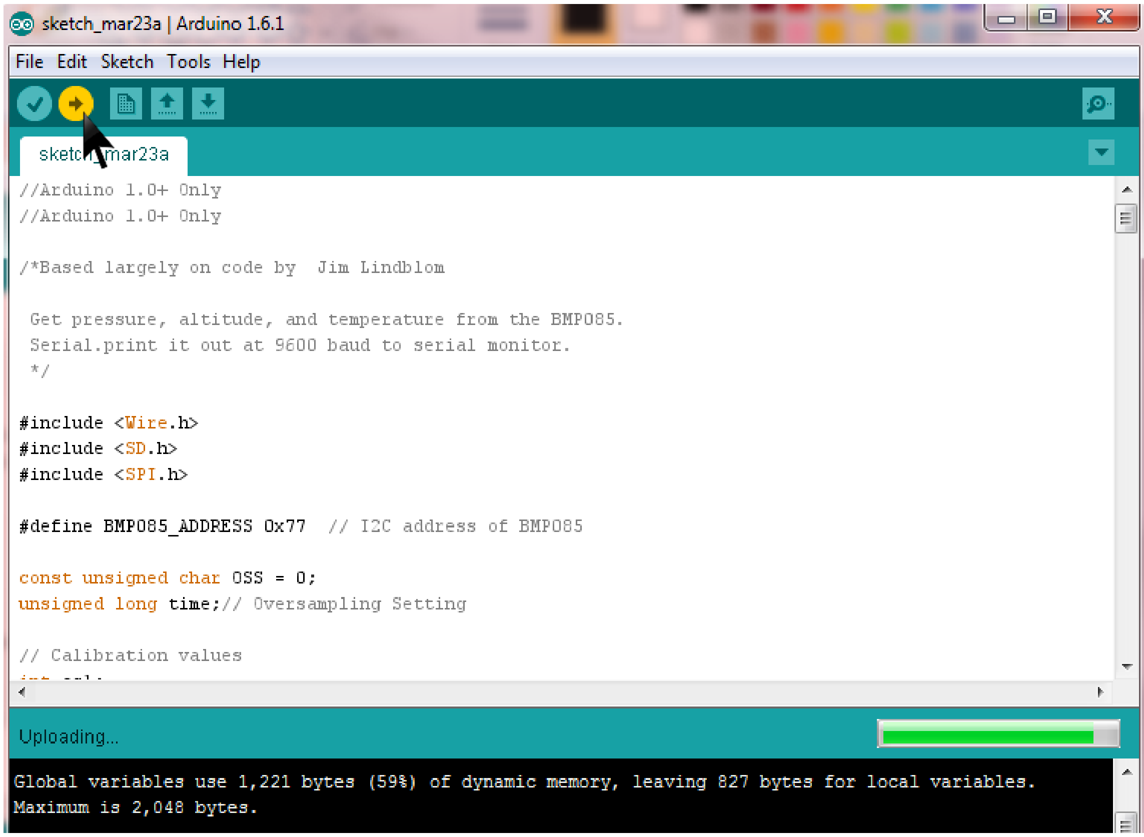


Figure 18: Upload Code

5. Time was recorded using stopwatch as coding uploaded
6. Put circuit inside the sphere device and fasten them tightly by using PTFE and Insulating tape as shown in Figure 19

Figure 19: Fully seal Pig tool

7. Next, fully submerged the tool in water using PVC Adapter (heavy object) for 10 minutes
8. After 10 minutes, took out device and unfasten them to remove memory from the circuit
9. All data and reading during the test were recorded and shown by the card
10. Tables and graphs of pressure and temperature with respect to time were prepared for analysis

iii. Pig Tool Test

<u>Objective</u>

To design a free floating pig with minimum risk of blocking pipe and determine pipe flowrate

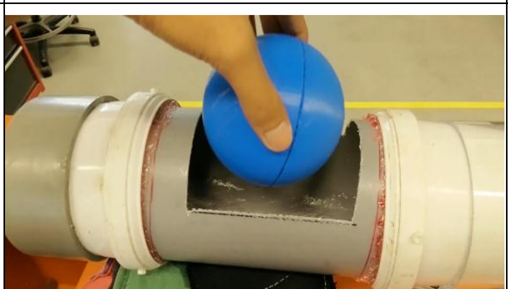
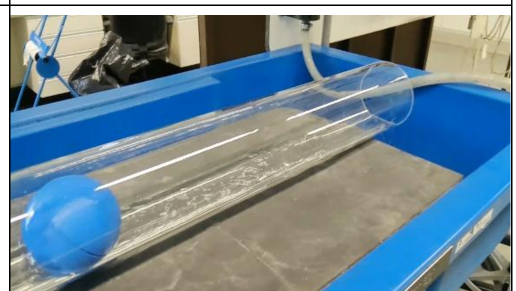
<u>Method</u>

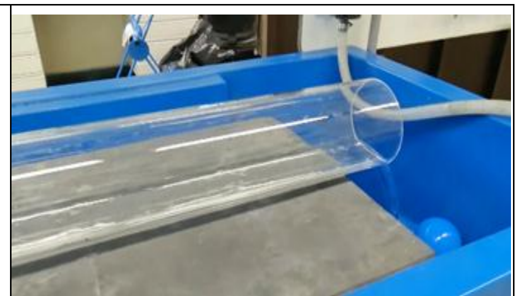
Pig tool is launch into 4 inch pipe with increasing inclination angle and retrieve at water tank

<u>Equipment</u>

Pig Tool, 2 meter acrylic pipe, 1 meter hose, Hydraulic Bench with Pump, PVC pig launcher, PVC Adapter

<u>Procedure</u>

1	Set up equipment	2	Turn on pump with no leaking at joints
			
3	Launch Pig tool into pig launcher	4	Floating pig navigate with water flow through pipe for the first run
			
5	Next run, increase pipe inclination angle from 0˚ to maximum angle that Pig tool can navigate inside the pipe	6	Record time when retrieved pig at water tank

			
7	Record maximum inclination angle	8	Calculate flowrate using Pipe Flowrate equation

Pipe Flowrate equation:

$$Flowrate = \frac{1}{4} \cdot \pi \cdot (pipe\ diameter)^2 \cdot velocity$$

Equation 2: Pipe Flowrate equation (source: 1728.org)

3.2.4 Data Collection and Analysis

The data obtained from the sensor were processed by the microprocessor and stored in the memory card. The data collected from the tests were used to verify the results. For future experiment using scaled pipeline, the data will be evaluated and analyzed in order to identify the type and location of the anomalies present in the pipeline. If the sensor fails to detect the anomalies in the pipeline, the product will be repaired or refurbished and the inspection will be rerun.

3.2.5 Results and Findings

The analyzed data were deduced to justify the results. The findings were used to conclude the report of the experiment.

3.3 Project Gantt Chart

The project will be carried out methodically with the key milestone for the FYP I and FYP II as shown on the following Gantt chart:

Table 1: FYP I & II Pigging Inspection Gantt Chart

		FYP 1														FYP 2													
No	**Description**	**Week**																											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	**Project Research and Study**																												
	Literature Review																												
	Technical Specification																												
	*Arduino Programming								*																				
2	**Design**																												
	Conceptual Design																												
	Detailed Design																												
	*Final Design of Pig Tool																						*						
3	**Materials & Equipment Selection**																												
	Materials Selection																												
	Sensors Identification																												
	*Confirmation on Materials & Equipment														*														
4	**Fabrication & Testing**																												
	Fabrication of Product																												
	Product Testing																												
	*Completion of Product Fabrication																									*			
5	**Data Analysis**																												
	Software Development																												
	Data Collection & Interpretation																												
	*Completion of Testing Phase																										*		
6	**Result & Finding**																												
	Report Preparation																												
	*Report Completion																												*

Progress		Milestone	*

3.4 Key Milestone

Figure 20 shows the key milestone of the project for the period of FYP I and FYP II. During FYP I, Arduino programming was completed during week 8. Then, followed by the finalization of the materials and equipment selection on week 14.

