MULTI-SENSOR PEOPLE COUNTING FOR REMOTE SANITARY FACILITY MONITORING

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Abstract

This MPhil thesis has involved collaboration with iPoint Technology, a company working with the South African (SA) government and water board to find methods to help manage and estimate the amount of water used within sanitation facilities. This is achieved by logging the number of people that used these sanitation facilities over a period of time, supported through sensor-based technologies and subsequent analysis of data from these sensors.

Due to the limited availability of fresh and clean water in SA due to changing climatic conditions, water conservation is a key requirement for the government. The lack of water and the potential for an outbreak of disease have been heightened due to its geography and placement. SA has been looking at different methods to improve water conservation from public sanitation facilities, transport vehicles and sanitation tanks.

This research contributes to this emerging subject area, of interest to a number of other developing countries, in several ways including identifying Internet of Things (IoT) devices that would be used effectively to support this study. Physical and cyber security of the developed devices emerged as one of the key requirements within this study, alongside the benefits and types of data analysis, which could be supported. Users needed to be both safe and secure with minimal chances of theft or damage to devices and leakage of data from the devices that could compromise user privacy.

This work involves a comparison of different methods for conducting data analytics, such as the use of a cloud-based platform. It also involves comparing different methods to support people counting and identifying where to store information before sending it to a cloud platform. A key research focus is on the creation of data fusion by using multiple sensors to minimize false positives.

Throughout this work, there have been key contributions achieved whilst working with key limitations of the real-world location, internet signal and government regulations on the utilisation of cameras. The primary contributions of this research are as follows:

Novel Distributed Technique:

1.1 Background information

Developed and deployed a novel distributed technique, which can efficiently be used alongside edge computing for people counting. This test was able to achieve an accuracy of 96.2%.

Case Study Implementation:

Conducted multiple case studies based in a real-world setting to validate the proposed method of people counting.

Framework for Future Research:

Developed a robust framework, this can be taken by future researchers which can use the information and method to look more in depth at people counting without the utilisation of cameras further.

The contributions of this thesis provide a foundation for people counting and sending information to a cloud platform by working in a limited means of signal strength and speed.

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Abbreviations

Abbreviation	Full word/words	Description
SA	South Africa	Using the first two characters of the countries name to make it simpler to read.
DDoS	Distributed Denial of Service	A DDoS is a method of attack that is created by creating a flood of Internet traffic directed at a particular target. [67]
WI-FI	Wireless Fidelity	Wi-Fi is a wireless networking technology that uses radio waves to provide wireless high-speed Internet access. [68]
IoT	Internet of things	IoT is a system and connection of singular or interchanged computing devices. IoT devices can range from mobiles, smart watches to motion sensors. [69]
LoRa	LoRa - long range	LoRa is a wireless technology that offers long range, low power, and secure data transmission for M2M and IoT applications. [70]
LoRaWAN	low-power wide-area network	LoRaWAN is a networking protocol that has been designed to wirelessly connect battery-operated items to the internet in regional, national, or global networks, and targets key Internet of Things (IoT) requirements such as bi-directional communication. [71]
USB	Universal Serial Bus	USB is an industry standard regarding

		specifications for cables for multiple purposes between computers, such as transferring data, charging and so forth. [72]
PIR	Passive Infrared	A PIR is an electronic sensor that measures infrared light radiating from object

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Chapter 1 Introduction

1.1 Background information

This project has been focused on developing a novel distributed technique, which can efficiently be used alongside edge computing for the purpose of people counting. This was designed for it to be used in remote and rural areas with low bandwidth communication by utilising sensor-based technologies, near Thandanani in Kwazulu Natal, 16 kilometres west of Durban. Despite industrial and infrastructure advancement that most urban parts of the country have experienced, there are serious difficulties in many areas.

South Africa (SA) is an advanced nation, although fundamental aspects of modern economics such as the availability of electricity, clean water, housing, and other necessities remain beyond a large swath of the population [49]. In many areas, the legacy of apartheid has left key areas of infrastructure yet to be developed. In Thandanani informal settlement, two of the primary areas of concern for the population are [81]. Firstly, the limited access to fresh water. Although SA has had to develop a resilient water industry to cope with drought through reusing and cleaning used water. Clean water and toilet facilities are only easily accessible to a certain number of citizens, these ranges from 71% to 79% depending on where this information is sourced. [44, 45]. The shortage of water remains a problem in Thandanani. Water services are often in a precarious financial situation as there is uncertainty over the government’s ability to sustain funding levels in the sector.

Secondly, the poor local infrastructure in Thandanani has led to problems with sanitary facilities. Most of the population do not have toilet facilities in their homes. Therefore, the SA government uses portable toilets, and septic tanks to allow citizens the ability to use a toilet facility. However, due to the distance between each facility and the inability to properly maintain and manage those issues and problems can arise. [48, 50, 51]. This leads to problems including an increased potential of the outbreak of viruses and diarrhoea from not ensuring a high level of cleanliness. These issues are critical as when it was founded in 1996, the constitution of the republic of SA stated the following at chapter 2 Bill of Rights section 26.

1.2 Project Description

"Everyone has the right to have access to sufficient food and water." In order to give effect to this right Parliament has enacted the Water Services Act 108 of 1997 [73]. The purpose of this Act is to provide for the right to basic water supply and basic sanitation services. The research undertaken for this project helps to address this significant issue by providing a method to monitor the number of people entering a facility. This will enable an estimation of the amount of water being used, to ensure that supply can meet demand. It can also be used in multiple locations with only minimal changes required [45].

Having a level of industrial collaboration with iPoint; who provided mediation between the client and ourselves, we were able to gain a higher level of insight into the technical aspect of the task. This also allowed us to communicate with the stakeholder and staff to manage expectation and adapt to the changes in requirements.

