

Major Project Report

by Thomas Rees

FILE	21107_THOMAS_REES_MAJOR_PROJECT_REPORT_78196_154288031 1.PDF (3.88M)		
TIME SUBMITTED	21-APR-2016 01:03PM	WORD COUNT	20703
SUBMISSION ID	56196694	CHARACTER COUNT	123423



Pothole Detection Proof Of Concept

By

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Project submitted as part of the requirements of the requirements for the award of
the B.Eng. (Hons) Electrical & Electronic Engineering.

April 2016

Student Declaration

I, Thomas Michael Rees declare that I am the sole author of this Project; that all references cited have been consulted; that I have conducted all work of which this is a record, and that the finished work lies within the prescribed word limits.

This work has not previously been accepted as part of any other degree submission.

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Form of Consent

I, Thomas Michael Rees hereby consent that my Project, submitted in candidature for the B.Eng. (Hons) Electrical & Electronic Engineering degree, if successful, may be made available for inter-library loan or photocopying (subject to the law of copyright), and that the title and abstract may be made available to outside organisations.

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19576	4,100	15,476	93

Abstract

The proposed hypothesis was can a pothole prevention system be designed while adhering to a student's budget and time scale. To prove this hypothesis a proof of concept project was created, which was aimed to simulate a road surface, simulate a pothole with a distance change and a detection circuit to trigger upon the pothole detection.

The main objective of the project was to keep the complete build under £100. Upon this designing and sourcing materials required throughout the project was a major challenge to overcome, as the original plan was to purchase a sensor off the shelf, but after market research an affordable reliable sensor that could operate to the proposed specification could not be found. This added extra design elements of the project which ultimately took focus off of particular sections of the project, but it was deemed vital to have a sensor that could detect distance changes to the proposed maximum speeds (maximum 70mph). The use and the exposure of different design, testing, and simulation software techniques was used (e.g. LABVIEW, Proteus, Easy PC, CCS Compiler, Terra Nova, and Arduino).

The final outcome of the project was a testing jig which was designed and built. This was used to simulate a pothole with a hole cut-out of a rotating platform, but the closest to simulating the road surface at this stage of the project to match the colour of the surface being black. A Sensor module was designed and built including a sensor shield this was tested throughout the project and calibrated to the requirements of the detection jig.

The main enclosure which held the control circuitry and power supply was also built and designed successfully.

The location data from the GPS was successfully applied to the project and transmitted on command for whenever a pothole was detected.

One key area that requires future design and investigation was that the sensors functionality at distances over 200mm was unsuccessful. So a decision was made to lower the distance to 100mm for POC of the system. Although not all objectives were achieved the final outcome of the project was a success.

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Chapter 1 - Report Introduction

1.1. Background:

Road maintenance is a topic of great discussion throughout UK media and the general public especially potholes. Maintaining and repairing pothole damage on road surfaces is a very important responsibility which is governed by each and every principle boundary (local council). According to the AA (1) all councils must have a system in place as to enable the effective reporting from the public of any road maintenance issues and may be liable if they do not act upon receiving a report or observing a defect during one of their own planned inspections. It would be an impossible task for the local authorities and the public road user to report and discover every pothole on UK roads. The result of this means that there will be hazardous roads on a person's travel that the council may not have any liability for, potentially leaving an individual with a hefty repair bill.

A brief case study of this was reported by the Bolton news (2) of where they found that 77 drivers were paid a total of £20,500 for suing their local authority for not resolving pothole defects in a sufficient time period. These pothole claims cost the UK tax payer an estimated £106,000,000 in just compensation claims and legal fees alone between the years of 2006 – 2010, which is an average of £26,500,000 a year according to the department for transport (3).

An average cost of what pothole damages could cause an individual's car throughout the UK but Boyce Lee states on his this is money website's article (4) that it costs an average of £247 per car, and with an average claim recorded in the UK every 11 minutes, over a year this amounts to 47,781 incidents. The costs cause immense strain on the UK economy, and the UK public road user.

To solve this problem a system could be designed so that it could alert a road user of a pothole incident (hit to the car) and once this happens record the GPS coordinates of the incident and then this information can be forwarded to a principle boundary authority, server, website or SATNAV. So that first the council can create a true priority system based on the live data capture being received, secondly to aid the user as evidence for legal aid to reclaiming repair bills back from the local authority and thirdly to record the data on a website so that anyone can get travel alerts and live updates through their SATNAV's as to avoid the potholes. This system would be a major form of prevention, with the potential of saving the end user and the UK tax payer money.

If the system was to have a success rate of just 0.1% it could help prevent 47.7 incidents a year which would result in the total savings of £11,800 to individuals for their car repair bills and possibly £26,500 to the UK tax payer due to potentially legal costs (based on the average repair cost of £247).

Based on the problem scenario explained above the proposed hypothesis was could a pothole prevention system designed be designed while adhering to a student's resources (budget and time scale).

1.2. Project Objectives:

Responding to the outlined hypothesis above, the following main objectives and criteria were decided upon as to aid with finding a suitable approach to the project;

- Source / design a sensor to recognise a pothole incident;
- Source a GPS module suitable for detecting the location of the incidents;
- Design and make a circuit to control circuit and communicate between the sensor and GPS;
- Create a testing and simulation jig, for the testing of the proof of concept design (example shown below);
- Keep the total design under £100 &
- Complete the project for April 2016 submission.

To aid you (the reader) to understand how and to the extent of which the project design was taken figure 1 was included, drawn (using Microsoft Visio 2013).

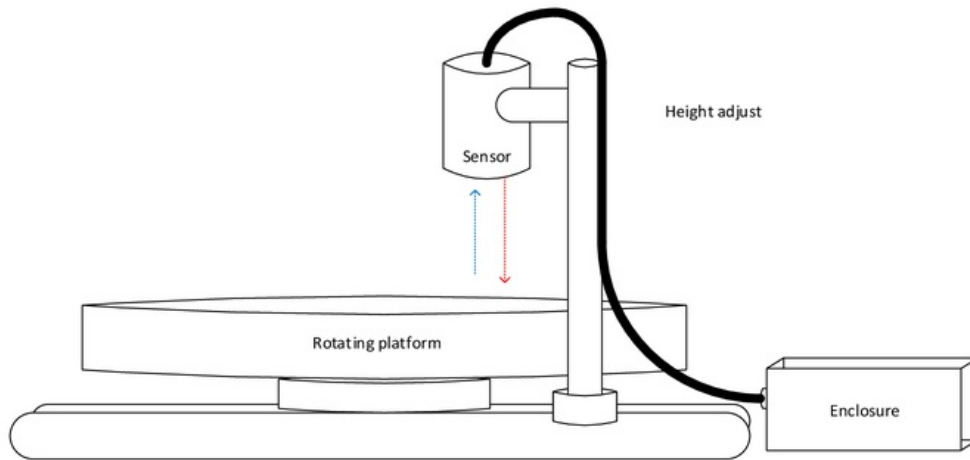


Figure 1 – Concept Design

Figure 1 – Concept Design was the original concept design of the entirety of the project.

The rotating platform would simulate the road moving under a vehicle. The height adjust could simulate the passing of a pothole on the road surface by quickly dipping the sensor up or down. The simulation of the pothole would be detected by the sensor that would trigger the GPS to transmit its data. The sensor would be mounted as illustrated to simulate it being mounted on the chassis of a vehicle. The concept idea was to have the main electronics (control circuit, Alarm circuit, GPS etc..) separate from the sensor which would be located in the enclosure as this is what would be done if this project was to be taken further in the future. They will be connected via a wire loom, as this best simulates how this system would be designed in industry. But future designed could be implemented to transfer the data wirelessly.

The design should achieve all the desired objectives outlined above which will give us a reasonable answer to the original hypothesis.

1.3. Specific Objectives:

The main objectives were listed above but to aid with completing a project such as this, the main objectives were expanded and categorized, also certain objectives were deemed essential or non-essential to finding a solution to the hypothesis and to aid with creating a priority system for time keeping throughout the project. In Chapter 5 (research) of the project a challenge arose which involved the requirement of an additional design of a sensor module as a pre-built and designed sensor could not be found within the budget of the project. This added an extra layer of complexity and time pressure. Which resulted in the final stages and build of the project being split into 2 steps. The first step was to build the sensor, test jig, and the main electronics controller to trigger an alarm when a pothole was detected, and the second step was to add the GPS data module to the project. Tables 1 – 7 are the expanded objectives to which aided with the planning of the project.

Section	Objective	Essential
Planning	Create a list of tasks and time scales for the project.	No
	Create a Gantt chart	No
Solution	Explain / Illustrate main Project Topic – Pothole Detection	Yes
	Design a proof of concept to that system	Yes
	Build proof of concept	Yes
Research	Create a research methodology	No
	Research into Project Topic e.g. market research, does a system exist?	No
	Research sensors for detecting potholes	Yes
	Research into a GPS modules	Yes
	Investigate which PIC to use for the project	Yes
	Research the best design practices	No
	Research design approach for mounting into car	No
	Research into specification of components required	Yes
Design	Design a sensor to detect potholes (NEW 21/10/15)	Yes
	Design a proof of concept Testing jig for the solution	Yes
	Design PCB for the proof of concept demonstration	No
	Design the enclosure and system wiring	Yes
	Integrate the GPS location data with the Pothole detection	Yes
Health & Safety	Create a safety analysis of design	No
	Perform a risk assessment of Implementation and final design outcome	No
Implementation	Build Sensor Design (New 21/10/15)	Yes
	Build design using a breadboard	Yes
	Build design using a Vero Board or onto a PCB	No
	Construct Proof of concept design	Yes
	Perform Testing and Calibration on Sensor Design (NEW 21/10/15)	Yes
	Implement testing of completed proof of concept system	Yes
	Construct Exhibition Board	Yes
	Complete project report	Yes
Evaluation & Conclusion	Perform an analysis of the proof of concept design (does it proof the concept?)	Yes
	Research into future requirements of the system	No
	Create an improvement comparison	No
	Research into how this could be marketed (cheaper parts, buy in higher quantity etc.)	No
	Explain the response of the Hypothesis	Yes
Presentation	Present Interim Viva	Yes
	Present Final Viva	Yes
	Present Exhibition Board	Yes

Table 1 – Project Objectives

Chapter 2 Planning

2.1. Time Scales:

Tables 2 - 7 below contain the list of all tasks along with initial time scales. These were used to create the project Gantt chart which was used throughout the project as to update the university on progress.

Planning Task List		
Task	Description	Time scale
Project Proposal / Justification Report	Create Project Proposal / justification	03/08/15 - 20/08/15
Planning Objectives	Create planning objectives	21/08/15 - 02/09/15
Planning Solution	Research into a solution for the project	03/09/15 - 30/09/15
Gantt Chart	Create a Gantt Chart	01/10/15 - 05/10/15
Project meetings / approval	Meeting with University, for project selection	03/08/15 - 05/10/15

Table 2 – Planning Tasks

Research Task List		
Task	Description	Time scale
Solutions	Perform Market Research into System Solutions	06/10/15 – 13/10/15
Sensors	Research into Pothole Sensors	14/10/15 – 21/10/15
GPS	Research into GPS Modules	22/10/15 – 29/10/15
PIC	Research into which PIC should be used for the project	02/11/15 – 09/11/15
Design	Research into the best design approaches	10/11/15 – 17/11/15
Specification	Research into the possible specification of components required	18/11/15 – 25/11/15

Table 3 – Research Tasks

Design Task List		
Task	Description	Time scale
(NEW) Sensor (21/10/2015)	Design a sensor to detect Potholes	26/11/15 – 17/12/15
POC	Design a proof of concept for the solution	18/12/15 – 01/01/16
PCB	Design a PCB	02/01/16 – 07/01/16
System	Design an enclosure layout and wiring for the system.	08/01/16 – 22/01/16

Table 4 – Design Tasks

Implementation Task List		
Task	Description	Time scale
Breadboard	Create the system onto breadboard for testing purposes	04/02/16 – 17/02/16
Vero Board	Assembly Sensor & Main Electronics onto Vero Board	18/02/16 – 02/03/16
PCB	Create PCB for completed system	03/03/16 – 16/03/16
Enclosure	Build electronics into enclosure to complete system	17/03/16 – 31/03/16
Testing	Test system to prove the concept	01/04/16 – 15/04/16

Table 5 – Implementation Tasks

Evaluation Task List		
Task	Description	Time scale
Analysis	Create a report to prove that the project is a success or not	17/03/16 – 31/03/16
Improvement	Create an improvement comparison for the design	01/04/16 – 15/04/16
Marketing	Create a research report into how this could be marketed	01/04/16 – 15/04/16

Table 6 – Evaluation Tasks

Presentation Task List		
Task	Description	Time scale
Viva Part 1	Present Project Idea and possible solutions	21/04/16
Viva Part 2	Present progress of project and research findings	03/08/15 – 21/04/16
Final Viva	Present completed project	28/04/16
Exhibition Board	Present POC design and demonstrate functionality	28/04/16

Table 7 – Presentation Tasks

2.2. Gantt Chart:

Figure 2 – Gantt Ref 1 and Figure 3 – Gantt Ref 2 are of the Gantt chart, this can also be found in the relevant section of the appendix. Modifications were made to the time scales in certain areas due to extra requirements. Tables 2 – 7 can be used for the time scales planned of the project.

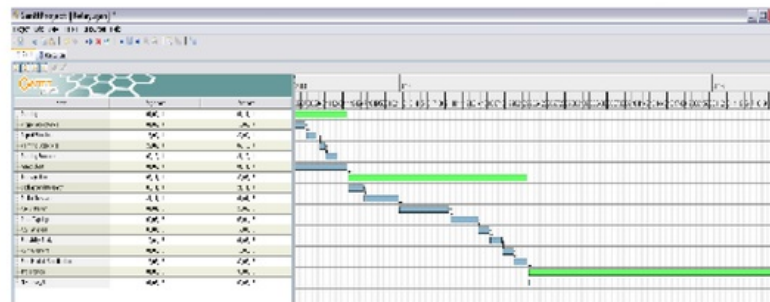


Figure 2 – Gantt Ref 1

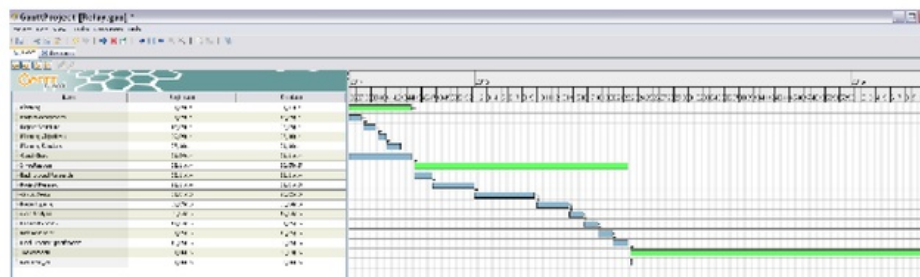


Figure 3 – Gantt Ref 2

Chapter 3 Research Methodology

3.1. Research Onion:

A research methodology was used to identify the most efficient and effective way for collecting, analysing and presenting research data. Several different methods and theories were found that could have been applied to the project the method selected was the research onion as this was advised by the university. The research onion used was based on Saunders diagram 2009 (5). The categories within the research onion that were deemed relevant to the project are as follows;

1. Research Philosophy - This is the process for the development of knowledge, Research philosophies applicable to this project are:
 - Positivism - This is the accurate means to research e.g. investigating the engineering problem so to replace assumptions (6). The use of this will be performed throughout the project by investigating solutions and proving that the concept works rather than assuming it does.
2. Research Approaches - This is the acknowledgement of what research must be performed.
 - Deductive Approach - This is the creating of theory and hypothesis and testing it using a research strategy. This will be performed by the creation of the system through research and testing to prove and solve the problem scenario.
3. Research Strategies - This is the plan to achieving the research goals.
 - Experiment - Research through experimentation, this will be done during the investigation of sensors and testing of the system.
 - Document review / Content analysis - This is the study of recorded human communications e.g. books. This will be done throughout the research, testing and implementation of the project.
 - Action Research - Contains physical elements of research such as system/organisation, design and implement a computerised solution, and evaluate the design decisions, results and conclusions. This will be performed as part of the investigation and testing of the system sensors.
4. Time Horizons - This is the time of which the project is intended for completion.
 - Longitudinal Research - This research extends over a long period of time. The project is over a 2 year period and the research will be continuous throughout the whole time scale.
5. Data Collection and analysis - This is the collection and analysis of data sets from within the project. This will be performed as part of the research and investigation of the project.
6. Research Methodology Summary;

Category	Relevant Methodology
Research Philosophy	Positivism
Research Approaches	The deductive approach
Research Strategies	Experiments, Document review / content analysis, and Action research
Time Horizons	Longitudinal Research
Data Collection and Analysis	Analysis of data sets

Table 8 - Research Methodology Conclusion

Chapter 4 Background Research

Chapter 1 aided with the introduction of the hypothesis and the desired outcome of the project.

Background research was performed to aid with the creation of the specification as to how the pothole detection system was to be designed and, the end product being very similar to the concept design shown above.

4.1. UK Laws:

Laws associated with potholes fall under section 41 of the highways act of 1980. A policy section states that whether the highway authority knew, or could reasonably have been expected to know, that the condition of the part of the highway to which the action relates was likely to cause danger to users of the highway will be liable (7), in context this section is and can be used as a get out clause for local authorities for when a public user is making legal action against them due to damages incurred from pothole incidents. The main point to take from this act is that the local authority's governing the roads in question would be responsible to their inspection. All councils have a maintenance schedule they would have created for every road that comes under their authority. The schedule per road is created depending on a number of factors like traffic, location, weather conditions, public environmental factors e.g. near a school or hospital and finally public reports. If risks are found or reported then an investigation will be initiated as to determine the level of risk to a road user, most risks are reported by public users some of which are negligible and low risks but the problem with this is that councils are not supplied with enough information to ensure they abide by section 41 of the highways act of 1980 above so will have to perform site visits to confirm and assess any risk reported to ensure no harm is incurred to the public, this is a massive drain on resources for any of the local authorities.

This put emphasis on the benefits of including GPS location data as it will save the council a lot of time in trying to locate the pothole via public descriptions for the visual inspections.

4.2. Pothole classification:

The definition of what a pothole is carries a lot of dispute among local authorities as pothole classification is determined by each and every local authority. A research specification was found from Rotherham metropolitan borough council's environment and development services Issued June 2014 (8). A pothole is defined as a flaw in the highway which reduces the effectiveness of the highway which causes a potential hazard and risk to the immediate road users. A sharp edged depression of $40\geq\text{mm}$ in depth which extends in any direction $300>\text{mm}$ will cause an immediate risk to the road users safety and should be repaired. As shown in Figure 4 – Pothole Dimensions.

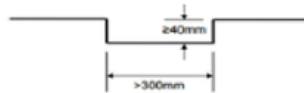


Figure 4 – Pothole Dimensions

These specifications were used during the experimentation and testing stages of the project, and were used to aid with the creation of the alarm protocols for the microcontroller.

1.3. Pothole Recording:

A website called Potholes.co.uk (<http://www.potholes.co.uk/potholes>) is currently promoting the general public to capture and fill in data manually of any potholes in their local areas. They display the data on their website so that anyone can view it and make changes to their travel arrangements if and when required. The final outcome of the project which would be the result of this proof of concept project would be to illuminate the need for the manual updating of such a website and perform all this automatically and then have the website data transferred to SATNAV's around the UK.



Figure 5 – Pothole Data Capture Website Example

Figure 5 – Pothole Data Capture Website Example was extracted from the website Potholes.co.uk (9) as you can see people are using and relying on this website for pothole updates. From the data they have currently captured we can see that the majority of potholes are being found on A and B roads throughout the UK. This gives us a good understanding as to what sort of roads the project will be used on.

1.4. Car Ride Height Specification:

The average ground clearance attained from autobytel et al Benjamin Hunting (10), the research was performed on the UK's top 10 biggest ground clearance SUV's, this should give us a practical maximum height for the project as SUV's are one of the popular and biggest domestic public cars on UK roads at the moment.