During FYP II, the project was continued and the final design of the product was finished during week 8. Next, the product fabrication was accomplished together with the completion of testing phase on week 12. Finally, report writing on the outcome of the project was done on week 14.

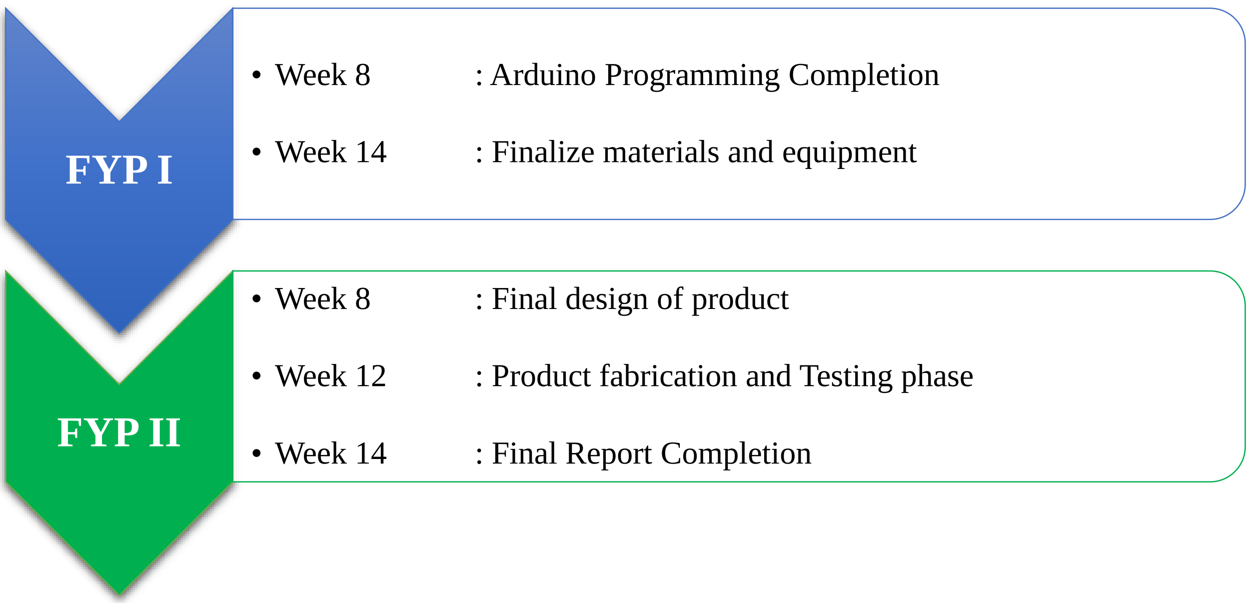


Figure 20 : Key Milestone for FYP I & II

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Design of Pig Tool

The detailed design of the Pig Tool was done by using CATIA. Figure 21 shows the assembly drawing of the Pig Tool and Table 4.1 shows the bill of materials for the Pig Tool. Full scale of assembly and detailed drawing were in Appendix 2.

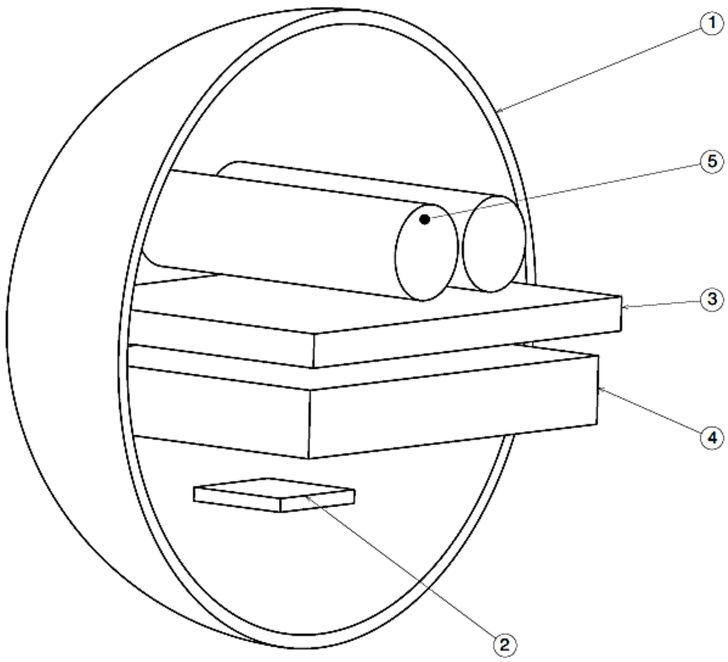


Figure 21: Assembly Drawing of Pig Tool

BILL OF MATERIAL		
NO	DESCRIPTION	QTY
1	INNER CORE	1
2	PRESSURE SENSOR	1
3	MICROPROCESSOR	1
4	SD SHIELD	1
5	BATTERY	1

Table 2: Bill of Material

4.2 Materials and Equipment Selection

Materials and equipment selection for the product were conducted. Based on research studies, the body materials and the interior components were identified based on the requirements of the project.

4.2.1 Body Materials

The body materials of the Pig Tool consisted of outer shell and inner shell. The inner shell was hard casing which encloses all the interior components to ensure no electrical components are exposed to the pipeline environment. The outer shell provides additional surface area to propel the device while reducing the ambient noises present in the pipeline. Table 2 shows the body materials identified for the Pig Tool.

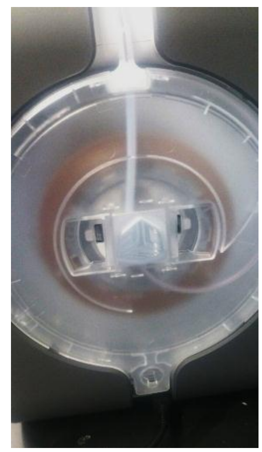


Figure 22: PLA material

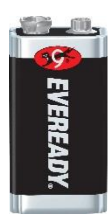
Table 3: Body Materials of the Pig Tool

No	Parts	Materials
1	Outer Shell	PLA Thermoplastic
2	Inner Shell	PLA Thermoplastic

4.2.2 Interior Components

The interior components of the Pig Tool were enclosed and secured in the inner shell of the Pig Tool. The interior components consisted of pressure sensor, SD shield, microprocessor, memory card, and power supply. These components were identified by finding the product with the best specifications that suit the requirement for the project. Table 4 shows the interior components of the Pig Tool required for the product fabrication and market price.

Table 4: Internal Components of Pig Tool

No	Components	Model/Type	Manufacturer	Remarks	Price
1	Pressure Sensor 	BMP 085	DFRobot	1 unit	RM 50
2	Microprocessor 	Arduino UNO R3	Arduino	1 unit	RM 80
3	Micro SD Card Shield 	Sparkfun	Myduino	1 unit	RM 46
4	Memory Card 	Micro SD	Kingston	4GB	RM 20
5	Power Supply 	9V Battery	Energizer	1 unit with a battery holder	RM 9
	TOTAL COST				RM 205

4.2.3 Sensors Specifications

The sensor was determined by the requirements to detect and locate multiple leaks in a pipeline. Based on detailed research and product availability in market, with aid from morphology chart as shown in Appendix 3, pressure sensor by DF Robot and micro SD Shield by sparkfun were the selected to execute the project main objective. The specification has been identified for both pressure sensor and SD Shield.

