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HoleHere

Pothole Detection for Road Vehicles

Final Report

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Abstract

Potholes pose a fatal danger to motorists, as well as a great financial burden to both road users and the authorities. As we embrace the age of the Internet of Things, there is an opportunity to formulate a solution with the technology at our disposal. Our solution intends to map pothole data that can save motorists money and possible harm, while simultaneously letting authorities be aware of where these dangers exist.

We begin by presenting research on the dangers that potholes present and the target audience that our product will impact.

This report continues by exploring the possible technologies that allow us to detect and map potholes. And subsequently analysing each proposed solution through a carefully formulated matrix selection method in order to tackle the problem within the guidelines we have outlined in our product design specification. The outcome is *HoleHere*, an apparatus that helps communities and motorists detect and map potholes for the safety of road users.

Most importantly, this report showcases a detailed technical analysis and feasibility study of *HoleHere* and our future vision for the lifetime of such an implementation.

1. Introduction

In both developing and developed countries, road networks can be either incomplete or intermittently maintained; therefore potholes are common in such places. These potholes pose a serious safety risk to road users and cost local governments millions in compensation claims. These risks are compounded when motorists utilise these road networks at night at high speeds. In developing countries particularly, the cars used are often older models without any modern pothole detection technology installed.

The presence and dangers of potholes cost governments and motorists a tremendous amount of money. The 'Annual Local Authority Road Maintenance' (ALARM) report published by the Asphalt Industry Alliance in the United Kingdom(UK) revealed that more than £30 million was spent in compensation claims in 2013[1], while the World Bank reported that governments in Africa could have saved $45 billion[2] over a decade if an additional $12 billion had been spent on timely road maintenance. This sum however, fails to fully outline the economic impact of potholes. Motorists with damaged vehicles may be unable to go to work, resulting in the inefficiency of human resource and opportunity cost for individuals who are now unable to travel[3].

For motorists, to encounter a pothole is a potentially fatal experience. Motorcyclists especially[4], since they only have stability as dictated by the two wheels in contact with the road surface. In fact, more than 11,000 people were killed by potholes and speed breakers in 2015 in India[5]. It is irrefutable that potholes pose a serious safety concern to motorists globally.

The above mentioned social and economic impacts due to potholes highlight that it is imperative that if the fixing cannot keep up with the appearance of potholes, that an intermediary is required. This intermediary is our product, *HoleHere*, it will serve as a notification system for all motorists affected by the dangers presented by potholes and also as an awareness network for local governments so that they might rectify potholes in an efficient manner. *HoleHere* builds on the premise of the Internet of Things[6], so that vehicles, maps and authorities may be aware of potholes before they do damage.

In our interim report, we investigated the efficacy of different technologies and their suitability to meet the needs of our design criteria, our group has expanded and deepened our research and understanding of the product that needs to be implemented. Since then, we have adapted and streamlined our approach for the detection of potholes so that it may be both cost-effective and reliable.

2. Design Criteria

As a guideline for our product design, we have formulated a detailed Product Design Specification (PDS) (refer to appendix A). The key points in the PDS form the major considerations for our design, they are listed below.

Performance

The focus for this product is to detect potholes and map the location of potholes. For this module to be efficient it will have to be able to work independently, and on battery power. The current model will be using a 9V battery. The GPS coordinates must be constantly taken, and when a pothole is detected, this coordinate should be stored on the SD card. The locations can then be used to map the locations of the potholes and thus create a map of the terrain in the specified area.

Life in Service

The product is expected to be used approximately 2-4 hours per day for 365 days per year. At least 3 years of full operation are expected. This will provide the users with a long enough period of use.

Target Product Cost

Considering the cost of parts required, the aim is to make the product as cost effective as possible. From our budget of a negotiable £50, and our market research in which 60.5% of the people surveyed said they would be willing to pay around £20 – £50, the target product cost is should be £20-£50 with £50 being the upper limit. This will provide a quality product at an attractive price.

Customer

The main customers will be people who travel in areas with poor road conditions and thus more potholes. This could include developing countries, countries with poor road conditions and people wanting to have an idea where potholes are. Furthermore, governments could also benefit from this product as this could help them better allocate infrastructure budgets, improve road conditions, and know where roads are in a poor condition.

Size

The product will need to be small enough as to not obstruct the vehicle it is attached to. Ideally the product would have a minimal affect on the appearance of the vehicle it is attached to.

Weight
The product will be as light as possible in order to minimally affect the vehicle it is attached to. Furthermore, this will reduce costs for shipping and thus make the product more affordable to be shipped and also purchased by the customer.

Ergonomics
The product needs to be easy to attach to a vehicle and placed at the front in order to easily be able to detect potholes ahead. Furthermore, there has to be an anti theft system included. This could mean a GPS tracking possibility, and a good attachment to the vehicle as to not be able to be stolen. The product should also be well fastened to the vehicle so as to not become loose and fall when driving on bumpy or non-ideal roads.

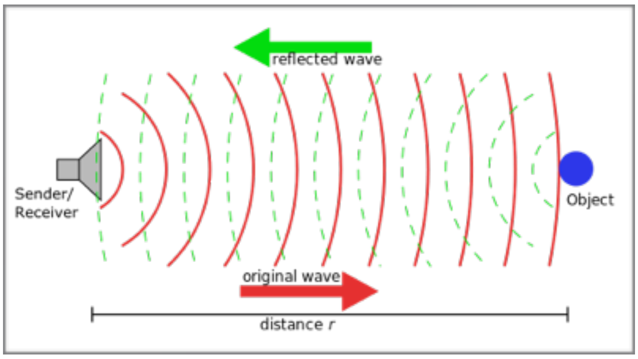
Quality and Reliability
The product is expected to detect potholes, and store their location on the SD card which can then be mapped for future use. The device should be accurate to within 80cm. Furthermore, the product should be of a high quality as to not break easily during usage.

3. Concept Designs Considered

This section showcases the 3 different technological subsystems we have analysed that may possibly address the problem as outlined in the introduction. Namely, they are Ultrasound sensors, Infrared Sensors and Haar Cascades.

Ultrasound Sensors

Ultrasound sensors are very popular and are already used in both civilian and military applications. For this project these sensors will be used in a similar fashion to SONAR.



A sound wave (above 20 kHz) is sent towards an object and it returns after a certain time delay proportional to the distance between the ultrasound transmitter or receiver and the object. The speed of sound in air (approximately 340 m/s) is known and constant, therefore the object's distance from the transmitter or receiver can be easily computed using the relationship, distance equals the product of speed and time.

For our application, the ultrasound sensor is used to detect a sudden change in depth between the car and the road surface by regularly measuring the distance between them.
Furthermore ultrasound is a sound wave hence it is immune to ambient electromagnetic interference e.g. visible light, infrared and ultraviolet light emitted by the sun and nearby objects. Also ultrasound sensors are simple, ubiquitous and easy to interface with. This is why we incorporated it in our prototype.

Infrared Sensors

This distance sensing technique is also very similar to ultrasound in simplicity, ubiquity and ease of use. However it has a major drawback which is it's susceptibility to ambient electromagnetic radiation i.e. interference. As a result it didn't feature in our prototype.

An infrared range finder is a 2 in 1 package consisting of an infrared transmitter and a charged coupled device (CCD) array[8]. The job of the infrared transmitter is to emit infrared light, while the CCD array is responsible for detecting and determining the angle of the reflected infrared beam.

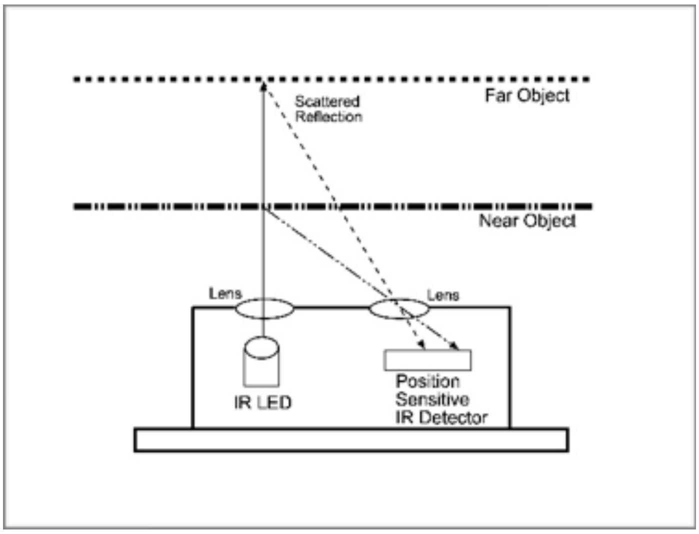


Diagram on left showing internal layout of infrared range finder.

The angle of the reflected beam is used to determine the distance of the object from the infrared range finder.

Similarly, the infrared range finder is used to detect a sudden change in depth between a car and the road surface by frequently measuring the distance between them.

Haar Cascades

This approach is very different from the other two previously considered approaches. It is far more complex and it relies heavily on software to get it to work as desired.

Haar cascades work based on machine learning. This is the same operating principle used for face detection in everyday cameras[9]. A cascade function is “trained” from a many of positive and negative images. It is then used to detect objects in other images. To apply this method to detecting potholes we need a suitable algorithm. Initially the algorithm will require a multitude of positive images (images of potholes) and negative images (images without potholes) in order to train the “classifier” (algorithm for statistical classification). Certain features will then need to be extracted from it.

Each feature is then applied on all the training images and an optimum threshold will be determined by “Adaboost” [10](machine learning algorithm) in order to classify the image as positive (pothole detected) or negative (pothole not detected). Features with a minimum error rate are then selected in order to best classify the pothole and non-pothole images.

4. Concept Selection

We utilise the Controlled Convergence Matrix Method in order to ascertain which solution is best suited to address the problem we have at hand.

Please refer to Appendix G for the Controlled Convergence Matrix.

After processing each viable solution and technology and weighing them against the importance of each of our identified design criteria as listed in the previous section, the Ultrasound Sensor is the most viable solution.

5. Concept Development

Solution Overview

The product of our concept selection is *HoleHere*, which amalgamates a micro-controller, an ultrasound sensor and a GPS module to meet our design criteria. In summary, *HoleHere* will be attached to a vehicle that will traverse an area/region/community where potholes are a persistent problem, and will write the GPS coordinates of a pothole as it detects them to a Secure Digital (SD) card. This information will then be passed on to local authorities and shared among the community and mapping services so that motorists and authorities may be alerted to the location of the dangers that exist in their surroundings. The details are listed explicitly in the sections below.

