Obstacle Detection Sub-System Requirements Specification (z3419283 – Alex Gee)

(To be read in conjunction with group System Wide SRS and Project Schedule - handed in by Luke Armstrong)

1. Scope.

1.1 Identification.

This document applies to the Obstacle Detection System (OD), a sub-system of the Automated Vehicle System (AVS).

AVS – Automated Vehicle System

- MF – Mounting Frame
- WC – Wireless Communications
- MC – Motor Control
- NM – Navigation and Mazing
- OD – Obstacle Detection
- LS – Location via Pozyx
- UI – User interface
- CH – RC Chassis
- OP – On-board power

On-board System Control Group – Name given to the group containing all of the on-board sub-systems required for the autonomous control of the AVS (WC, MC, NM, OD, LS)

1.2 Overview.

The obstacle sensing system shall utilise the HC-SR04 Ultrasonic sensor Arduino module to calculate the distance to any objects within its range. Using the location and Euler angles data from the Location System it shall then calculate the grid reference containing the object, and output this to the navigation system. This will allow the Navigation System to perform improved, more informed route planning.

1.3 Document overview.

This document shall outline the high-level sub-system requirements of the Obstacle Detection System (OD), which is a sub-system on the Autonomous Vehicle System (AVS). Each requirement will be given a unique requirement ID (AVS-OD-XX), a planned Verification method, Traceable requirements, rationale/explanation and the related states/modes. This document will then be used in the future to drive further low-level requirements setting and design of the OD, in order to meet the system level requirement statements of the AVS.

2. Referenced documents.

2.1 Stakeholder requirements:

2.1.1	Project Brief: Autonomous Indoor Navigation of an Unmanned Ground Vehicle	Version 1	Mar 2018

2.2 Autonomous Vehicle System Documentation

2.2.1	Autonomous Vehicle Requirements Specification	Version 1	23/03/2018
2.2.2	AVS Project Plan (Gannt Chart)	Version 1	23/032018

2.3 Other:

2.3.1	Arduino Uno Information Page		22/03/2018
2.3.2	DHT22 Datasheet		
2.3.3	DHT11 Datasheet		
2.3.4	TMP36 Datasheet		
2.3.5	LM35DZ Datasheet		
2.3.6	Obstacle Detection System - Theoretical Overview (Annex A.)		
2.3.7	Obstacle Detection System - Hardware Component Decision Analysis (Annex B.)		

3. Requirements.

3.1 Required states and modes.

Not used.

3.2 Function and performance requirements.

3.2.1 Obstacle Detection Range Requirements.

Requirement ID: AVS-OD-01	**Requirement Statement** The Obstacle Detection System shall detect obstacles inside the grid, to 95% reliability at a minimum of 10cm.
Verification Method Demonstration	**Verification Description** The ODS sensors' range shall be demonstrated on a non-integrated circuit (i.e. breadboard), by aiming them at an obstacle 10cm away 100 times and checking output grid reference matches required reliability. Once integrated onto the AVS the ODS shall be demonstrated while the AVS is both moving and stationery, by placing obstacles in known grid locations and confirming that the ODS outputs the correct grid reference.
Traceability AVS-22	**Rationale/explanation** The given grid space has grid squares with size of 50x50cm hence for the AVS to detect an obstacle in any box directly adjacent, when the AVS is located in the centre of the current box, the lower limit of 10cm allows for sensors to be offset from the centre of the AVS by up to 40cm if required.
States/Modes applicability: Not used	

3.2.2 Obstacle Detection Accuracy Requirements.

Requirement ID: AVS-OD-02	**Requirement Statement** The Obstacle Detection System shall detect obstacles within range to an accuracy of $\pm 24cm$
Verification Method Demonstration	**Verification Description** The ODS sensors' range shall be demonstrated on a non-integrated circuit (i.e. breadboard), by aiming them at obstacles at various known ranges and checking output distance is within limits.