Access to experience technical staff was extremely helpful since it allowed us to gain practical insights and real-world contexts provided by industry partners. iPoint directed us towards the use of the cloud platform; Davra, to see the accuracy and speed of data being gained and displayed in a simplified method. This has helped speed up the process of the project.

1.2 Project Description

Due to ongoing problems faced due to the location inside of SA such as sending data to a cloud platform and receiving commands from the cloud has high latency. Given that, they are dealing with an unknown amount of people. Mobile network connections are unreliable; therefore, any service using mobile network connectivity can be unreliable and therefore problematic. Finally, depending on external connectivity also opens up higher security risks meaning it can be more vulnerable to cyber-attacks.

The overall research aim from these problems is to develop a novel method of data fusion by using multiple sensors to minimize false positives finding a method to have information sent to a cloud repository by using robust devices that can be deployed, replaced, or upgraded. This information will be collected by using sensors instead of relying on a human counting the number of people using the facility; the information will then have an aggregate function conducted on it prior to sending it to the cloud. The overall aim and objective was to develop and implement a people counting system.

This would obtain result by removing the need for iPoint to send sensor data to the cloud constantly via a manual method. The on-board computer will conduct most of the data analytics by locally processing on the device followed by sending the summarised data to the cloud.

However, the proposed algorithms will consider context information when deciding where the data analysis should happen. iPoint has different sections of work on a large project which is explained more in Chapter 3 along with the different devices that can be used.

Regardless of it having different areas of work, it can address challenges that the company faces. Their overall aim is to develop a novel data processing architecture, which can transmit analytic data across different nodes; that can be found in the architecture structure. The overall objective of this document is for an accurate people counting method to be conducted in a rural and isolated location.

1.3 Research Objectives

To address the challenges faced by iPoint & the research objectives, the main aim is to develop a novel data capturing architecture that is capable of capturing analytics and sending it to a cloud platform. This means that iPoint will be able to send bundles of data that are collected by the device at specific times instead of constantly sending singular pieces.

The overall research aim of this project has been to:

- Develop a novel method of data fusion by using multiple sensors to minimize false positives. This will require devising a method to send collected information to a cloud repository by utilizing robust devices that can be deployed, replaced, or upgraded.

This information will be collected by utilising sensors instead of relying on a human counting the number of people using the facility; this information will be aggregated prior to sending it to the cloud.

The motivation has been to help manage and estimate the amount of water used within a rural location of Thandanani in Kwazulu Natal. This can be achieved by counting the number of people using a cleaning facility to estimate and gain insight into how much water is used. This was planned to help SA know when to provide both an empty septic tank and a water tank.

The following research questions will be addressed:

- Find the most appropriate sensor/sensor combination to capture data regarding the number of people using a facility.
- Determine the most suitable method to achieve a high level of data accuracy in regards to previously conducted work; this information was gained by looking at previous work in Chapter 2.
- Ensure that both the security and anonymity of all data collected is achieved.
- Ascertain the best method that efficiently and effectively transmits the quantity of information required.

There is an explanation in chapter 7 regarding each of these objectives. The onboard computer will conduct most of the data analytics locally and will only send the summarised/aggregated data to the cloud. The objective therefore needs to include reducing the data size to one, which can be sent to the cloud platform from a rural location.

This will be achieved by designing and developing a novel data processing architecture and method for people counting using IoT devices and sensors. The target is to ensure a prominent level of accuracy has been achieved, adding practicality to the utilisation of this approach.

The researcher will undertake the development of novel data processing architecture by creating and testing self-organised and reconfigurable IoT infrastructure that integrates resources from multiple layers such as edge and cloud. This needs to be used in unison with the IoT Davra platform, which was required by iPoint to meet their specifications.

The objectives of this research will be achieved by establishing which combination of sensors would be applicable to obtain a high level of accuracy and reliability. This will be verified by observing and comparing different methods of counting people and methods to both store and format the information before sending it to a cloud platform.

1.3.1 Devices

Below is a brief overview of the benefits, drawbacks, and specifications of the three main devices used during this thesis.

Raspberry Pi 4

Raspberry Pi is a single-board computer, which has three main benefits: low cost, large online presence/community, and a small size device. If any help is, needed using the device there is a lot of information online. It has been designed to be used easily, and quickly and it can effectively create prototypes for a multitude of different projects. This allows the ability to evaluate and create applications, which will work in tandem with multiple types and quantities of sensors such as a camera and an infrared sensor [76].

Arduino board

Arduino is an open sourced electronics physical platform, these boards are simple to use but can be difficult to master, due to the multitude of sensors that can be used with it. Arduino was initially created as a "tool for fast prototyping, which was aimed at students without a background in electronics and programming." (Arduino docs. 2021.) As soon as it reached a wider world, the Arduino board started changing to adapt to new needs and challenges, differentiating its offer from simple 8-bit boards to products for IoT applications, wearables, 3D printing, and embedded environments. Over the years the Arduino board has been used in a large number of projects, ranging from everyday objects to complex scientific instruments [77].

Grove kit

The Grove kit is a connection prototype system that is modular and standardised. It utilises a building block approach to connect and assemble electronics specifically made for it, which, allows for easier physical connections to work with and build compared to traditional wired, and solder based approaches. The Grove system consists of a base unit and numerous modules with standardised connections which allow ease of use. This kit, however, requires the inclusion of a Raspberry Pi to make it useful and practical; using a Grove kit helps ensure that connection to sensors and other devices is more secure, compared to a standard breadboard connection [78].

1.3.2 Requirements location

This section was made to explain the use of Edge and to give a brief overview of what Edge devices are and can achieve.