Components and Production

HoleHere includes the components listed below:

Component	**Cost (£)**	**Supplier**
Arduino Uno	16.16	RS Components
SRF08 Ultrasound Range Finder	30.60	RS Components
LS20031 GPS receiver	59.00	Amazon UK
SN74AHC125 Level Shifter	0.27	RS Components
2GB SD memory card	5.28	RS Components
1k resistor	0.14	EEE labs
2x 1.8k resistors	2 x 0.16	EEE labs
LED	0.18	EEE labs

At a total of £111.95 for the prototype implementation of *HoleHere*, the resultant cost is extremely low. This is brought into context particularly due to the scope of impact that *HoleHere* will have. Affecting small communities with thousands of people and saving authorities more money (as outlined in the introduction) than they would spend to implement and maintain *HoleHere*.

Yet, it is unwise to think that the components are the only constituents of the cost. For a vehicle to scan the roads, regular updating the mapping will be required to keep *HoleHere* relevant to the target audience. This is another challenge we encountered in our vision of implementation.

Technical Problems

Firstly, it was necessary to write and modify code for the micro controller to successfully process the input of both the GPS module as well as the Ultrasound sensors so that the micro controller could identify a pothole.

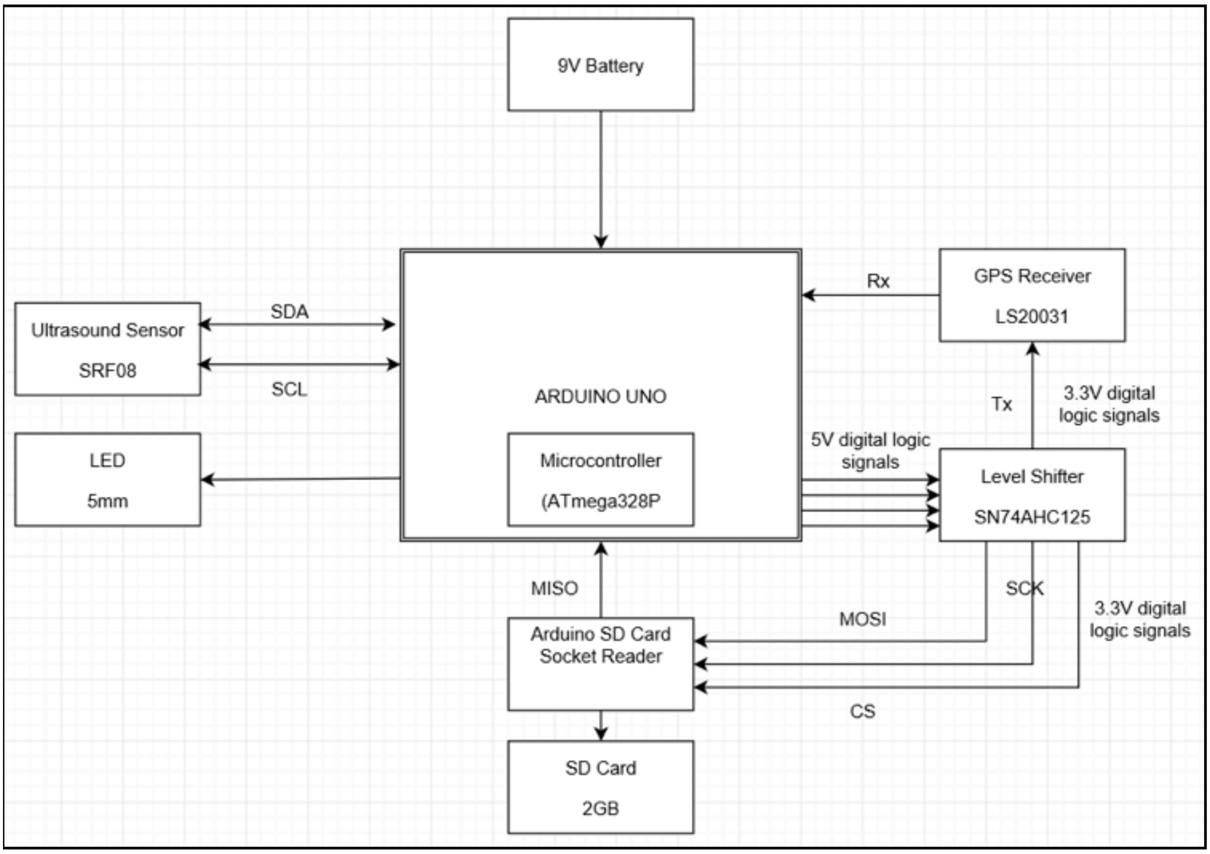
Secondly, a great deal of familiarity with the equipment was necessary in order for us to be able to implement *HoleHere*. For example, the initialisation of the GPS module proved to be extremely troublesome. For there was a requirement for it to lock onto a satellite and calibrate the baud rate setting on the equipment before it could be used for autonomous operation. The issue with the baud rate extends to both the Ultrasound sensor as well as the SD card, for it had to be synchronised across all platforms before valid readings could be attained.

Lastly, when considering the testing phase of *HoleHere*, it became apparent that we would not have the resource, time nor equipment to test out the full-scale product on a suitable platform. Hence some sort of downscaling had to be practiced. We used a box as a frame for which the prototype would be attached, furthermore, this meant that the financial limitations are taken into account, and testing can still be done to determine how well the prototype works. Given a budget of a negotiable £50, only the price of the components will be factored into the final price of the total project. As such, by scaling down the frame to which the system is attached to, we have managed to provide a workable means of testing the prototype and also solved a financial issue that would have maxed out our small budget.

Technically, the project was equivalently stripped down to a bare bones model. This bare bones model includes the ultrasonic transducer used to determine the distance between the front of the box and an object/ road, and Arduino programmer, a GPS unit, and an SD Card writing module. This allows for the prototype to be functional, and also does not require the prototype to follow any specific display requirements of a vehicle display screen were it to be used with a vehicle. Further technical limitations provided a new outlook to the scope of the project which were not initially thought of. The initial proposed project was one where potholes were to be detected and the driver would be given an alert of some sort. However, with the financial restrictions, and need for multiple kinds of technology, a different approach to the project was taken.

The most noteworthy adaptation however, is that now, rather than detecting the potholes in advance, and alerting the driver to the possible risk, we shifted focus to mapping the potholes. This idea was further encouraged by our supervisor Dr. Simos Evangelou, especially taking into consideration the technological limitations of the Ultrasound Sensor.

Principles of Operation



The block diagram above shows the inter-connectivity between the major components for *HoleHere*. Descriptively, the Arduino UNO interfaces with a number of input and output devices as shown above. The input devices are the GPS receiver and Ultrasound Sensor. The LED and SD card are output devices. External processing of the Arduino's 5V digital logic signal is achieved using the level shifter module, which converts the Arduino's 5V logic standard to a 3.3V logic standard compatible with the GPS receiver and SD card socket reader.

Communication between the SD card socket reader and the Arduino is via 4 unidirectional lines namely MISO (Master Input Slave Output), MOSI (Master Output Slave Input), SCK (Serial Clock Line) and CS (Chip Select).

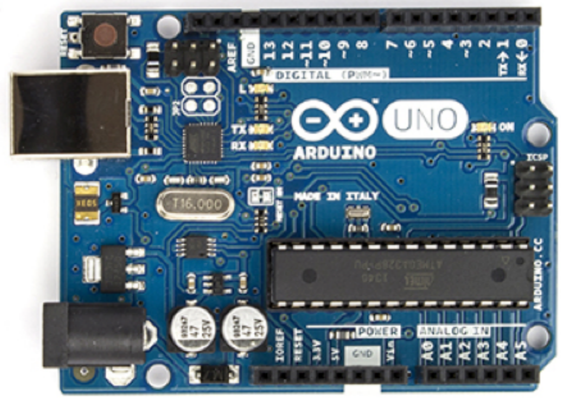
The Arduino [11] and GPS communicate by 2 unidirectional lines which are called Rx (for receiving TTL serial data) and Tx (for transmitting TTL serial data).

The ultrasound sensor communicates with the Arduino via 2 bidirectional lines which are called SDA (Serial Data Line) and SCK (Serial Clock Line).

Our prototype uses 3 main technologies which are the Arduino UNO, the ultrasound range finder and the GPS receiver. Subsequent paragraphs explain the function and technicality of each technology and how they work together to contribute to the function of *HoleHere*.

<u>Arduino UNO</u>

The Arduino UNO is the brain of our prototype. It is an open-source microcontroller programmable kit which has many key features that make it well suited for our application. It is cheap, simple to use due to the many available libraries online and extremely flexible (i.e. it can be used in many applications and easily adapted to meet the needs of another design by changing the source code).

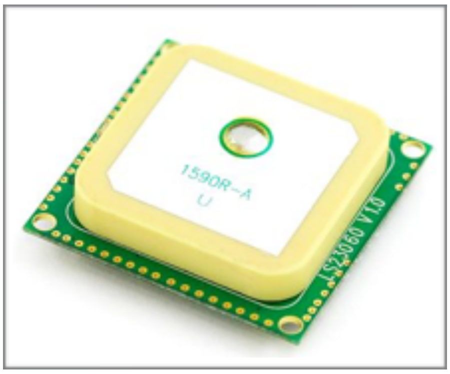


The Arduino UNO boasts an 8-bit microcontroller (ATmega328P) capable of being clocked at up to 20MHz[12]. However it has a limited flash memory of 32KB which is insufficient for data logging, hence an external SD card is required. Of which we use in *HoleHere*. Numerous hardware peripherals are available for use with the Arduino UNO and the Arduino IDE is compatible with many OS' such as Windows, Macintosh OSX, and Linux operating systems[13]. These features further highlight why it will serve as the processing centre of our prototype.

All the individual components of our prototype communicate with each other via the Arduino UNO. Initially the GPS is configured by the Arduino and the ".log" file is opened inside the SD card. A high signal is sent by the Arduino to light an LED if both the SD card is detected and a ".log" file is opened inside the SD card. The Arduino sends a signal to the ultrasound range finder module and processes the received signal in order to compute the distance of an object placed in front of the ultrasound range finder module. An algorithm is then implemented by the Arduino which processes this distance and decides whether the object detected was indeed a pothole or not. If and only if the object was a pothole the Arduino communicates with both the GPS receiver module and the SD card in order to store the immediate GPS coordinates in the SD card.