	Once integrated onto the AVS the ODS shall be demonstrated while the AVS is both moving and stationery, by placing obstacles at various known distances and checking output distance is within limits.
Traceability AVS-22	**Rationale/explanation** The given grid space has grid squares with size of 50x50cm hence to accurately allocate an obstacle to a grid reference, the obstacle must round up or down to the correct reference.
States/Modes applicability: Not used	

3.2.3 Inputs Conversion To Obstacle Grid Reference Requirements

Requirement ID: AVS-OD-03	**Requirement Statement** The Obstacle Detection System shall convert inputs from the range sensors (distance to detected obstacle) and the Location System (current AVS location and heading) into a grid reference representing the location of an obstacle.
Verification Method Test	**Verification Description** Before full integration, the Location System and OD shall be interfaced in the test grid, with a number of obstacles at different known grid locations. The full system will be emulated by outputting the OD output grid references to a Serial Monitor, confirming correct locations from each of the sensors in their respective directions.
Traceability AVS-22	**Rationale/explanation** Once the ODS has received necessary inputs, this information must be combined in a useful way, i.e. to calculate the location of the detected obstacle.
States/Modes applicability: Not used.	

3.3 External interface requirements.

3.3.1 Interface identification and diagrams.

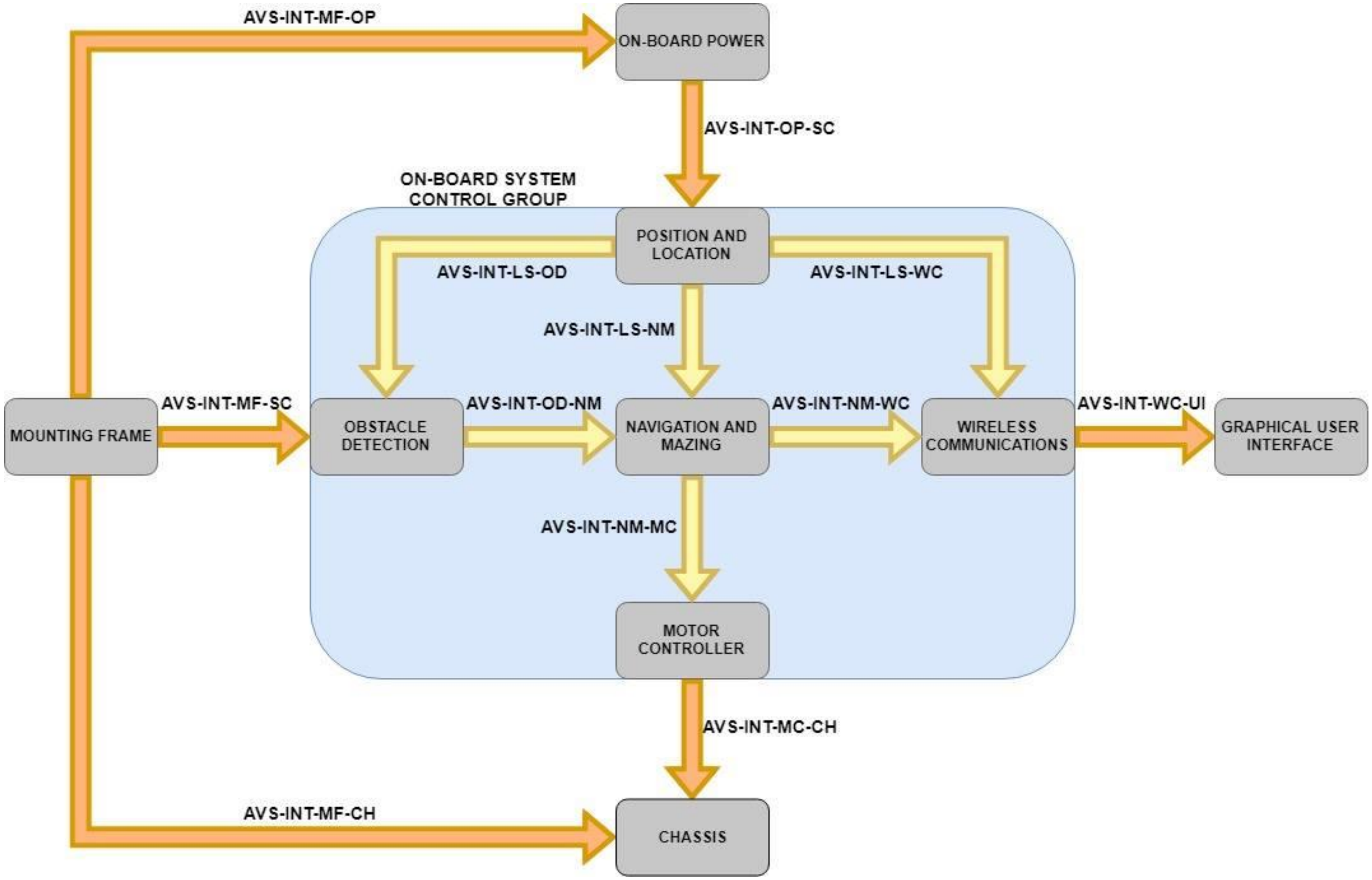

Figure 1: AVS Interface Diagram

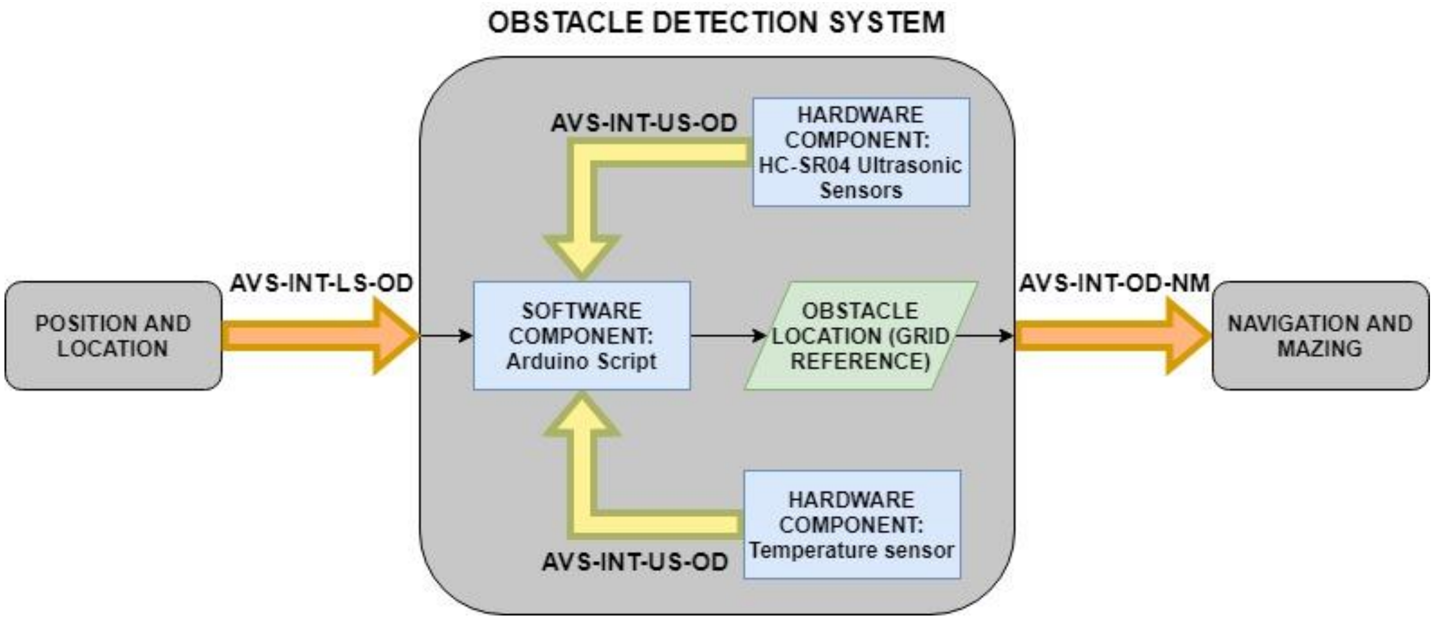

Figure 2: Obstacle Detection System Interfaces Diagram

3.3.2 ODS and Location System Interface (AVS-INT-LS-OD) – Current Location Requirements

Requirement ID: AVS-OD-04	**Requirement Statement** The Obstacle Detection System shall interface with the Location System receiving current location as an input.
Verification Method Demonstration	**Verification Description** Before full system integration, known input shall be fed to the OD to confirm it receives correct inputs. Upon full system integration, the same testing will occur to ensure geometry is correct.
Traceability AVS-22	**Rationale/explanation** For the ODS to correctly calculate the grid square of the detected obstacle, the AVS location inside the grid reference must be known in order to conduct the geometric calculations.