1.3 Research Objectives

EDGE

An Edge device is a piece of equipment that serves the purpose of transmitting data between the device, local network, and the cloud. They can transmit and change data format between different protocols, in the local devices and into the cloud where the data will be processed. Local devices use protocols like Bluetooth, WI-FI and LoRaWAN. This is needed for sending the collected information to the following platform: cloud. This is necessary since looking at the data that has been collected, actions can happen accordingly to better the situation in the general area.

The cloud is a term that is used to describe a global network of servers. The cloud is not a physical item, but instead is an electronic system commonly with a vast network of remote servers, which are linked together and meant to operate together. These servers can be made and designed to store and manage data, and run pre-set applications, which can be overall beneficial for this project to manage data that has been, collected [75].

The company that owns the cloud; due to there being multiple, needs to ensure they follow key laws such as GDPR [79]. This means that the company will need to ensure they have a prominent level of cybersecurity meaning that iPoint will not need to include a high level of security to their device. Yet, it would still be prevalent to have a standard level of security in place for the devices to communicate with each other.

For this work, the information that has been obtained needs to be sent to a cloud platform, this being the Davra platform. This needs to be simple to understand and accurate, by using this cloud platform the information will be safe and more accessible by going to one website instead of the physical locations. Also, the information can be displayed in multiple methods instead of only text and numbers, graphs and charts can be automatically made from the information that has been collected.

1.3.3 Document layout

This document has been broken down into the following sections:

Chapter 2 Literature Review

This literature review considers documents that evidence different methods for people counting. It assesses the sensors deployed, the locations and the technical setups for individual and multiple sensors. It was evident that many different approaches needed to be considered to obtain a solution in the given scenario.

Chapter 3 Problem and Requirement Gathering

This chapter is focused on listing and explaining the problems and requirements that have been gathered throughout this work.

Chapter 4 Analysis and Design

This chapter works off the previous chapter that listed the potential methods and measures to help rectify the problem and meet the requirements.

Chapter 5 Implementation, testing and scenarios

This chapter is focused on theoretical scenarios and how certain sensors could work to achieve the desired objective, it has been broken into a total of three scenarios looking from a best case to the worst regarding the location's integrity and access points.

Chapter 6 In The Wild Evaluation

This chapter looks at the tests done in the wild, meaning in real world location testing, the preparation for it and having different sensors working together. The purpose of this is to find and show, which group of devices will gain a higher level of accuracy, by utilising graph images to compare which has collected the most relevant amount.

Chapter 7 Conclusion and Reflection

This chapter is focused on the conclusion in regard to the overall project that has been completed thus far. It will also look at the practicality and achievability followed by reflecting on the project currently in regards to the overall thesis.

Chapter 8 References

This chapter is where all references used in this thesis have been listed linking to the work and research that has been conducted by other people to ensure they are given the correct credit since their information has been used.

Chapter 2 Literature Review

2.1 Introduction

In this chapter, an overview of previous work and developments in the field of electronic people counting is presented, showing usability and practicality. This is followed by a detailed examination of information from previous studies conducted by researchers in a similar field of people counting, and current popular methods of people counting confirm that this can be broken down into four distinct perspectives.

1. Single sensors,
2. Multiple sensors,
3. Alternative and uncommon sensors,
4. Utilisation of cameras

The key issues are the levels of accuracy that can be achieved using a key sensor or sensors. Software engineering approaches have been used to ensure a high level of accuracy, but other factors such as weather conditions and sensor locations must be considered.

Based on this, it is concluded that a stable design method must be focused and meet the needs of viable and technical aspects, such as detecting a human, counting them, and having the information logged and sent to the cloud platform. Many of the papers in this literature review use the cloud platform to store data; however, they choose various methods to display the results in visual and table formats.

2.2 Overview

An increasingly large amount of data in the human environment has been collected by companies, industries, and educational facilities. Key factors, such as in [1], were the key placement of the room they were working in. Key aspects needed to be monitored, such as air temperature and humidity, to ensure that the conditions of the room were logged. The most basic and ubiquitous form for this information to take is to count the number of people in any location.

In general, people counting is listed in the field of Multi-Object Tracking and Detection (MOTD), as explained by N. Cahyadi and B. Rahardjo [20]. This has been beneficial to many subjects, such as, but not limited to, business and security since methods of detecting and tracking have been used to analyse human behaviour. The use of sensors has been vital in the development of multi-object detection and tracking. These sensors can be designed with different methodologies for detection.

There is generally a large amount of research on this subject, regarding the use of sensors to count people. This has demonstrated the increasing importance this form of monitoring has in societies across the globe. According to [25], sensors have been used in key areas of research, such as identifying the number of people in a room.

Some examples of these sensors include but are not limited to, the following:

- PIR, motion detection sensor.
- Ultrasonic, using sound waves for detection.
- IR infrared red, which uses lasers to detect someone, is seen by the laser being broken.

Due to the multitude of different sensors and the different environments and variables in which they are deployed, it is important to make the correct choice for the sensor and placement.

For example, a PIR motion sensor will be more appropriate in a scenario such as the monitoring of underground passenger train numbers, as this will not be affected by wind drag from tunnels, compared to an ultrasonic sensor, which will be highly impacted by sound waves and wind movement. In many situations, multiple sensors working together is the best way to ensure a high level of accuracy will be achieved.

This literature review has examined papers from a variety of different situations and sources, such as different universities and students, which have used sensors to count and monitor the number of humans entering and exiting a location.

This analysis has revealed the most accurate sensor types and positioning in different situations. This information helped in the development of this project by providing evidence of factors that will influence accuracy and create awareness of some of the more unusual solutions and options available.