In summary the Arduino UNO is essential for setting up the GPS receiver and SD card and checking if the latter is functional, implementing an algorithm for detecting a pothole by interpreting data obtained from the ultrasound range finder module and communicating with the real world the whereabouts of an encountered pothole through the SD card.

LS20031 GPS receiver



The LS20031 is a GPS receiver which means it works on the same principles as any GPS receiver i.e. it works based on the principle of trilateration described below.

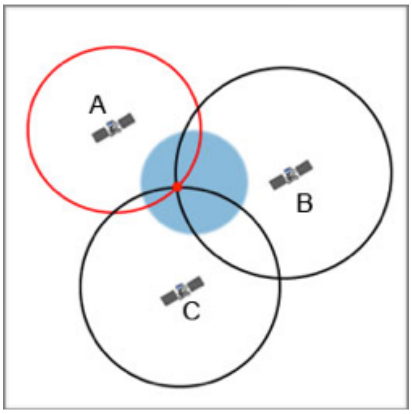
What is GPS?

GPS stand for Global Positioning System. It was originally developed by the US government for military navigation but it's now widely used by the public in many devices e.g. a SatNav, mobile phone, laptop and handheld GPS[14]. GPS is a network consisting of between 24 and 32 satellites that sit in a constellation orbiting Earth at a distance of at least 20,000km from the earth's surface[15]. This distance doesn't exceed the orbiting distance of geostationary satellites which is approximately 35,000km.

The more satellites in the global positioning system the more precise the data received will be. For instance if one satellite failed or transmits faulty signal, it will be negated by the signal sent from another satellite in the constellation. A minimum of 4 GPS satellites are visible at any time regardless of your current location on the planet. Each satellite transmits the current time and its position routinely. The GPS receiver then calculates how far away each satellite is from the time taken for the transmitted message to arrive knowing these signals travel at the speed of light. The exact location of the GPS receiver can be found once the GPS receiver has information on how far away at least three satellites are from it using a process called "trilateration".[15]

Principle of Trilateration

The principle of trilateration[14] relies on three intersecting circles, spheres or triangles to determine the absolute or relative location of points. If the distance from satellite A to the GPS receiver is known this implies the GPS receiver could be located anywhere on the circumference of circle A. If the distance from satellite B to the GPS receiver is also known



this means the GPS receiver will now be located at one of the two points where circle A and B intersect. Knowing the distance from satellite C to the GPS receiver as well provides all the information required to isolate the exact location of the GPS receiver i.e. the GPS receiver is at the singular point where circles A, B and C intersect. However in reality the GPS receiver determines its location using overlapping spheres rather than overlapping circles.

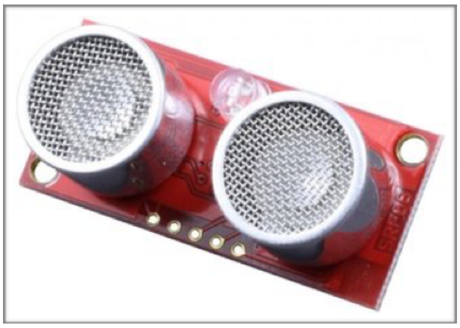
This particular module used provides additional information such as satellites in view, active satellites and ground speed. However, at this juncture, these additional features are not required, hence the LS20031 GPS receiver will be configured to only display RMC (recommended minimum specific GNSS data) NMEA (marine electronics communication standards) record.

Example GPS coordinate received:
$GP**RMC**,053740.000,A,2503.6319,N,12136.0099,E,2.69,79.65,100106,,,A*53 [16]

Name	**Example**	**Units**	**Description**
Message ID	$GPMRC		RMC protocol header
UTC Time	053740.000		hhmmss.sss
Status	A		A=data valid or V=data not valid
Latitude	2503.6319		ddmm.mmmm
N/S Indicator	N		N=north or S=south
Longitude	12136.0099		ddmm.mmmm
E/W Indicator	E		E=east or W=west
Speed over ground	2.69	Knots	True
Course over ground	79.65	Degrees	
Date	100106		ddmmyy
Magnetic variation		Degrees	
Variation sense			E=east or W=west (Not shown)
Mode	A		A=autonomous, D=DGPS, E=DR
Checksum	*53		
<CR> <LF>			End of message termination

The LS20031 module also has an update rate of up to 10Hz. Therefore the GPS coordinate received from a car driving at the maximum speed limit in UK (31.1 m/s) will be accurate with an error of 3.1m due to the update rate limitation. This value adds to the standard inaccuracy of GPS receivers which is within 3 to 15m, 95% of the time[17].

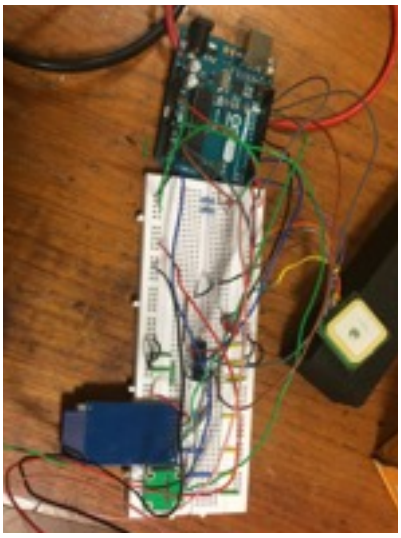
<u>The SRF08 Ultrasonic Range Finder</u>



This device are the eyes of *HoleHere*. It is responsible for providing input information about the contour outline of the road surface by measuring distance (depth between car bumper and road surface). [18] The SRF08 module emits eight 40 KHz soundwave pulses (called pings) lasting 200µs and "listens" for the echo of each ping. The pings return back as an echo to the SRF08 module and the Arduino analyses them to estimate the distance of the object placed in the path of the SRF08 module. The ranging time of this module is by default 65ms i.e. equivalent to a range of 11m. However the SRF08 is only capable of a maximum range of 6m.

The minimum width for a hole to be considered a pothole in the UK is 20cm [19] and the speed of sound in air is approximately 340 m/s. This means the wavelength of the sound waves emitted by the SRF08 module are 23.5 times smaller than the minimum pothole width in UK, hence diffraction would have a negligible effect on the readings obtained using this module.

The minimum depth for a hole to be considered a pothole in the UK is approximately 40mm[19]. Assuming a large car has a ground clearance >300mm [20] which is approximately equal to the distance between the car's bumper and the road surface. Using these parameters, the time taken for the echo wave to return back to the module is approximately 2ms (assuming the speed of sound is 340 m/s in air). This implies the range of the SRF08 ultrasonic sensor will need to be restricted to approx. 2ms from the Arduino code. The maximum speed limit on a dual carriageway in the UK is 112km/hr (8) i.e. 31.1m/s. Based on these facts the distance a car travels when in a pothole between each sample by the SRF08 module is > 6.3 cm. This value is tolerable considering the minimum width of a pothole in the UK is 20cm [19].



The interplay between these 3 major components result in our product implementation, *HoleHere*. For the flowchart documenting what happens to a signal that is processed by the system, please refer to Appendix B. For the Arduino code that implements the previously mentioned flowchart, please refer to Appendix C.

How *HoleHere* works:
The ultrasound module samples the distance, d, from the car's bumper to the road surface at a rate faster than the maximum speed of the car. When a sudden increase in d is detected (car enters pothole) a timer is initialised. The timer is terminated when a sudden decrease in d (car exits pothole) is detected. A pothole is assumed to be detected after the timer reaches a certain threshold value. Immediately after these two events have occurred a signal is sent to store the current GPS coordinate in an SD card.

The GPS and SD card need to operate in sequence hence GPS receiver is initialised to a baud rate of 4800. Baud rate is simply the number symbol changes or signalling events per unit time.

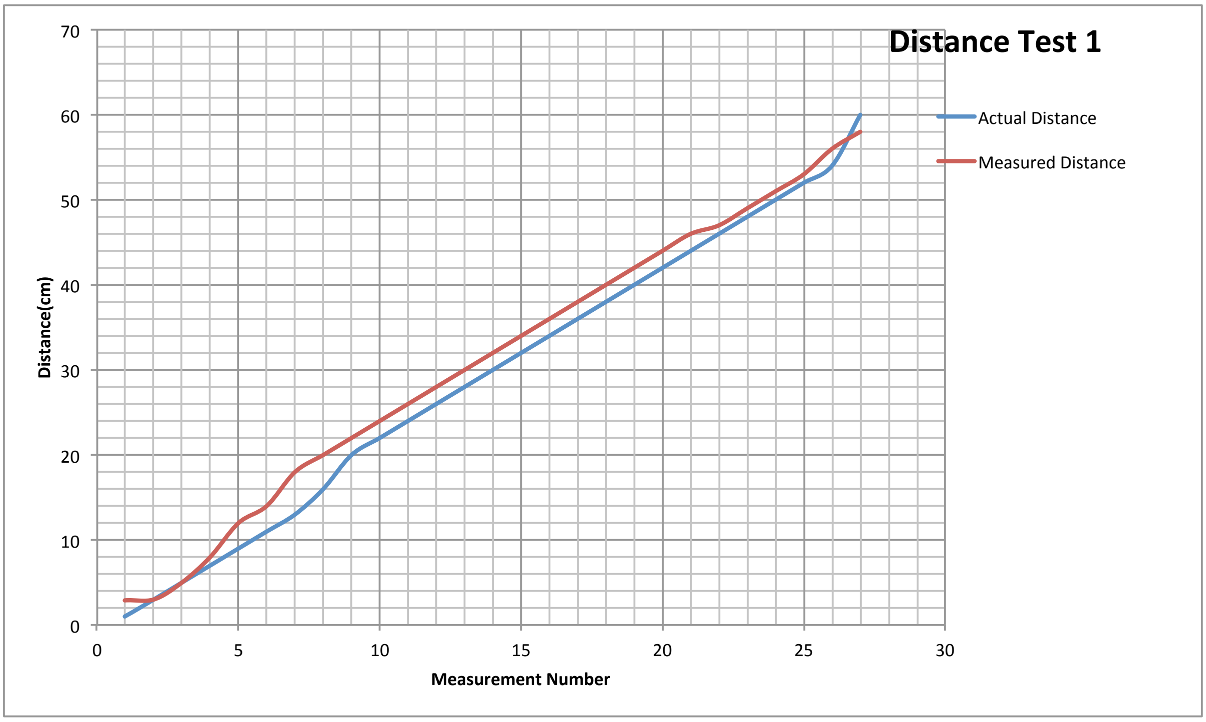
Challenges

In spite of the potentially successful technical implementation of our product, we foresee that there will still be a challenge to attain the widespread social and economic benefits that we sought out to achieve. This is because that cooperation from the authorities and local mapping services are crucial for how much the product will be used. For without a centralised updating platform, the information retrieved will quickly lose relevance as potholes get filled and new ones emerge. Or should governments not recognise the help that *HoleHere* can provide for their communities, the information will be as good as useless.