Car	Distance
LR4 Land Rover	12.1"
GL Class Mercedes-Benz	12"
Range Rover	11.63"
4Runner TRD Toyota	11.1"
Grand Cherokee Jeep	10.8"
Wrangler Jeep	10.6"
Xterra Nissan	9.1"
Land Cruiser Toyota	8.9"
Cherokee Jeep	8.7"
Forester Subaru	8.7"
Max	12.1" (30.734cm)
Min	8.7" (22.098cm)
Average	10.4" (26.416cm)

Table 9 – Car Ride Height Specification

From the results we determined that the maximum distance was 30.7cm, the average was 26.4cm and the minimum was 22.1cm and as discussed previously the minimum pothole depth is 40mm taken this and the average UK SUV's height a value of 30cm was decided as this is 4cm further than the average height of the UK SUV's.

For example: Distance from sensor

5cm = 5V, 10cm = 4.5V, 15cm = 4V, 20cm = 3.5V, 25cm = 3V, 30cm = 2.5V and 35CM = 2V

From this example normal distance condition of sensor = >3V if a pothole was detected the distance would increase and then ideally a voltage change would occur so that the sensor = <2V.

1.5. Car speed Specification:

The average travel speed of cars on a single and dual carriage way was obtained from the governments department for transport statistics (11) web archive. They found that 60% of road users would stick to the speed limits, and that the average speed for a road user would be 45mph on a single carriageway, 66mph on a dual carriageway and 67 on a motorway.

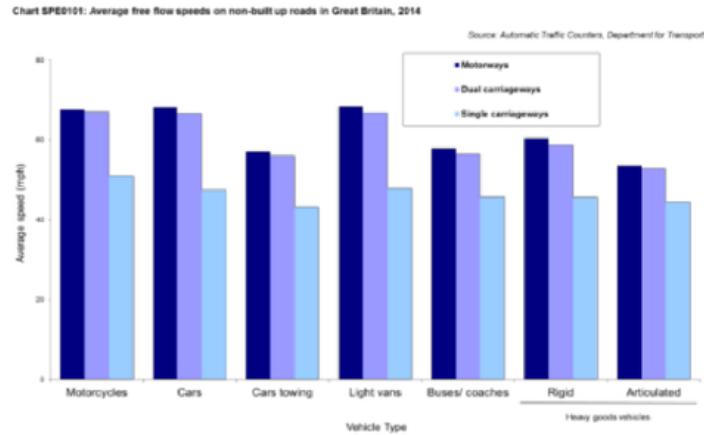


Figure 6 – Graph of Car Speed

Using the research contained in the government report Thomas performed the following calculations to aid with the investigation of the report.

Miles Per Hour to Millimetres Per Second	1mm	5mm	10mm
10mph = 16093.4mh / 3600 = 4.5ms = 4500mms	4.5KHz	900Hz	450Hz
20mph = 32186.9mh / 3600 = 8.9ms = 8900mms	8.9KHz	1.8KHz	890Hz
30mph = 48280.3mh / 3600 = 13.4ms = 13400mms	13.4KHz	2.7KHz	1.4KHz
40mph = 64373.8mh / 3600 = 17.9ms = 17900mms	17.9KHz	3.6KHz	1.8KHz
50mph = 80467.2mh / 3600 = 22.4ms = 22400mms	22.4KHz	4.5KHz	2.3KHz
60mph = 96560.6mh / 3600 = 26.8ms = 26800mms	26.8KHz	5.4KHz	2.7KHz
70mph = 112654mh / 3600 = 31.3ms = 31300mms	31.3KHz	6.3KHz	3.2KHz

Table 10 – Sensor Rep Rate Calculation

For the transducers to record distances every 1mm at the maximum speed of 70mph it would require a minimum reputation rate of 32 KHz (31.25uS), these speeds are very high and could work out very complicated when it comes to programming the microchip to react to these sort of time scales. A decision was made to use a recording distance of every 5mm of travel for the best accuracy vs the most efficient and effective specification required for the project. The result of which means the sensor transducer rep rate decided upon was 7 KHz (142.86uS) minimum.

1.6. Background Research Conclusion:

The background research highlighted some of the requirements for the design of the system.

The selected requirements were.

Pothole classification = $\geq 40\text{mm}$ depth and $> 300\text{mm}$;

Sensor recording distance = 300mm ;

Sensor recording Speed = $> 7\text{ KHz}$.

Chapter 5 Market Research

5.1. Market Research:

Jaguar Land Rover announced during a conference in June 2015 that they are investing research time and development into their own pothole detection system. It would be a safe assumption that manufactures are currently searching for the next car technology to aid with the sales of their cars. Thomas performed market research into what systems exists, the most relevant items he found and their basic specifications are as follows;

1. Surface Systems & Instruments Inc. have developed a range of road surface analysing systems the most applicable is their High Speed Profiling system as shown on the right (12). It uses laser technologies to detect height changes in the profile of the road. Its records any data captured using GPS position data. The base line price of the system is >£50,000 (13).



Figure 7 – SSI Image

Speed	Accuracy	GPS	Transducer	Price
5mph -70mph	3KHz	Yes	Laser	>£50,000

Table 11 – SSI Specifications

2. Geophysical Survey Systems, Inc. design and manufacture technology targeted for road maintenance, their most applicable product is the road Scan 30. As shown on the right (14). It uses Radar technologies to detect profile and depth changes to a road surface. The base line price of the system is assumed to be around the same as surface systems & instruments although a quote from the manufacture is still awaiting.



Figure 8 – GSS Image

Speed	Accuracy	GPS	Transducer	Price
5mph -70mph	1.5KHz	Yes	Radar	>£?

Table 12 – GSS Specifications

3. Jaguar Land Rover is a car manufacture and as mentioned above they are currently designing their own Pothole detection system as shown on the right (15). The system concept is very similar to Thomas has designed of where it detects a pothole hit and stores this information and passes that information on to the next car. The system utilise magnaride which is a form of suspension sensor that can detect ride height changes. The specification of the system is not released yet but we know it will be using WIFI hotspots and GPS to record the location of the detected pothole.



Figure 9 – JLR Image

Speed	Accuracy	GPS	Transducer	Price
5mph -70mph	/	Yes	Magnaride	N/A

Table 13 – JLR Specifications

The systems researched above all work on the same principles of monitoring the differences in height from a set location e.g. from the chassis of the vehicle to the road surface, using non-contact technologies. Based on this further research into the different kinds of sensors that could accomplish distance measurement based on the project scenario was performed, a decision was made to focus research efforts into non-contact technologies. As found above and from discussion with university tutors.

5.2. Sensor Market Research:

1. Time of flight (TOF) sensors tend to use variations of light transducers to measure depth for example light detection and ranging (LIDAR) is commonly used throughout robotics and several different kinds of industry for the measurement of distances. NOAA helps explain (16) that it works by pulsing light energy onto an object and then it records the time taken for the light to return (TOF), it performs this at high frequency using a narrow Laser beam and using other information like GPS location and scanners, and from this it can create very detailed 3d images of objects. There were several different methods and sensors found that could perform TOF measurements, the most relevant sensors found are listed below.

- LIDAR Lite.

The LIDAR LITE Laser Rangefinder module as shown on the right (17) is manufactured by pulsed Light. The key specifications found were;

Power Supply	Accuracy	Range	Rep	Cost
5v	0.025m	60m	500Hz	£90.53

Table 14 – LIDAR Lite Specification



Figure 10 – LIDAR Lite

- TOF VL6180

The TOF VL6180 range finder sensor module as shown on the right (18) is manufactured by spark fun. The key specifications found were;

Power Supply	Accuracy	Range	Rep	Cost
2.8v	+/- 3% of (MD)	10cm	10Hz	£16.15

Table 15 – TOF VL6180 Specification



Figure 11 – VL6180

- LEDDAR

The LEDDAR tech one Sensor as shown on the right (19), is manufactured by LEDDAR tech. The key specifications found were;

Power Supply	Accuracy	Range	Rep	Cost
5v	+/- 6mm	40m	70Hz	£135.37

Table 16 – LEDDAR Specification



Figure 12 - LEDDAR

2. Ultra-Sonic sensors operate on the same principles as the TOF sensor discussed above but instead of light energy it operates using sound energy e.g. (It transmits a sound wave and waits for the echo return). The sound energy is Ultrasonic so is transmitted over 20KHz (20). A few major difference between ultra-sonic and TOF is that sound moves a lot slower than light and the target detection beam would never be able to be as small as a laser beam. Ultra-sonic sensors are used in industry automation and robotics and prices can range from pounds to thousands of pounds, the most relevant sensors are listed below.

- Devantech SRF08

The Devantech SRF08 is an ultra-sonic range finder as shown on the right (21) is sold by robot shop. The key specifications are;

Power Supply	Accuracy	Beam Size	Range	Rep	Cost
5v	+/- 10mm	Large	6m	50Hz	£28.44

Table 17 – Devantech SRF08 Specification



Figure 13 – SRF08

- Devantech SRF235

The Devantech SRF235 is another ultra-sonic range finder as shown on the right (22) sold by robot shop. The Key specifications are;

Power Supply	Accuracy	Beam Size	Range	Rep	Cost
5v	+/- 10 mm	Small	1.2m	100Hz	£88.54

Table 18 – Devantech SRF235 Specification



Figure 14 – SRF235

- HC-SR04

The HC-SR04 is an ultrasonic range finder as shown on the right (23) sold by robot shop. The key specifications are;

Power Supply	Accuracy	Beam Size	Range	Rep	Cost
5v	+/- 10 mm	Medium	5m	20Hz	£2.28

Table 19 – HC-SR04 Specification



Figure 15 – HC.SR04

3. There are several different forms of technology for measuring depth / distance e.g. gamma ray and x ray imagine, of which could be excellent for a project such as this but due to cost restraints and the health and safety protocols that would have to be implemented these have been ignored. Further research into other forms of laser technologies was implemented. These sensors utilize how an IR LED or transistor changes state depending on how much IR light they are exposed to. In essence it is a way to measure how far a distance is by the measurements of reflected light onto the sensor.

- Sharp GP2Y0A51SK0F

The Sharp GP2Y0A51SK0F as shown on the right (24) is an Infrared distance sensor and works on the same principles as the sensors above but transmits using an infrared light energy source. The key specifications are;

Power Supply	Accuracy	Beam Size	Range	Rep	Cost
5v	+/- 5 mm	small	80cm	25Hz	£6.19

Table 20 – Sharp GP2Y0A51SK0F Specification

- Sharp GP2Y0A02YK0F

The Sharp GP2Y0A02YK0F as shown on the right (25) is an infrared distance sensor the same as the above but its key specification are different, it's designed for further distance sensing, and the key specifications are;

Power Supply	Accuracy	Beam Size	Range	Rep	Cost
5v	+/- 5 mm	Small	150cm	25Hz	£10.18

Table 21 – Sharp GP2Y0A02YK0F Specification

- Avago HSDL-9100-021

The Avago HSDL-9100-021 as shown on the right (26) is another IR distance sensor very similar to the ones above except that it's manufactured by a different supplier. The key specifications are;

Power Supply	Accuracy	Beam Size	Range	Rep	Cost
1.5v	?	Small	20cm	71KHz	£1.51

Table 22 – Avago HSDL-9100-021



Figure 16 – GP2Y0A51SK0F



Figure 17 – GP2Y0A02YK0F



Figure 18 – HSDL-9100-021

5.3. Market Research Conclusion:

Throughout the market research we have looked at the different systems that currently exist and several different forms of sensors for measuring distance. From all the research gathered a sensor module or a relevant sensor technology that would operate to the required specification of the project was not found within the student budget. The result of this was discussed within the interim viva of the project, to which the university tutors requested that further research be performed into photo transistors as they should be able to meet the requirements.

Chapter 6 Investigation – Sensor

The research performed in section 5 of this report confirmed that a sensor module suitable for the project could not be found. This meant that further investigation, design and testing into the creation of a distance sensor that could operate to the required specification outline previously would have to be performed. Chapter 6 covers all the investigation, design and testing of the sensor module of the project. Having to implement a second element of design work added an increased amount of complexity and work for the project which would have to be accounted for within the project time scales. An alteration into the priority of tasks within the Gantt chart was performed to counteract this problem. The tasks for the creation of a distance sensor were separated into different stages these were:

- Stage 1 – Background research, component research and component testing.
- Stage 2 – Concept Design, Initial testing design, calibration testing and calibration analysis.
- Stage 3 – Final Design and final testing.

6.1. Sensor Objectives:

The objectives decided upon for the sensor design were;

Section	Objective	Essential
Sensor	The required rep rate of the Sensor would be 7 KHz minimum	Yes
	Required sensing distance of the sensor: 300mm	Yes/No
	5v Power Supply	No
	5v Output Max	No
	Low current consumption	Yes
	Safe and free from risks	Yes

Table 23 – Sensor Design Objectives

6.2. Distance Sensor Design:

A very high rep rate was required for sensing potholes at potentially high speed. In light of this and having discussions with University lecturers a decision was made to focus efforts into the use of Photo diodes. As Diode have very fast switching states.

6.2.1. Stage 1 - Background Research:

1. Diode basics;

John Wiley & sons (27) helps explain on the electronic tutorial website that a diodes basic construction is made up of P-type (Anode) and N-type (Cathode) semiconductor materials connected together. These different materials produce different electrical characteristics, because of the way they are constructed they allow the component to conduct in one direction and insulate in another. An ideal Diode would block all reverse bias voltage, the conventional electrical characteristics of a standard diode as shown in the graph on the right (28) aid to demonstrate that this is not the case in the real world.

The standard switching and settle rate time of a diode could be as long as 4 μ S (29) which is the equivalent to 250KHz of switching, the required sensor rep rate was 7KHz to a potential of 32KHz which means the use of a diode will be fast enough for what the project requires.

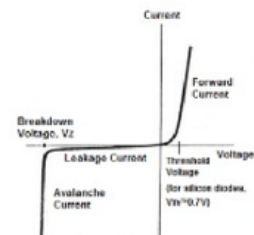


Figure 19 – Diode Characteristics

2. Photoelectric effect;

Boston University (30) aided with the explanation of what the photoelectric effect is, It is the effect of electrons being emitted from a material due to a high enough light energy (photons) being shone onto the materials surface. This phenomenon can be observed when shining a light onto an LED. As we know electricity is based on the free movement of electrons, this movement causes an in balance of the number of electrons to protons in an atom which causes a negative or positive ion state, the result of which means a current is produced this is none as a photocurrent. IR LEDs are also affected by this phenomenon but they are more sensitive to IR light due to their filtered lenses. The more concentrated the IR light the more photocurrent is produced. This is the basic operation of how solar cells work.

3. Photo Diode;

Walter G. Jung helps explain in his handbook Op Amp Applications (31), that photo diodes generate a small amount of current which is equal to the light it's subjected to, as explained within the photoelectric effect.

A photo diode operates on the principles of the photoelectric effect of where photocurrents are produced as light is reacting with the sensitive material inside which is exposed to the light source due to a light port or a transparent component enclosure. An IR Photo Diode works on the same principles but its design and construction has been tuned to be more sensitive to the IR light frequency with the use of light filters on the body of the component this is why IR LED are sometimes black or grey. There are several different forms of operation of which we could utilize to monitor the state changes of the component.

- Photovoltaic Operation;

This is when you have a photo diode set up in an arrangement so that it is zero biased. Which is better explained with the diagram taken from the art of electronics by Paul Horowitz & Winfield Hill (32) ;

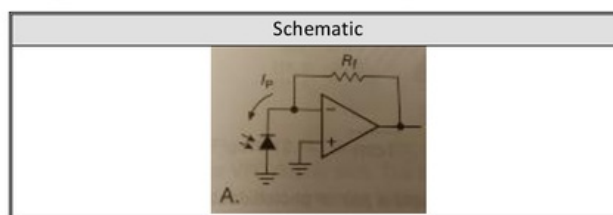


Figure 20 – Photovoltaic Operation

Walter G. Jung helps explain in his handbook Op Amp Applications (31), that this can be the most precise linear operation. And has no dark current flowing in this mod. The main items of interest are it has a zero bias, no dark current, linear operation, and low noise, typically used for precision applications and tends to have slower switching speeds. Any noise induced to this set up would be the thermal noise of the diode.

- Photoconductive Operation;

This is when the photo diode is set up in an arrangement so that an external reverse bias is applied.

Which is better explained with the diagram taken from the art of electronics by Paul Horowitz & Winfield Hill (32);

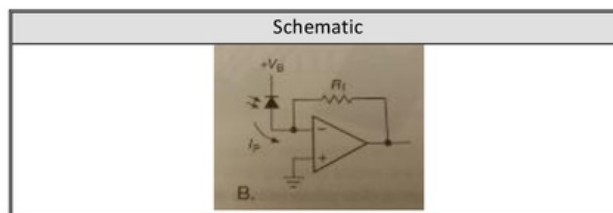


Figure 21 – Photoconductive Operation

Walter G. Jung helps explain in his handbook Op Amp Applications (31), that photoconductive state is set in a reverse bias, it allows dark current to flow, it's nonlinear, suffers from noise including thermal noise, but it has fast switching speeds.

4. Phototransistor;

In essence a photo transistor is the same as a photo diode except that the output current is increased by the transistor gain of β e.g. photo diode $1\mu\text{A}$ and a photo transistor $100\mu\text{A}$ ambient light levels.

The base of the transistor is subjected to light of which creates the base current to change the state of the component.

An example of this is in the diagram below taken from the art of electronics by Paul Horowitz & Winfield Hill (32);

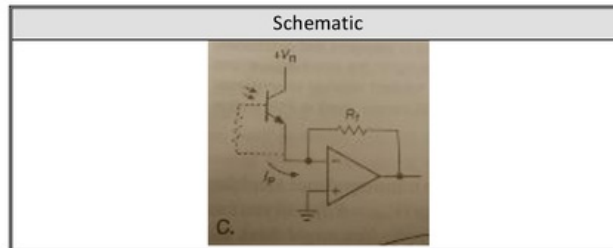


Figure 22 – Photo Transistor

A. P. Godse et al U. A. Bakshi in the book basic electronics, volume 1 (33), explain that when the incident light is at a certain level it will begin to conduct heavily. According to Tim Williams in his book the circuit designers companion (34) he states that typical switching speeds of a transistor could be a total of 250nS which is 4MHz . From previous research we worked out that the maximum speeds required of the sensor could be in the range of 32 KHz (maximum). So the switching states of the transistor should not be an issue for detecting at these speeds. From the research found a sensor could be designed that will transmit a IR light beam using some form of LED and then monitor the state effect of the transistor of the transistor. Further experiments may prove to be a useful form of high speed distance change sensor.

5. Op-Amp Equation

Part of the design will involve Op-AMPS to capture the output voltage of the sensor the following equation were used as part of the sensor design further on.

- Inverting OP-AMP

Equation
$\text{Gain (AV)} = -\frac{Rf}{R1}$

Equation 1 - Inverting OP-AMP

- Non Inverting OP-AMP

Equation
$\text{Gain (AV)} = 1 + \frac{Rf}{R1}$

Equation 2 - Non Inverting OP-AMP

6.2.2. Stage 1 - Component Research:

There were several different forms of IR LED researched that could have been tested to prove their suitability. Table 24 concludes the selected components that were decided upon. These were selected in 2 different combinations. One combination consists of a standard IR diode and photo diode that tend to be used in transmission data like remote controls. The beam focus tends to be more wide spread which could make it easier for the receiving diode to detect the reflected light as it will have a larger surface area covered. The second combination was a more powerful laser diode which has a narrow beam which should hold a high intensity of IR light to the target required but may prove trick to be detected due to the smaller surface area. According to the manufactures data sheet TT Electronics (35) the high powered laser diodes are especially design for long range transmission, a decision to use an IR Photo transistor especially chosen to match the output wave length of the high power laser diode was selected instead of a photo diode.

The overall decision to test these two combinations was an assumption as research for reflected light off of a certain material colour could not be accurately found based on the project scenario, so this would have to be found through experimentation.