States/Modes applicability:
Not used

3.3.3 ODS and Location System Interface (AVS-INT-LS-OD) – Current Heading Angle Requirements

Requirement ID: AVS-OD-05	**Requirement Statement** The Obstacle Detection System shall interface with the Location System receiving current heading angle as an input.
Verification Method Demonstration	**Verification Description** Before full system integration, known input shall be fed to the OD to confirm it receives correct inputs. Upon full system integration, the same testing will occur to ensure geometry is correct.
Traceability AVS-22	**Rationale/explanation** For the ODS to correctly calculate the grid square of the detected obstacle, the AVS location and heading inside the grid reference must be known in order to conduct the geometric calculations.
States/Modes applicability: Not used	

3.3.4 ODS and Navigation System Interface (AVS-INT-OD-NM) – Obstacle Location Requirements

Requirement ID: AVS-OD-06	**Requirement Statement** The Obstacle Detection System shall interface with the Navigation System, outputting the correct grid references of detected obstacles to the Navigation System.
Verification Method Demonstration	**Verification Description** Before full system integration, and after the first stage testing of requirement AVS-ODS-03 is verified, the Location System and ODS shall be interfaced with the Navigation System and placed in the test

	grid, with obstacles at known locations, confirming that the in range obstacles are added to the Navigation System's obstacle list.
Traceability AVS-22	**Rationale/explanation** Once the ODS has calculated the location of the obstacle, it must output its findings to the navigation system for more informed route planning.
States/Modes applicability: Not used.	

3.3.5 Obstacle Detection System and HC-SR04 Internal Hardware Interface (AVS-INT-US-OD)

Requirement ID: AVS-OD-07	**Requirement Statement** The Obstacle Detection System shall internally interface with the HC-SR04 Ultrasonic Sensors to receive distance to detected obstacle as an input.
Verification Method Demonstration	**Verification Description** Before full system integration a Serial Monitor will be setup to confirm that the Arduino is receiving distance data from the HC-SR04.
Traceability AVS-30	**Rationale/explanation** Once the ODS has calculated the location of the obstacle, it must output its findings to the navigation system for more informed route planning.
States/Modes applicability: Not used.	

3.3.6 Obstacle Detection System and Chosen Temperature Sensor Internal Hardware Interface – IF REQUIRED (AVS-INT-US-OD)

Requirement ID:	**Requirement Statement**

AVS-OD-08	The Obstacle Detection System shall internally interface with the HC-SR04 Ultrasonic Sensors to receive distance to detected obstacle as an input.
Verification Method Demonstration	**Verification Description** Before full system integration a Serial Monitor will be setup to confirm that the Arduino is receiving distance data from the HC-SR04.
Traceability AVS-30	**Rationale/explanation** Once the ODS has calculated the location of the obstacle, it must output its findings to the navigation system for more informed route planning.
States/Modes applicability: Not used.	

3.4 Safety requirements.

Not used.

3.5 Security requirements.

Not used.

3.6 System environment requirements.

Not used.

3.7 System quality factors.

3.7.1 High Integrity C++ Version 4.0 Standards

Requirement ID:	**Requirement Statement**
AVS-OD-09	The Obstacle Detection System Arduino script shall be in accordance with the High Integrity C++ Version 4.0 Standards
Verification Method	**Verification Description**

Inspection	The script will be inspected at the mid-point and end of each milestone and compared against the Version 4.0 Standards documentation.
Traceability AVS-31	**Rationale/explanation** For the purpose of maintainability and usability, enabling other users to make changes in the future. It will also ensure efficient programming so as to fit on the 32Kb of Arduino built-in memory.
States/Modes applicability: Not used.	

3.8 Appearance and surface finishing requirements.

Not used.

3.9 Design and construction constraints.

3.9.1 Arduino microcontroller

Requirement ID: AVS-OD-10	**Requirement Statement** The Obstacle Detection System shall be implemented fully on the Arduino microcontroller (software and hardware components).
Verification Method Inspection	**Verification Description** The system will be inspected to ensure no reliance on any other hardware devices.
Traceability AVS-30	**Rationale/explanation** Requirement set by the stakeholder in order to allow for complete wireless operation.
States/Modes applicability: Not used.	