The fact that HoleHere cannot be a self-sustaining solution implores that it is mandatory that an organisation needs to take charge of the implementation and marketing the use of the product in order to reap the benefits. In order to go about doing this, we hope to conduct a feasibility study with government bodies in communities in India and England to gauge their receptiveness of taking up such a project under their management structure.

Testing HoleHere

Ultrasound sensor reliability:
This experiment aims to objectively gauge the accuracy of the Ultrasound Sensor. We performed an experiment to determine the reliability of the sensor by measuring the distance from different surfaces. The fixed variables included the angle of the sensor to the surface and the perpendicularity of the distance readings from the surface. The only variable was the distance between the sensor and the surface so that the truest relation between the actual and recorded data could be ascertained.



The graph above describes how the sensor reacted to measuring distance and is compared to the actual distance measured using a measuring tape from the surface. These readings were taken over 3 sessions to ensure repeatability. The graphs and hard data can be found in Appendix D.

We conclude from this experiment that there is a maximum deviation of 2cm from the actual readings and hence it shows that the ranging capabilities of the Ultrasound Sensor are largely reliable.

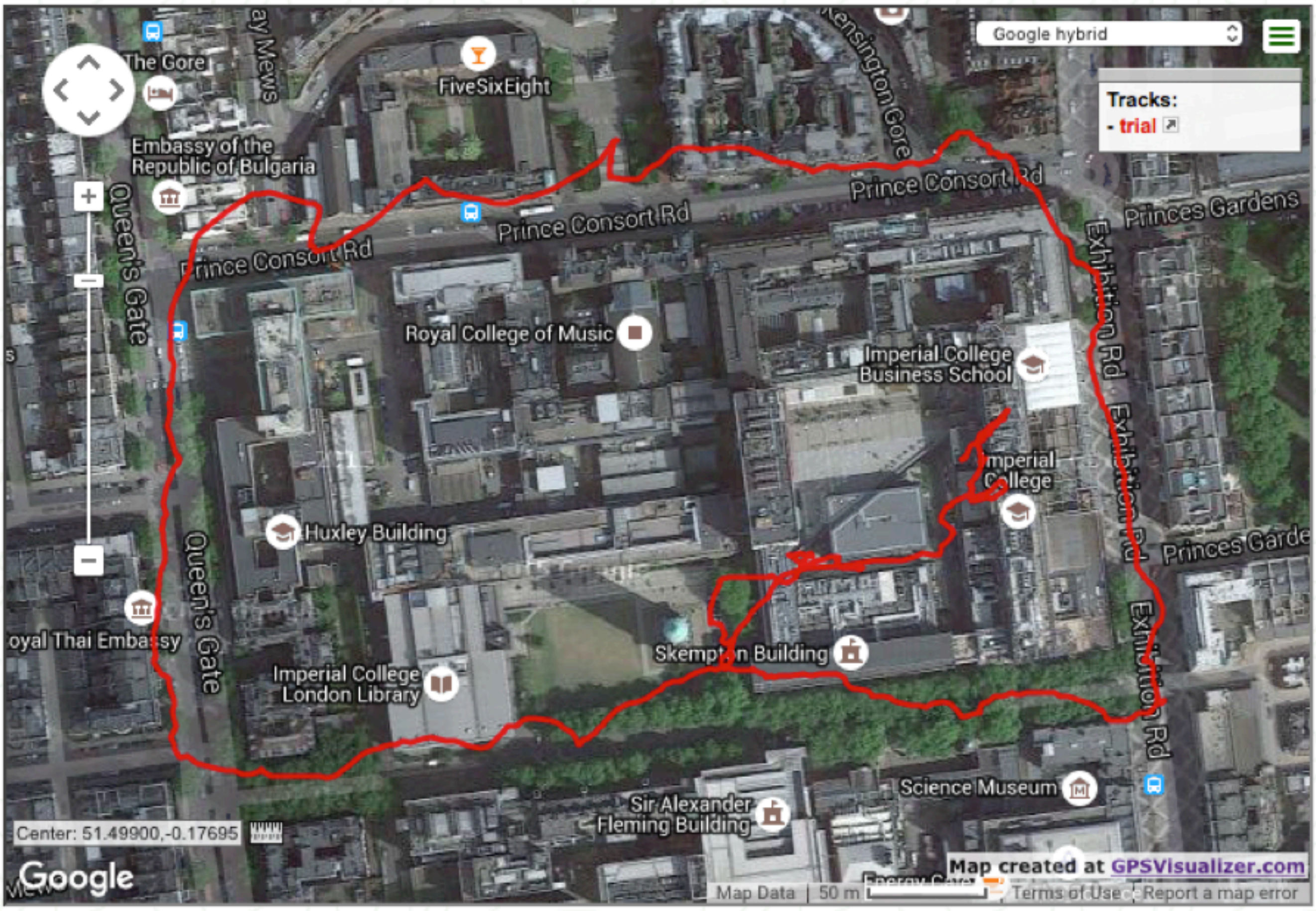
GPS Module reliability:

This experiment aims to gauge the reliability of the GPS module with regards to the accuracy of the GPS readings recorded. The conduct of this experiment was as follows: we calibrated and set all the necessary parameters (Baud rate: 4800) for *HoleHere* and subsequently walked a 1 block circuit around South Kensington, making sure to maintain our speed throughout the process, this allowed us to check back against the readings written to the SD card. Analysing the gaps between the readings recorded as well as the functionality of the GPS module under confined spaces.

```
$GPRMC,173852.000,A,5129.9395,N,00010.5106,W,0.21,296.10,090316,,,D*7B

$GPRMC,173853.000,A,5129.9395,N,00010.5107,W,0.96,242.83,090316,,,D*74

$GPRMC,173854.000,A,5129.9393,N,00010.5119,W,1.67,251.51,090316,,,D*78
```

The data on the SD card was stored as shown above. Processing was required using the c++ code below in order to input the coordinates the website http://www.gpsvisualizer.com to view it on Google maps.

```cpp
#include <iostream>
#include <sstream>
#include <fstream>
#include <string>
#include <cstdlib>

using namespace std;

struct coordinate{
    double lat;
    double lonn;


    string str(){

        double lat1 = lat-5100;
            stringstream ss;

            ss <<  "51" << "°" << lat1<< "'"<<"N"<<"," ;
            ss << "0" << "°" << lonn << "'"<< "W" << endl;
            return ss.str();
        }
};

int main(){
    ifstream infile;
    ofstream outfile;
    string filename, filename1;
    coordinate cordx;
    double cordxx1, cordxx2;
    cout << "what are the filename" << endl;

    cin >> filename;
    cin >> filename1;

    infile.open (filename.c_str());
    if(!infile.is_open()){
            cout << "protocol file not found" << endl;
            exit (EXIT_FAILURE);
            }
    outfile.open(filename1.c_str());
    if(!outfile.is_open()){
            exit(EXIT_FAILURE);
    }
    outfile << "Latitude,Longitude" <<endl;
    while (infile >> cordxx1 >> cordxx2){
        cordx.lat = cordxx1;
        cordx.lonn = cordxx2;
        outfile << cordx.str();
    }
    infile.close();
    outfile.close();
}
```



Post-processing, the plot of the path taken is shown above. It corresponds extremely closely to the path that we had taken and the frequency of the readings indicate that there are no gaps at which readings were not taken.

<u>Derivation of Maximum Sampling Rate and it's Impact:</u>

In this experiment, we aim to derive the maximum sampling rate of *HoleHere*, so that we may ascertain at what speed of the moving vehicle would *HoleHere* maintain it's functionality and reliability.

The conduct of this experiment was purely by bookwork, looking at the data sheets of the components and identifying the limiting factor to which the speed at which data could be written.

	Ultrasound Sensor	SD Card	GPS Module
Maximum Baud Rate	20000	4800	57600

From the table above[12], the SD card is the limiting factor. The code we have written to implement the pothole detection with the Arduino platform is hence set to a rate of 4800baud. Our code implementation leaves a time of 50 milliseconds between readings. This corresponds to a frequency of 20Hz in taking readings. This is way below the maximum sampling frequency of our ultrasound sensor of 40KHz.

The data communication with the SD Card is at 4800 baud. The size of buffers that stores data to the SD Card is 128 bytes. One byte has 8 bits. So this is equal to 1024bits. The number of NMEA lines that can be written to the SD Card per second:

$$\boxed{\textit{Number of NMEA lines per second} = \frac{\textit{BaudRate}}{\textit{Number of bits per NMEA line}}}$$

Using the above formula, we get that 4.6875 lines can be written per second. This is the same as saying the frequency of data writing to SD card is 4.6875Hz.

From all we have calculated and inferred above, the maximum speed of travel of whatever vehicle that will carry our pothole detection device will have to correspond to the speed associated with the frequency at which we can detect that we have a pothole and process the data before taking the next reading. This means our max speed has to be associated with the frequency at which we process the data – write to SD Card.

From our definition of what an standard pothole is, the pothole has to at least have a width of 30cm in any direction and a depth of at least 4cm. we would like to be able to detect a difference in readings if there should be any within at least this 3cm window. Time corresponding to 4.6875Hz of SD card data transfer is 0.21333s. This means that the maximum distance we should have travelled in 0.21333s is 3cm. This means that our maximum speed is

$$\boxed{\textit{Speed} = \frac{\textit{Distance}}{\textit{Time}}}$$

Using formula above is 14.0625cm/sec. This corresponds to 5.0625km/h. This is relatively slow and we can see that the speed we can move at is greatly affected by the SD Card data transfer. A possible solution to increasing the speed is to use an SD Card that can operate at a higher baud rate.