/	General	Power Supply	Forward Voltage	Beam Size	Spectrum	Dark (I)	Light (I)	Cost	Image
Standard IR Diode Set up 1	Emitter Diode King Bright L-53SF4C IR Emitter (2290442)	5v (20mA)	1.6v	Small Beam	880nm	/	/	£0.24	 Figure 23 – L-53SF4C (36)
	Receiver Photo diode Fairchild QSD2030F Photodiode (2453251)	5v	1.3v	±20°	880nm	10nA	25uA	£0.60	 Figure 24 – QSD2030F (37)
High Power IR Diode Set up 2	Emitter Laser Diode OPTEK OPV302	5v (12mA)	2.2v	Small Beam	850nm	/	/	£9.90	 Figure 25 – OPV302 (38)
	Receiver Photo Transistor Vishay BPW85B	5v	/	±25°	850nm	200nA	8mA	£0.45	 Figure 26 – BPW85B (39)

Table 24 – Component Research

6.2.3. Stage 1 - Component Tests (IR):

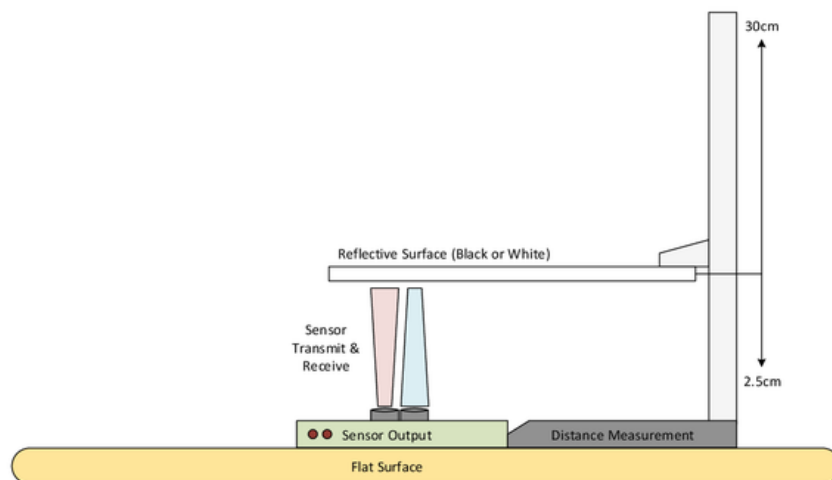


Figure 27 – Sensor Development testing

These tests were performed to find the maximum detectable distance achievable with the components depending on the colour of the target.

Figure 27 – Sensor Development testing (created using Microsoft Visio 2013) was the test configuration used for the component tests as to gather the results of the set up one and two. A white and then a black detection target were moved from 25mm to 300mm away from the sensor combination. The effected state of the components the photo diode and photo transistor were recorded onto a spreadsheet (using Microsoft Excel 2013). All experiments and raw data can be found in the appendix, but the following graphs are of the analysed raw data from the experiments.

Set up 1 was performed by supplying power to the IR LED and then recording the generated voltage (state change) of the photo diode.

Set up 2 was performed by supplying power to the laser diode and then recording the resistance change between the collector and emitter (state change) of the photo transistor.

1. Experiment 1 - Standard IR Diode Set up 1

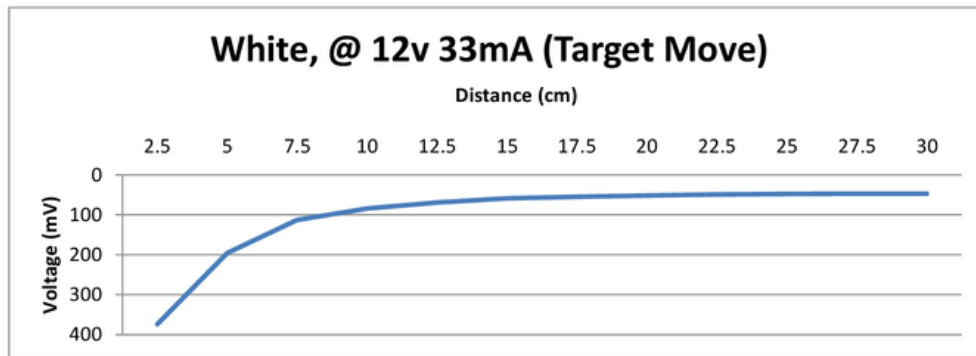


Figure 28 – Experiment 1 Set Up 1

Experiment 1 was performed with a white target which moved away from the photo diode. Analysing the data from the experiment, it's evident that after 175mm the IR photo diode was no longer reacting to any reflected IR light as the voltage has depreciated to a flat line level. This level it reaches is the background light affecting the component as a dark room could not be used. 175mm is below the suggested specification of the project.

2. Experiment 2 - Standard IR Diode Set up 1

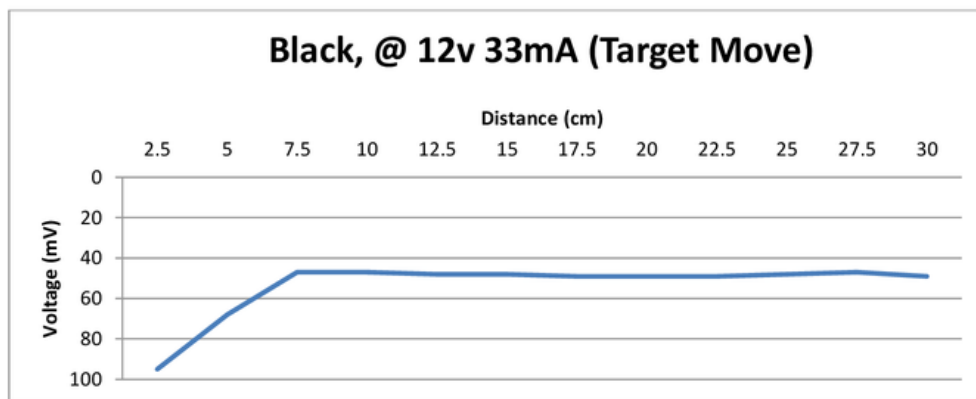


Figure 29 – Experiment 2 Set Up 1

Experiment 2 was performed using a black target which moved away from the photo diode. Analysing the data from this experiment, it's evident that after 75mm the IR diode was no longer reacting to any reflected IR light. We can tell this from the graph as the voltage has depreciated to a flat line level, the level of which has returned the same voltage output as in experiment 1 which also aides to prove the background lighting conditions were the same during the tests.

No further analysis was performed as both tests for black and white were below the suggested distance of the sensor.

This proved that the use of the standard IR Diode Set up 1 would not be sufficient for the task in hand.

3. Experiment 3 - High Power IR Diode Set up 2

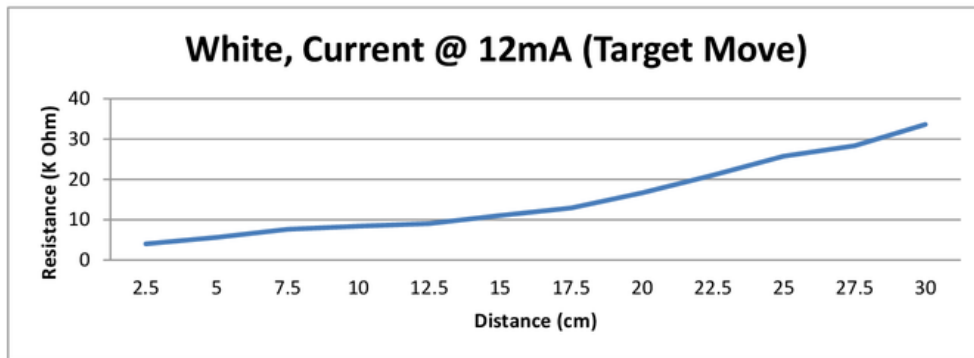


Figure 30 – Experiment 3 Set Up 2

Experiment 3 was performed using a white target which was moved away from the photo transistor. The experiment was taken to the limit of the equipment used (being 300mm). Analysing the data from this experiment, we can see that from 0 to 300mm the reflected IR light was affecting the photo transistor output. From the graph we can see that the output is exponential as we would expect from a pure distance change.

4. Experiment 4 - High Power IR Diode Set up 2

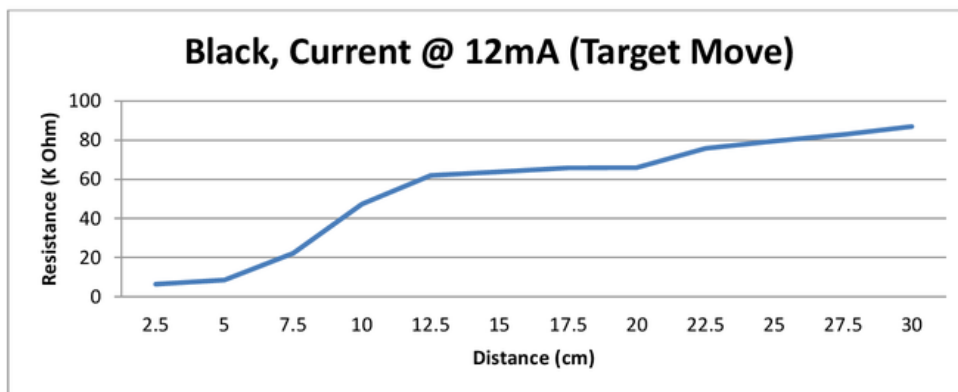


Figure 31 – Experiment 4 Set Up 2

Experiment 4 was performed using a black target which was moved away from the photo transistor. Analysing the data from the experiment, we can see that the trend of this result is consistent as the one performed in experiment 3 (increasing exponentially), although the transistor state change resistance readings are a lot higher (almost double) which is consistent with a colour change from black to white. Equation 3 was generated from the available data within the photo transistor data sheet (can be found in the appendix) its purpose was to attain what the minimum and maximum state change resistance would be and then compare this to the results received in experiment 4. This was performed to prove that the results obtained are not background noise but are consistent with a reflective reading.

/	Equation	
	<i>Resistance = Voltage / Current</i>	
	Dark Resistance	Light Resistance
Data Sheet	$25\text{M}\Omega = \frac{5\text{v}}{200\text{nA}}$	$625\Omega = \frac{5\text{v}}{8\text{mA}}$
Testing White	65.5K Ω	625 Ω
Testing Black	150K Ω	625 Ω

Equation 3 – Dark & Light Phototransistor Resistance

As we can see the maximum dark current of the photo transistor would give us a resistive value of 25M Ω . And the maximum light current of the photo transistor would give us a resistive value of 625 Ω . Both set of results gave us the maximum light resistance during the distances <50mm. The maximum dark value reached for both experiments at 300mm were:

- Black = $5\text{V} / 150\text{K}\Omega = 33.3\mu\text{A}$,
- White = $5\text{V} / 65.5\text{K}\Omega = 76.3\mu\text{A}$.

These outputs sound small but when compared with the maximum (8mA) light current and the minimum dark current (200nA), they are in fact nowhere near the dark current status.

- Black: 33,300nA
- White: 76,300nA

Now it is more clear and evident as to where the sensor sensitivity is and aids to prove that the sensor resistivity state change is being affecting by the reflected IR light at the maximum tested distance range of 300mm.

6.2.4. Stage 2 - Distance Sensor Possible Design:

1. Concept Design

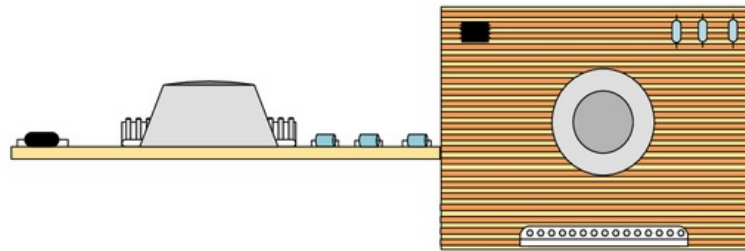


Figure 32 – Concept Design Sensor 1

Throughout the component testing it was noticed that ambient light was having a direct effect on the resistive state change of the photo transistor, to aid with reducing any possible effect that this may have a decision to create a light shield to enclose the sensor was made. As shown in Figure 32 – Concept Design Sensor 1 (designed using Microsoft Visio 2013). This should reduce the effects of background light on the photo transistor significantly. It should also reduce the risk of any IR laser radiation leakage.

2. Concept Schematic

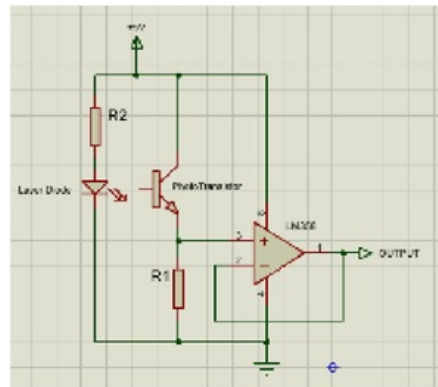


Figure 33 – Concept Schematic

Figure 33 – Concept Schematic is the concept schematic which was drawn on Proteus. This was used to test and simulate the sensor. A decision was made towards the future design, development and possible future manufacturing; the decision was to use as few components on the sensor PCB as possible. This was decided upon as the fewer components used then smaller the PCB footprint and the smaller the footprint the cheaper the design and manufacturing will be. This meant that for items like signal conditioning and any other elements of control they were implemented on the main electronic PCB design.

3. Light Shield

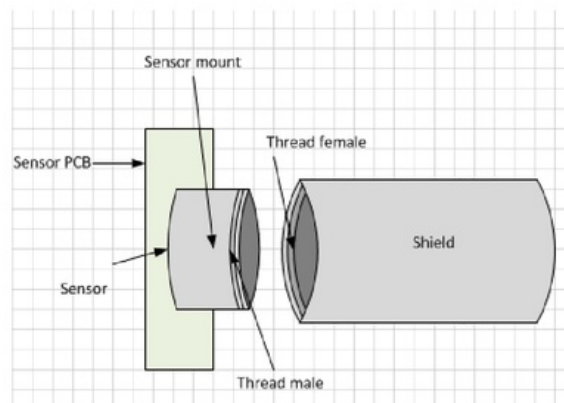


Figure 34 – Sensor Shield

Figure 34 – Sensor Shield was designed using (Microsoft Visio 2013). The idea of the design was to allow a clamp to hold onto the shield keeping it and the sensor still during testing and demonstration purposes of the project.

The problem with that was when the sensor needed to be dismounted for alterations it couldn't without dismantling the clamp and disrupting its position which meant that whenever the sensor was mounted again for testing and calibration purposes it would never be in the exact same position allowing for inaccuracy's to develop. So a design was made to allow for an easy detachable system as demonstrated above without the need to detach the shield. This design resolved issues of inaccuracy of testing, prevented ambient light conditions affecting the sensor, and aids to reduce the risk of laser radiation leaking from the sensor.

4. Calibration Sensor Build

To test the initial design shown in Figure 33 – Concept Schematic a prototype PCB was built in accordance with IPC-610 standards with various test points so that an analysis of data could be performed using national instruments lab view

Figure 35 – Calibration Sensor Build are photos of the build. This is what was used for the calibration tests.

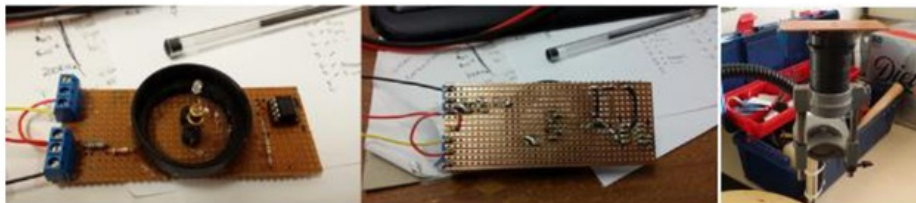


Figure 35 – Calibration Sensor Build

6.2.5. Stage 2 - Distance Sensor Calibration Testing:

National Instruments LABVIEW was used to perform the functional and the calibration analysis tests of the sensor modules Figure 36 – LABVIEW Test Program and Figure 37 – LABVIEW Results Window are the automated test set up that were created and used to log the analogue data output from the sensor module.

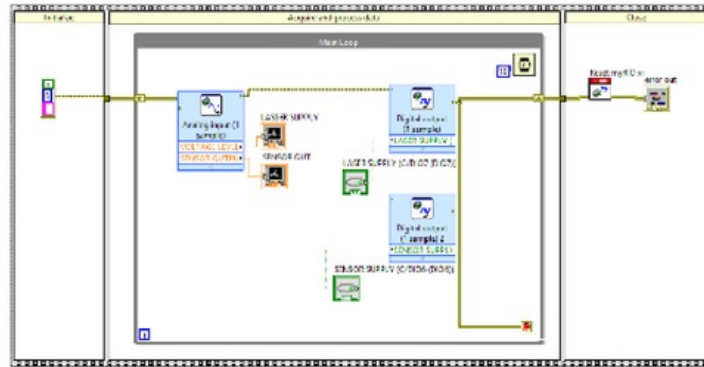


Figure 36 – LABVIEW Test Program



Figure 37 – LABVIEW Results Window

The calibration tests performed were to access the true extent to how much an effect background lighting levels were having on the photo transistor readings. The data was analysed as to identify the best fit calibration for the project, the results from this continue in section 6.2.6 Calibration Analysis.

Figure 38 – Calibration Test Set Up below is of the test set up performed for calibration.

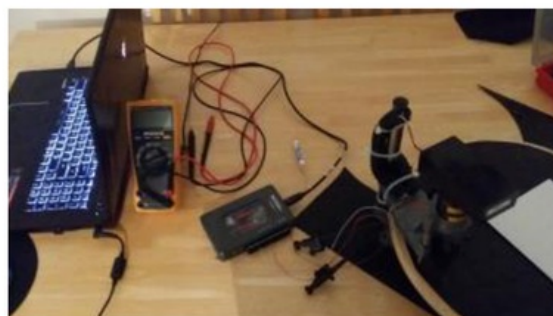


Figure 38 – Calibration Test Set Up

6.2.6. Stage 2 - Calibration Analysis:

1. Testing Set Up

Figure 39 – POC Testing Jig illustrates the testing performed for the calibration tests and the final POC testing performed. As you can see the rotating plate has now got cut out which will alter the depth recorded by the sensor to simulate the passing of a pothole. The purpose of the calibration testing is to determine the output voltages of this testing during different external light levels e.g. night, day, afternoon, as to aid with the main design of any signal condition requirements for the project.

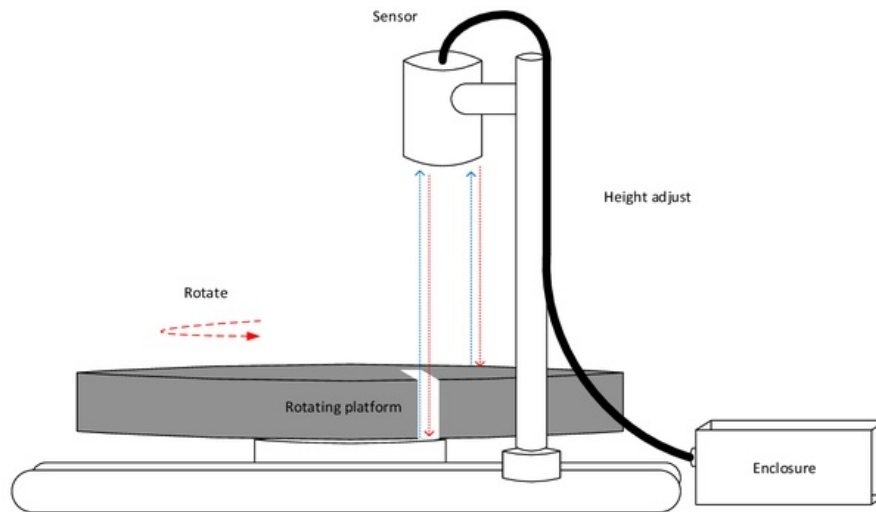


Figure 39 – POC Testing Jig

2. Analysis of Results

The results were stored onto Microsoft excel as show below. Further analysis was performed to attain a reasonable calibration outcome for the sensor shown below. The light level of 120 was performed during normal lighting conditions of an Electronics Lab to simulate the average use of this project. A Samsung note-3 light sensor was used to attain a different light level for testing purposes although a reasonable conversion to Lux sensitivity could not be achieved it was deemed suitable enough for what was required of the calibration tests e.g. (record the difference in light level).