4.2.3.1 Pressure Sensor

The method is based on the analysis of pressure variation produced by a leakage in the pipeline network. The leakage detection procedure is performed detecting significant discrepancies between pressure measurements obtained from the pigging inspection and generate leakage signature that allows leakage localization.

Figure 23 : DF Robot Pressure Sensor (source: dfrobot.com)

The sensor (dfrobot.com) provide accurate Altitude, Pressure and Temperature data. Pressure output can be resolved with output in fractions of a Pascal and Altitude can be resolved in fractions of a meter. The device also provides 12-bit temperature measurements in degree Celsius. Table 4 shows the mechanical specifications of device.

Table 5: Pressure Sensor Specifications

Parameters	**Minimum**	**Typical**	**Maximum**	**Unit**
Pressure Sensor				
Measurement range	300	N/A	1100	hPa
Pressure Absolute Accuracy	-0.4	N/A	-0.4	kPa
Supply Voltage	1.62	2.5	3.6	V
Supply Current	N/A	5	N/A	µA
Operating temperature	-40	N/A	85	˚C

4.2.3.2 MicroSD Shield

MicroSD Shield by SparkFun equips Arduino with mass storage capability and for data logging and especially when running out of memory space in Arduino project. Communication with micrSD card is achieved over an SPI interface.

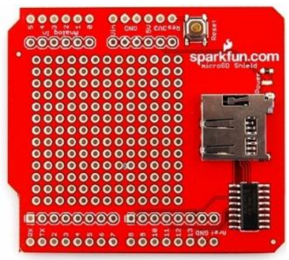


Figure 24: SparkFun microSD Shield (source: sparkfun.com)

The SD library allows for reading from and writing to SD cards on Arduino Shield. The Sparkfun shiled performs on Arduino and uses pin 8 for CS. A step by step guide to assemble the microSD shiled is provided in Sparkfun Tutorial web. Shield assembly requires soldering which helps make a good, physical and electrical connection. All 28 shiny volcanoes of solder are everytihing soldered with double checks for bad solder joints as shown in Figure 25 below. Then it is connected to Arduino board to implement a file system.

This shield comes with a microSD socket, a red power indicator LED, and a reset button, but Arduino R3 Stackable Header kit need to be installed.

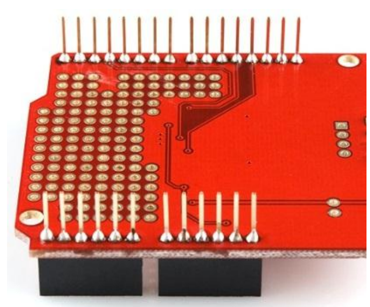


Figure 25: All pins are completely soldered on shield

4.2.3.3 Microprocessor

The microprocessor used for the Pig Tool is the Arduino Uno R3. It has 14 digital input/output pins, 6 analog inputs, a USB connection, a power jack, and a reset button. It can be connected to a computer with a USB cable or can be powered with an AC –to –DC adapter or battery. Figure 26 shows the Arduino Uno R3 that is used as the microprocessor for the Pig Tool.

The data obtained from the sensors will be processed by the Arduino, and will be stored to the memory card. Table 4.6 shows the specifications of the Arduino Uno R3.

Table 6: Arduino UNO R3 Specifications

Parameters	**Description**
Operating Voltage	5 V
Input Voltage	6-20 V
Digital I/O Pins	14
Analog Input Pins	6
Clock Speed	16 MHz

Figure 26: Arduino UNO R3 (Source: Arduino)

4.3 Product Fabrication

As discussed earlier, the product fabrication of the Pig Tool is divided into two: fabrication of the core and fabrication of the inner components.

4.3.1 Pig Tool Shell

As discussed earlier, the Pig Tool was fabricated by using Cube 3D Printer (source: cubify.com) with PLA Thermoplastic as the body materials. The process was completed in 5 working days and total cost for the fabrication was RM 400. Therefore, the final design of the product was done in a hollow-spherical shape and successfully manufactured. Design of product in CATIA is in Appendix 4.

Figure 27, 28 and 29 shows the final product of Pig Tool. The interior components of the product will be enclosed inside the spherical ball.

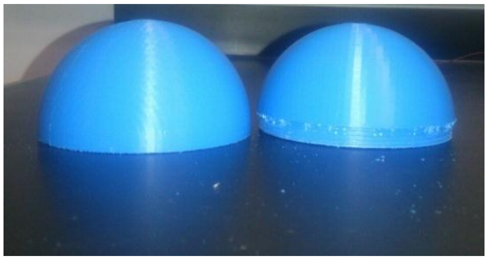


Figure 27: Pig Tool sphere parts

Figure 28: Outer part of pig Tool

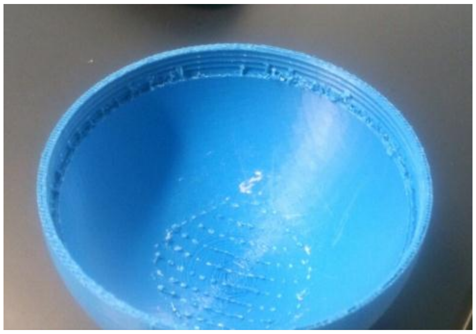


Figure 29: Bottom: Inner part of Pig Tool

4.3.2 Interior Components

All the components were wired to the microprocessor and powered by using a 9V battery. The data was processed by the microprocessor and stored to the memory card by connecting to the MicroSD Shield. Figure 30 shows the final electrical components that are used for the Pig Tool. The interior components are place inside the sphere Pig Tool.

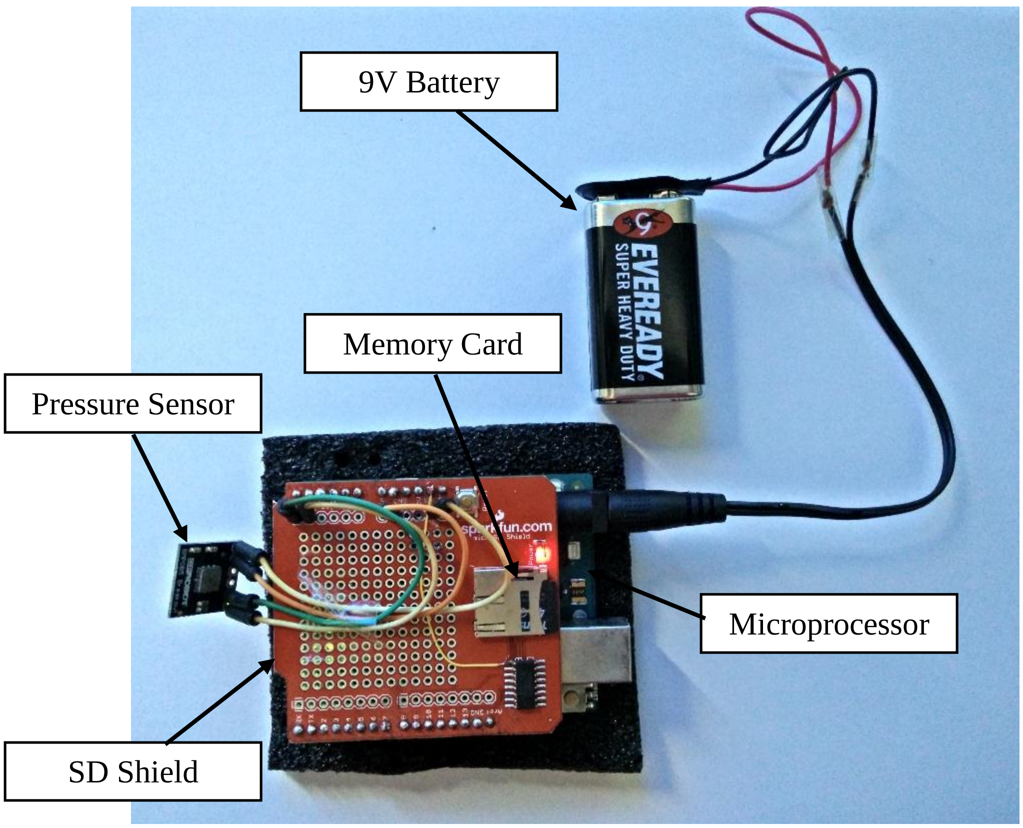


Figure 30: Interior Components of Pig Tool

4.4 Testing

As mentioned earlier in section 3.2, total of 3 indirect test were performed due to difficulty in obtaining the pipeline facilities such as Leak Test, Sensor Test, and Pig Tool Test. The results are shown as follow:

i. Leak Test

Observation

The wrapping of tape on Pig Tool was still attached sealed. However, tissues inside the tool are totally wet as show in Figure 31.

Figure 31:
Left: Wrapping of tape on Pig Tool

Middle and Right: Tissues are observed in wet condition

Reason

Small leaking due to incomplete or less seal applied

Conclusion

After 24 hours, leak was identified on the Pig Tool and it is not safe to put the electronic components inside. However, another test was conducted and no leaking identified if the tool is submerged for 10-15 minutes. Hence, the maximum time of the ball can be submerged inside water is approximately 15 minutes.

ii. Sensor test

Observation

Three outputs are measured in the test such as time, pressure and temperature as well as altitude. The outputs measured are presented in Serial Monitor as shown in Figure 32. After the test completed, the data stored in the memory card is extracted and analyzed. The results obtained are tabled and plotted in a graph of temperature and pressure against time as shown below.

Reason

Sensor was capable of detect differential temperature and pressure after tested with hot and cold water

Conclusion

- ✓ Pressure sensor : detect surrounding temperature and pressure. Pressure change when Temperature change
- ✓ Microprocessor : process data from sensor. Data stored in memory card
- ✓ Circuit : run using battery with closed system

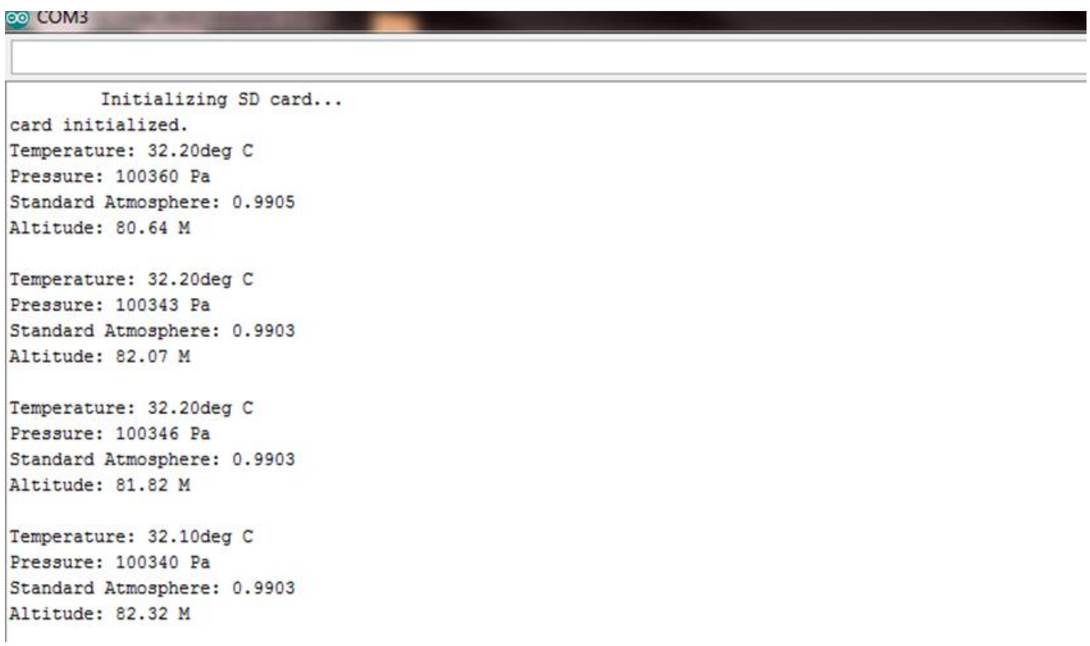


Figure 32: Serial Monitor of Arduino

Hot water (1 liter) + Normal water (8 liter)		
Time (s)	Temperature (°C)	Pressure (Pa)
0	31.20	100492
30	31.20	100492
60	31.20	100492
90	31.20	100492
120	31.20	100486
150	31.20	100486
180	31.10	100467
210	31.10	100467
240	31	100450
270	31	100444
300	31	100443
330	30.9	100433
360	30.6	100431
390	30.2	100428
420	30.2	100424
450	30.2	100424
480	30.2	100422
510	30.1	100416
540	30	100411
570	29.8	100401
600	29.5	100388