Meeting the Design Criteria

The above mentioned prototype meets the requirements for performance. It is able to work off the 9V battery reliably. It consistently takes GPS readings and readings for distance, storing these to the SD Card. The product should have no problem working for the designated period of time of 3 years, however, the battery may be required to be replaced. The cost of the prototype was close to the limit of £50, however, with more of the parts being bought in bulk rather than individually, this price can be brought down, and thereby making the product more appealing to a wider customer base. Through the market research conducted, there is customer base willing to purchase and use the product. For the government, this can easily be seen as a positive tool for them to be using. The weight of the product is small enough not to cause inconvenience, and also small enough not to degrade the look of the vehicle. The product will come in a plastic cover when it is finally sent out for mass production. This provides an aesthetic appearance and also enables the product to be in a compact casing. The device is accurate for the testing distance of 80cm which is more than the height of most vehicle bumpers. The prototype manages to successfully comply with the design criteria and thus, any improvements made will only improve the quality of the product further.

6. Project Management

There are several factors that served as cornerstones for the management of this project, they are elaborated upon below.

Leadership Structure

Leadership of the team was passed between several individuals, each focusing on a specific task and level of progress at specific milestones. Our project was split into 3 major chapters, the 'interim report', 'prototype and field testing', and lastly, the 'final report'. In such a manner, the focus of the group was sharpened, allowing us to maximise the time spent at each meeting, to deliver independent work that contributed toward a collaborative effort that allowed us to complete each report or build the deadlines by our own internal deadlines.

Overcoming Obstacles

Technical difficulties with regard to product design were rife as our knowledge on certain fields was limited, but that did not mean that we were stifled in our progress. We sought out the opinion and input of our project supervisor, Dr. Simos Evangelou to gain better technological insight and practical input. This was particularly relevant to when we were initially planning on making a range sensor using SONAR technology, only to learn that the limitation of the sensor we had at hand was greatly inadequate for the task that we hoped to achieve.

Resolving Conflict

Naturally, there were instances of conflict within the group throughout the project. Anticipating this problem, we formulated a conflict solving strategy during our second meeting. We had laid out the ground rules and came to a common understanding: Firstly, there should only be professional criticism without personal attacks. Secondly, that conflicts that could not be resolved would be disputed with the input of our supervisor, Dr. Simos Evangelou.

Deliverables and Coordination

Through each and every stage, great emphasis was placed on the objectivity of our meetings and to ensure that deadlines and deliverables were duly completed so that the entire group could progress. We utilised the diagrammatic approach of the Gant chart (Appendix E) to track deliverables and set internal deadlines that contributed to the success of the project.
Each meeting we had was catalogued with minutes(Appendix F), that outlined the topics of discussion, participation as well as the actionable items that were to be completed before the next meeting. Our cooperation was greatly aided through the use of several tools for productivity. We used Google Drive as a platform to share all group inputs that allowed each member to work off the progress of each other.

7. Future Work

HoleHere

From our empirical testing alone, it was inconclusive that *HoleHere* would be effective for implementation as a real-world pothole detection and mapping system. And upon critical analysis, there are empirical data that we need in order to ensure of this. Firstly, the reliability of the ultrasound sensors needed to be ascertained, given that wind and the wheel's contact with the road would provide substantial noise. Secondly, we would like to have incorporated additional sensors that would take into account the natural oscillation of the vehicle's suspension so as to ensure that distance readings and pothole detection was always accurate. The above mentioned issues required in-depth mathematical modelling and detailed analysis testing in order to be successfully implemented. In spite of the lack of conclusive evidence, we still maintain that a system that is able to reliably map pothole data will be able to save many lives, and save motorists' lives and governments a great deal of money.

In order to reap the full benefits of our product, coordination with local communities and existing mapping services must be integrated. Hence, apart from the additional testing and components as mentioned in the previous paragraph, an acceptance study among developing communities with pothole laden roads should be conducted. One such example would be in the regions of Tamil Nadu in India. Yet, the acceptance of local authorities to implement such a system in their communities will be the the crucial point, for it is only through their support would there be a centralised system to which motorists can depend; Which would also allow the motorists to be assured that their governments are aware and can be held accountable for the maintenance of their road conditions.

Exploring Options

However, a more realistic aim exists to greatly simplify the design criteria that we had outlined. The only hindrance was the cost and complexity of the design. In the course of our research, we delved into stereo camera technology as well as pothole recognition algorithms through Haar Cascades. The latter included an algorithm that runs similar to facial recognition technology, whereby an algorithm begins to learn to recognise the key features of a face just by processing many many images of faces. The use of image technology disassociates ourself with the interference that may be caused by wind and external noise and greatly increases reliability. It also functions to meet our original objective of creating independent offline systems that could be implemented in cars that allowed drivers to be warned of potholes ahead of time and give them sufficient notice to evade danger.

This can be implemented using Raspberry Pi with an attached camera module, which will capture images from in front of the vehicle and will be able to identify potholes using algorithms similar to face detection. The principle behind the pothole detection is Object Detection using Haar cascade classifiers[]. It's a cascade function which is learns from a large number of positive and negative samples. This procedure involves the OpenCV program, which runs through large collection of positive samples (Images containing potholes) and negative samples (Images of roads that do not include potholes) to learn what a pothole might look like. The details of this operation are listed in Appendix ASDF.

However, such an implementation would then deviate from our intention of alerting authorities on the state of their roads, since such modules would be purpose built to be installed independently on vehicles without prior pothole detection technology, to serve as an early warning system.

8. Conclusion

From the design criteria we had chosen, the decision matrix we had used as a basis of comparison indicated that the Ultrasound Sensors would be the most suitable technology for us to formulate a pothole detection and mapping system. Yet, through the process of experimenting and prototyping we were faced with many challenges that disallowed us from fully realising the functions of *HoleHere* that we had sought out to achieve.

Despite rescaling the scope of our project to suit the financial constraints and technological limitations of Ultrasound Sensors, it makes clear that substantial background research was imperative in the preliminary stages. This would have allowed us to make a more informed choice about the selection of the sensor to be used. Not taking into account the empirical data we were unable to take, the baud rate limitations already indicate that the maximum speed at which we may record pothole information is about 5km/h, this greatly reduces the incentive to use such a system.

However, this does not mean that there is no potential for this implementation. It is still irrefutable that potholes are a major cause of concern for both motorists and governments, both from a social and fiscal sense. Hence we still maintain that the market exists for an intermediary to exist, to provide awareness for motorists and to hold governments accountable for the maintenance of their road networks.

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10. Appendices

Appendix A - Product Design Specifications

1. <u>Performance</u>

The focus for this product has changed from detection of potholes before hand, to detecting potholes and detailing the location of the potholes. This can therefore be used as a means to map new areas, or for rural areas to map potential problems for drivers. The most important thing about the performance of this product is that it detects the pothole, and that it records the location of the pothole. For this module to be efficient it will have to be able to work independently, and on battery power. The current model will be using a 9V battery, however in the future, a way of connecting to the car battery will be determined, so that it can easily be connected to any vehicle. The GPS coordinates are constantly taken, and when a pothole is detected, this coordinate is stored on the SD card. The locations can then be used to map the locations of the potholes and thus create a map of the terrain in the specified area.

2. <u>Environment</u>

The environment of our product is of great importance. The product will mostly be used in unmapped areas, as such it must be able to withstand many conditions, such as heat, cold, humidity, rain, and snow. The product should be able to withstand temperatures of -15 to 40°C, 0 to 4000 meters of altitude and 20% to 95% of humidity. Furthermore, the product must also be water proof. Since the main focus of the product is to map areas, and more importantly the location of potholes, it must be able to withstand the aforementioned conditions to effectively achieve its aim.

As far as environment footprint, the final product will have a minimal footprint. In the end it will be able to connect to the car battery, or through a USB connection in the vehicle, thus being completely green from a carbon footprint aspect. The product will be used outdoors, and as such should be properly protected from the conditions so that it can function optimally. This could mean placing a protective cover on the product as to protect it from rain and other precipitation.

3. <u>Life in Service</u>

The product is expected to be used approximately 2-4 hours per day for 365 days per year. This come from the estimate that the average working person has a job lasting 9-5 or another 8 hour window such as 8-4. In this case, during that time the driver will most likely not be using their vehicle. Next taking into account sleeping hours, and that a healthy sleep is around 8 hours, the product will again not be used from around 10-6 or 11-7. Thus the main time of use would be commuting to and from work, which depending on the distance, could be anywhere from 15 minutes to 1 hour or more each way. Thus this brings us to the approximation of 2-4 hours per day for 365 days. At least 3 years of full operation are expected.

4. Maintenance

The maintenance for the product should be minimal. Ideally, the only maintenance required should be the change of a battery. With this in mind the module should be easily accessible so that the battery may be easily changed. This will provide easy usability, and make the product more attractive to prospective buyers.

5. Target Product Cost

Considering the cost of parts required, the aim is to make the product as cost effective as possible. From our budget of a negotiable 50£, and our market research in which 60.5% of the people surveyed said they would be willing to pay around 20 – 50£, the target product cost is around 20-50£ with 50£ being the upper limit. This will provide a quality product, as well as an added safety feature for drivers.

6. Competition

Currently Mercedes has an automatic pot hole detection system offered on some vehicles, which automatically adjusts the suspension of the car upon detecting a pothole[22]. This however we do not consider comparable to our product since it is detecting the pothole in advance, and only adjusting the suspension, not taking into account the location of the pothole. Jaguar Land Rover [7] have also stated that they want to begin research on a pot hole detection system that will provide data about that location of the pothole and make it available to other cars after it has been detected. This is similar to our product; however, we want our product to be customisable to any car as an aftermarket enhancement. Furthermore, this is currently planned only for Jaguar Lan Rover and Jaguar vehicles, and so other drivers will not be able to benefit from this. Google was also granted a patent [24] in regards to mapping potholes. However, they have not commenced any further implementation. Furthermore, the Google patent uses the onboard GPS of vehicles in order to determine the location of potholes. For developing countries, this technology is not as readily available as it is in developed countries, and as such, our product will be more accessible to the populations in developing countries. Thus we are making an affordable product which is able to be attached as an aftermarket accessory, without the requirement for any new technology in the vehicle it is attached to.