3.9.2 Battery constraints

Requirement ID:	Requirement Statement
AVS-OD-11	The Obstacle Detection System shall be solely reliant on on-board available battery for all power requirements.
Verification Method	**Verification Description**
Inspection	The system will be inspected to confirm all power is coming from on-board batteries (i.e. no attached power cables).
Traceability	**Rationale/explanation**
AVS-09	Requirement set by stakeholder in order to allow for complete wireless operation.
States/Modes applicability:	
Not used.	

3.9.3 HC-SR04 Ultra sonic sensors

Requirement ID:	Requirement Statement
AVS-OD-12	The Obstacle Detection System shall be solely reliant on the 3x HC-SR04 provided for obstacle detection.
Verification Method	**Verification Description**
Inspection	The system will be inspected to confirm that no other obstacle/distance sensors have been used.
Traceability	**Rationale/explanation**
AVS-30	Requirement set by stakeholder due to availability and budget.
States/Modes applicability:	
Not used.	

3.9.4 Arduino Compatible Programming Language

Requirement ID:	Requirement Statement

AVS-OD-13	The Obstacle Detection System scripting shall be in an Arduino compatible programming language.
Verification Method Demonstration	**Verification Description** The system will be run to confirm that the ODS scripts run on the Arduino.
Traceability AVS-30	**Rationale/explanation** The Arduino Uno is the microcontroller in use and hence the programming language and scripts must be compatible with this to ensure system works.
States/Modes applicability: Not used.	

3.9.5

3.10- Personnel-related requirements.

Not used.

3.11 Training-related requirements.

Not used.

3.12 Support-related requirements.

Not used.

3.13 Other requirements.

Requirement ID:	**Requirement Statement**
AVS-OD-14	The Obstacle Detection System milestones shall adhere to timeframes outlined in the Project Plan timings Gantt chart.
Verification Method Inspection	**Verification Description**

	At the end of each phase the milestones will be checked against the project plan to confirm timings have been met, and to confirm the timings of the next milestone.
Traceability	**Rationale/explanation** To deliver the final project on time, smaller milestones are required along the way to ensure progress is being made and the project isn't falling behind.
States/Modes applicability: Not used.	

6. Notes.

Not used.

A. Appendices.

A. Obstacle Detection System – Theoretical Overview

B. Obstacle Detection System – Hardware Component Decision Analysis

ZEIT4230 Engineering Design Practise (z3419283 - Alex Gee)
Obstacle Detection System - Theoretical Overview:

1 Hardware

1.1 HC-SR04 Ultrasonic Sensors

The HC-SR04 is the main (internal to system) hardware that the ODS will utilise. It has an ultrasonic transmitter and receiver module to measure the distance to an object within its range (2-400cm) [1]. Ultrasonic sensors send out an ultrasonic sound wave pulse, measuring the time taken to detect a reflection and using the known speed of sound to calculate the distance to an object. The HC-SR04 specifically transmits an 8-cycle burst at 40kHz as shown in Figure 1 and returns a pulse width equal to the time taken for a reflection to be detected.

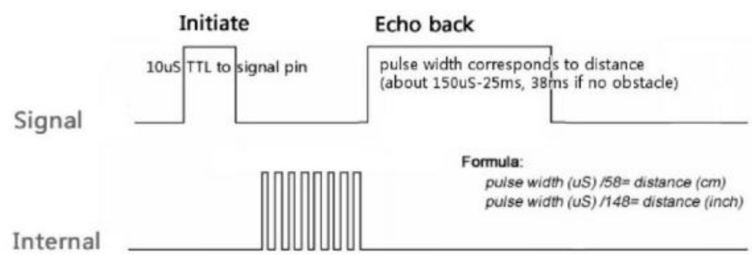

Figure 1: Operation Signals [1]

This reflection time is the time taken for the signal to travel from the transmitter, to the object and back again, and hence for one way distance d it must be divided by 2 as shown in equation 1.

$$d = \frac{ct}{2} \tag{1}$$

Where c is speed of sound and t is the pulse width.

Since sound tends to travel outward from the source in all directions, getting a narrow beam is inherently difficult. The expected angular performance of the sensor is shown below in Figure 2.