Light Level		Resistance		Voltage Out					
		Photo Tran (KΩ)	Potentio meter (KΩ)	Black (V)			White (V)		
				Mat	Paper	Difference	Mat	Paper	Difference
No light	0	721	100	0.289	0.527	0.238	0.278	1.82	1.542
Night	20	583	100	0.448	0.637	0.189	0.449	1.938	1.489
Night + Moon	40	293	100	0.4	0.67	0.27	0.488	1.986	1.498
Dawn	60	172	100	0.465	0.784	0.319	0.503	2.12	1.617
Mid-day	120	157	100	0.588	0.808	0.22	0.578	2.257	1.679
Direct sunlight	800	109	100	2.31	3.09	0.78	3.08	3.257	0.177
Mid-day	120	157	150	0.798	1.224	0.426	0.823	3.404	2.581

Table 25 – Background Light Calibration

The sensor distance from the target during the calibration testing was performed at 200mm from the target (the simulated road surface (black Mat)) this was to ensure that worst case scenario of full exposure of reflected light could penetrate up towards the sensor.

Future development and testing of the sensor would be performed at a distance of 100mm from the target this decision was made to first limit the risk of reflected laser radiation exposure during university demonstrations, and to allow for easier development and demonstrations to the University for the Proof of concept.

The testing above proved the average resistance value of the photo transistor depending on light radiation was around 157KΩ, a decision to maintain the potentiometer at 150KΩ was decided upon for future functionality tests of the project.

6.2.7. Stage 3 - Final Design:

1. Final Design Schematic

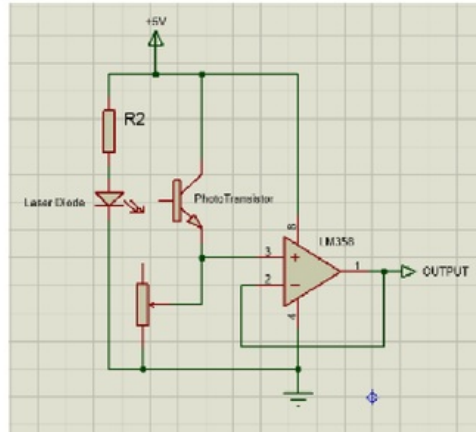


Figure 40 - Final Sensor Design

Figure 40 - Final Sensor Design, is of the final design has incorporated a resistor pot of which was used to control the potential difference of the output of the photo transistor to ground. The value of the resistor pot was determined by the calibration tests performed earlier being 150K Ω .

In affect we are using the photo transistor and the resistor pot as a simple voltage divider circuit referenced to a 5V supply as to ensure the maximum voltage output of 5v could not be exceeded.

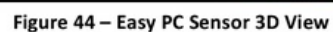
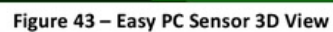
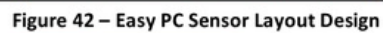
The pot will act like a level shifter for if ambient light affects the sensor output.

The op-amp is working as a voltage follower off of the potential divider circuit taking advantage of the high impedance of the op-amp as to ensure that no voltage or current drain will affect the output of the photo transistor.

The future mounting place of the sensor will be on a vehicles chassis. Further design would be required for the sensors enclosure for chassis mounting purposes and for the most suitable mounting location onto a vehicle which wasn't covered within this project. The design element of the sensor enclosure was only so that it would suitably attach to the testing jig for simulation purposes.

Some design decisions were made in light of some of the most obvious design criteria's. The first decision made was to have as few components on the sensor as possible as to reduce costs, size, and repair times. The second and final decision was to ensure a quick and easy detachable design was included which has been performed.

Easy PC software was used to design and generate a PCB of the desired concept design of the sensor module. The transistors used within the software are to represent the 3 pin laser diode and 3 pin photo transistor used on the sensor. The design is simple and small saving time and money for future manufacturing costs. Due to time constraints of the project the PCB could not be built. For the POC project a decision was made to assemble the sensor design onto VERO board instead of using bread board as that would not be suitable for the mounting requirements of the testing jig.



3. Sensor PL

To calculate the true cost of the sensor PCB a quote as to the cost of the PCB manufacturing was required. A manufacture call Ladyada was used. The dimensions of the PCB created on easy pc was submitted to their website as shown below. The quoted price from the manufacture (minimum order of 100) was £1.32 per unit.

Width (inches)	Length (inches)	Quantity (minimum)	Size (square inches)
1 inches	2 inches	100 PCBs	2 square inches

[Calculate Costs](#)

Prototype PCBs, no soldermask or silkscreen, usually 1-3 day turn.

PCB Manufacturer	# PCBs	Cost Per	Cost	Shipping	Total	Notes
Barebones PCB	100	1.32	132	20	152	Can deduct cost from future production orders

Figure 45 – Sensor PCB Manufacturing

Table 26 is the complete parts list of the sensor design. The prices quoted are per unit, Based on an initial manufacturing of 100.

Sensor Parts Lists					
No.	Part Description	Vendor	Vendor PN	QTY	Price
1	Vero Board	Rapid	34-0500	1	1.32
2	Resistor	Farnell	(Generic Component)	1	0.04
3	POT	Farnell	9355090	1	1.11
4	Photo Transistor	Farnell	1045380	1	0.45
5	Laser Diode	Farnell	1089548	1	9.5
6	LM358 Op-AMP	Farnell	2295980	1	0.36
7	3 Way Connector	EBay	(Generic Component)	1	0.22
Total					£13

Table 26 – Final Sensor PL

4. Final Pictures of Design

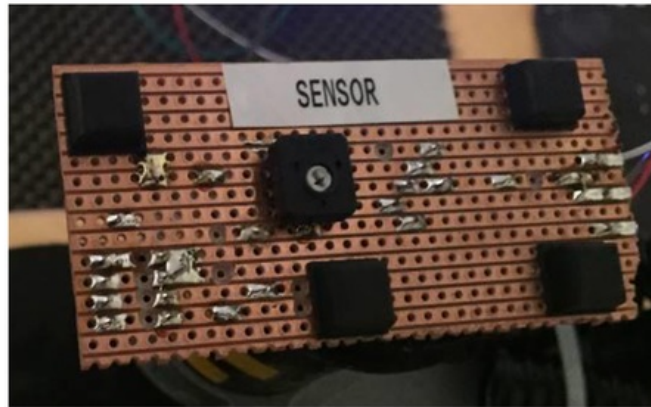


Figure 46 – Final Assembly Top Design

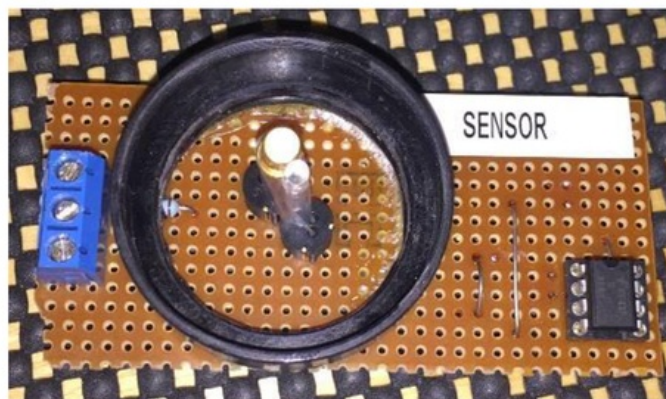


Figure 47 – Final Assembled Bottom Design

There was not enough time to build the designed PCB. So the design was built using Vero Board, this was chosen instead of using bread board as we required a strong structure for the mounting onto the sensor shield.

5. Pothole detection Tests.

The pothole detection tests were performed with the calibration resistor set to 150K Ω . The sensor was mounted as shown in Figure 39 – POC Testing Jig. The first tests were performed at a distance of 300mm, but all tests performed failed, the voltage level differences between a pothole and no pothole was small and too noisy. A decision was made to adjust the distance until a significant voltage level difference could be observed to allow for easy demonstration. A distance of 100mm from the target was tested. The data from this was captured using national instruments LabVIEW and were based upon the calibration data captured above.

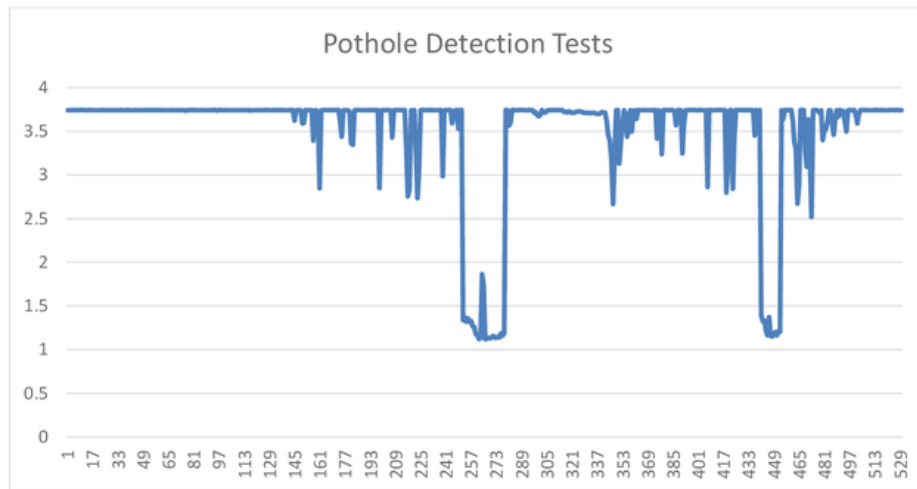


Figure 48 – Pothole Detection Tests

From the analyses of Figure 48 – Pothole Detection Tests, when a pothole passes the sensor it would have a significant voltage drop which we could easily apply a program to trigger at the relevant voltage. From this a decision was made to trigger the pothole detection at <2V, as this is below any noise interference.

6.3. Distance Sensor Design Conclusion:

Challenges presented themselves throughout different stages of the design process of the sensor.

One of the challenges overcome was the use of LABVIEW which was used as a data acquisition tool. This was new territory that had never been performed before which resulted in new skills and abilities having to be learned to undertake the tasks.

It is important to identify that a decision was made to demonstrate the operation of the project to the university based upon a distance of 100mm not a distance of 300mm as the voltage differences between a distance change was very small in fact any noise or light interference may have affected its overall operation as proven within the calibration tests performed above, this would require further investigation and design implementation of which there was not enough time or student budget to implement, which aides to identifying an answer to the hypothesis of the project. Further demonstration of the sensor changing under reflective material was performed which could prove to be a secondary use for the sensor design. It could be used as a lane avoidance system for motor way driving, which will be discussed further in Chapter 16 of the report.

Comparing the outcome of the sensor to the defined objectives previously in section 6.1 we can see that the sensor design was overall a success.

Section	Objective	Essential	Achieved
Sensor	The required rep rate of the Sensor decided was 7 KHz minimum but ideally a rep rate of 32KHz. (Design uses a Photo Transistor which has a total switching steady state speed of 4.3uS (232.56KHz)	Yes	Yes
	Required sensing distance of the sensor: 300mm Could not achieve a distance sensor of 300mm a distance sensor of 150mm was used to demonstrate functionality of system.	Yes	No
	5v Power Supply	No	Yes
	5v Max Output	Yes	Yes
	Low current consumption	No	Yes
	Safe and free from risks	Yes	Yes

Table 27 – Distance Sensor Conclusion

Chapter 7 Investigation – GPS

7.1. GPS Modules:

As discussed throughout the report we require a GPS sensor to record the position of the triggered pothole. The table below concludes the main requirements of the GPS module for the project. Further marker research was performed to find the most suitable sensor for the project.

Section	Objective	Essential
GPS	Low Current Consumption	No
	Accuracy standard 5-10M	Yes
	Frequency >10Hz	Yes
	Power Supply +5V	No
	Price <£50	Yes

Table 28 – GPS Objectives

1. Adafruit Ultimate GPS Module.

The Adafruit Ultimate GPS Module as shown on the right (40), was designed to be used with the arduino system but can be used for others. This module contains a micro SD slot, battery slot and a proto typing area, the extra parts of the system were deemed a possible advantage. The key specification of the module were;

Sensitivity	Update Frequency	Accuracy	Communication	Current	Power supply	Price
-165dBm	10Hz	5-10M	TTL	20mA	+5V	£31.73

Table 29 – Adafruit Ultimate GPS Module Specifications

2. Spark Fun Venus GPS

The spark fun Venus GPS module as shown on the right (41), its main feature is its size which is 10mm x 10mm x 1.3mm. The module does contain a SD card but it can utilize its own internal memory of 75Kb. The size of the module was deemed a possible advantage. The key specifications of the module were;

Sensitivity	Update Frequency	Accuracy	Communication	Current	Power supply	Price
-165dBm	20Hz	5-10M	SPI	90mA	3.3V	£35.26

Table 30 – Spark Fun Venus GPS Specifications

3. Phidgets USB GPS

The Phidgets USB GPS module as shown on the right (42) was found via the supplier robot shop. Its main features were direct USB communication capabilities and that the supplied battery would allow the module to run for 1 month without any external power requirements. This was deemed a possible advantage. The key specifications of the module were;

Sensitivity	Update Frequency	Accuracy	Communication	Current	Power supply	Price
-161dBm	10Hz	5-10M	TTL	50mA	5v	£42.36

Table 31 – Phidgets USB GPS Specifications



Figure 49 - Adafruit GPS Module



Figure 50 – Spark Fun Venus GPS



Figure 51 – Phidgets USB GPS

7.2. GPS Module Testing:

A decision was made to use the Adafruit Ultimate GPS Module. This was chosen as it was the cheapest of the three researched and it has the addition of the SD card which could be used as a form of data storage as part of future developments.

Testing was performed to ensure that the GPS module was working correctly and to identify what the output data was to aid with further research. To test the GPS module an Arduino Kit was used as another form of data acquisition tool this allowed for a direct connect from the GPS module to a PC utilising the USB serial converter on the Arduino Uno PCB. Figure 52 – GPS Module Test (Arduino) below is the output data from the GPS.

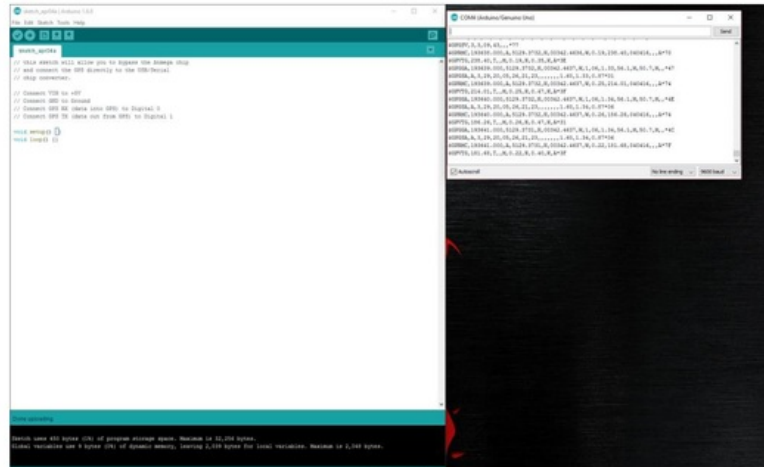


Figure 52 – GPS Module Test (Arduino)

In the first 5 seconds of operation the GPS begins to output data which is invalid as it searched for a GPS satellite. After this the GPS starts to constantly stream location data like the following

```
$GPRMC,193804.000,A,5129.3768,N,00342.4682,W,0.16,356.78,040416,,A*7C
```

This line of data holds all the valuable location data we are interested in.

```
$GPRMC,193804.000,A,5129.3768,N,00342.4682,W,0.16,356.78,040416,,A*7C
```

193804.000 – This is the current GMT of when the data was captured, therefore this was taken at 7:38 pm, 4 seconds and not 0 milliseconds. The output time does not include a conversion of day light savings or time zones so this will have to be worked out manually.

A – This is the status of code of whether the GPS has a satellite fix or not. An A means it has a fix, and a V means it does not have a fix.

5129.3768,N – This is part of the location data, therefore my location from this would be Latitude 51 degrees, 29.3768 decimal minutes North.

00342.4682,W – This is part of the location data, therefore my location from this would be Longitude 3 degrees, 42.4682 decimal minutes West.

The rest of data is disregarded for this project as it is not required but is mainly speed and velocity readings.

To ensure the location data was correct it was typed into Google Maps in the following format

```
+51° 29.3768', -3° 42.4685'
```

The result of which was correct (location address is 15 Glynstell Road, Porthcawl, Bridgend CF36 3NN, South Wales, UK).

7.3. GPS Modules Conclusion:

The testing of the GPS module proofed that it works correctly and as required for the project. Further research into how to transfer and analysis the output data from the GPS was performed in section 8.

Section	Objective	Essential	Achieved
GPS	Low Current Consumption	No	Yes
	Accuracy standard 5-10M	Yes	Yes
	Frequency >10Hz	Yes	Yes
	Power Supply +5V	No	Yes
	Price <£50	Yes	Yes

Table 32 – GPS Objectives Conclusion

Chapter 8 Investigation – Data Transmission

8.1. RS232:

The future design plan for the project is to transfer the GPS data coordinates of the pothole wirelessly to a server of which could upload the data automatically via a python script to a website and then to the local authority. But for this project the transmitted data will be sent to a VT (e.g. Tera Term) via an FTDI lead. As you may have guessed from the GPS module chosen the selected means of transmitting data is RS232 between the GPS to PIC and PIC to (Rs232 converter to TTL) PC.

Data transmission via RS232 was selected firstly as it is one of the easiest and basic transmission protocols to learn according to Bijal Parikh (43)(which is explained why in the next paragraph).

For the data transmission from the GPS to the PIC we are only interested in the data lines, one of which is called the RX which is the receive pin so data flows into it (e.g. like data from another sensor or receiving a command), and the second data line is the TX which is the transmit pin so data flows out of it (e.g. like commands or the GPS data to the PIC). There is no clock used for synchronization, so the RS232 is governed by a standard speed protocol which is the number of bits sent per second also known as baud rate. The GPS module purchased for the project transmits data at a pre-set rate of 9600bps, therefore 1 bit of data is transmitted every 104.2uS (1 second / 9600bps). This was the main reason as to why sending and receiving data via RS232 was chosen as the main interfacing as no other interfacing would be required, making it a lot easier. It was also selected due to the vast popularity between the hobbyist and professionals who have built projects of their own, meaning that there was a lot of information and resources to hand to aid with research and design processes.

When the GPS module does not transmit the TX data line will sit (high) at -12V, and when the device needs to send data it pulls the TX line (low) at +12V for 104.2uS which is a start bit which is 0. It will then transmit each bit of data at a period of 104.2uS after it has completed that line of transmission it will stay (high) for a minimum of 104.2uS to transmit the final data bit of 1 to end the transmission and then continue this sequence depending on when something else is transmitted. For the receive data line it's the inverse of the previous statement. The main difference is that when the data line level changes it activates an internal timer that waits half of the bit rate time so in this instance it would wait 52.1uS this is to prevent noise spikes affecting it and once it has waited it then reads the data value. It then waits the standard speed rate which for this is 104.2uS before it reads again so that it reads half way through the first data bit sent to prevent chopping of data transmission. It performs this until it reads the end bit data.

Several problems were encountered when trying to communicate via RS232 between the GPS and the PIC these have been further analysed and explained during step 2 – Transmission of data from GPS to PIC during the Main design of the project.

Chapter 9 Investigation – Microcontroller

9.1 Microcontroller Selection Criteria:

The following key items were required for the microcontroller to operate for the task in hand.

- Analogue inputs;

1 x IR Photo transistor (diode) Input.

- Digital inputs;

1x Start, 1x Stop, 1 x Laser Diode Control, 1 x LED Alarm, 5 x SPI, and 2 x GPS

- Total Pin Requirements;

1 x Analogue to digital inputs, 11 x Digital inputs, 1 x 5v supply and 1 x GND. Therefore the total minimum pin outs required was 14.

- Program Memory;

An assumption was made as to what the maximum programme size would be for a scenario like this.

Using knowledge gained from previous university modules the assumed size decided upon was 16Kb.

This value should be more than what is required but to ensure that the system does not inherit a negative outcome from an assumption on memory size, then the program memory size specification should be $\geq 16\text{Kb}$.