7. Shipping

The product is expected to be relatively small and light, such that there should be no problems when delivering it. Since the majority of the product is electronic components, the best place for purchasing parts at a cost effective price is in East Asia. The product could also be assembled in East Asia, and then delivered to different continents through sea routes or air routes. The product should be safely packaged in multiple layers of protection as to withstand any possible drop during the transportation period. The product should also come out of the box being easy to install to the appropriate vehicle.

8. Packing

The device will be packed in a cardboard box. The packaging should be compact and easy to ship. There will not be any further requirements to protect the electronic components from humidity as the product will be water proof. The packaging will occur in China, after the product has been made. As with any product the packaging usually indicates the quality of the product. As such the product shall be well packaged so that upon arrival the user is delighted with the initial delivery.

9. Quantity

At this point, a prototype has been created. From our market research we can see that there is a demand for such a product. Approximately, 89.7 % of the people surveyed indicated they would find this product useful, and 60.5% said they would be willing to pay 20 - 50£. As such, initially 100 of the product will be made. However, these will be made in batches, and so after one batch is made, and sold, the next batch will begin being made.

10. Manufacturing Facility

The initial parts required for the product will be bought in bulk in China. Then they will be assembled at the assembly plant and then distributed accordingly upon being bought. The initial prototype was built using the facilities provided by the EEE department at Imperial College London.

11. Customer

The main customers will be people who travel in areas with poor road conditions and thus more potholes. This could include developing countries, countries with poor road conditions and people wanting to have an idea where potholes are. Furthermore, governments could also benefit from this product as this could help them better allocate infrastructure budgets, improve road conditions, and know where roads are in a poor condition.

12. Size

The product will need to be small enough as to not obstruct the vehicle it is attached to. Ideally the product would have a minimal affect on the appearance of the vehicle it is attached to.

13. Weight

The product will be as light as possible in order to minimally affect the vehicle it is attached to. Furthermore, this will reduce costs for shipping and thus make the product more affordable to be shipped and also purchased by the customer.

14. Materials

The materials used need to be resistant to outdoor driving conditions. This means that they should not corrode and be water proof.

15. Aesthetics, Appearance and Finish

The product will be made in such a way to be hardly noticeable on the vehicle. The final product will have a nice modern looking casing, which will provide protection against the elements as well as make the product look modern.

16. Ergonomics

The product needs to be easy to attach to a vehicle and placed at the front in order to easily be able to detect potholes ahead. Furthermore, there has to be an anti theft system included. This could mean a GPS tracking possibility, and a good attachment to the vehicle as to not be able to be stolen. The product should also be well fastened to the vehicle so as to not become loose and fall when driving on bumpy or non-ideal roads.

17. Standards and Specifications

At this stage, the product is not expected to conform to any standard. There were no standards found for pothole detection systems other than the previously mentioned competition's articles.

18. Quality and Reliability

The product is expected to detect potholes, and store their location on the SD card which can then be mapped for future use. The device is accurate with in the tested distance of up to 80cm. This was the tested distance as not many vehicle bumpers are higher than this off the ground. Furthermore, the product should be of a high quality as to not break easily during usage.

19. Shelf Life (storage)

The product does not have a maximum shelf life as the components involved do not spoil over time.

20. Testing

The product will be first tested on a scalable model of a car and if time and conditions permit tested on a real vehicle.

21. Processes

Currently, an Arduino compatible ultrasonic transducer is being used.

22. Time Scale

The time-scale for the current design and prototyping phase is 6 months. We have currently built a proto type in this time.

23. Safety

General safety standards regarding the electronic components and materials being used must be respected.

24. Company Constraints

The maximum budget for the current phase is 50£ (negotiable).

25. Market Constraints

The feature of pothole detection seems to be a topic of interest for car companies, and so we can be assured that this market will remain throughout the course of the project. Furthermore, the market research conducted indicates that there is an interest in such a product.

26. Patents, Literature and Product Data

Google has been approved for a patent for using the GPS in vehicles to locate potholes. However, we do not see this as causing troubles because our product is different, and is intended to be solely an aftermarket add on to vehicles.

27. Legal

Not Applicable.

28. Political and Social Implications

The acceptance of such a product could have positive implications to the general public helping reduce the number of accidents and injuries. At the same time, it could aid the governments in the proper allocation of budgets for infrastructure.

29. Installation

The product should be ready to use when opened. The only action required should be affixing it to the vehicle and turning it on. The product will be battery powered to make it simple for customers to attach to their vehicles.

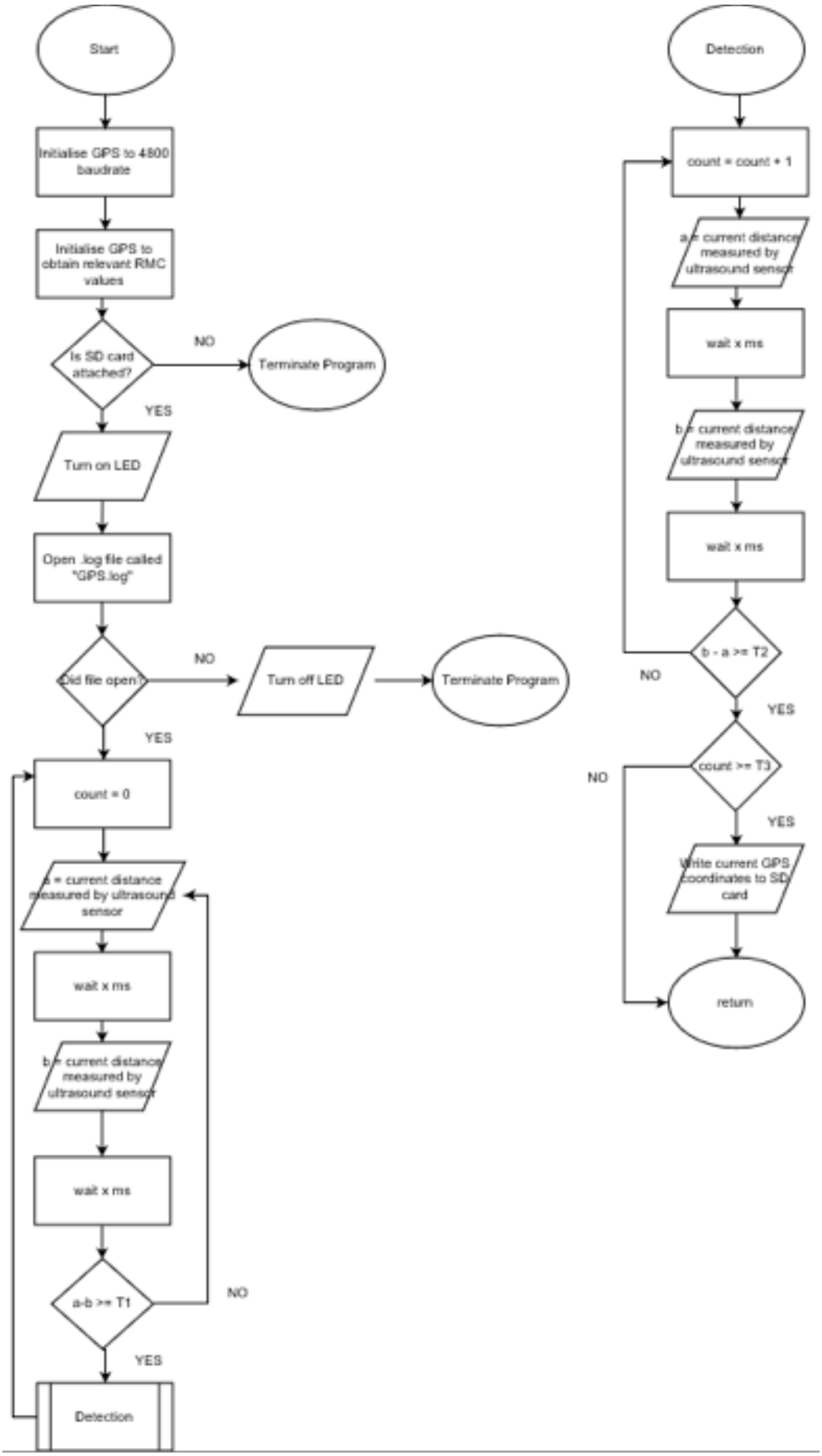
30. Documentation

An instruction manual needs to be produced along with the product providing detailed, graphic steps on how to attach the product to the vehicle bumper.

31. Disposal

The product should not contain hazardous or toxic parts. In case this is not possible, instructions on how to deal with them must be included. The parts containing metal must be collected as well as the batteries for safe disposal.

Appendix B - Flowchart for Detection



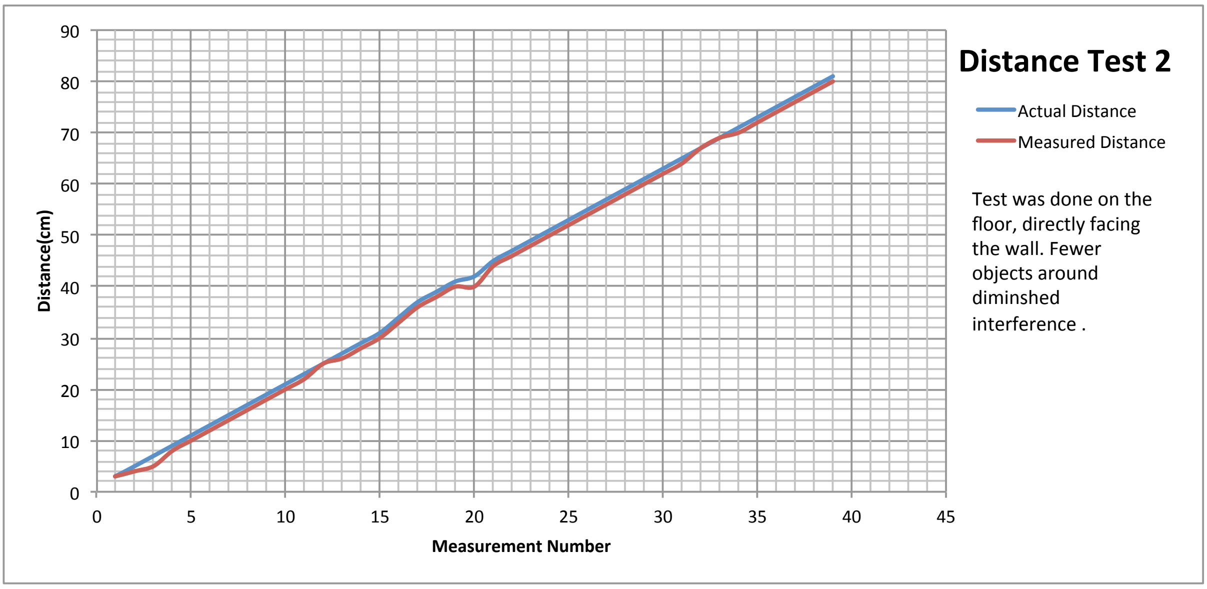
Appendix C - Arduino Code for Flowchart Implementation