Table 7: Temperature and Pressure Reading of hot water

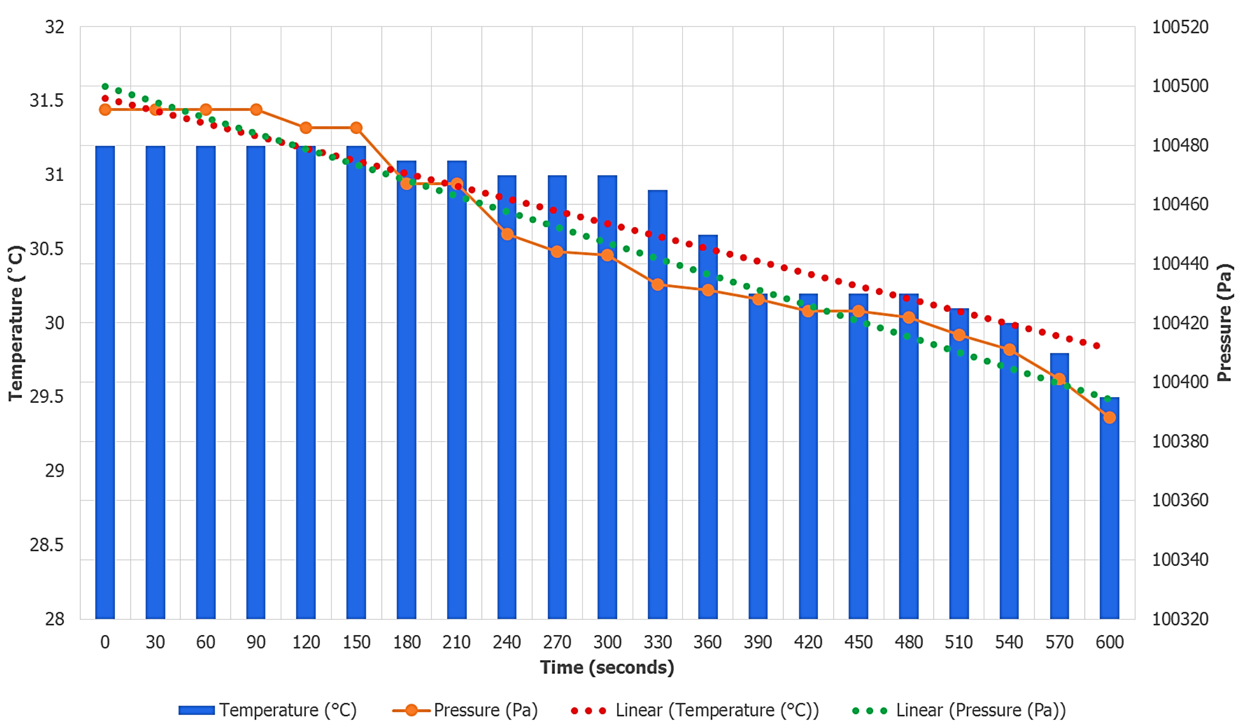


Figure 34: Graph of Temperature and Pressure over Time

Cold water (6 liter) + Normal water (3 liter)		
Time (s)	Temperature (°C)	Pressure (Pa)
0	28.3	100326
30	28.3	100326
60	28.3	100326
90	28.3	100326
120	28.3	100326
150	28.3	100326
180	28.3	100326
210	28.3	100326
240	28.4	100337
270	28.4	100337
300	28.4	100337
330	28.4	100337
360	28.6	100349
390	28.6	100349
420	28.7	100355
450	28.7	100355
480	28.8	100367
510	28.8	100368
540	28.9	100368
570	29	100377
600	29.1	100378

Table 8: Temperature and Pressure Reading of cold water

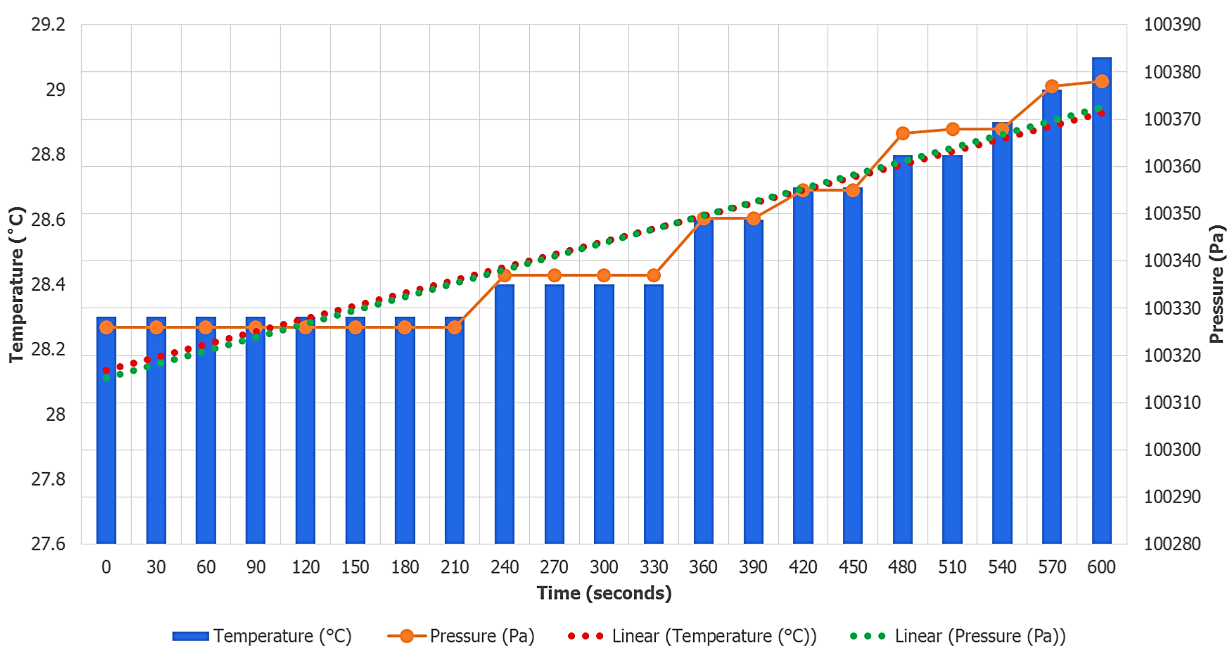


Figure 35: Graph of Temperature and Pressure over Time

From the sensor test conducted, after 10 minutes, it can be seen that there was a slight decrease in temperature by using hot water while increase in temperature when using cold water. The time allocation was 10 minutes because of limitation of time that the Pig Tool can be submerged in the water which is approximately 15 minutes. Further than that could lead to risk of electronic components inside the tool to be affected by water and later damaged.

Theory of Heat Transfer is applied in this experiment. Heat transfer consist of transfer of heat energy because of a temperature difference (Wikibooks, 2014). Based on Table 7, first test conducted shows that initially the temperature of hot water detected by sensor was constant at 31˚C for 2 minutes and then dropped to 29˚C after 8 minutes. The ambient temperature was 29˚C.

Next, second test performed shows that the temperature of cold water was constant at 28˚C for 3 minutes and then raised to 29˚C after 7 minutes as shown in Table 8.

For discussion purpose, temperature measured in the first test as shown in Figure 34 will dropped until reach ambient temperature. On the second test, there was slight increase of temperature indicated by the linear line of temperature from Figure 35 which at the end achieved the same degree as ambient temperature. Yet, this conclude that the sensor was capable to measure the drop and rise of temperature.

Moreover, based on Figure 34 and Figure 35, pressure reading shown by sensor will decrease when temperature are decrease and vice versa for both test runs. From the theory of Ideal Gas Law,

$$PV = mRT$$

Where,

P = pressure

V = volume

m = mass

R = Gas constant

T = temperature

Therefore,

$$P \propto T$$

The increase in temperature will result in the increase in pressure, as P is directly proportional to T. Thus, the result obtained, is in accordance to the Ideal Gas Law, and it proves that the pressure sensor is able to detect the temperature and pressure change of the surrounding.

From the indirect test performed, if the temperature and pressure were able to be detected by the sensors, processed by the microprocessor, and stored in the memory storage, it can be concluded that the pressure sensor will be able to detect leaks by differential pressure and temperature in an actual test run by using pressurized pipeline that will be performed in the future experiment.

iii. Pig Tool Test

Observation

Pig Tool was successfully launch and navigate through Arcylic pipe and later retrieve at the water tank.

- Time taken : 6 seconds
- Length of pipe : 2 meter
- Velocity of Pig Tool : 0.33 m/s
- Flowrate : 55.7 gpm (using Equation 2)
- Max. Inclination angle : 17˚

Reason

Pig Tool was propelled and moved in parallel with water flow inside the Acrylic pipe as shown in Figure 36. Maximum inclination angle is the limitation angle before leaking occurred between pipe joints as shown in Figure 37.

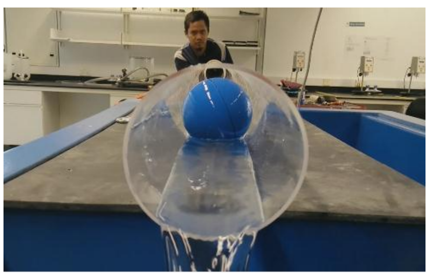


Figure 36: Pig Tool navigate inside Arcylic pipe

Figure 37: Pipe joints of PVC adapter and Arcylic pipe

Conclusion

Sphere device is successfully floating once launch into the pipe and navigate with the flow of water. No leaking identified in the sphere device and PVC adapter/joint when adhesive sealant applied.

CHAPTER 5

CONCLUSION

5.1 Conclusion

Based on the objectives of this project, the Pig Tool needs to be able to flow freely in a pipeline with minimum risk of blocking a pipeline, and to develop a sensitive leak detection system which can detect leaks in a pipeline. However, due to the lack of availability of pipeline facilities, indirect tests were performed such as Leak Test, Sensor Test and Pig Tool Test.