- Oscillator / Clock Speed;

There is 1 sensor operating at 7 KHz, therefore there was 7,000 readings every second. An overestimation of 50 instructions per reading was decided upon (this figure was used previously in other modules throughout in University) therefore $7,000 * 50 = 350,000$ per second. There are 4 clock pulses per instruction therefore $350,000 * 4 = 1,400,000$ instructions per second. Therefore a minimum clock speed greater than 1,500,000 was required. But a decision to use an overestimated value of 4MHz as the minimum was used (doubling the value was used previously in other university modules).

- AtoD Resolution;

Equation (2dp)
Total possible distance recordable 0 to 300mm. (2dp)
8bit resolution = 256 steps, $301\text{mm} / 256 \text{ steps} = 1.18\text{mm}$
10bit resolution = 1024 steps. $301\text{mm} / 1024 \text{ steps} = 0.29\text{mm}$
12bit resolution = 4096 steps, $301\text{mm} / 4096 \text{ steps} = 0.07\text{mm}$

Equation 4 – A to D Resolution

A decision to use a resolution of 10bit

- Selection Comparison;

The selection was performed using Microchips component selection website the above specification was input into the search criteria. The resulting pic selected was the PIC18F26K22.

9.2 Microcontroller Conclusion:

Minimum Specification	Microchip Specification
X1 Analogue Inputs	Up to 17
X11 Digital Inputs	>11
SPI Capabilities	2 SPI & 2 I2C
X14 Number pins required	28 pin maximum
16Kb programme memory	64Kb programme memory
4Mhz Clock speed	16Mhz Clock Speed
10bit resolution	10bit resolution

Table 33 – Microcontroller Conclusion

The pic decided upon should be more than suitable for the project in hand a lot of the items are way above the specification but this was decided upon as to allow for future developments.

Chapter 10 Investigation – Conclusion

10.1. Conclusion:

In respect of creating a solution to the problem scenario and performing all the research elements required as to aid with the design stages of the project it would have to be deemed a success. But also a failure in that the added complexity and design, testing and assembly work required for solving the problem of the sensor caused a time lapse in the overall planned time scale compared with what was first planned. A decision was made to lose an element of the design stages as to recover this time back, the design and assembly of a PCB was chosen to be withdrawn as the project will still be a success being built on bread board.

Chapter 11 Main Design

11.1. Introduction:

This section of the report is the main design of the system. As part of the design process Thomas created block diagrams, functional flow charts, circuit block diagrams as to aid with the creation of the micro controller program.

11.2. System Block Diagram:

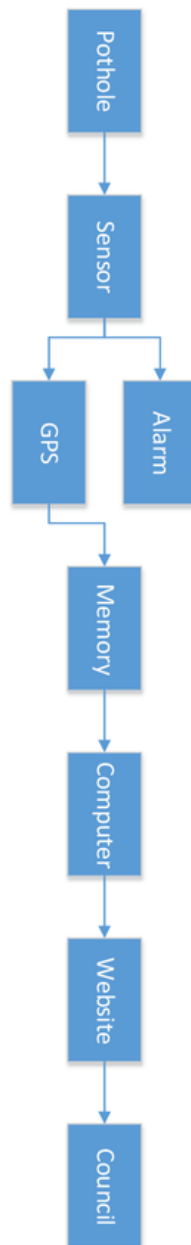


Figure 53 – System Block Diagram

This is the system block diagram of the project. It starts with the pothole which gets detected by the sensor, the sensor then triggers a visual alarm and the GPS module which will transfer and save its location to the memory of the project. The memory of the project can then be manually transferred by the user to a computer of which the data can then be uploaded to the applicable website.

11.3. Circuit Block Diagram:

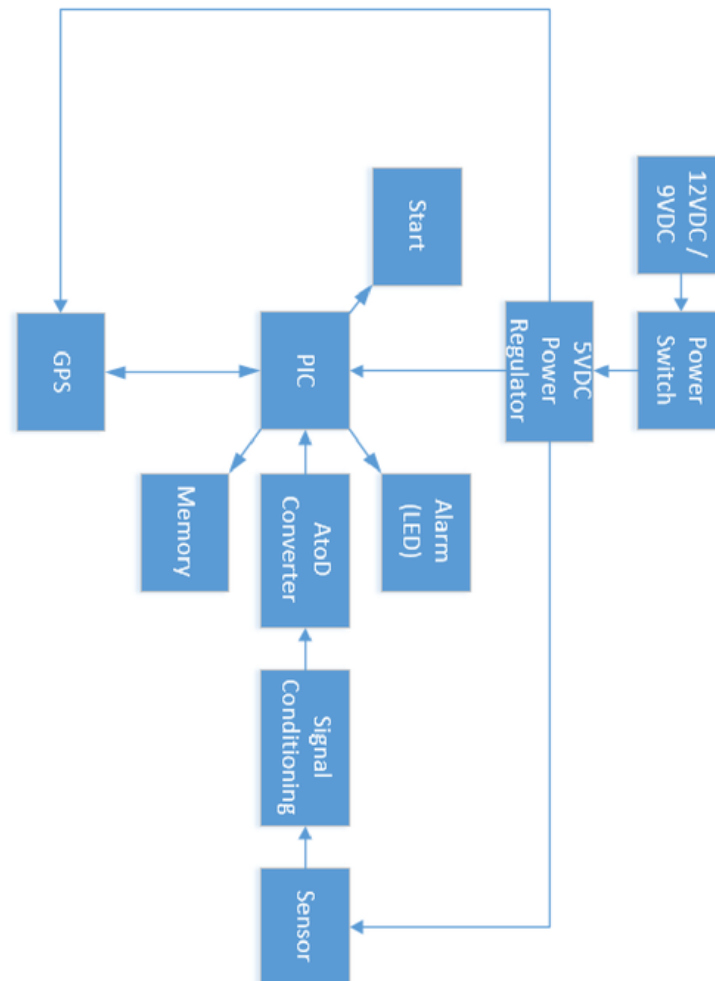


Figure 54 – Circuit Block Diagram

This is the circuit block diagram of the project. As you can see the project will be supplied via a 12VDC supply (to simulate the car battery) and then regulate this to 5VDC. The Pic is to control all the functions of the project design. The block diagram above aided with the schematic design of the project.

11.4. Programming Flow Chart:

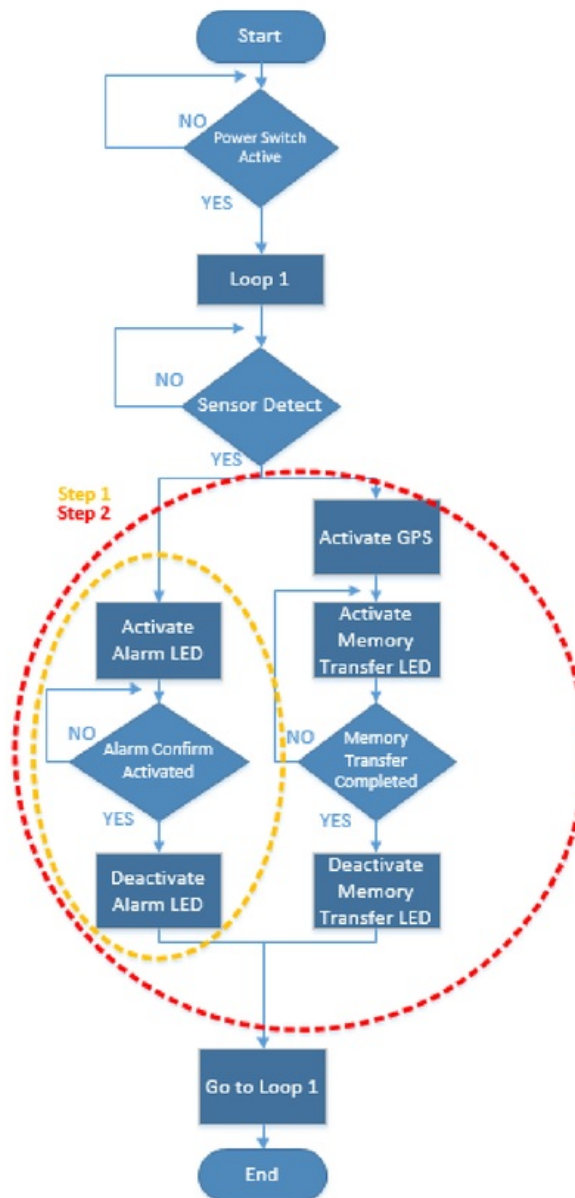


Figure 55 - System Flow Chart

This is the top level programming flow chart of the project. This was used in conjunction with the CCS coding and compiling software to create the C program used to control the PIC of the project. The project was split into 2 different sections to make it easier to design and simulate, the first section was to incorporate the sensor design to trigger the Alarm LED and the second (step 2) to incorporate step 1 and the transfer of GPS data transfer.

11.5. Step 1 – Main C Program:

The C program below was created using the compiler software called CCS which was recommended by the University. CCS project wizard was used to create the initial set up required for the PIC. The rest of the programme was written using knowledge obtained through university and through research. The following code is for step 1 of the main design of the system. All code can be found within the appendix.

```
#include <18F26K22.h>
#device ADC=8

#FUSES PRIMARY           //Primary clock is system clock when scs=00
#FUSES FCMEN              //Fail-safe clock monitor enabled
#FUSES IESO               //Internal External Switch Over mode enabled
#FUSES NOPUT             //No Power Up Timer
#FUSES NOBROWNOUT        //No brownout reset
#FUSES BORV19            //Brownout reset at 1.9V
#FUSES PBDEN             //PORTB pins are configured as analog input channels on RESET
#FUSES CCP3BS            //CCP3 input/output multiplexed with RB5
#FUSES HFOFST            //High Frequency INTRC starts clocking CPU immediately
#FUSES TIMER3BS         //Timer3 Clock In is on pin B5
#FUSES CCP2BS            //CCP2 input/output multiplexed with RB5
#FUSES MCLR              //Master Clear pin enabled
#FUSES STVREN            //Stack full/underflow will cause reset
#FUSES NOLVP             //No low voltage prgming, B3(PIC16) or B5(PIC18) used for I/O
#FUSES NOXINST           //Extended set extension and Indexed Addressing mode disabled (Legacy mode)
#FUSES NOPROTECT         //Code not protected from reading
#FUSES NOCPB            //No Boot Block code protection
#FUSES NOCPD            //No EE protection
#FUSES NOWRT            //Program memory not write protected
#FUSES NOWRTC           //Configuration registers not write protected
#FUSES NOWRTB          //Boot block not write protected
#FUSES NOWRTD          //Data EEPROM not write protected
#FUSES NOEBTR          //Memory not protected from table reads
#FUSES NOEBTRB         //Boot block not protected from table reads

#use delay(internal=4MHz)
#define PIC_ON          PIN_A0
#define PH_DATA          PIN_A1
#define LED_ALARM        PIN_A2
#define GPS_CTRL         PIN_A3
#define PIC_START        PIN_A4
#use rs232(baud=9600,parity=N,xmit=PIN_C6,rcv=PIN_C7,bits=8,stream=PC)
```

Figure 56 – C Program #H File Stage 1

The header file (H file) is used as the define page, it's used as the initial set ups and protocols used by the microchip. Notes have been included within each define to state their use. But the main items of interest in this section are:

The setup of the ADC port to 8bit. A higher bit rate would not be required for the purposes of a project such as this e.g. we are looking at a rapid depth change of 40mm.

The setup of the internal oscillator to 4MHz as 16MHz (the maximum) would not be required. This decision was made to save battery.

The use of RS232 set to a baud rate of 9600, with a stream name of PC, this was used to send the analogue value of the sensor to the PC to aid with debugging and testing.

```

#use rs232(baud=9600,parity=N,xmit=PIN_C6,rcv=PIN_C7,bits=8,stream=DATA)
#use delay(internal=4Mhz)
void main()
{
    setup_adc_ports(sAM1); //ADC Port Setup
    setup_adc(ADC_CLOCK_INTERNAL|ADC_TAD_MUL_0); //ADC Port Setup
    unsigned int8 value; //value Setup
    int1 start; //value setup
    unsigned int8 count; //value setup
    int8 flag1; //value setup
    set_adc_channel(1); //ADC Port Set to channel 1
    delay_ms(500); //Adds a delay to the initial set ups
    printf("PoTHole_Capture_Project\r\n"); //Name of Project
    printf("Thomas_Rees\r\n"); //Name of Author
    printf("Firmware_Version_1\r\n"); //Firmware Version
    printf("Loading.....\r\n"); //Confirms a Main Programm Delay for Settings to load
    delay_ms(100); //Adds a delay to the initial set ups
    printf("Press_Start_to_begin\r\n"); //Main Programm Ready
    while (true)
    {
        start = input_state(PIN_A4); //start value is equal to PIC_Start input pin
        if (start==0) //If start button pressed
        {
            delay_ms(100); //Debounce delay
            if (start==0) //If start button still pressed
            {
                flag1++; //Increase flag 1 by 1
                if (flag1>10) //If flag 1 is greater than 10
                {
                    flag1=100; //Set flag 1 to 100
                }
                if (flag1~100) //If flag 1 is equal to or greater than 100
                {
                    printf("Start_Button_Pressed\r\n"); //Sends start button has been pressed
                    delay_ms(500); //Delay of 500 before setting flag 1 to new setting
                    flag1=200; //Set flag 1 to 200
                }
            }
        }
    }

    while (flag1~200) //Performs command when flag 1 is equal to or greater than 200
    {
        output_low(PIC_ON); //Puts PIC ON LED ON
        value = read_adc(ADC_START_AND_READ); //Sets value to read ADC input of pic
        count = value/5; //Math function to scale value
        count*= 2; //Math function to scale value, scaled 0 to 100 and stored to count
        printf("count=%X\n\r",count); //Sends the data from value to the virtual terminal
        if (count<40) //Sets trigger point of LED_ALARM
        {
            output_low(LED_ALARM); //Sets output low if Less than preset value
            output_low(GPS_CTRL); //Sets output low if less than preset value
        }
        else //Sets on else statement to operate with the if statement
        {
            output_high(LED_ALARM); //Sets output high if higher than preset value
            output_high(GPS_CTRL); //Sets output high if higher than preset value
        }
    }
}

```

Figure 57 – C Program #C File Stage 1

The C file is the main control file of the program.

- We started with setting up the ADC Port on AN1 and channel 1 and for the ADC to operate of the pics internal clock.
- Value, Count and Flag1 were set to an unsigned (meaning positive value) int8 as the analogue bit value was 8 so there would be no need to count passed 255.
- Start was set to int1 there is no signage required for this as the value can only be 0 to 1.
- After Set ups a delay of 1 second was decided as to allow code to settle.

The rest of the program has notes depicting what each line is performing. The main function of the program above is to first set up all the values of the counters required and to confirm to the user what he is expected to do e.g. press start button, the program is designed to wait for the start button to be pressed in the future this command could be changed to a speed detection of the car to auto start the system. Once the start button has been pressed the relevant counters are set so that the main program can run and trigger when a pothole is detected.

11.7. Step 1 – Main Schematic Design:

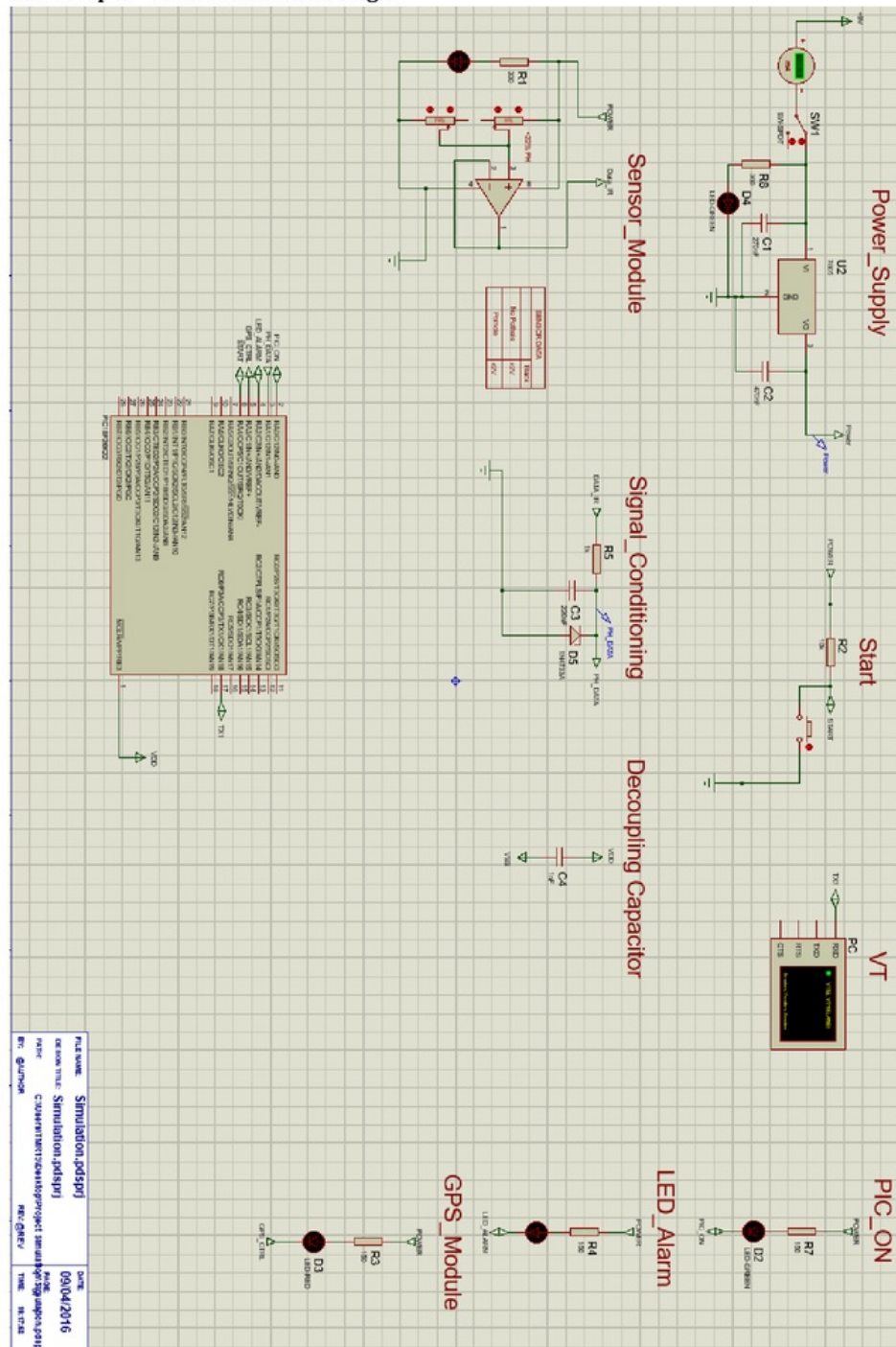


Figure 58 – Schematic Design Stage 1

11.8. Step 1 – Main Description:

Step 1 was the pothole detection design programme without any location data.

The initial design was to include a 5VDC power supply from a 9VDC battery as to demonstrate to the university. To alert the user that the 9VDC battery is connected a green power led is included.

All LED used:

Power LED Green ($9V - 2.2V = 6.8V / 360\Omega = 18.8mA$)

PIC ON LED Green ($5V - 2.2V = 2.8V / 150\Omega = 18.6mA$)

PIC Alarm LED Red ($5V - 2.2V = 2.8V / 150\Omega = 18.6mA$)

PIC GPS LED Red ($5V - 2.2V = 2.8V / 150\Omega = 18.6mA$)

The battery will be electrically isolated from the circuit via a switch. The 9VDC will be converted to 5VDC via a 7805 voltage regulator. Which also includes smoothing capacitors to aid with the prevention of voltage spikes. The 5VDC supply's the all sections of the design.

The start programme of the circuit is controlled by maintaining a high status on PIN_A4, until the switch is pressed which takes PIN_A4 to a low status. A resistive load of 10K was used between the 5VDC and the switch as to prevent a short circuit between ground and 5VDC once the switch is pressed.

The sensor was designed as above.

The signal condition of circuit consisted of a 1K resistor and 5.1V Zener diode so that any voltage higher than that would be dumped to ground as to protect the microcontroller from over voltage spikes.