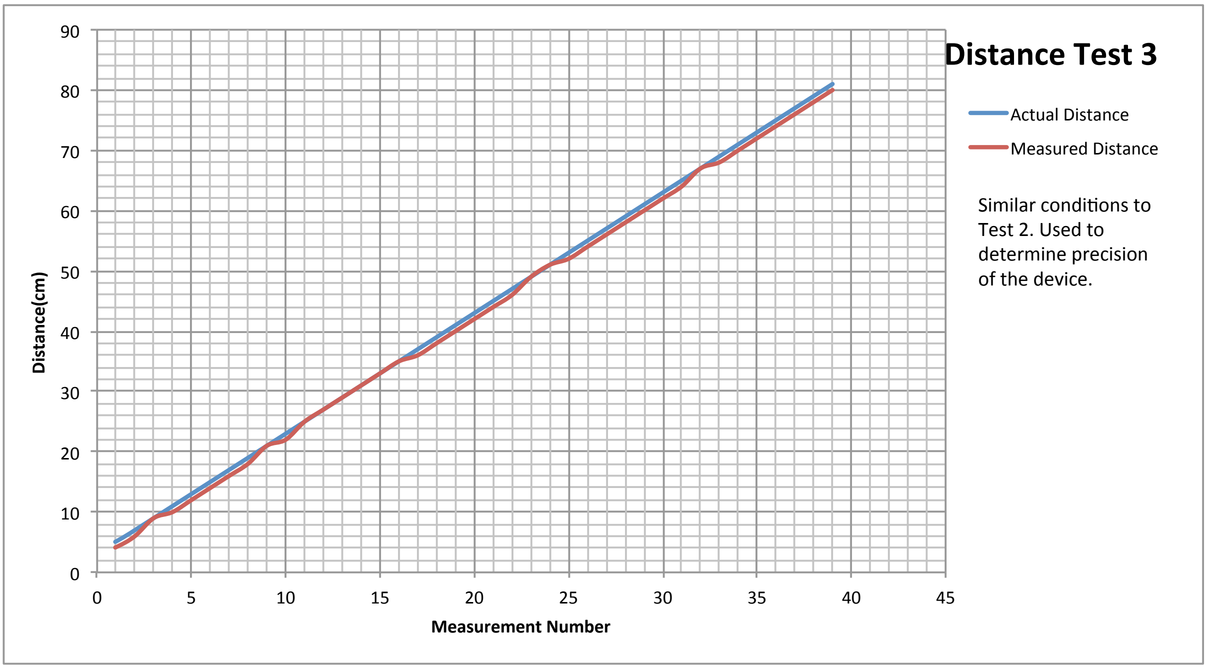
pothole_detect1

```
#include <Wire.h>
#include <SoftwareSerial.h>
#include <SD.h>
#include <SPI.h>
#define LED 8           // status LED for SD operations
#define BUFF_MAX 128    // size of GPS & SD buffers

File GPSlog;


#define LCD_RX              0x02                                    // Software serial pin for rx
#define LCD_TX              0x03                                    // Software serial pin for tx
#define SRF_ADDRESS         0x70                                    // Address of the SRF08
#define CMD                 (byte)0x00                              // Command byte, values of 0 being sent with write have to be masked
                                                                    // as a byte to stop them being misinterpreted as NULL this is a bug
                                                                    // with arduino 1.0
#define LIGHTBYTE           0x01                                    // Byte to read light sensor
#define RANGEBYTE           0x02                                    // Byte for start of ranging data
#define LCD03_CLEAR         0x0C                                    // Byte to clear LCD03 screen
#define LCD03_SET_CUR       0x02                                    // Byte to tell LCD03 we wish to move cursor
#define LCD03_HIDE_CUR      0x04                                    // Byte to hide the cursor

SoftwareSerial lcd_03 =  SoftwareSerial(LCD_RX, LCD_TX);    // defines a new software serial port for lcd_03

byte highByte = 0x00;                           // Stores high byte from ranging
byte lowByte = 0x00;                            // Stored low byte from ranging
const int pingPin = 7; //added now

void setup() {
   Wire.begin();
  delay(100);                                    // Waits to make sure everything is powered up before sending or receiving data

  Serial.begin(4800);

   pinMode(10, OUTPUT);   // Per SD library notes, pin 10 must be set to output
  pinMode(LED, OUTPUT);

  if (!SD.begin(4)) {        // SD card detected?
    digitalWrite(LED,LOW);   // turn off staus LED if SD detection fails
    return;
  }
  else   digitalWrite(LED, HIGH); // turn on LED if SD detection is OK

  GPSlog = SD.open("GPS.log", O_CREAT | O_WRITE);  // open/append to a file GPS.log
  if (!GPSlog) {               // test if file can be opened
    digitalWrite(LED,LOW);     // turn off status LED if file open fails
    return;
  }
  else digitalWrite(LED, HIGH);  // turn on status LED if file open is OK
}

void loop(){
  int T1 = 0x03;
  int count = 0;
  int a, b;


  while ((b-a) <T1){
   a = getRange();                // Calls a function to get range
  delay(50);               //wait for 0.1 of a second
   b = getRange();
  }

  if ((b-a)>=T1){
    detection();
  }

}
```

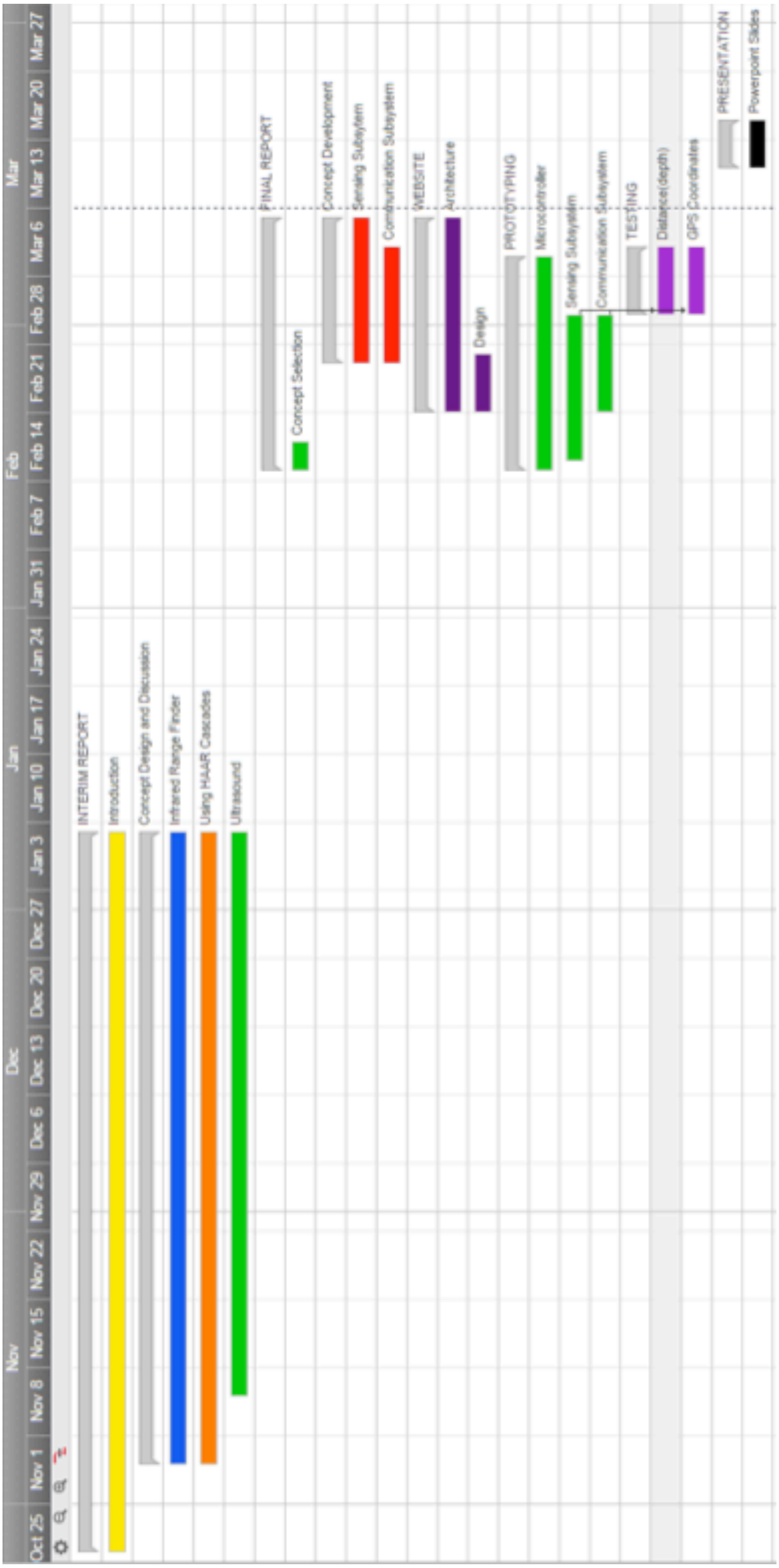
```
void writegpstosdcard(){
  char inBuffer[BUFF_MAX];     // buffer used to read NMEA lines from GPS
  byte outBuffer[BUFF_MAX];    // buffer used to write NMEA lines to SD card
  int sizeBuffer = 0;          // counter of how many chars per line

  while (Serial.available()>0)  // if serial data available from GPS
  {
    sizeBuffer = Serial.readBytesUntil('\n', inBuffer, BUFF_MAX);  // read one NMEA line from GPS until end of line
    for (int i = 0; i < BUFF_MAX; i++) outBuffer[i] = inBuffer[i];   // create CSV file on SD
    int j = 0;
    if (GPSlog) {
      GPSlog.write(outBuffer, sizeBuffer);  // write GPS NMEA output to SD
      GPSlog.print("\r\n");
      GPSlog.flush();
      digitalWrite(LED, HIGH);  // Keep LED on so long as SD logging is working.
    }
    else {
      // if the file didn't open, turn LED off
      digitalWrite(LED, LOW);  // turn LED off if writing to file fails
    }
  }

}
int getRange() {                                  // This function gets a ranging from the SRF08

  int range = 0;

  Wire.beginTransmission(SRF_ADDRESS);             // Start communticating with SRF08
  Wire.write(CMD);                                 // Send Command Byte
  Wire.write(0x51);                                // Send 0x51 to start a ranging
  Wire.endTransmission();

  delay(100);                                      // Wait for ranging to be complete

  Wire.beginTransmission(SRF_ADDRESS);             // start communicating with SRFmodule
  Wire.write(RANGEBYTE);                           // Call the register for start of ranging data
  Wire.endTransmission();

  Wire.requestFrom(SRF_ADDRESS, 2);                // Request 2 bytes from SRF module
  while (Wire.available() < 2);                    // Wait for data to arrive
  highByte = Wire.read();                          // Get high byte
  lowByte = Wire.read();                           // Get low byte

  range = (highByte << 8) + lowByte;               // Put them together

  return (range);                                  // Returns Range
}

void detection(){                    //checks to see wether the size of the pothole is as expected
  int count = 0;
  int a, b;
  int T2 = 0x03;            //ths represents 3cm
  while(((b-a) < T2) || (count < 1000)){
    count++;
    a = getRange();
    delay(50);
    b = getRange();
  }
  if(count >1000){
    writegpstosdcard();
  }
}
```