2.3 Single sensors

Most of the papers that have been read have chosen to deploy single sensors. This could be due to many factors, including cost and ease of deployment. The primary goal is to achieve a high level of reliability, accuracy, and practicality. From reading these documents, cost effectiveness is a common benefit of using a single sensor, as explained by

N. Sugumaran, G. V. Vijay, and A. Devi in their work [2] that a decent method of people counting would require an expensive security system to be used, whereas their study shows there are alternative methods for people counting. Cost is a key factor for this project, as it is being deployed in an area of poverty.

Other papers, such as [21], have highlighted that single sensors are simpler to deploy compared to utilising multiple sensors. They deployed their sensor on doorways, which is a similar situation for this project. The use of a single sensor can provide a high level of accuracy and practicality, even in a crowded situation. The table below shows results from [33] gained using a single IR sensor in a crowded corridor.

Table 1 Single sensor test conducted result

Method	Correct	False positive	False negative	Total	Accurate rate
Direct clustering	270	3	41	314	86.9%
Simple classifier (Head-shoulder detection without SVM)	292	11	11	314	93.0%
Head-shoulder detection with SVM (proposed method)	300	7	7	314	95.5%

(Z. Chen, W. Yuan, M. Yang, C. Wang, and B. Wang 2016) [33]

The accuracy levels that were achieved were high, but performance is enhanced by the addition of software engineering through support vector machines (SVM). In this project, an SVM was considered at the initial stages; however, the application node RED, which was chosen for this project, did not allow for an SVM. The accuracy obtained without the additional time to create the SVM was satisfactory for this project.

From the information shown in [33], it is clear that an IR sensor alone is a highly accurate device, and it was an option chosen for this project. However, IR is unable to detect if the item breaking the line is human or if it is an object that obstructs the beam. Therefore, other additional solutions needed to be considered to help ensure accuracy when counting people.

2.4 Multiple sensors

The papers considered in this literature review have also suggested the use of multiple sensors, such as multiple laser sensors, which can affect the level of accuracy. Depending on their function and placement, they can work in unison, providing complementary information. An example is the sensor combination deployed by Chen in [33], which was able to identify the number of people seen by the sensors regardless of whether there was more than one person passing at a time. They have found the accuracy level to be about 95% for people counting and direction detection.

This has demonstrated that the use of multiple sensors can be beneficial to the level of accuracy achieved by having the sensors work in tandem. Nevertheless, their results were based on in lab experimental processes rather than in the field. They have not mentioned any consideration of variables, including object barriers and environmental factors. Another method to count people with the use of multiple sensors is shown by Khan and Ali [3]. They deployed a system using IR along with ultrasonic sensors on a Raspberry Pi to count the number of visitors. This system included an ongoing announcement of numbers. Lab experimentation with different numbers of people entering and leaving the room was undertaken. They concluded that using radar-based human detection has an over 80% detection probability with a 1.58% falsehood. However, factors such as speed, proximity, and load carrying affected the levels of accuracy. The announcement aspect was not required for our project; however, the use of Raspberry Pi was an accessible and low-cost solution.

Some of the papers reviewed have used multiple sensors for counting people, followed by using another type of sensor for transmitting the collected information. This two-stage approach was used by Viriyavisuthisakul et al. [8] They were monitoring numbers in a queue by using a USB camera to collect data which was connected to a Raspberry Pi to allow the information to be sent to the cloud platform.

Another option for using multiple sensors was to conduct more in-depth and accurate tests by having two sensors work in tandem. This was done in [16] by Teklu Urgessa et al., who used two paired laser sensors in a laboratory that were connected to an Intel Edison board and found that the sensors were able to detect people entering and exiting through the door. This was an accurate system, but for this project, the Intel Edison board would have been too costly as compared to the Raspberry Pi.

2.5 Alternative and uncommon sensors

Alternative sensors, such as an Xbox 360 Kinect device which was used in two separate documents, one of these studies used it [26] showed there is a multitude of device types for people counting, such as vision sensor, infrared sensor, ultrasonic sensor, and depth camera.

Due to the Kinect device’s specifications and capabilities, it is not commonly used. This sensor makes a scanned approximation of a human body structure. It operates using a camera. Some of the tests that were conducted on its effectiveness showed it does have uses. When positioned looking down at people’s heads, it can count reliably, accounting for several variables, as looked at in [26], such as an individual’s height, speed of walking, proximity to another, and many other variables. Their paper also evaluated the device with people moving at a quick pace. Volunteers ran past the sensor and the system still successfully tracked and counted each person.

This shows that the Kinect, even though it is uncommon, is capable of quickly and accurately counting the number of people passing by it. This suggests that the device would be usable and useful for people counting. Its use of grayscale through a monochrome depth sensing video stream enables it to account for height and distance variation.

However, even though it has a depth sensor, the information is gauged from a VGA resolution of 640×480 pixels. It only has 11-bit depth and provides low sensitivity at 2,048 levels of sensitivity. These low specifications are a major limitation of the device, affording it limited flexibility beyond its original design intention.

Therefore, it will not be used for our project; nevertheless, the process of using an alternative device demonstrated that it is useful to consider devices that hitherto may have been disregarded.

2.6 Utilisation of cameras

A common and widely used approach for people counting and identifying them is by using cameras, either singular or multiple. This has been looked at in depth in [12]. Multiple surveillance methods are required for the detection and tracking of people. Camera tracking is ubiquitous in modern living.

Cameras with the purpose of counting people are often seen in specific locations, such as getting on and off a bus [27] or accessing a building. It is evident that because most modern societies are accustomed to surveillance through the use of cameras, this would be easier to use and less of a concern for people.