A smoothing capacitor is in parallel with the Zener load resistor which aides with the prevention of any noise.

Decoupling caps have been used to smooth the supply between VDD and VSS and reduce any noise induced to the system.

11.9. Step 1 Simulation Tests:

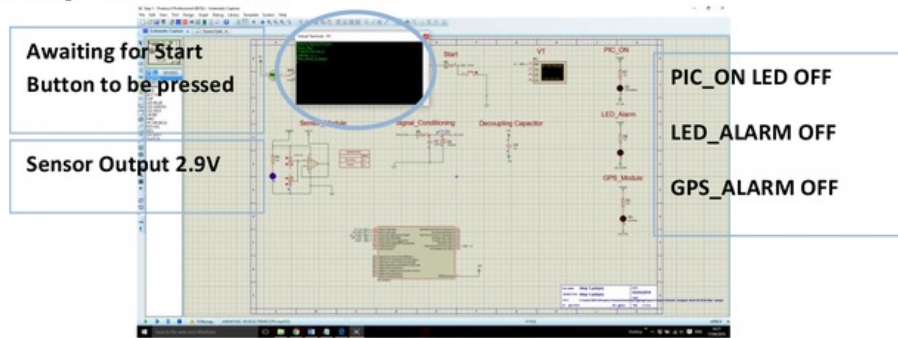


Figure 59 – Schematic Simulation 1

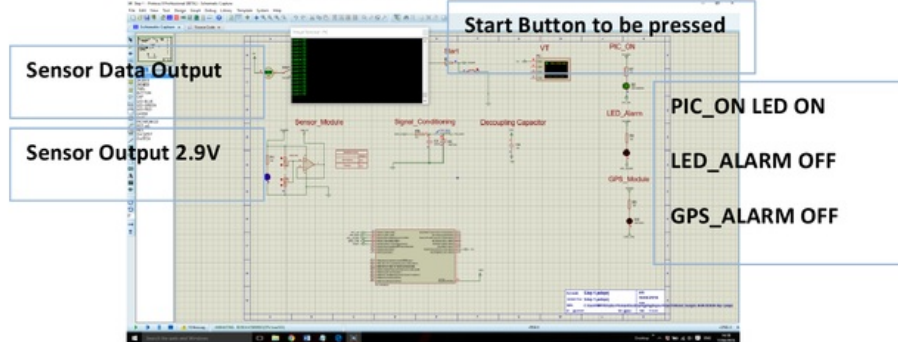


Figure 60 – Schematic Simulation 2

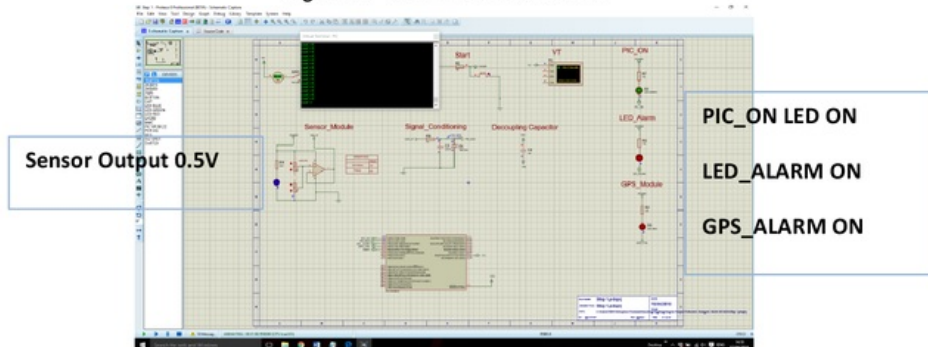


Figure 61 – Schematic Simulation 3

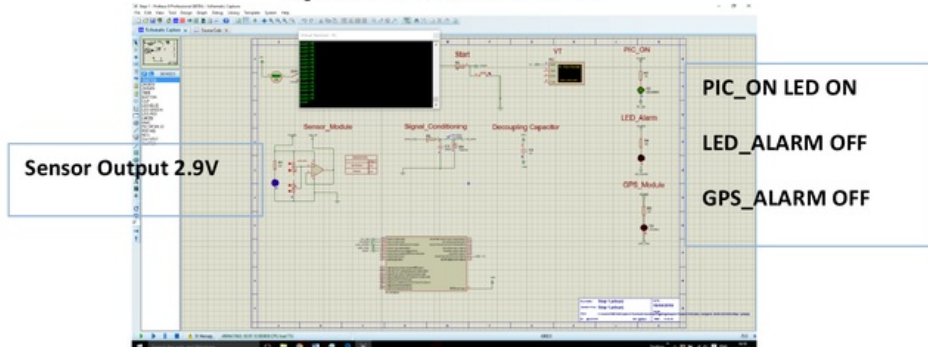


Figure 62 – Schematic Simulation

11.10. Step 2 –Transmission of data from GPS to PIC:

Step 2 contains all the design, simulation and fault analyses implemented as part of the development for the transmission and receiving of the data from the GPS module and the parsing of this to the PC on command via a TTL converter. Various codes and simulations were performed during the development of step 2 these are as follows.

1. The first attempt of receiving data from the GPS module was by using the command fgetc and fputc.

- 'fgetc' returns a character from a specified stream,
- 'fputc' writes a character to the specified stream.

This code was tested using Proteus as shown in Figure 63 – Test 1 Code and Figure 64 – Test 1 Simulation (Character Transfer).

```
1 #include <main.h>
2 #use rs232 (baud=9600,parity=N,xmit=PIN_C6,rcv=PIN_C7,bits=8,stream=data)
3 #use delay(internal=4MHz)
4
5
6 void main ()
7 {
8     int a;
9
10    while (true)
11    {
12        a=fgetc(data);
13        fputc(a);
14    }
15 }
```

Figure 63 – Test 1 Code (Character Transfer)

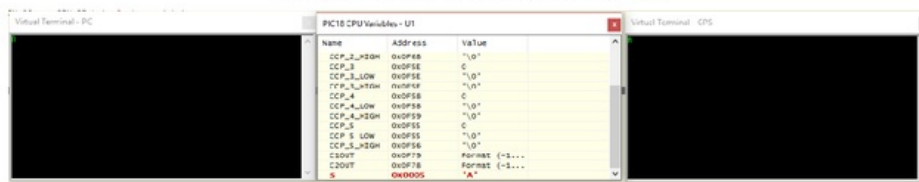


Figure 64 – Test 1 Simulation (Character Transfer)

The data character **A** was returned from the stream and moved to the specified location as shown in the image above (in red). Then it was sent out to the Virtual terminal. The command line waits for the character to be received before it moves onto the next command. The next test was to transmit the GPS data through this command.

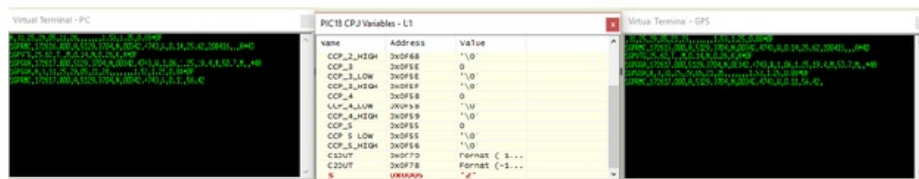


Figure 65 – Test 1 Simulation (GPS Transfer)

This was then tested using real data from the GPS module. Figure 65 – Test 1 Simulation (GPS Transfer) operated in the same manner as Figure 64 – Test 1 Simulation (Character Transfer). The next stage of testing was performed to include a simple start switch to see simulate the activation of the circuit for when a pothole is detected to ensure correct functionality. The code for this can be found in Figure 66 – Test 1 Code (Switched GPS Transfer).

Figure 66 – Test 1 Code (Switched GPS Transfer)

The screenshot displays a Proteus simulation environment. On the left, a circuit diagram is shown with a 5V power source connected to a 10k resistor (R2). R2 is connected to a switch labeled 'START'. The other side of the switch is connected to a 300 resistor (R1), which is then connected to a green LED (D1). The LED's other terminal is connected to ground. A red box highlights the LED and its label 'D1 LED-GREEN'. Below the circuit, a list of components and their values is shown, including 'R1C1:20K', 'R1C2:10K', 'R1C3:10K', 'R1C4:10K', 'R1C5:10K', 'R1C6:10K', 'R1C7:10K', 'R1C8:10K', 'R1C9:10K', 'R1C10:10K', 'R1C11:10K', 'R1C12:10K', 'R1C13:10K', 'R1C14:10K', 'R1C15:10K', 'R1C16:10K', 'R1C17:10K', 'R1C18:10K', 'R1C19:10K', 'R1C20:10K', 'R1C21:10K', 'R1C22:10K', 'R1C23:10K', 'R1C24:10K', 'R1C25:10K', 'R1C26:10K', 'R1C27:10K', 'R1C28:10K', 'R1C29:10K', 'R1C30:10K', 'R1C31:10K', 'R1C32:10K', 'R1C33:10K', 'R1C34:10K', 'R1C35:10K', 'R1C36:10K', 'R1C37:10K', 'R1C38:10K', 'R1C39:10K', 'R1C40:10K', 'R1C41:10K', 'R1C42:10K', 'R1C43:10K', 'R1C44:10K', 'R1C45:10K', 'R1C46:10K', 'R1C47:10K', 'R1C48:10K', 'R1C49:10K', 'R1C50:10K', 'R1C51:10K', 'R1C52:10K', 'R1C53:10K', 'R1C54:10K', 'R1C55:10K', 'R1C56:10K', 'R1C57:10K', 'R1C58:10K', 'R1C59:10K', 'R1C60:10K', 'R1C61:10K', 'R1C62:10K', 'R1C63:10K', 'R1C64:10K', 'R1C65:10K', 'R1C66:10K', 'R1C67:10K', 'R1C68:10K', 'R1C69:10K', 'R1C70:10K', 'R1C71:10K', 'R1C72:10K', 'R1C73:10K', 'R1C74:10K', 'R1C75:10K', 'R1C76:10K', 'R1C77:10K', 'R1C78:10K', 'R1C79:10K', 'R1C80:10K', 'R1C81:10K', 'R1C82:10K', 'R1C83:10K', 'R1C84:10K', 'R1C85:10K', 'R1C86:10K', 'R1C87:10K', 'R1C88:10K', 'R1C89:10K', 'R1C90:10K', 'R1C91:10K', 'R1C92:10K', 'R1C93:10K', 'R1C94:10K', 'R1C95:10K', 'R1C96:10K', 'R1C97:10K', 'R1C98:10K', 'R1C99:10K', 'R1C100:10K', 'R1C101:10K', 'R1C102:10K', 'R1C103:10K', 'R1C104:10K', 'R1C105:10K', 'R1C106:10K', 'R1C107:10K', 'R1C108:10K', 'R1C109:10K', 'R1C110:10K', 'R1C111:10K', 'R1C112:10K', 'R1C113:10K', 'R1C114:10K', 'R1C115:10K', 'R1C116:10K', 'R1C117:10K', 'R1C118:10K', 'R1C119:10K', 'R1C120:10K', 'R1C121:10K', 'R1C122:10K', 'R1C123:10K', 'R1C124:10K', 'R1C125:10K', 'R1C126:10K', 'R1C127:10K', 'R1C128:10K', 'R1C129:10K', 'R1C130:10K', 'R1C131:10K', 'R1C132:10K', 'R1C133:10K', 'R1C134:10K', 'R1C135:10K', 'R1C136:10K', 'R1C137:10K', 'R1C138:10K', 'R1C139:10K', 'R1C140:10K', 'R1C141:10K', 'R1C142:10K', 'R1C143:10K', 'R1C144:10K', 'R1C145:10K', 'R1C146:10K', 'R1C147:10K', 'R1C148:10K', 'R1C149:10K', 'R1C150:10K', 'R1C151:10K', 'R1C152:10K', 'R1C153:10K', 'R1C154:10K', 'R1C155:10K', 'R1C156:10K', 'R1C157:10K', 'R1C158:10K', 'R1C159:10K', 'R1C160:10K', 'R1C161:10K', 'R1C162:10K', 'R1C163:10K', 'R1C164:10K', 'R1C165:10K', 'R1C166:10K', 'R1C167:10K', 'R1C168:10K', 'R1C169:10K', 'R1C170:10K', 'R1C171:10K', 'R1C172:10K', 'R1C173:10K', 'R1C174:10K', 'R1C175:10K', 'R1C176:10K', 'R1C177:10K', 'R1C178:10K', 'R1C179:10K', 'R1C180:10K', 'R1C181:10K', 'R1C182:10K', 'R1C183:10K', 'R1C184:10K', 'R1C185:10K', 'R1C186:10K', 'R1C187:10K', 'R1C188:10K', 'R1C189:10K', 'R1C190:10K', 'R1C191:10K', 'R1C192:10K', 'R1C193:10K', 'R1C194:10K', 'R1C195:10K', 'R1C196:10K', 'R1C197:10K', 'R1C198:10K', 'R1C199:10K', 'R1C200:10K', 'R1C201:10K', 'R1C202:10K', 'R1C203:10K', 'R1C204:10K', 'R1C205:10K', 'R1C206:10K', 'R1C207:10K', 'R1C208:10K', 'R1C209:10K', 'R1C210:10K', 'R1C211:10K', 'R1C212:10K', 'R1C213:10K', 'R1C214:10K', 'R1C215:10K', 'R1C216:10K', 'R1C217:10K', 'R1C218:10K', 'R1C219:10K', 'R1C220:10K', 'R1C221:10K', 'R1C222:10K', 'R1C223:10K', 'R1C224:10K', 'R1C225:10K', 'R1C226:10K', 'R1C227:10K', 'R1C228:10K', 'R1C229:10K', 'R1C230:10K', 'R1C231:10K', 'R1C232:10K', 'R1C233:10K', 'R1C234:10K', 'R1C235:10K', 'R1C236:10K', 'R1C237:10K', 'R1C238:10K', 'R1C239:10K', 'R1C240:10K', 'R1C241:10K', 'R1C242:10K', 'R1C243:10K', 'R1C244:10K', 'R1C245:10K', 'R1C246:10K', 'R1C247:10K', 'R1C248:10K', 'R1C249:10K', 'R1C250:10K', 'R1C251:10K', 'R1C252:10K', 'R1C253:10K', 'R1C254:10K', 'R1C255:10K', 'R1C256:10K', 'R1C257:10K', 'R1C258:10K', 'R1C259:10K', 'R1C260:10K', 'R1C261:10K', 'R1C262:10K', 'R1C263:10K', 'R1C264:10K', 'R1C265:10K', 'R1C266:10K', 'R1C267:10K', 'R1C268:10K', 'R1C269:10K', 'R1C270:10K', 'R1C271:10K', 'R1C272:10K', 'R1C273:10K', 'R1C274:10K', 'R1C275:10K', 'R1C276:10K', 'R1C277:10K', 'R1C278:10K', 'R1C279:10K', 'R1C280:10K', 'R1C281:10K', 'R1C282:10K', 'R1C283:10K', 'R1C284:10K', 'R1C285:10K', 'R1C286:10K', 'R1C287:10K', 'R1C288:10K', 'R1C289:10K', 'R1C290:10K', 'R1C291:10K', 'R1C292:10K', 'R1C293:10K', 'R1C294:10K', 'R1C295:10K', 'R1C296:10K', 'R1C297:10K', 'R1C298:10K', 'R1C299:10K', 'R1C300:10K', 'R1C301:10K', 'R1C302:10K', 'R1C303:10K', 'R1C304:10K', 'R1C305:10K', 'R1C306:10K', 'R1C307:10K', 'R1C308:10K', 'R1C309:10K', 'R1C310:10K', 'R1C311:10K', 'R1C312:10K', 'R1C313:10K', 'R1C314:10K', 'R1C315:10K', 'R1C316:10K', 'R1C317:10K', 'R1C318:10K', 'R1C319:10K', 'R1C320:10K', 'R1C321:10K', 'R1C322:10K', 'R1C323:10K', 'R1C324:10K', 'R1C325:10K', 'R1C326:10K', 'R1C327:10K', 'R1C328:10K', 'R1C329:10K', 'R1C330:10K', 'R1C331:10K', 'R1C332:10K', 'R1C333:

Figure 67 – Test 1 Simulation (Switched GPS Transfer)

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2. The initial design plan was to use a simple get and put command but after performing simulations we proved that this was not suitable. Therefore a new design plan was created. This was to include the ability to store the data in a sub routine (buffer) and call it when required. To perform this extensive research and experiments were performed the end result of which is as follows. A following code was written to operate as desired.

```
#include <main.h>
#define GPS_RX_PIN_C7
#define PC_TX_PIN_C6
//use rs232(baud=9600,rcv=GPS_RX,stream=GPS)
//use rs232(baud=9600,xmit=PC_TX,stream=PC)
//use delay(internal=4096)
char c;
INT buffer_index;
boolean found;
CHAR GPRMC[60];
void parse ();
void main ()
{
    while (true)
    {
        int start1;
        int flag1;
        start1 = input_state(PIN_A4);
        if (start1==0)
        {
            delay_ms(10);
            if (start1==0)
            {
                flag1++;
                if (flag1>10)
                {
                    flag1=100;
                }
            }
            if (flag1>=100)
            {
                printf("Start_Button_Pressed\n");
                output_low(LED);
                break;
            }
        }
    }
}
```

//Sends GPS Characters to this location
//Interrupt called buffer_index (keeps track of the position in buffer)
//Flag to determine if a GPRMC statment is found
//Main buffer to hold the data to parse to PC

//Sends start1 value to this location
//Sends flag1 value to this location
//Start value is equal to PIC_Start input pin
//If start1 is equal to 0
//Debounce delay
//If start1 is still equal to 0
//Increase flag1 by 1
//If flag1 is greater than 10
//Sets flag1 value to 100
//If flag1 is greater than or equal to 100
//Confirm that start button has been pressed
//Output main LED to ON
//Leaves loop programe

Figure 68 – #C File Step 2 Design Intro

Figure 68 – #C File Step 2 Design is the initial set up of the programme created it includes the necessary define commands and the interrupts used throughout the programme. To begin it follows the same standard path as used in step 1 design performed above of where the start button must be pressed, except when this happens it breaks the first while loop allowing the programme to continue to the next section loop (it also turns the PIC_ON LED to ON).

```
while (true)
{
    setup_adc_ports(sANI1);
    setup_adc(ADC_CLOCK_INTERNAL|ADC_TAD_MUX_0);
    unsigned int8 value;
    unsigned int8 count;
    set_adc_channel(1);
    delay_us(100);
    int b;
    int A;
    value = read_adc(ADC_START_AND_READ);
    count = value/5;
    count*= 2;
    printf("count=>%u\n\n",count);
    if (count<40)
    {
        output_low(LED_ALARM);
        output_low(GPS_CTRL);
        parse();
        fprintf(PC, "$Pothole_Location_Data = ");
        for(b=0;b<60;b++)
        {
            fprintf(PC, "%c",GPRMC[b]);
        }
        fprintf(PC, "\n\n");
        delay_ms(1000);
    }
    else
    {
        output_high(LED_ALARM);
        output_high(GPS_CTRL);
    }
}
```

//ADC Port Setup
//ADC Port Setup
//value Setup
//value Setup
//ADC Port Set to channel 1
//Adds a delay to the initial set ups
//sends b value to this location
//send A value to this location
//Sets value to read ADC input of pic
//Math function to scale value
//Math function to scale value, scaled 0 to 100 and stored to count*/
//Sends the IR sensor value
//If the sensor value count is less than 40
//Output LED Alarm to ON
//Output GPS CTRL to ON
//Brings data from parse loop
//Starts data with pothole location:
//loops through data for a value
//Sends the GPS data to the PC
//prints a new line to keep data output clean
//Delay of GPS printing to prevent line interference
//If IR value greater than 40
//Sets LED ALARM OFF
//Sets GPS CTRL OFF

Figure 69 - #C File Step 2 Design Main Control

Figure 69 - #C File Step 2 Design Main Control, contains the main control commands and functions for the design, here it holds a lot of the same information as in step 1 but to include the memory variables of the GPS routines and call parse function which is to load the GPS control of the programme.

```

void parse()
{
    buffer_index=0;
    found=false;
    c=fgetc(GPS);
    while(!found)
    {
        while (c != '$')
        {
            c = fgetc (GPS);
        }
        c = fgetc (GPS);
        if(c == 'G')
        {
            c = fgetc (GPS);
            if(c == 'P')
            {
                c = fgetc(GPS);
                if(c == 'R')
                {
                    c = fgetc(GPS);
                    if(c == 'M');
                    {
                        c = fgetc(GPS);
                        if(c == 'C')
                        {
                            c = fgetc(GPS);
                            found=true;
                            while(c != '$')
                            {
                                c = fgetc(GPS);
                                GPBMC[buffer_index]=c;
                                buffer_index++;
                            }
                        }
                    }
                }
            }
        }
    }
}

```

//Parse function loop
//TX buffer
//flag setting
//grabs character from GPS
//Found flag set
//Waits for '\$' before starting loop
//grabs character from GPS
//grabs character from GPS
//Waits for 'G'
//grabs character from GPS
//Waits for 'P'
//grabs character from GPS
//Waits for 'R'
//grabs character from GPS
//Waits for 'M'
//grabs character from GPS
//Waits for 'C'
//grabs character from GPS
//found flag set to true
//when c is not equal to the '\$'
//grabs character from GPS
//Sends to C
//Increment buffer index by 1

Figure 70 - #C File Step 2 GPS Data Filter & Control

Figure 70 - #C File Step 2 GPS Data Filter & Control, is to control the GPS data output and to move data to the buffer index on command or parse it through to the data line. One problem noticed with the GPS is that it sends you all data of which the majority of it means and adds nothing to the project and makes the data capture looks messy, this was overcome by including an If array which is operated by the fgetc character grab. Meaning that before any data is stored to the buffer it must begin with \$GPRMC which as discovered in chapter 7 of the report is the main data script for the location data we require. A simulation of Proteus was perform to ensure the programme operated as desired.