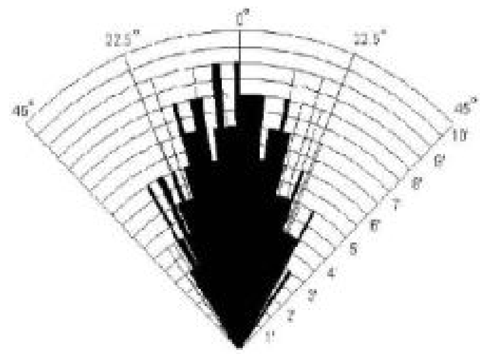

Figure 2: HC-SR04 Performance Results [1]

The beamwidth $\approx \pm 30°$, with a range of up to 400cm (i.e. 8x50cm grid squares), hence the sensor will pick up obstacles left and right of its front but it will be difficult to distinguish which box it is in. As an example some basic trigonometry shown in equation 2, shows $\approx$ 3 grids to the left and right of the forward box at the 300cm mark will be picked up:

$$\begin{aligned} \tan(30°) &= \frac{300cm}{x} \\ \implies x &= 300\tan(30°) \\ &= 173.2cm \\ &\approx 3.5 \text{ grid squares} \end{aligned} \tag{2}$$

This is shown in Figure 3

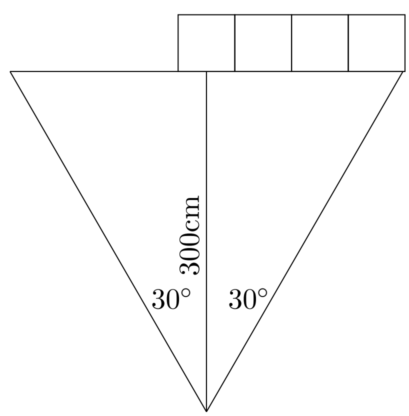

Figure 3: HC-SR04 Beamwidth

1.2 TMP36 Temperature Sensor

Based on the temperature dependence of the speed of sound (see Section 2) a temperature sensor may be required. A comparison of the various sensors found at core electronics can be seen below in Table 1.

Sensor	**Accuracy ($°C$)**	**≈ Error at 400cm**	**Cost**	**Notes**
DHT22	±0.5	±0.35	$13.18	Temperature and humidity
DHT11	±2	±1.41	$5.80	Temperature and humidity
TMP36	±2	±1.41	$2.18	
LM35DZ	±0.4	±0.28	$3.40	Supply Voltage: 4V - 30V

Table 1: Temperature Sensor Options [5], [4], [6], [7], [8]

The error has been calculated by combining equations 1 and 4, with a known distance of 400cm as shown below:

$$\begin{aligned} error &= d_{actual} - d_{measured} \qquad \text{Where:} \\ d_{measured} &= \frac{c_{measured} t}{2} \\ t &= \frac{2d}{c_{actual}} \\ c_{measured} &= 331.4 + 0.6 \times (T + T_{error}) \end{aligned} \tag{3}$$

Note: t = duration, d_{actual} = 400cm, $d_{measured}$ = calculated distance from error temperature, $c_{measured}$ = calculated speed of sound based on error temperature, c_{actual} = known speed of sound at $20°C$

2 Speed of Sound

The speed of sound changes based on the medium it is travelling through. For the purpose of this project the effect of temperature will be the main consideration and its effect can be found according to equation 4 below:

$$c = 331.5 + 0.6T \tag{4}$$

[3] At $20°C$, $c = 343m/s$ which can be used as a good estimate in simple circumstances, however if a higher degree of accuracy is required, temperature will need to be considered.

3 Trigonometry

To make the calculations of where the obstacle is relative to the sensors and in turn relative to the Location System device (POZYX), the following trigonometric functions must be understood:

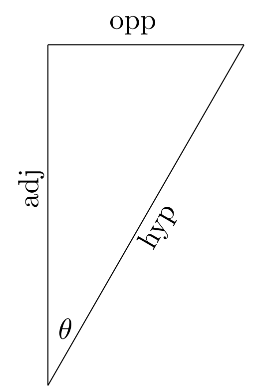

Figure 4: Right Angled Triangle

$$\begin{aligned}
\sin(\theta) &= \frac{opp}{hyp} \\
\cos(\theta) &= \frac{adj}{hyp} \\
\tan(\theta) &= \frac{opp}{adj} \\
hyp^2 &= opp^2 + adj^2
\end{aligned} \tag{5}$$