The indirect tests was conducted in order to prove three major things. First, the Leak Test is to ensure the Pig Tool is fully sealed and the circuit is not affected by any leaking. This is significant to avoid the electronic components inside the tool are not exposed to environment. Secondly, the Sensor Test is to confirm the pressure sensor is able to detect the surrounding temperature and pressure. The change in temperature will cause in the change in pressure. Microprocessor which is Arduino has successfully process data obtained by the sensor and the data stored in memory card. Meanwhile it is proven that the circuit can run using battery with closed system.

Moreover, the electronic components, including the sensor and microprocessor are able to run by using a battery, as the Pig Tool is a closed system which requires it to be deployed in a pipeline, or to put simply as a wireless device.

Third, the Pig Tool Test performed to test the mobility of Pig Tool. The sphere tool has the ability to float during navigation inside an Acrylic pipe with minimum risk of blocking pipe.

In a nutshell, if the temperature and pressure were able to be detected by the sensors, processed by the microprocessor, and stored in the memory storage, it can be concluded that the pressure sensor will be able to detect, and be stored in an actual test runs that will be performed in the future.

5.2 Limitations

During the process of completing the projects, various difficulties and obstructions were faced which resulted in the limitations on the construction of the pipeline facilities to test the Pig Tool.

The product was not able to be run in an actual pipeline. This is due to the lack of availability of pipeline facilities to test the product. This is because of the difficulty in manufacturing the facilities due to high cost and an ample amount of time required to manufacture the pressurized pipeline. Therefore, indirect tests were performed.

5.3 Recommendations and Future Works

For future works, the circuit configuration can be build and improve in terms of design and selection of electric components. The circuit can be produced in simplified version which is minor size than existing circuit thus it can be inserted in smaller size of Pig tool and can inspect small pipeline with diameter of less than 4 inch.

Thirdly, the Pig Tool needs to be tested in an actual pipeline with simulated leaks to test the functionality of pressure sensor. Besides, it needs to be tested in an actual 4 inch pipeline in order to test the mobility of the Pig Tool, in order to proof that a Pig Tool can move freely in a pipeline with minimum risk of blocking a pipeline.

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APPENDICES

ARDUINO PROGRAMMING

```
//Arduino 1.0+ Only

//Arduino 1.0+ Only

/*Based largely on code by  Jim Lindblom

 Get pressure, altitude, and temperature from the BMP085.

 Serial.print it out at 9600 baud to serial monitor.

 */

#include <Wire.h>

#include <SD.h>

#include <SPI.h>

#define BMP085_ADDRESS 0x77  // I2C address of BMP085

const unsigned char OSS = 0;

unsigned long time;// Oversampling Setting

// Calibration values

int ac1;

int ac2;

int ac3;

unsigned int ac4;

unsigned int ac5;

unsigned int ac6;

int b1;

int b2;

int mb;

int mc;

int md;

// b5 is calculated in bmp085GetTemperature(...), this variable is also used in bmp085GetPressure(...)

// so ...Temperature(...) must be called before ...Pressure(...).

long b5;

void setup(){

  Serial.begin(9600);

   Wire.begin();

   bmp085Calibration();

   Serial.println("Initializing SD card...");

  // make sure that the default chip select pin is set to

  // output, even if you don't use it:

  pinMode(10, OUTPUT);
```

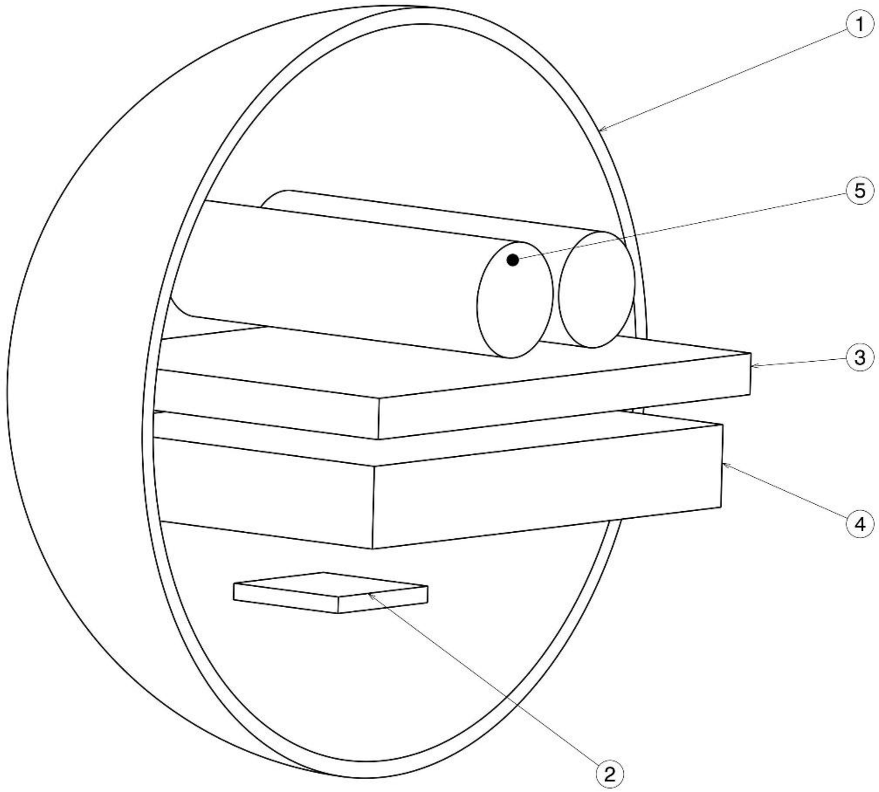
```
  // see if the card is present and can be initialized:
  if (!SD.begin(8)) {
    Serial.println("Card failed, or not present");
    // don't do anything more:
    return;
  }
  Serial.println("card initialized.");
      }
void loop()
{
  float temperature = bmp085GetTemperature(bmp085ReadUT()); //MUST be called first
  float pressure = bmp085GetPressure(bmp085ReadUP());
  float atm = pressure / 101325; // "standard atmosphere"
  float altitude = calcAltitude(pressure); //Uncompensated caculation - in Meters

  Serial.print("Temperature: ");
  Serial.print(temperature, 2); //display 2 decimal places
  Serial.println("deg C");

  Serial.print("Pressure: ");
  Serial.print(pressure, 0); //whole number only.
  Serial.println(" Pa");

  Serial.print("Standard Atmosphere: ");
  Serial.println(atm, 4); //display 4 decimal places

  Serial.print("Altitude: ");
  Serial.print(altitude, 2); //display 2 decimal places
  Serial.println(" M");


File dataFile = SD.open("test5.txt", FILE_WRITE);
if (dataFile)
{
 dataFile.print("Temperature: ");
 dataFile.print(temperature, 2);
 dataFile.println("deg C");

 dataFile.print("Pressure: ");
 dataFile.print(pressure, 0);
 dataFile.println(" Pa");

 dataFile.print("Standard Atmosphere: ");
 dataFile.println(atm, 4);

 dataFile.print("Altitude: ");
 dataFile.print(altitude, 2);
 dataFile.println(" M");
```

```
 dataFile.println();

 dataFile.close();

}

  Serial.println();//line break
  delay(5000); //wait a second and get values again.
}
// Stores all of the bmp085's calibration values into global variables
// Calibration values are required to calculate temp and pressure
// This function should be called at the beginning of the program
void bmp085Calibration()
{
  ac1 = bmp085ReadInt(0xAA);
  ac2 = bmp085ReadInt(0xAC);
  ac3 = bmp085ReadInt(0xAE);
  ac4 = bmp085ReadInt(0xB0);
  ac5 = bmp085ReadInt(0xB2);
  ac6 = bmp085ReadInt(0xB4);
  b1 = bmp085ReadInt(0xB6);
  b2 = bmp085ReadInt(0xB8);   mb = bmp085ReadInt(0xBA);
  mc = bmp085ReadInt(0xBC);
  md = bmp085ReadInt(0xBE);
}

// Calculate temperature in deg C
float bmp085GetTemperature(unsigned int ut){
  long x1, x2;

  x1 = (((long)ut - (long)ac6)*(long)ac5) >> 15;
  x2 = ((long)mc << 11)/(x1 + md);
  b5 = x1 + x2;

  float temp = ((b5 + 8)>>4);
  temp = temp /10;

  return temp;
}

// Calculate pressure given up
// calibration values must be known
// b5 is also required so bmp085GetTemperature(...) must be called first.
// Value returned will be pressure in units of Pa.
long bmp085GetPressure(unsigned long up){
  long x1, x2, x3, b3, b6, p;
  unsigned long b4, b7;
  b6 = b5 - 4000;
  // Calculate B3
```

```
  x1 = (b2 * (b6 * b6)>>12)>>11;
  x2 = (ac2 * b6)>>11;
  x3 = x1 + x2;
  b3 = (((((long)ac1)*4 + x3)<<OSS) + 2)>>2;

  // Calculate B4
  x1 = (ac3 * b6)>>13;
  x2 = (b1 * ((b6 * b6)>>12))>>16;
  x3 = ((x1 + x2) + 2)>>2;
  b4 = (ac4 * (unsigned long)(x3 + 32768))>>15;

  b7 = ((unsigned long)(up - b3) * (50000>>OSS));
  if (b7 < 0x80000000)
    p = (b7<<1)/b4;
  else
    p = (b7/b4)<<1;

  x1 = (p>>8) * (p>>8);
  x1 = (x1 * 3038)>>16;
  x2 = (-7357 * p)>>16;
  p += (x1 + x2 + 3791)>>4;
  long temp = p;
  return temp;
}

// Read 1 byte from the BMP085 at 'address'
char bmp085Read(unsigned char address)
{
  unsigned char data;

  Wire.beginTransmission(BMP085_ADDRESS);
  Wire.write(address);
  Wire.endTransmission();

  Wire.requestFrom(BMP085_ADDRESS, 1);
  while(!Wire.available())
    ;

  return Wire.read();
}

// Read 2 bytes from the BMP085
// First byte will be from 'address'
// Second byte will be from 'address'+1
int bmp085ReadInt(unsigned char address)
{
  unsigned char msb, lsb;
  Wire.beginTransmission(BMP085_ADDRESS);
  Wire.write(address);
  Wire.endTransmission();
```