11.11. Step 2 Simulation Tests:

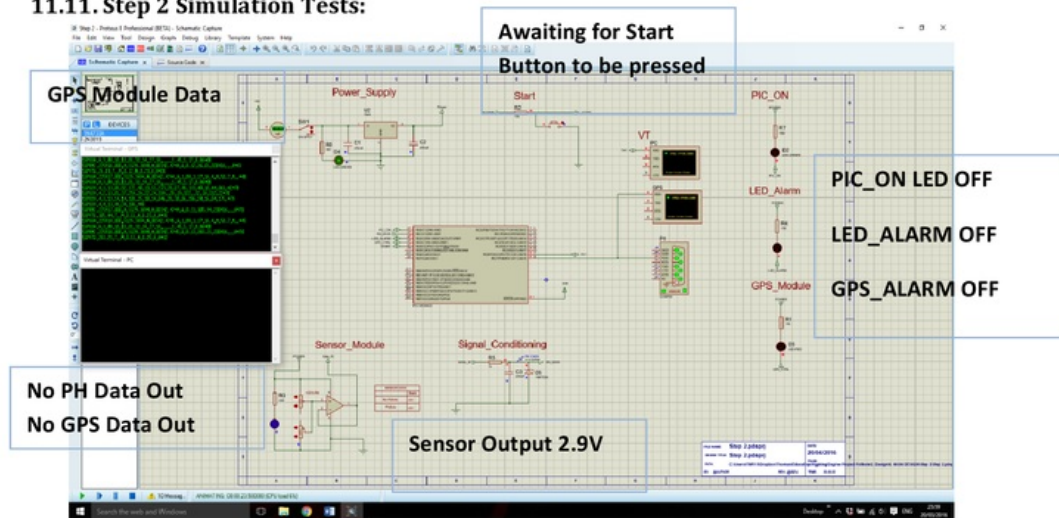


Figure 71 – Test 2 Simulation, #1

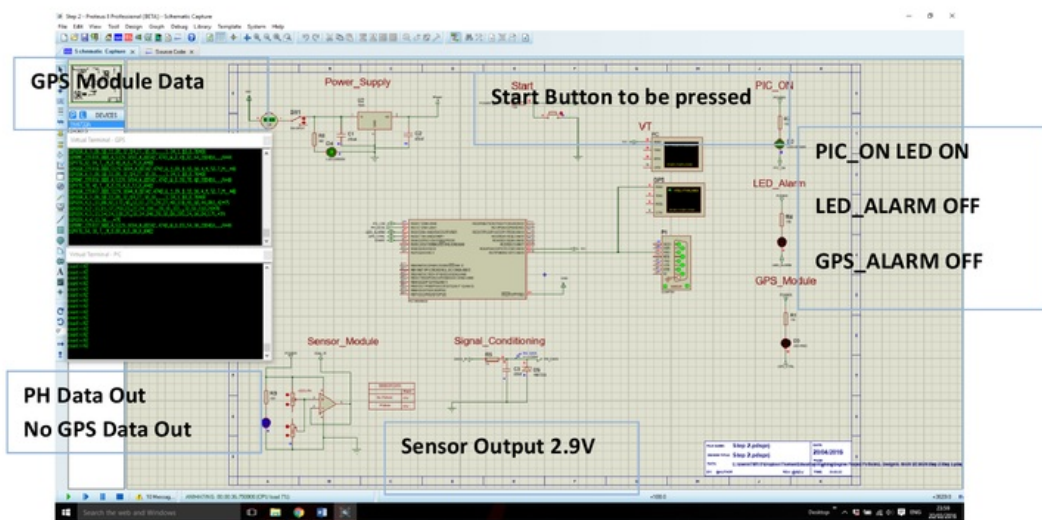


Figure 72 – Test 2 Simulation, #2

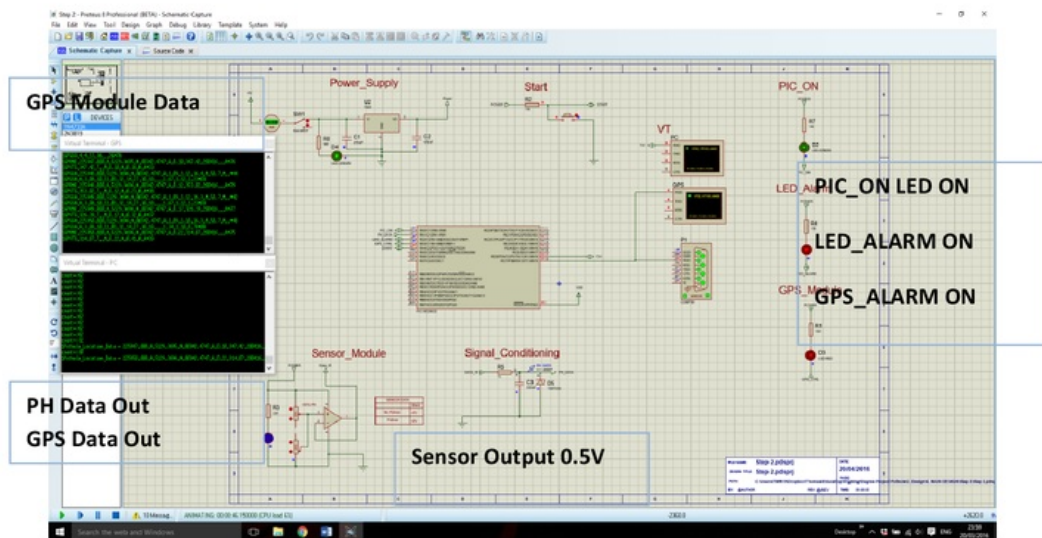


Figure 73 – Test Simulation, #3

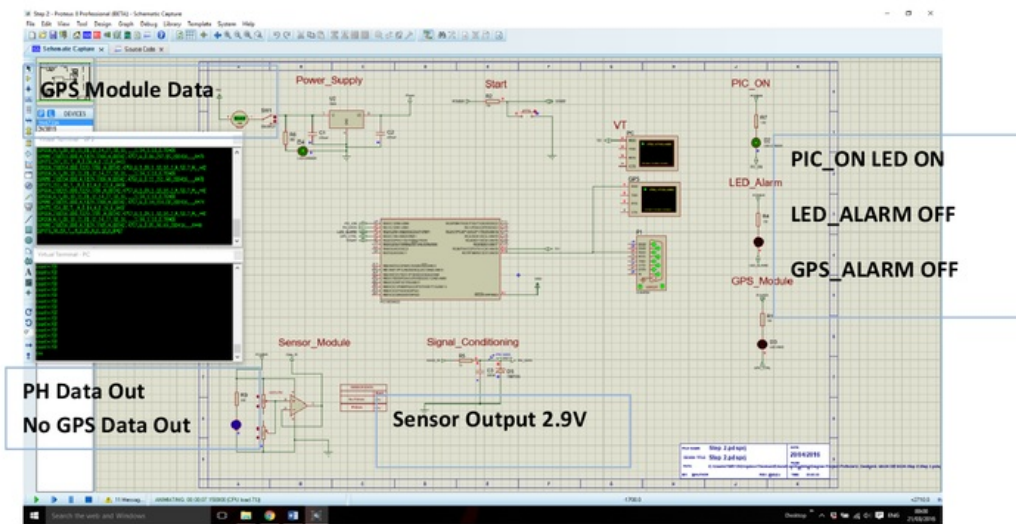
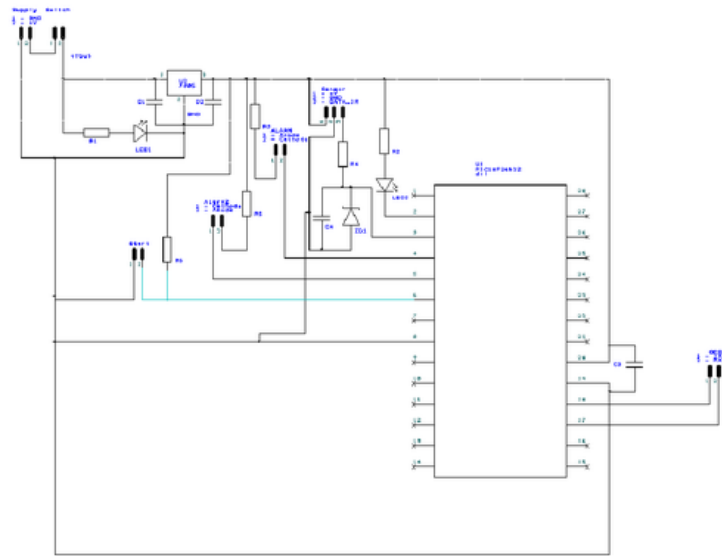


Figure 74 – Test Simulation, #4

Easy PC software was used to design and generate a PCB of the main module. Due to time constraints of the project this was never created but built using breadboard.



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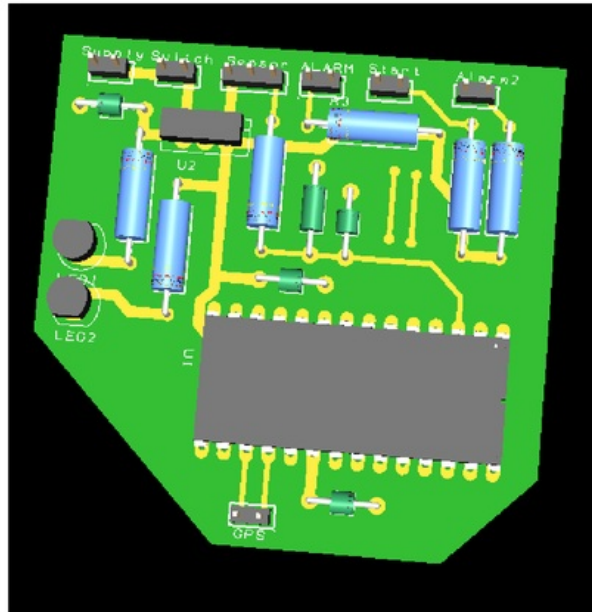


Figure 77 – Easy PC 3D Image Top

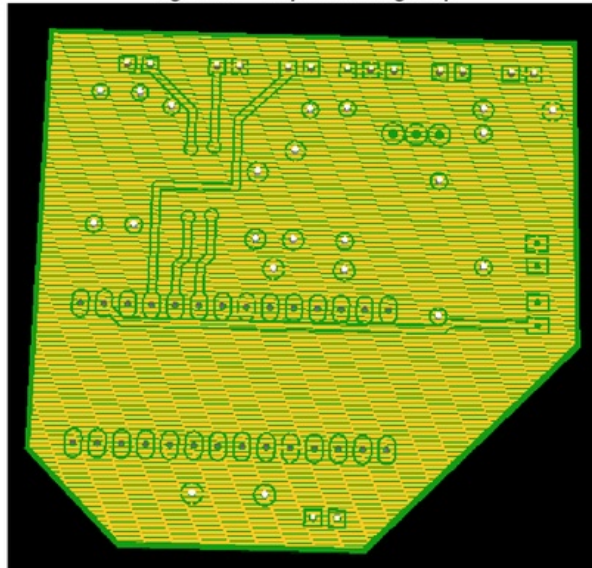


Figure 78 – Easy PC 3D Image Bottom

11.14. Component PL:

To calculate the true cost of the main design of the sensor a quote as to the cost of the PCB manufacturing was required. A manufacture call Ladyada was used. The dimensions of the PCB created on easy pc was submitted to their website as shown below. The quoted price from the manufacture (minimum order of 100) was £2.95 per unit.

Width (inches)	Length (inches)	Quantity (minimum)	Size (square inches)
2.25 inches	2.5 inches	100 PCBs	5.625 square inches

[Calculate Costs](#)

Prototype PCBs, no soldermask or silkscreen, usually 1-3 day turn.

PCB Manufacturer	# PCBs	Cost Per	Cost	Shipping	Total	Notes
Barebones PCB	100	2.95125	295.125	20	315.125	Can deduct cost from future production orders

Figure 79 – PCB Manufacturing Quote

Table 34 is the complete parts lists of the main design of the system

Sensor Parts Lists					
No.	Part Description	Vendor	Vendor PN	QTY	Price
1	PCB	Ladyada	/	1	2.95
2	Resistor	Farnell	(Generic Component)	6	0.16
3	Capacitor	Farnell	(Generic Component)	4	0.60
4	Switch	Farnell	2468742	1	0.0173
5	Power switch	Farnell	1203338	1	1.34
6	LED Bezel	Farnell	1217238	3	1.23
7	LED	Farnell	(Generic Component)	4	0.584
8	7805	Farnell	1469096	1	1.59
8	2 Way Connector	EBay	(Generic Component)	6	1.32
9	3 Way Connector	EBay	(Generic Component)	1	0.22
10	Crimps	Farnell	(Generic Component)	30	1.00
11	Crimp Housing	Farnell	(Generic Component)	14	2.00
12	Enclosure	Farnell	301449	1	1.67
13	Wires	Farnell	(Generic Component)	/	2.00
Total					£16.6813

Table 34 – Main Design PL

Chapter 12 Risk Assessment

To ensure all safe working practices was adhered to throughout all assembly, testing and design tasks of the project, a risk assessment was created.

Severity Probability	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (1)	2	3	4	5
Probable (2)	3	4	5	6
Occasional (3)	4	5	6	7
Remote (4)	5	6	7	8

Severity	Catastrophic (1)	
	Critical (2)	
	Marginal (3)	
	Negligible (4)	
Probability	Frequent (1)	>1 times a day
	Probable (2)	<1 times a week
	Occasional (3)	<1 times a month
	Remote (4)	<1 times a year

Table 35 – Risk Assessment Matrix

RISK ASSESSMENT

#No.	Task	What is the Hazards?	Who may get Harmed?	Probability (1 - 4)	Severity (1 - 4)	Score (2 - 8)	Controls Measures ?	Actioned ?	Probability After Control (1 - 4)	Severity After Control (1 - 4)	Score (2 - 8)	Actioned by?
1	Assembly (Soldering)	High Temperature	Student	1	3	4	PPE - Heat protection Gloves, Training of Soldering equipment	Yes	3	4	7	TR
2	Assembly (Soldering)	Fumes	Student	1	3	4	Fume Extraction Fan	Yes	4	3	7	TR
3	Assembly (Soldering)	Eye & musculo Skeletal Strain	Student	3	4	7	Take Regular Breaks	Yes	4	4	8	TR
4	Assembly (Soldering)	Electrical Faults	Student	3	3	6	PAT Tested Equipment	Yes	4	3	7	TR
5	Assembly (Soldering)	Housekeeping	Student	2	4	6	Keep a strict Housekeeping Schedule	Yes	4	4	8	TR
6	Assembly	Sharp Knife	Student	3	3	6	PPE - Gloves	Yes	3	4	7	TR
7	Testing	musculo Skeletal Strain	Student	3	4	7	Take Regular Breaks	Yes	4	4	8	TR
8	Testing	Electric Shock	Student	3	2	5	PAT Testing, Work & Test Safe! to University working pollops	Yes	4	2	6	TR
9	Testing	Laser IR	Student / Others	2	2	4	Made a Shield to reduce probability, & Laser Warning stickers for Project	Yes	4	2	6	TR
10	General	Manual Handling	Student	4	4	8	Work Safely	Yes	4	4	8	TR

Table 36 – Risk Assessment

Chapter 13 Build

13.1. Design & Construction Techniques:

All images below were taken during the assembly process of the project alongside each image is an explanation of the stage of the process. All work implemented was performed and adhered to the risk assessment performed in chapter 12.

13.2. Evidence Portfolio of Assembly Stages:

1. Photo 1



Figure 80 – Photo 1 Testing jig assembly

The assembly of the testing jig of the project. The rotational jig was a Lazy Susan from Ikea located in a car boot sale for £2.50, and the stand was damaged Dremel Drill Stand. They were combined together with wood screws to create the testing jig shown above. The difference between the image above and the final outcome is the distance.

2. Photo 2

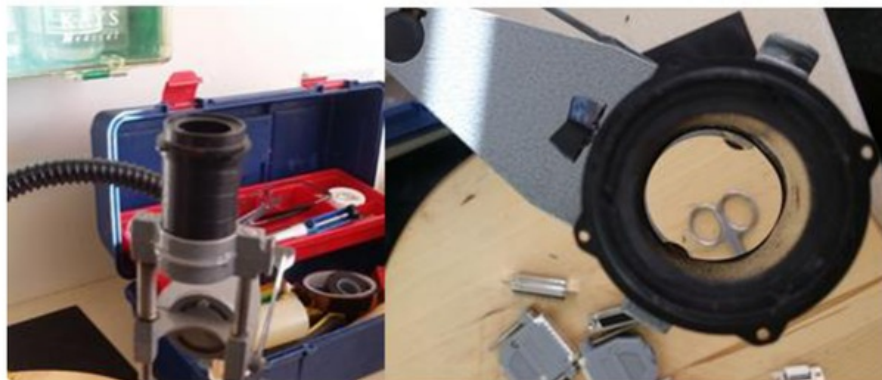


Figure 81 – Sensor Shield Assembly

The assembly of the laser shield and shield mount. The shield was made out of a damaged Dermal housing and the shield mount was made out of a scrap camera lens mount which were put together using a metal adhesive.

3. Photo 3

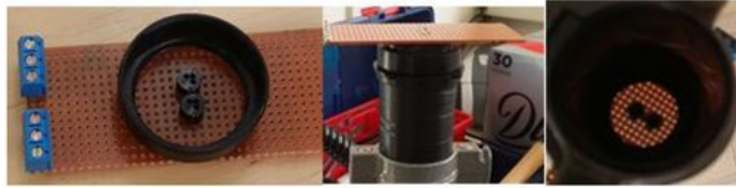


Figure 82 – Sensor Assembly

The assembly of the sensor module, the sensor was built onto Vero board due to time constraints of the project it was not possible to assemble it onto a self-contained PCB. The mount bracket is the mating part of the scrap camera lens. Which was held to the Vero board using RTV.

4. Sensor PCB Pictures

Reference figure 44 and 45 page 46. The sensor was built onto Vero board following the designed schematic of the circuit. Using standard soldering tools and equipment.