Viriyavisuthisakul et al. [8] developed automatic queue monitoring using a low-cost IoT sensing platform. They achieved an accuracy level of 95%. Along with the cameras, they used Progressive Block software to measure the number of people in the queue.

Using specialised software, a camera can be “trained” so that it is capable of identifying and listing people, animals, and other items. This is beneficial since it meets the project needs of counting the number of people using the bathroom. Due to its rural and open location, several animals may wander into the space; therefore, it was important not to count everything that entered and left. Regardless of how demanding this sounds; it is quite commonplace to distinguish between humans and other sources of movement. As explained in [14], people counting is commonly used for video surveillance, security, and statistical information. Counting people in a clustered scenario is challenging for many sensors, but a camera can be configured to overcome many of these problems. A deep learning technique trains the camera to be fit for the needs required and has proven to be of great success with object detection and classification.

As with the utilisation of sensors, cameras could be placed in multiple locations and viewpoints, including overhead, in front, and at incline [14]. Depending on the angle, key information on people counting can be achieved while also ensuring anonymity.

As shown in the paper [5] entitled Top View Person in Detection and Counting for Low Compute Embedded Platforms, it was possible to monitor a small area from an overhead view and count the number of people passing through the monitored area. With this, it is possible to obtain an accuracy of 97% at only 20 fps. As good as this result is, this study was only conducted in a small area, and this lack of specific measurement of the area monitored makes the set-up difficult to evaluate thoroughly.

However, its value in large-scale real life situations may be limited, although they did evaluate in 11 different locations. The light source of the location could also affect results, as looked at by [5] in their study. Due to key events such as the change in the level of illumination, the overall accuracy level can change.

They placed a single USB camera in a real life location to view and count people. They used a LINE Notify approach, whereby if the line were crossed, the person would be counted. This was an easier method than simply identifying a person by their head. They did manage to achieve a high level of accuracy with a relatively substantial number of people present, as [8] looked at in their work. In their study, they were able to achieve an average accuracy rate of 95% for 42 people being seen. However, this method can be subject to limitations, such as some false positives triggered by sudden changes in the lighting. From the literature regarding camera solutions, it appears key factors such as consistent lighting are essential [8]. Finally, one crucial factor to plan for, as explained in [12], is the knowledge and planning around a site’s geometry and the specification of the camera to be used.

Camera location determines what information will be obtained from both that location and its placement. The need to ensure that the information that is obtained is accurate and relevant requires prior knowledge of the site, including an awareness of the footfall as well as the type of camera being used.

2.7 Findings and outcomes of the literature review

The papers considered in this review of literature have demonstrated many different solutions to the problem of people counting. Many of the papers reviewed have obtained a successful solution, all with different technical methods. This yields a varied number of results depending on positioning and the types of sensors used.

From the information obtained from each study, they obtained a successful solution to the problems they encountered. From this, there are a wide variety of single sensors available, especially in terms of ease of use and cost efficiency, but by having multiple sensors, we are able to achieve better accuracy. Sun et al.'s [12] point regarding the knowledge of the particular site specifications is also a key consideration for this project. They wanted to keep in mind and plan to ensure the robustness of the device and how it may be received by the general public.

The following is a breakdown of reference numbers 3, 8, 26, and 33, since they were the most prominent in this literature review. In the work conducted by Khan et al. [3], they worked on a Raspberry Pi 3 model B that was connected to two ultrasonic sensors along with two LCD displays to show in real time the number of people seen. They have explained their method of work and showed how they have achieved a human detector which has better than 80% detection probability with only a false positive of 1.58%. The researchers evaluated different distances for the sensors to work and concluded that 30 cm from the sensors would be the most ideal for detecting a person passing by the sensors at a speed of 5 km/hr. From this thesis from their research, I could get a better idea of different sensor combinations due to them explaining the accuracy that can be achieved from different sensors such as IR and Ultrasonic.

The method of meeting their requirements for Viriyavisuthisakul et al [8] was by using a Raspberry Pi 3 model B with Raspbian and a USB webcam that was able to see at a 60-degree angle using the OpenCV library. The processing frame rate is 8.45 frames per second with a 320×240 video resolution. The total cost of their system was claimed to be less than $200, which is exceptionally low in comparison to off-the-shelf systems. They have done an in-house test with 42 people and were able to gain an average accuracy rate of 95% regarding counting the number of people and 86% regarding the alerting process. The main problem with this method was the chance of false positive alarm errors, which happen with sudden light changes.

The work that has been conducted by Coskun et al. [26] used a Kinect sensor for their work, which captured vision data from the device's camera. The sensor was attached to a ceiling facing down; this allowed the sensor to count people. The Kinect sensor camera has a resolution of 640 × 480 pixels with 11-bit depth and provides 2,048 levels of sensitivity. It has been stated that they have used the OpenCV library; they did this for image processing to help ensure a high level of accuracy. They, however, did not state how accurate this people counting method was, but by looking through the document and images, it was clearly quite accurate. Especially due to the multitude of tests in different scenarios conducted from a single person with their arms down to multiple people at once.

In the Chen et al. [33] study, they used head-shoulder detection using a single laser sensor. There has been a lot of pre-planning in this thesis, such as using mirror reflection, so the device works as a double-scanning system regardless of it being a single laser sensor. They conducted multiple tests with 314 people walking past the sensors in 303 seconds; depending on the sensor type used, different results were gained:

Direct clustering 86.9%

Head- shoulder detection without SVM 93.0%

Head-shoulder detection with SVM 95.5%

From the tests that they conducted, they were able to achieve a higher level of accuracy by utilising support vector machines (SVM). From this, we were able to get a better understanding of what can be achieved with a single device instead of relying on multiple.