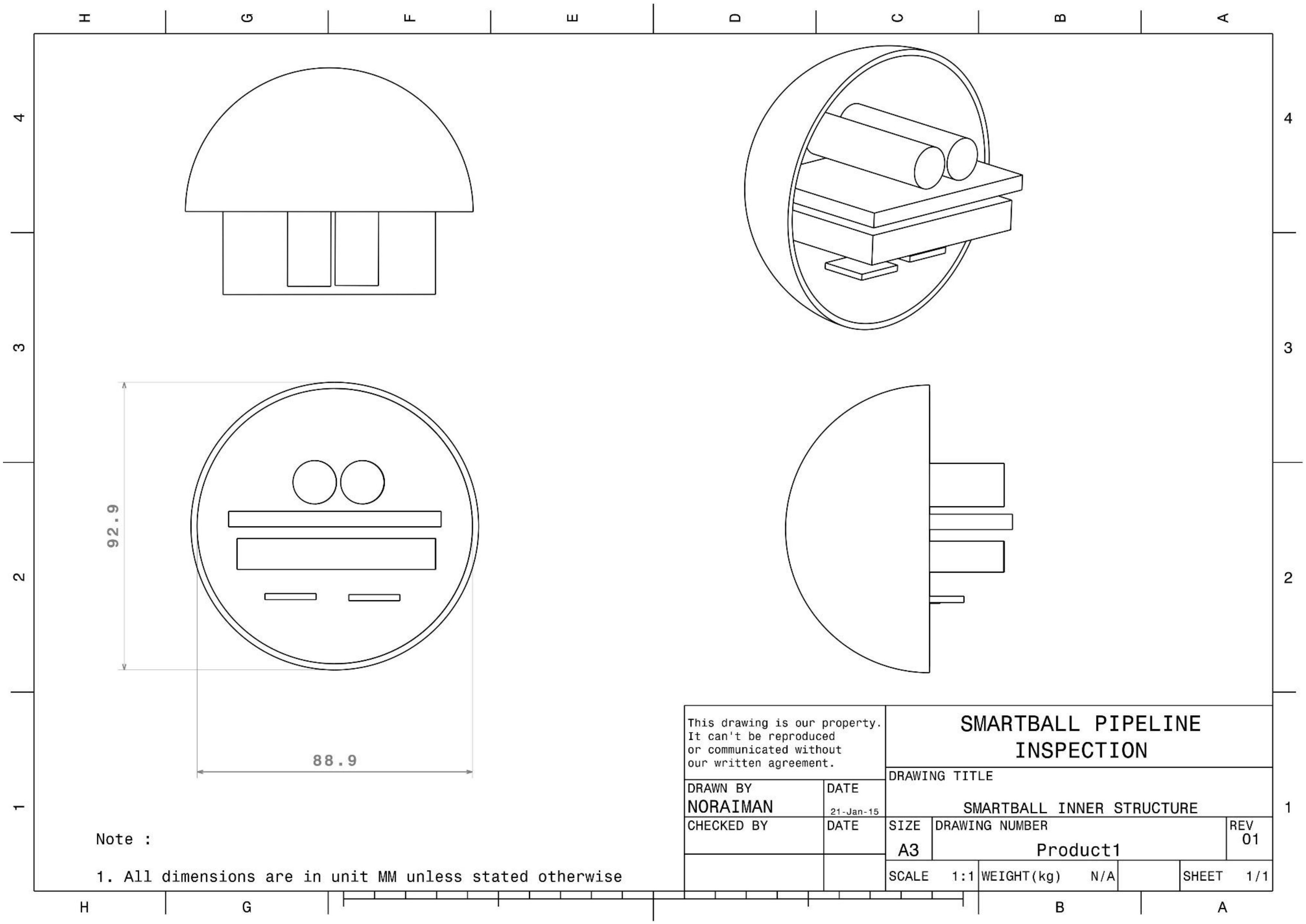
```
Wire.requestFrom(BMP085_ADDRESS, 2);
  while(Wire.available()<2)
    ;
  msb = Wire.read();
  lsb = Wire.read();

  return (int) msb<<8 | lsb;
}
// Read the uncompensated temperature value
unsigned int bmp085ReadUT(){
  unsigned int ut;

  // Write 0x2E into Register 0xF4
  // This requests a temperature reading
  Wire.beginTransmission(BMP085_ADDRESS);
  Wire.write(0xF4);
  Wire.write(0x2E);
  Wire.endTransmission();    // Wait at least 4.5ms
  delay(5);

  // Read two bytes from registers 0xF6 and 0xF7
  ut = bmp085ReadInt(0xF6);
  return ut;
}

// Read the uncompensated pressure value
unsigned long bmp085ReadUP(){

  unsigned char msb, lsb, xlsb;
  unsigned long up = 0;

  // Write 0x34+(OSS<<6) into register 0xF4
  // Request a pressure reading w/ oversampling setting
  Wire.beginTransmission(BMP085_ADDRESS);
  Wire.write(0xF4);
  Wire.write(0x34 + (OSS<<6));
  Wire.endTransmission();

  // Wait for conversion, delay time dependent on OSS
  delay(2 + (3<<OSS));
```