Appendix D - Graphs for testing on Ultrasound Ranging





Appendix E - Gant Chart



Minutes: 190216

In attendance: Andrei, Abba, Yemi, Yong, Florin
Absent: Petros

Points of Discussion:

1. Amendment of code to work the SRF08 sensor
    - Analysed the Arduino code to learn of how to implement the sensor capabilities
    - 2 different sensors on the board, light and sound, successfully implemented to get readings on the computer
    - **Conclusions**: Potential for implementation of lighting notifications for the driver, on top of pothole detection
    - **Follow-up**: Discuss

2. Testing of ranging sensor on styrofoam track
    - Sensor successfully noticed the drop in height when pointed at a decline of approximately 45 degrees
    - **Conclusions**: The sensors are functional
    - **Follow-up**: Research on the rate at which readings are taken

3. Real-world application discussion
    - Discussion on how the threshold value for the sensors should be set
    - If threshold is set such that drops or increases by a constant are registered, the system would then fail to take into account gentle inclines or declines as well as bends
    - Derivative of the readings should then be taken, so that only sudden changes are registered
    - **Conclusions**: The usage of 2 sensors, with one pointing slightly ahead of the other so that derivatives may be taken in quickly and to minimise error as compared to if one sensor did both jobs
    - **Follow-up**: Ask supervisor on the feasibility and professional opinion on the pros and cons of above mentioned implementation.

Minutes: 260216

In attendance: Andrei, Yemi, Yong, Petros
Absent: Sahil, Florin, Abba

Points of Discussion:

1. Final Report Discussion
   - Ascertained which parts of the report could be done while waiting for the prototype to come in
   - Delegated different segments of these ‘independent’ tasks to be completed by Tuesday (010316)
   - Decided on referencing style to be used throughout the report – Harvard referencing
   - Decided on research topics that need to be done and presented in the final report and the members to do them
   - **Conclusions**: To begin work immediately on the components of the final report which do not require data from the prototype
   - **Follow-up**: Present findings for these parts on Tuesday (010316), and decide on the coming tasks

2. Website Discussion
   - Petros updated that he has already been looking into the development of the website
   - **Conclusions**: Website will be checked and created with several generic headings so that we could fill in the content seamlessly
   - **Follow-up**: Show website

3. Final Presentation Discussion
   - Discussed about the demonstration aspect of the presentation
   - Decided tentatively that we would film the operation of our prototype
   - **Conclusions**: Need to decide on the testing parameters of the prototype and how to go about demonstrating it’s successful fulfillment of our design criteria
   - **Follow-up**: As abovementioned

To-do (By 010316):

Yemi	**Andrei**	**Florin**	**Petros**
Research – Road Statistics: 1. What is considered a pothole 2. Road Surface statistics 3. Where it is needed – viable application 4. Related Information	Report Writing: 1. Concept Designs Considered 2. Concept Selection (Including matrix) 3. Update version of PDS	Prototype Testing: 1. How we intend to go about testing the prototype 2. Identify the data that will be important for us to know	Website: 1. Put together the shell of the website with relevant headings 2. Check on the suitability of the designed website and the hosting on the Imperial server

Abba	**Sahil**	**Yong**
Prototype: 1. Update on the progress of the prototype 2. Fix the Prototype	Research – Product Components: 1. What components are in the product/prototype 2. The functionality of each product 3. How the system works – (Work together with Abba)	Report Writing: 1. Abstract 2. Introduction 3. Design Criteria 4. Appendix - Minutes

Minutes: 040316

In attendance: Andrei, Yemi, Yong, Sahil, Florin, Abba
Absent: Petros

Points of Discussion:

4. Final Report Discussion 2
   - Updated group members with the details of the marking scheme and how where each portion is to be found in the final report (Exact guidelines are found in the Google drive, or in the email marked 040316)
   - Delegated different segments of these independent tasks to be completed by Tuesday (080316) (Exact tasks in table listed below)
   - **Conclusions**: All independent reports and technical study of components to be completed by 080316
   - **Follow-up**: Remaining time between 080316 and submission deadline to be spent on fine-tuning the report and critical analysis of data retrieved.

5. Prototype Discussion
   - Abba updated that all the correct parts have arrived and will put together a functioning prototype by 080316
   - The GPS module will be attempted to be integrated but without promise
   - All components planned to have been integrated will be analysed and researched on and included in the final report to comprise the 'breadth of research' component
   - Florin will give detailed proposal on experiments to be conducted to retrieve relevant information on the prototype – which are to be used for critical analysis
   - **Conclusions**: Working prototype to be assembled by 080316
   - **Follow-up**: Commence immediate testing

To-do (By 080316):

<table>
<tr><th><u>Andrei</u></th><th><u>Florin</u></th><th><u>Petros</u></th></tr>
<tr>
<td>Report Writing:

1. Refer to the rough report outline</td>
<td>Prototype Testing:

1. Detailed proposal of testing procedure – Where, how

2. Craft experiments pertinent to a critical analysis of the product – Accuracy, dependability, speed

3. Future works – Our foray into the implementation of the camera and the recognition algorithm and justification as to why that is the way forward</td>
<td>Website:

1. Put together the shell of the website with relevant headings

2. Check on the suitability of the designed website and the hosting on the Imperial server</td>
</tr>
</table>

<table>
<tr><th><u>Abba</u></th><th><u>Sahil / Yemi</u></th><th><u>Yong</u></th></tr>
<tr>
<td>Prototype:

3. Update on the progress of the prototype

4. Fix the Prototype (MUST)</td>
<td>Research – Product Components:

4. What components are in the product/prototype

5. The functionality of each product – (Flowchart? Diagrams? Your decisions)

6. How the system works – (Work together with Abba)</td>
<td>Report Writing:

5. Future works

6. Project Management

7. Concept Development

8. Final report skeleton</td>
</tr>
</table>

Appendix G - Controlled Convergence Decision Matrix

Criterion	Ultrasound		Infrared		Haar Cascades	
Performance	The detection of potholes is most important. From the research and primary tests conducted this will be achievable. Furthermore, the location of the potholes must also be stored. From testing done, the location can be successfully stored on the SD card.	3	The detection of potholes is most important. Through the research conducted, this seems possible. However, the wave nature of infrared can be affected by the ambient light and other electromagnetic spectrum waves.	-	This option is different from the others. This is involving machine learning concepts, and thus will be more programming based. Through the research done, it sounds possible for it to detect potholes. However, implementing it with the knowledge we currently posses may be difficult.	-
Competition	The competition in this field is not very established. Companies like Mercedes and Jaguar Land Rover have implemented systems of detecting potholes ahead, and adjusting the suspension but not of mapping them. Google has been granted a patent for using the car's GPS for mapping locations of potholes, but many cars in developing countries still do not have the required technology. Thus this product has a bight future.	3	The competition in this field is not very established. Companies like Mercedes and Jaguar Land Rover have implemented systems of detecting potholes ahead, and adjusting the suspension but not of mapping them. Google has been granted a patent for using the car's GPS for mapping locations of potholes, but many cars in developing countries still do not have the required technology. Thus this product has a bight future.	S	The competition in this field is not very established. Companies like Mercedes and Jaguar Land Rover have implemented systems of detecting potholes ahead, and adjusting the suspension but not of mapping them. Google has been granted a patent for using the car's GPS for mapping locations of potholes, but many cars in developing countries still do not have the required technology. Thus this product has a bight future.	S
Target Product Cost	The cost of the final product falls under the negotiable 50£ budget we were given.	3	The expected cost is in the required range	S	The expected cost is in the required range	S

Criterion	Ultrasound		Infrared		Haar Cascades	
Size	The size of the product is acceptable to be able to be attached to the front bumper of a vehicle.	3	The size is expected to meet the requirements	S	The size is expected to meet the requirements	S
Customers	There are a range of potential customers for this product, ranging from motorcyclists, vehicle drivers and also the government.	3	There are a range of potential customers for this product, ranging from motorcyclists, vehicle drivers and also the government.	S	There are a range of potential customers for this product, ranging from motorcyclists, vehicle drivers and also the government.	S
Market Constraints	From the research conducted, there is a need for this product. Furthermore, our market research further shows us that there is a demand for such technology.	3	From the research conducted, there is a need for this product. Furthermore, our market research further shows us that there is a demand for such technology.	S	From the research conducted, there is a need for this product. Furthermore, our market research further shows us that there is a demand for such technology.	S
Installation	The installation should be easy to do. The module will be battery powered, and so it must only be attached to the vehicle to work.	3	The installation should be easy to do. The module will be battery powered, and so it must only be attached to the vehicle to work.	S	The installation should be easy to do. The module will be battery powered, and so it must only be attached to the vehicle to work.	-
Net Score		21		1		2
Ranking		1		3		2