5. Photo 4

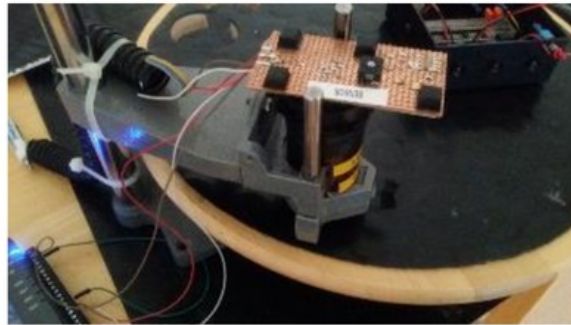


Figure 83 – Sensor Mounted on jig

The sensors mounting position on the testing jig. Was changed during testing of the sensor design as the distance was causing an issue over the accuracy of the designs performance.

6. Photo 5

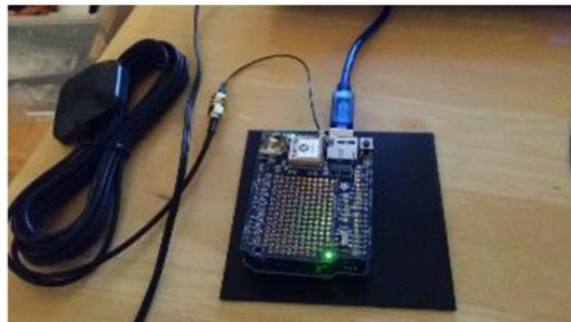


Figure 84 – GPS Module

The GPS module used throughout the assembly, this picture was taken during the testing process of the system.

7. Photo 6

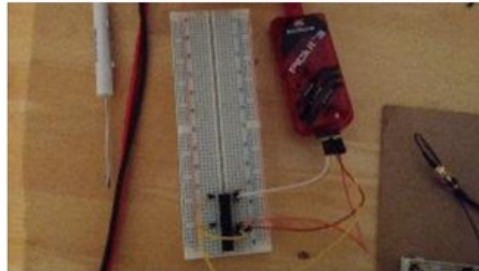


Figure 85 – PICKIT 3

Once the C code was simulated using Proteus it was compiled using CCS PIC C compiler software and then downloaded onto the PIC using MPLAB IPE to connect to the PICKIT 3 programmer. The connection of the PIC shown above.

8. Photo 7



Figure 86 – Complete System Design

The image above represents the completed system.

Chapter 14 Build Test

The first tests were performed as part of step 1 of the system design.



Figure 87 – Test 1

Demonstration of Battery LED.

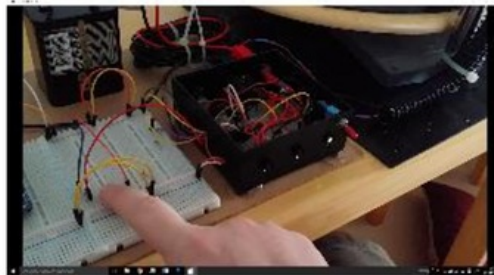


Figure 88 – Test 2

Demonstration of start button operating



Figure 89 – Test 3

No Pothole – No LED Alarms



Figure 90 – Test 4

Pothole – LED Alarms. Refer to Chapter 11 section 11.11 Step 2 simulation tests for functionality tests of GPS and PH data to the PC via an FTDI (TTL converter Lead).

Chapter 15 Analysis of Testing Procedures

Chapter 15 evaluates on all the work performed throughout the project as to reflect on the repeatability and accuracy of all the tests, experiments, and simulations performed throughout the project.

The tests performed in section 6.2.3 Component tests (IR) were performed using calibrated Lab equipment (a DMM, Distance Meter, and Power Supply) in an effort to increase the accuracy of the experiment. Although every effort was made towards the repeatability of the testing in reflection a few processes could have been altered to increase its performance and repeatability.

The testing was performed over 2 days at the same time (winter early morning) as an attempt to maintain the same ambient light conditions to the components under tests, as it was noticed that even slight changes in ambient light would alter the expected output which would affect the overall accuracy of the tests. The result of this caused further design work into creating a sensor shield to try and reduce any ambient light exposed to the sensor this would not have been done without performing the experiments. If a repeat of the tests were to be performed again a controlled lighting room or a dark room could be used as to ensure the exact same light conditions are present at all times during the component testing. This would have made the test a lot more accurate and repeatable.

To simulate the colour of the road a black material mat was used. If the testing was to be performed again ideally a real road surface like Tar would be used, as the current material used could only simulate the colour reflection not the road surface texture. If the project was to be taken further in the future, further testing into this category may prove that further design alterations and calibrations of the sensor would be required, when it is to be used on a road.

In conclusion it is my opinion that the tests although could have been performed in a more accurate way are valid in that we proved that certain components can detect distances better than others which allowed us to design an appropriate sensor around this to the best of my abilities. And that the colour of the reflected targets makes a tremendous difference. If we were to repeat the test again it would prove the same trend of results.

In section 6.2.5 - 6.2.7 various tests were performed using software like National Instruments LabVIEW in an attempt to automate streams of data to an excel spreadsheet as to eliminate human error and reduce administrative workloads. This worked extremely well. A DMM and Samsung Note 3 light sensor were also used during these tests.

The first tests were performed to try and create a calibration database of the designed sensor under certain ambient light conditions. Similar to the above response a controlled lighting room would have been the best and most accurate way to perform a test like this. Instead a dark lab with a dimmer switch and a lux sensor on a mobile phone was used in an attempt to control the lighting conditions. The accuracy of the lux sensor on the mobile phone may not have been as accurate as desired but it was consistent as to allow the testing to achieve its purpose.

The testing was deemed a success as a defined calibration was decided upon from a standard set of results.

The final tests of the sensor were performed using LabVIEW. The purpose of the tests was to prove whether a pothole could be observed from the output data. The data and the graphs were analysed and

the results of which, you could clearly see a defined difference for when a pothole passed. If these tests were performed again they would generate similar results observed in this report.

In section 7.2 GPS Module Tests testing was performed using an Arduino PCB and the Arduino software a FTDI lead and a portal software called Tera term. The test performed was simple and efficient as the main purpose was to ensure correct functionality of the module.

Section 11.8 was the schematic simulation test performed using the software called Proteus. Proteus is industry standard software, so an assumption could be made into the accuracy and the reliability of the software results. The simulation of the project was a great way to test the programmed code before running the test in the real world.

Chapter 14 tests were the real world functionality of the built items as to ensure that the project functioned as required. The testing was performed using the sensor jig designed previously. The jig was able to prove that the concept works but it does fail in being able to truly simulate a car at 70mph traveling over a pothole. If these tests were to be performed again then the testing would be performed using a car so that the maximum speed and the reflective material (road) could be tested as to allow for more real and accurate data which would improve the design of the POC project.

To conclude all the testing performed throughout the project was done so towards the highest of abilities and to the budget of a student. The results from the implemented tests, experiments and simulations were accurate enough for a design to be implemented that does begin to prove the concept of the outlined project. The testing and design would have been a lot easier if money and time were unlimited. For future developments of the project further calibration data of the true environment would be key and the implementation of alternative sensors like an Accelerometer would improve the design dramatically for weather constants like rain and snow that would disrupt a sensor like this.

Overall I would deem that the project was a success in that we have been able to prove that a control system could be designed by a student for the detection and logging of potholes.

Chapter 16 Conclusion & Recommendations

Can a proof of concept design be created for a pothole detection system while adhering to a student's budget and time scale was the hypothesis put forward. The answer to this hypothesis is a mixed response of Yes and No. There were several successes and failures throughout the project which have given a mixed opinion as to the performance and towards the final answer of the original hypothesis.

But to conclude on the project I believe that we proved the hypothesis as we were able to successfully design and test a control system that would identify and log the location of a pothole.

During the initial research of the project it was soon identified that a comical product for detecting potholes did not yet exist which highlighted a potential future as well as the importance of such a project. Problems were soon highlighted while undertaking the market research in that a sensor for detecting changes in depth at the maximum response speeds required could not be found within the budget limitations of the project, this was an interesting discovery but inadvertently added extra complexity to the project of which was not envisaged at the early planning stages of the project.

Further challenges presented themselves like having to learn new design process and techniques part of which included the use of industry standard software that had to be self-taught to implement vital stages of the project research and design. One of these in particular was the use of National Instruments LabVIEW which was used for data capture a lot of results during the sensor testing of the project, this again added extra complexity to the project which resulted in further time loss of the project, but did allow for further testing of the sensor to create the beginnings of a calibration data base to increase the performance of the design.

A major hurdle to overcome was the understanding of how to design and implement a C programme to control the main design of the project. This was overcome with university support and a lot of trial and error and self-taught methodology to successfully create a programme that would operate as required. Due to initial assumptions errors were made with how to govern the data transfer for the GPS to the PIC. Early programming and simulation tests of the RS232 control commands were successful but the transition from simulation to using real world hardware proved more problematic. With further research it was discovered that an interrupt routine would be required to resolve this error.

The design of a testing jig was implemented to try and simulate the passing of a pothole, as the use of a vehicle to test the performance of the project in the real world was deemed too expensive as the possible insurance and damages that may be incurred would be higher than the student budget. The jig itself operates as desired and aides with proving the concept of the project although it cannot simulate the real world it is a very useful demonstration aid. A sensor shield was also created which increased its performance from ambient light noise interference and to lower any risk of leakage light radiation.

As part of the report introduction and the planning stages of the project, objectives were set out as to aid with answering the hypothesis of the project, table 37 concludes the completed objectives against the essential objectives of the project.

Section	Objective	Essential	Completed
Planning	Create a list of tasks and time scales for the project.	No	Yes
	Create a Gantt chart	No	Yes
Solution	Explain / Illustrate main Project Topic – Pothole Detection	Yes	Yes
	Design a proof of concept to that system	Yes	Yes
	Build proof of concept	Yes	Yes
Research	Create a research methodology	No	Yes
	Research into Project Topic e.g. market research, does a system exist?	No	Yes
	Research sensors for detecting potholes	Yes	Yes
	Research into a GPS modules	Yes	Yes
	Investigate which PIC to use for the project	Yes	Yes
	Research the best design practices	No	Yes
	Research design approach for mounting into car	No	No
Design	Research into specification of components required	Yes	Yes
	Design a sensor to detect potholes	Yes	Yes
	Design a proof of concept Testing jig for the solution	Yes	Yes
	Design PCB for the proof of concept demonstration	No	Yes
	Design the enclosure and system wiring	Yes	Yes
Health & Safety	Integrate the GPS location data with the Pothole detection	Yes	Yes
	Create a safety analysis of design	No	Yes
	Perform a risk assessment of Implementation and final design outcome	No	Yes
Implementation	Build Sensor Design	Yes	Yes
	Build design using a breadboard	Yes	Yes
	Build design using a Vero Board or onto a PCB	No	No
	Construct Proof of concept design	Yes	Yes
	Perform Testing and Calibration on Sensor Design	Yes	Yes
	Implement testing of completed proof of concept system	Yes	Yes
	Construct Exhibition Board	Yes	Yes
Evaluation	Complete project report	Yes	Yes
	Perform an analysis of the proof of concept design (does it proof the concept?)	Yes	Yes
	Research into future requirements of the system	No	Yes
	Create an improvement comparison	No	Yes
Presentation	Research into how this could be marketed (cheaper parts, buy in higher quantity etc.)	No	Yes
	Present Interim Viva	Yes	Yes
	Present Final Viva	Yes	Not Yet
	Present Exhibition Board	Yes	Not Yet

Table 37 – Conclusion Table

Using table 37 we can see that from the essential objective category list we have achieved 100% of all outlined objectives and from the total objective list we have achieved 94% (including final Viva and exhibition board). This aides to show that from a planning and objective stance the project was a major success.

Although there was one down fall during the final testing stages of the completed sensor build this was that it cannot successfully detect differences in distance without noise interference at the researched distance of 300mm when the reflective target material is black. Based on this failure and for what was mentioned briefly in chapter 6 during component and sensor experiments that the colour of the reflective material made a difference to the output of the sensor. An analysis was performed using the design created in this project based on another possible future use for the designed sensor as it stands now without any additional modifications.

A potential use could be for motorway lane cross over avoidance which according to Doug Newcomb (44) is becoming a popular trend at the moment with car manufactures like Volvo, Honda, Kia and Mazda all starting to use the technology within their cars.

The testing was performed comparing voltage level output of the sensor depending on certain materials at a distance of 200mm.

The testing jig was used again but where the pothole detection (Hole cut outs) would be a different reflective material was put underneath which gave us a voltage increase the tests below analyses the changes between the colours.

1. Future Sensor Testing – Reflective Testing.

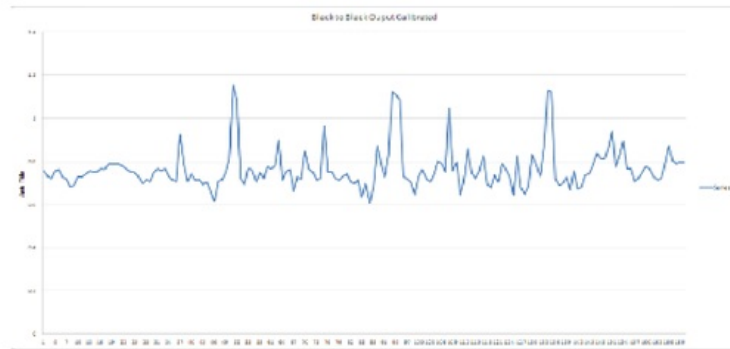


Figure 91 – Black Mat to Black Paper Output Calibrated

Figure 91 – Black Mat to Black Paper Output Calibrated, was performed using a black Mat as used throughout the project and then black paper put where the pothole target would normally be, the output voltage gave a peak voltage of 1.2V (maximum). Which can clearly be seen.



Figure 92 – Black Mat to Black Fabric Output Calibration

Figure 92 – Black Mat to Black Fabric Output Calibration was the next test performed as performed above but a black fabric mat was used as another variation in the black reflective material (road) which gave a maximum output voltage of 1.85V. There was now a big difference in peak voltages when compared with the average voltage trend of the black mat

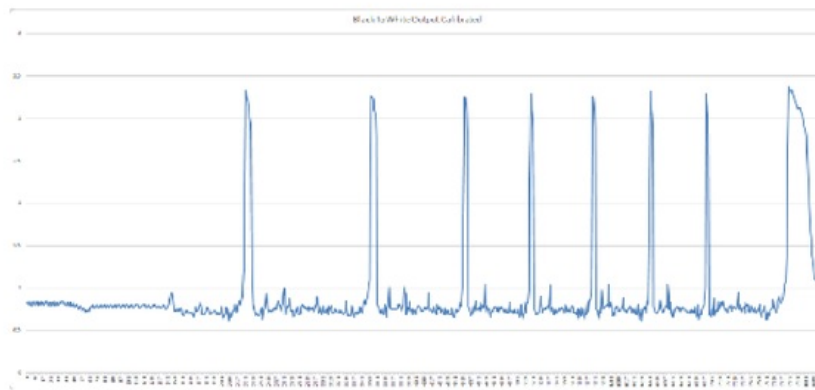


Figure 93 – Black Mat to White paper Output Calibrated

Figure 93 – Black Mat to White paper Output Calibrated was performed using the same testing jig but using the colour white as the reflective output tests. The output gave a much higher peak voltage than that of using a black background. The output maximum from the tests reached 3.7V which is double the maximum output value of the black reflective material tests.

These tests prove that the designed sensor can adapt to difference scenarios and projects by implementing simple changes to the C programme could transform this project to utilize what has been researched and perform a completely different task.

The new C programme for this testing was quickly changed as shown in figure 62 below. To demonstrate how easy it could be.

```
#include <uart.h>
void main()
{
    //=====INITIAL COMMAND SET-UP 1.=====
    setup_adc_ports(AN0); //ADC Port Setup
    //AN0 Port Setup
    //value setup as unsigned int
    unsigned int start; //value setup as unsigned int
    unsigned int stop; //value setup as unsigned int
    unsigned int count; //value setup as unsigned int
    unsigned int count1; //value setup as unsigned int
    set_adc_channel(1); //ADC Port Set to channel 1
    delay_us(100); //Adds a delay to the initial set up
    //=====END 1.=====
    while(TRUE)
    {
        //=====SWC Command 2.=====
        start = input_state(PIC_START); //start value is equal to PIC_Start input pin
        stop = input_state(PIC_STOP); //stop value is equal to PIC_STOP input pin
        if(start == 0) //if start value is = 0 then move to next line
            continue; //if start value is still = 0 after debounce delay move to next line
        count1++; //Increment count1 by 1
        if (count1 > 1) //If count1 is greater than 1 move to next line - (start button pressed)
        {
            //=====Stop command 3.=====
            if(stop == 0) //if stop value is = 0 then move to next line
            {
                delay_us(50); //switch debounce delay
                if(stop == 0) //if stop value is still = 0 after debounce delay move to next line
                {
                    count1--; //Subtract count1 by 1
                }
            }
            //=====PIC Run LED Command 4.=====
            if (count1 > 1) //if count 1 = 1 move to next line
            {
                output_low(PIN_LED); //Sets PIN_LED low
                //=====SWC Command 5.=====
                value = read_adc(ADC_START_READ); //Sets value to read ADC input of pic
                count = value/5; //Math function to scale value
                count = 2; //Math function to scale value, scaled 0 to 100 and stored to count
                printf("count=%d\n", count); //Sends the data from value to the virtual terminal
                if (count > 10) //Sets trigger point of LED_ALARM
                {
                    output_low(LED_ALARM); //Sets output low if less than preset value
                }
                else //Sets on else statement to operate with the if statement
                {
                    output_high(LED_ALARM); //Sets output high if higher than preset value
                }
            }
        }
    }
}
```

Figure 94 – Future Design C program

Now the LED alarm is triggered at a different voltage level being >3V which was taken from the testing performed above.

Chapter 17 Reflection

The transition from undertaking a Foundation degree at Swansea University to the top up degree at University of Wales Trinity St David was a difficult yet rewarding experience.

Comparing the knowledge I knew before starting the major project and the knowledge and personal development I have gained throughout this journey is staggering.

The major project has given me the opportunity to challenge my personal communication skills through having to perform vivas, mentor talks, speaking with fellow students, colleagues and sales representatives. Which before starting the project I always found hard, but because of the major project I find it easier to communicate clearly which has increased my confidence tremendously.

From the start of the project I set myself with objectives and from that I performed all the necessary research and experiments to enable a design to be generated and simulated which then allowed the end product to be built and tested.

Throughout several stages of the project I have had to use several different software packages which were CCS, Easy PC, Proteus and LabVIEW these are industry standard packages which I was very excited to learn as I knew they could aid with possible future career development and opportunities.

Another personal development through mistakes made is time management throughout the project I was always finding myself running out of time on certain tasks which would have a dramatic knock on effect on others. But now learning how to prioritize workloads and objective planning, will prevent this in the future. The understanding of how to analyse data and knowing what decisions needed to be made upon those results and findings was another personal skill gained, as I was having to perform this continuously throughout the design and experiment aspects of the project.

Learning from mistakes made throughout the project and if I was to perform a project like this again I would be stricter with my research, especially when it comes to the project scenario. This will allow for better decision making as to how I would best resolve that in terms of design saving time and money. For instance the project hypothesis was to design a system of detecting a Pothole hit to a vehicle and I made a decision to use non-contact technologies to read a distance change but in reflection I shouldn't have assumed non-contact technologies were the best path for the project in fact an accelerometer could have been used to detect the shock impact of a pothole to a vehicle which would have given us the exact same outcome as the current design.

This has increased my awareness of how vital research is and understanding the true nature of the work requirements which will be a vital life skill to take forward in my working career.

The purpose of undertaking the top up degree is so that I could move to the next stage in my career making the transition from Technician (which I have been for 6 years) to Engineer. Opportunities of employment arose from undertaking the major project. In an interview I attended I spoke about the skills and knowledge I had gained from undertaking the major project as part of my degree (especially promoting the software packages and utilising the improvements I had made with my personal communications skills), and because of this and as of the 4th April 2016 I have successfully reached for transition from Technician to Engineer in my Career from accepting a job opportunity to become a Hardware Test Engineer.

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Chapter 19 Appendix

A digital copy of the Appendix has been supplied with the hard copy of the report.
The appendix has been sorted into a folder format with clearly defined sections.