AdVanScan: Sensor Team

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Introduction

Optimising Royal Mail delivery routes and schedules is difficult due to a lack of data on the initial and real-time fill levels of delivery vans.

Currently, post-delivery questionnaires completed by van drivers are used to estimate fill levels. However, such methods are subject to low uptake rates and bias.

In this work we present a novel integrated system based on *depth sensor grids*, which reliably relay van fill levels in *real time*.

Approach: Depth Sensor Grid

Our approach implements an two dimensional grid of depth sensors attached to the ceiling of a delivery van. A one-dimensional grid is show in Fig 1.

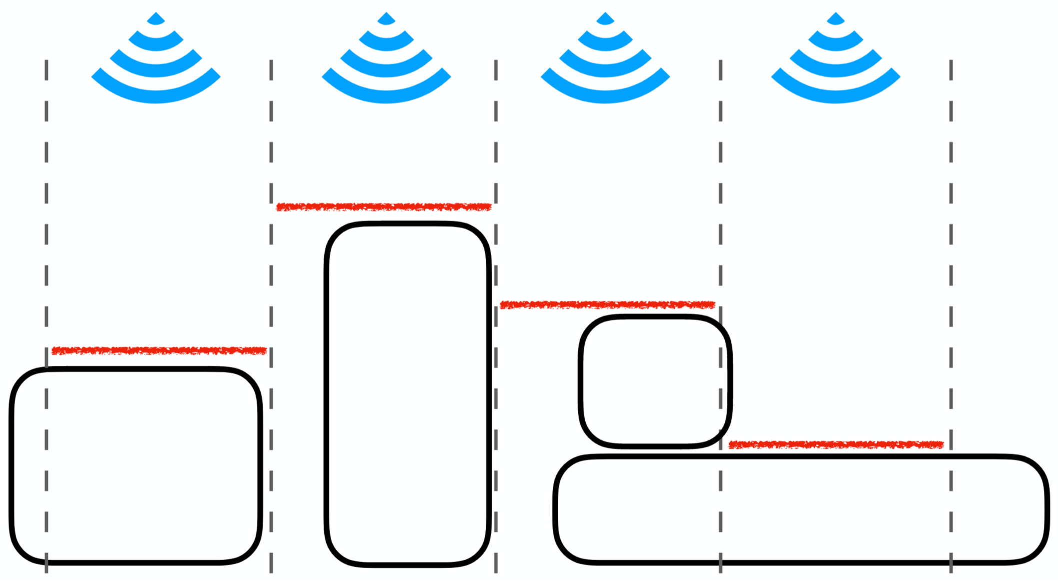

Figure 1: Sensor grid

Our implementation uses a 3×5 sensor grid. This resolution was deemed sufficient to achieve the requested error levels. This was determined through simulations using Unity as a rendering engine.

Challenges

- **Decreasing accuracy with the distance to sensor**—Sensor accuracy is good at short distances (i.e. a full van), however a tight field-of-view (FoV) is desired so that spurious readings are not encountered further away due to overlapping sensing regions.
- **Uneven surfaces**—Inaccurate measurements can be obtained if waves are not reflected directly back to the receiver. This could be mitigated by using enough sensors so that there is redundancy.
- **Resolution**—Tall narrow objects skew the readings heavily, when lower resolutions are used.

References

[1] ELECFreaks. *Ultrasonic Ranging Module HC - SR04*, July 2013. Available at `https://www.electroschematics.com/wp-content/uploads/2013/07/HCSR04-datasheet-version-1.pdf`, Rev. 1.

Acknowledgements

This project was proposed and supported by Royal Mail, EPSRC and Imperial College London. A special thanks to Jeremy Bradley and Ben Glocker for their support and advice throughout.

Hardware and Circuit Overview

To reduce cost, we decided to employ inexpensive HC-SR04 ultrasound sensors [1]. These sensors come in a small package with two control and two power signals necessary for proper operation shown in Fig 3. They are operated by applying a $10\mu s$ pulse on to the TRIG pin. An ECHO signal pulse is provided in return, with a duration directly proportional to the round-trip distance from the sensor. The behaviour of these signals is illustrated in Fig 2.

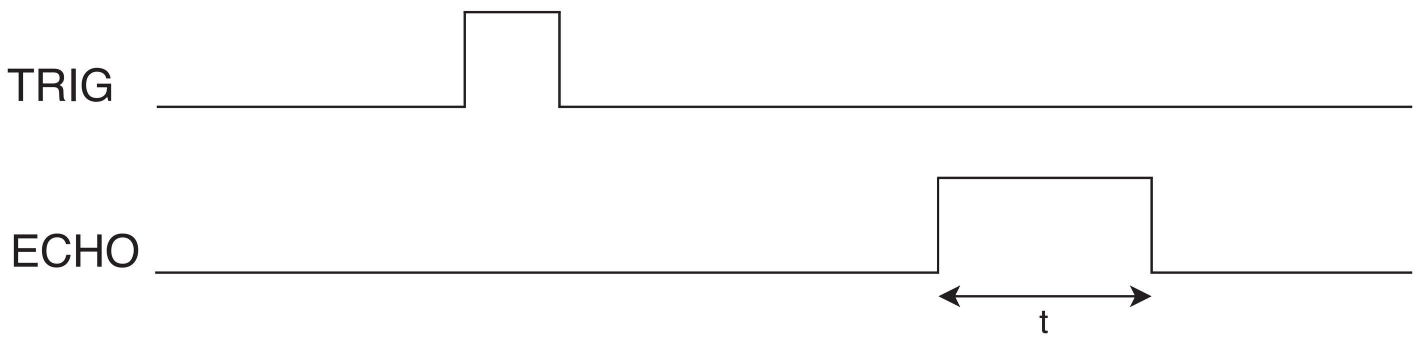

Figure 2: Control signals from HC-SR04 sensor package

Figure 3: HC-SR04 sensor package

After timing the pulse, t, the distance observed by the sensor is given by the following equation:

$$\mathrm{D(cm)} = \frac{\text{speed of sound(cm/s)} * \text{pulse time(s)}}{2} = \frac{34300 * t}{2}$$

We created a modular circuit using two 16:1 multiplexers, an array of sensors, as well as a Raspberry Pi. The Raspberry Pi is connected to the sensors by the multiplexers which implement individual sensor selection. This way, it only controls one TRIG and listens to one ECHO at a time. The simplified circuit diagram and physical implementation are shown in Fig 4.