Using the information gained from these four documents alone, a lot of information was obtained regarding the different methods that could be used to resolve the problems faced in this thesis.

2.8 Key findings

The key findings from this literature review have been that there is no single optimal technical solution for this problem, but the literature suggests that there are a variety of approaches that could be considered.

By reading about the different levels of accuracy achieved, even when using the same type of device, it is clear that the quality of the device must also be considered. By researching each device separately, we can ensure that a continuous level of accuracy is achieved instead of having a single sensor miss count.

Some theses went in depth about location and sensor placement. By working with the strength of the sensor and ensuring it is placed in an ideal location or by not restricting it, it can help ensure that accuracy is obtained.

One of the final key findings found was the preparation and mitigation of variables, such as in reference [5]. With a change in the level of illumination, the overall accuracy level can change. By considering an in-depth look at the location where the sensors will be placed, we can try to mitigate these variable changes.

2.9 Summary

By looking at these theses, it is clear we would not be able to agree on, generalise a method, or approach that would apply to all potential environments and tasks, so time and effort will be needed to do physical research on the best approach for this scenario.

This chapter was focused on examining all the options and methods of work that were used above, both individually and in combinations. This will also mean the consideration of matters to ensure a high level of anonymity and public acceptance to find the best solution for our site. By reading the previous research studies, we were able to use the information shown as a cornerstone of the overall research by knowing key matters such as methods that were not fit for purpose and how key sensor combinations would work.

However, we were able to get a better understanding of how different sensors could work together or by themselves, such as when a PIR sensor detects new body heat and can activate an IR sensor instead of requiring the IR sensor to remain active, which heightens the chance of the device burning out.

Chapter 3 Research methodology

This chapter is focused on the research methodology with the collaboration with iPoint which was designed to integrate academic rigor with practical applicability, leveraging agile approaches to manage the project process effectively. The use of agile methodologies, particularly SCRUM, was central to this process, ensuring continuous improvement, flexibility, and stakeholder involvement.

3.1 Research design

The research design for this study aims to investigate the effectiveness and accuracy of a people counting system utilising IoT for a rural location but tested in a university building. This study employs a mixed-methods approach, combining quantitative measurements to assess accuracy and performance with qualitative insights to understand both internal and external factors whilst testing and practical implementation challenges.

The research design was created to seamlessly integrate academic rigor with practical industry process, focusing on iterative development and continuous feedback through an Agile framework. We have been relying only on primary research that has been obtained through the use of real world testing after in house testing of devices and data collection.

3.2 Agile project management

We have utilised an agile project management approach to this thesis, which utilises a methodology emphasizes collaboration, adaptability, and continuous improvement throughout the development process.

Whilst utilising this Agile project management method we were able to emphasizes adaptive planning over rigid long-term planning. This was chosen to be used since in the early stages of this thesis, priorities and requirements evolved from the stakeholder meaning changes in approach and methods were needed. The ability to pivot quickly based on new insights, external factors or changes from the client’s needs ensure that the project remains aligned with iPoint, the stakeholder and Cardiff University.

By using an Agile focused methodology we focused on the six main stages [105] which are as follow plan, design, develop, test, deploy and review. By using this system we were able to effectively plan and create the perceived best system required for this project.

This was chosen to be used over alternative management methods such as waterfall due to many factors such as the adaptability. Waterfall follows a linear and sequential approach compared to Agile which allows for flexibility in responding to changes throughout the project lifecycle. By using Agile over waterfall we were able to engage with iPoint throughout the process, and manage risks proactively. These advantages make Agile suited for dynamic environments and this project with its early evolving requirements.

3.3 Research strategy

The research strategy for this thesis is designed to systematically investigate the accuracy and performance of an IoT-based people counting system whilst ensuring anonymity. A mixed-methods approach is adopted to provide both quantitative and qualitative insights, ensuring a comprehensive understanding of the system's capabilities and practical implications.

Whilst conducting the work on this thesis key areas of justification have been required and they are as followed:

3.3.1 Justification for using mixed methodology

We have chosen to use a mixed methodology approach since it has allowed for a comprehensive understanding of the research problem by combining qualitative and quantitative approaches.

By integrating qualitative and quantitative data, mixed methodology facilitates methodological triangulation. Triangulation enhances the credibility and validity of research findings by corroborating results across different methods. The development of a people counting device involves technical, operational, and user-centric considerations. A mixed methodology allows researchers to adopt a holistic approach to problem-solving.

By combining different methodological approaches, mixed methodology enhances the validity and reliability of research findings. Qualitative methods provide depth to understand factors such as movement speed in real-world settings, while quantitative methods offer statistical rigor and generalizability of results. The complementary nature of these approaches strengthens the overall research framework, ensuring robust conclusions and actionable insights for device development.

In conclusion, the justification for using a mixed methodology in developing a people counting device using IoT sensors without a camera lies in its ability to offer a comprehensive understanding, methodological triangulation, holistic problem-solving approach, and enhancement of research validity and reliability. This approach ensures that the device is not only technically proficient but also effectively addresses user needs and operational challenges in the real world diverse environment.

3.3.2 Justification for using real world footfall

The utilisation of real world footfall testing was chosen over solely in house tests due to the range of real world variables that could be tested. Such as but not limited to, group counting, clothing and speed variation, this could impact on the level of accuracy of the tests.

Whilst in house testing has been conducted when testing sensors this was acting as a prerequisite before real world testing, hence the high use of real world footfall tests. In house tests experiments that have been conducted do help show the usability and benefits of key sensors and design. However, this normally only has a small number of variables between each test when compared to real world testing which have drastic variables such as height, sex and clothing materials.