References

[1] Cytron Technologies Sdn. Bhd., 2013, Cytron Technologies, accessed 19 March 2018, <http://web.eece.maine.edu/~zhu/book/lab/HC-SR04%20User%20Manual.pdf>

[2] BBC 2013, BBC, accessed 19 March 2018, <URLofsite>

[3] Wong, C 2000, hypertextbook, accessed 20 March 2018, <https://hypertextbook.com/facts/2000/CheukWong.shtml>

[4] Liu, T Core Electronics, accessed 20 March 2018, <https://core-electronics.com.au/attachments/DHT22.pdf>

[5] Aosong Electronics, accessed 20 March 2018, <https://akizukidenshi.com/download/ds/aosong/DHT11.pdf>

[6] National Semiconductor, accessed 20 March 2018, <http://www.futurlec.com/Linear/LM35DZ.shtml>

[7] Analog Devices, Core Electronics accessed 20 March 2018, <http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Sensors/Temp/TMP35_36_37.pdf>

[8] Core Electronics, accessed 20 March 2018, <https://core-electronics.com.au/search/?fq%5Bcategory%5D=Temperature+%26+Humidity&fq%5Bcategory_id%5D=892&q=%2A%2A>

ZEIT4230 Engineering Design Practise (z3419283 - Alex Gee) Obstacle Detection System - Hardware Component Decision Analysis:

1 Sensors

1.1 TMP36 Temperature Sensor - Future Purchase (if required for error minimisation to meet limits or for optimisation purposes)

Requirement AVS-0D-02, the Obstacle Detection System shall detect obstacles within range to an accuracy of $\pm 24cm$ in order to allow for rounding to the correct grid reference. If this is requirement not initially met, or for other optimisation reasons to be determined, a higher level of accuracy may be required.

As discussed in the Theoretical Overview document, the speed of sound varies with different temperatures and humidities. To minimise this effect and allow the system to be accurate in a larger range of environments an on-board temperature and humidity sensor can be added to accommodate for this.

Table 1 below shows the range available at Core Electronics and compares them based on accuracy and cost.

Sensor	**Accuracy ($^{\circ}C$)**	**$\approx$ Error at 400cm**	**Cost**	**Notes**
DHT22	± 0.5	± 0.35	\$13.18	Temperature and humidity
DHT11	± 2	± 1.41	\$5.80	Temperature and humidity
TMP36	± 2	± 1.41	\$2.18	
LM35DZ	± 0.4	± 0.28	\$3.40	Supply Voltage: 4V - 30V

Table 1: Temperature Sensor Options [2], [1], [3], [4], [5]

Humidity: While the DHT22 and DHT11 sensors can measure the humidity, the effect of humidity in comparison to temperature is relatively small, and there is also no simple relationship between humidity and speed of sound. As such the humidity sensing part of these two is irrelevant in comparisons.

Accuracy/Error: As can be seen based on the accuracies, all of the sensors are able to produce a relatively small error (to the $\pm 24cm$ requirement) at the max range of the HC-SR04 sensors (i.e. under 2cm). This means that all four sensors are viable.

Cost: The cost of the DHT22 is relatively large compared to the overall budget of \$150 (almost 10%), while the TMP36 and LM35DZ offer the same or better accuracy than the DHT11 for a smaller price leaving them as the finalists.

Final Choice (budget-allowing) - LM35DZ
For a 33% cost increase (from $\approx$ \$2 $\rightarrow$ \$3) the LM35DZ offers a 75% accuracy increase and hence is the final choice (assuming the budget allows for the extra \$1 at the time of purchase).

References

[1] Liu, T Core Electronics, accessed 20 March 2018, <https://core-electronics.com.au/attachments/DHT22.pdf>

[2] Aosong Electronics, accessed 20 March 2018, <https://akizukidenshi.com/download/ds/aosong/DHT11.pdf>

[3] National Semiconductor, accessed 20 March 2018, <http://www.futurlec.com/Linear/LM35DZ.shtml>

[4] Analog Devices, Core Electronics accessed 20 March 2018, <http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Sensors/Temp/TMP35_36_37.pdf>

[5] Core Electronics, accessed 20 March 2018, <https://core-electronics.com.au/search/?fq%5Bcategory%5D=Temperature+%26+Humidity&fq%5Bcategory_id%5D=892&q=%2A%2A>