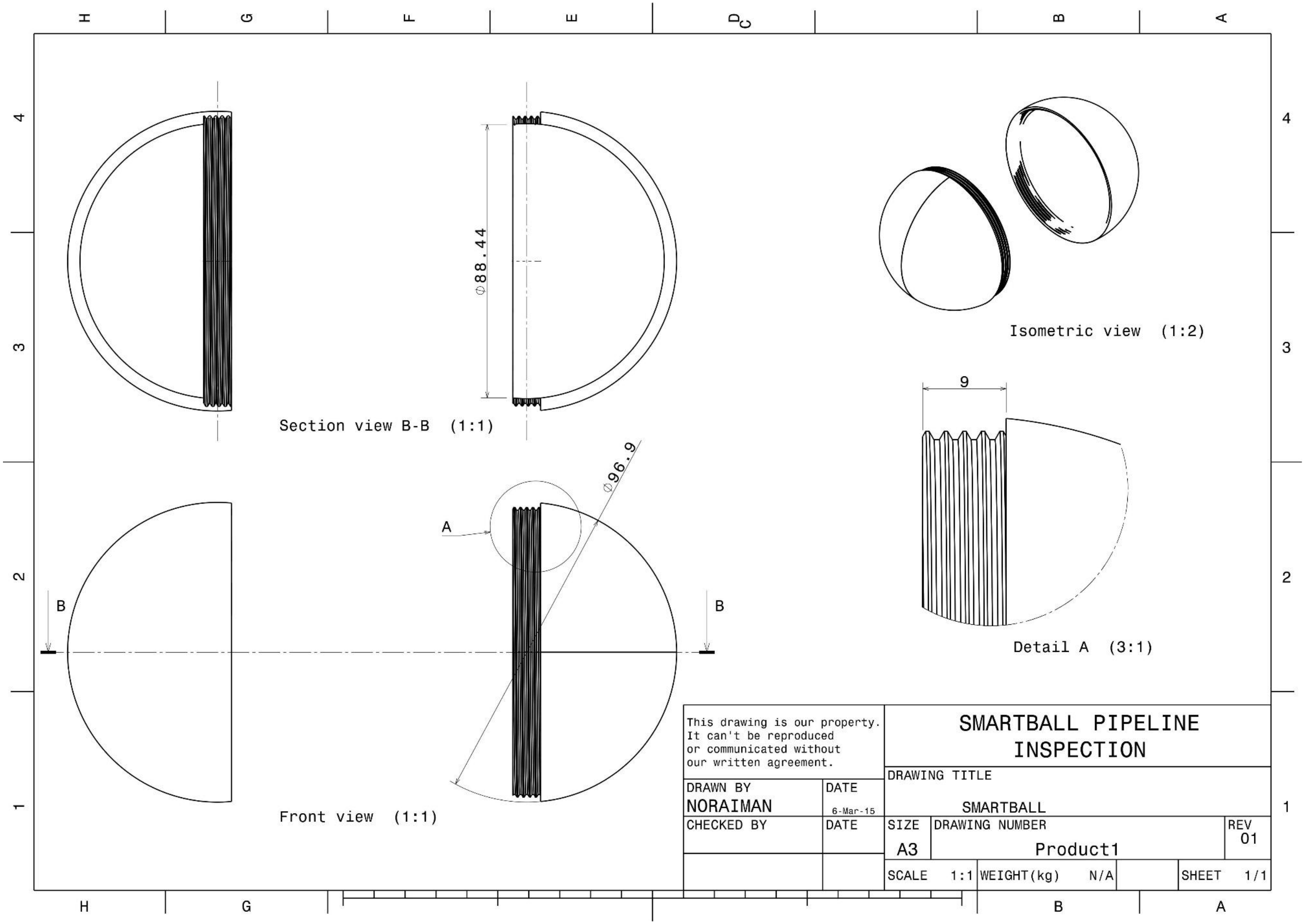
```
  // Read register 0xF6 (MSB), 0xF7 (LSB), and 0xF8 (XLSB)
  msb = bmp085Read(0xF6);
  lsb = bmp085Read(0xF7);
  xlsb = bmp085Read(0xF8);

  up = (((unsigned long) msb << 16) | ((unsigned long) lsb << 8) | (unsigned long) xlsb) >> (8-OSS);

  return up;
}

void writeRegister(int deviceAddress, byte address, byte val) {

Wire.beginTransmission(deviceAddress); // start transmission to device
  Wire.write(address);       // send register address
  Wire.write(val);         // send value to write
  Wire.endTransmission();     // end transmission
}

int readRegister(int deviceAddress, byte address){

  int v;
  ire.beginTransmission(deviceAddress);
  Wire.write(address); // register to read
  Wire.endTransmission();

  Wire.requestFrom(deviceAddress, 1); // read a byte

  while(!Wire.available()) {
   // waiting
  }

  v = Wire.read();
  return v;
}

float calcAltitude(float pressure){

  float A = pressure/101325;
  float B = 1/5.25588;
  float C = pow(A,B);
  C = 1 - C;
  C = C /0.0000225577;

  return C;
}
```



BILL OF MATERIAL		
NO	DESCRIPTION	QTY
1	INNER CORE	1
2	PRESSURE SENSOR	1
3	MICROPROCESSOR	1
4	SD SHIELD	1
5	BATTERY	1

SMARTBBALL PIPELINE INSPECTION	
DRAWING TITLE	SMARTBALL INNER STRUCTURE
DRAWN BY: NORAIMAN	DATE: 21-Jan-15
CHECKED BY	DATE
DESIGNED BY: XXX	DATE: XXX
SIZE: A3	DRAWING NUMBER
REV	01
SCALE	2:1
WEIGHT(kg)	N/A
SHEET	1/1


92.9
88.9
Note :
1. All dimensions are in unit MM unless stated otherwise
This drawing is our property. It can't be reproduced or communicated without our written agreement.
SMARTBALL PIPELINE INSPECTION
DRAWING TITLE
SMARTBALL INNER STRUCTURE
DRAWN BY
NORAIMAN
DATE
21-Jan-15
CHECKED BY
DATE
SIZE
A3
DRAWING NUMBER
Product1
REV
01
SCALE 1:1
WEIGHT(kg) N/A
SHEET 1/1


Section view B-B (1:1)
Ø88.44
Isometric view (1:2)
9
Detail A (3:1)
A
Ø96.9
B
B
Front view (1:1)
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SMARTBALL PIPELINE INSPECTION
DRAWN BY
NORAIMAN
DATE
6-Mar-15
CHECKED BY
DATE
DRAWING TITLE
SMARTBALL
SIZE
A3
DRAWING NUMBER
Product1
REV
01
SCALE 1:1
WEIGHT(kg) N/A
SHEET 1/1

MORPHOLOGY CHART

Decomposition		Option 1	Option 2	Option 3
Supply	Type of power supply	Batteries (AA) 	DC/Wall Adapter 	USB Cable 
Microprocessor	Arduino Board	Arduino UNO R3 	Arduino Nano 	Arduino Fio 
Sensor	Leak detection & location	Pressure Sensor (Semiconductor) 	Pressure Sensor (Breakout) 	Pressure Sensor (DF Robot) (BMP 085) 
SD Shield	Data logging and storage	Sparkfun Micro SD Shield 	DF Robot SD Module 	

PIG TOOL DESIGN BY CATIA