This approach ensures that the quantitative data provides empirical evidence of the system’s accuracy and performance. Triangulating these data sources enhances the overall validity and reliability of the study, providing a holistic view of the IoT-based people counting system’s effectiveness and usability.

3.4 Data collection

The data collected, which has been sent to the Davra cloud platform, was exclusively conducted by the chosen sensors for this project. However, through the testing process, to see the level of accuracy achieved, we have also deployed both person counting and camera recording along with sensors.

This has been done to compare the information collected to ensure it was to a sufficient and acceptable level. People counting devices using IoT sensors without a camera have been a critical component.

This phase encompasses several steps: sensor deployment, data acquisition and initial data analysis. Throughout the data collection phase, regular monitoring and adjustments are made to ensure data integrity and relevance. Any issues with sensor performance or data transmission have been promptly addressed to maintain the quality and reliability of the collected data.

As a precautionary measure, if collected data failed to be sent to the cloud platform, the file containing this information would make a backup and attempt to submit the information once again in the next day.

3.5 Data analysis

Once data has been collected by the sensors it will be sent to the cloud platform once a full day of data collection has been completed. Collecting data this way means that there was a lot of information that could be looked through for analysis.

The practical work is to be placed in South Africa, however their governmental body has requested that the information collected would not have identifying information about the people counted. We achieved this requirement by only collecting timestamps when the devices have been activated. From this however, information that could be analysed has been minimized apart from detecting when the location is used and roughly by how many people.

3.6 Industrial collaboration

Throughout the thesis we have been working with staff at iPoint who helped and guided us through both decision making and practical testing. The industrial collaboration with iPoint was fundamental to the thesis success. It provided practical insights and industry-specific knowledge that were crucial in addressing the problem situation and shaping the research methodology. The collaboration was characterized by sharing knowledge and experience, with iPoint giving us a view on real world operations while contributing to academic knowledge.

Communication and conversations regarding problems or ideas was easily discussed with iPoint since we were using an Agile approach [80]; this allowed us to have daily meetings. This Agile methodology was designed and created for the continuous delivery of working software that is created in rapid succession.

However, Agile is not just a set of prescriptions for exactly what actions are to be taken in software development as it can be used in information gathering and allow quick changes to the overall work. The outcomes were focused and relevant, ensuring the developed solutions were directly applicable to iPoint's customer want and expectation.

Daily SCRUM meetings were a vital component of the agile approach, ensuring continuous communication and alignment. In these short, focused meetings, we were able to report on what was completed and if any issues arose that required help to correct it. This regular check-in process allowed for quick identification and resolution of issues.

Active engagement and participation were key aspects of the collaboration. Regular communication through frequent meetings, SCRUM meetings, and brainstorming sessions ensured continuous engagement and alignment between both parties. This also facilitated a robust feedback loop, where iPoint provided ongoing feedback on the research progress, ensuring that the solutions remained aligned with industry needs and practical constraints.

An iterative, agile approach was adopted, with continuous input from iPoint shaping the research direction and adjustments being made based on real-time feedback. Prototypes were developed and tested within iPoint’s operational context, ensuring that the solutions were both innovative and practically viable.

By utilising both a mixed methodology approach and Agile we were able to ensure we could use a multiphase design by conducting tests with slight or major differences, which achieved both qualitative and quantitative method approach throughout the series of tests to address the research objectives. It is a way of thinking about collaboration and workflows and is a set of values that help dictate choices in regard to what is made and how it is made.

The choice to use the Davra cloud platform was from the client we were working with. This was still a new cloud platform at the time of work, but with the guidance from iPoint who had experience with this platform, it was simple to utilise it.

Reflecting on the industrial collaboration, it is evident that iPoint's involvement was needed for this thesis. The collaboration ensured that the research was not only academically rigorous but also directly applicable to real-world problems faced by iPoint, enhancing its relevance and potential impact. From them we have gained practical insights into research and innovative solutions.

There were challenges, particularly in coordination and adaptability, but these were effectively managed through regular communication. The research methodology was flexible to accommodate the early changes of requirements of thesis. In conclusion, the industrial collaboration with iPoint was pivotal in shaping both the problem situation and the research methodology, ensuring that the research outcomes were grounded in real world applicability and industry relevance.

Chapter 4 Analysis and Design

This chapter is focused on examining the main details of the problem faced in SA, followed by an analysis of the devices that are to be used to collect and store the information from the sensors to the cloud platform.

4.1 Problem

Significant areas of SA are in a state of struggle due to the limitations of water [82]. This is due to many factors, such as geographical location, a lack of local facilities, and climatic changes. All of these contribute to a lack of clean, drinkable water that leads to the potential outbreak of disease [82, 83]. Different regions of SA have examined different approaches to ensure enough clean and usable water is available.

Rural areas tend to favour the use of septic tanks to clean and reuse the water collected; this avoids the need for extensive pipe work and infrastructure. Nevertheless, this approach can lead to tanks overflowing, spilling effluent in the locality, and risking disease. The septic tank requires regular maintenance and management. By monitoring the usage of the toilet facilities, an efficient programme for tank replenishment could be devised.

The project was planned and agreed upon by the SA government and water board to find methods to help manage the amount of water used by logging how many people have used local toilet facilities. The location chosen for the pilot study was in Thandanani, in rural SA. The main target of this thesis is to examine different IoT methods to count the number of people using the bathroom facilities. It must also evaluate different sensors and sensor combinations to determine the appropriate devices for this location. The main aim is to count the number of people using the facilities to quantify the amount of water being used.

To address the problems and challenges faced in this thesis, we aim to develop a novel data processing architecture that is capable of sending collected information to the cloud platform once the information size has been minimised. The on-board computer will conduct most of the data analytics locally and will only send the summarised or aggregated data to the cloud.