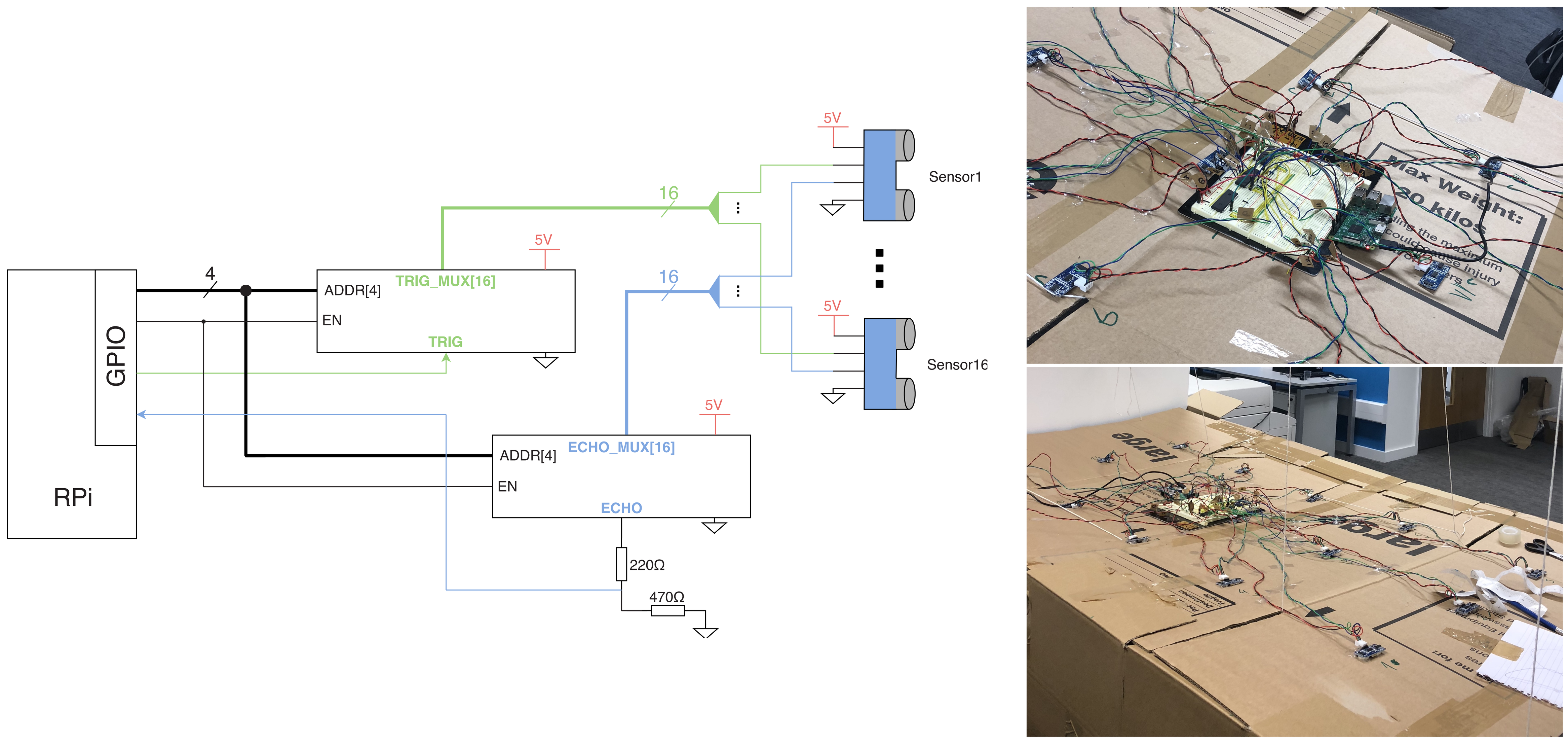

Figure 4: High-level overview of the circuit and physical implementation.

Procedure: Van Fill Estimation

The 15 sensors are fired sequentially and the distance measured by each is recorded. Sequential firing prevents interference between sensors.

Approach 1: Relative Percentage Calculation—The distances observed by each sensor in an empty van are recorded ahead of time. Each sensor measurement obtained when measuring a van fill is then compared to its baseline empty value and expressed as a percentage representing how 'full' that sensor's column is. The percentage fill for each sensor is averaged and this gives an estimate of the overall percentage fill of the van.

Approach 2: Polynomial Regression—A 4th order polynomial fit was used to address the non-linear relationship between the sensor readings and the true volume. The model was trained on 17 sensor readings for multiple van configurations with known ground-truth percentage fills.

Evaluation

- Both approaches were tested for 80 measurements across 8 different van fill configurations with known percentage fills.
- The relative percentage calculation achieved an average 10.5% error, whereas the polynomial fit was within 5.6% of the true volume.
- There is a clear tradeoff between the complexity and variance for the two proposed models. The polynomial fit can achieve a significantly lower error, however requires more setup time to collate training measurements for the different van sizes. Whereas, the relative percentage calculation uses a first order approximation that can be integrated into a new van through just knowing its dimensions ahead of time.