4.2 Project requirements

This section identifies the needs of this project by evaluating previously conducted work in the field of people counting. The different methods that were used will be compared to gauge which is the most accurate and beneficial for this problem. A key research need was to consider the physical and cyber security of the developed devices to ensure that both the devices and the users were safe while minimising the chances of theft, damage, and leakage of data arising from the devices.

Meetings with iPoint were required to ensure the needs of the project were known and achievable. These meetings occurred from the early research stages to the later testing stages of the project. Cameras were not allowed in this project since it was to be deployed for public convenience, and this infringes on individuals' privacy.

Due to the restrictions on the use of cameras, it has become necessary to look at alternative sensors and devices that could be used. Fortunately, other sensors have been evaluated to see how applicable they would be to the overall project. As can be seen in the following few pages, the usability of these sensors was evaluated to determine their practicality.

Over the course of this project, the coding method that has been used has changed to Node-RED. This is a programming tool for wiring together hardware devices and APIs to online services in a simple and straightforward flow-based program. This was invented by J. Paul Morrison in 1970.

To create an application, Node-RED requires 'nodes' to be dragged and dropped into the flow that is currently being worked on. Morrison described an application's behaviour as a network of black boxes in the current workspace that are wired together. This can work with the Davra platform that we are using to both send and receive information. Using this application allowed for quick changes and news tests to be conducted without the need to write or change pre-existing code.

4.3 Davra

The Davra platform has been built to allow the creation of IoT applications. Davra provides a wide range of services, ranging from IoT device management. By collecting and storing data, running requirements against the data, and entity modelling, to name but a few, these services enable the application developer to focus on the application and deliver value in the shortest possible time. If the required outcome has been set, such as creating a table full of updated logs of activities, then the Davra platform is capable of displaying them [74].

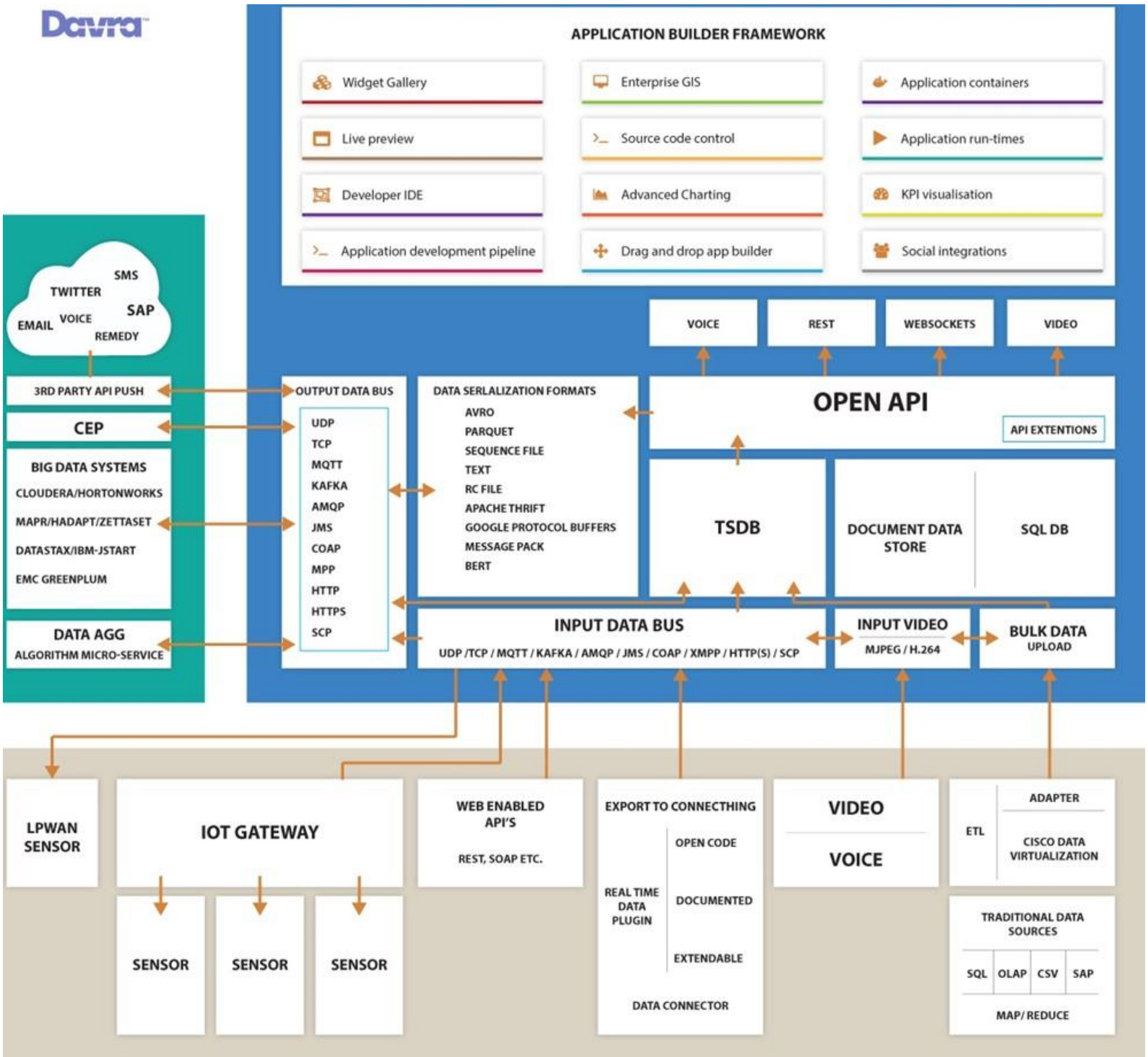

Figure 3.1 The architecture of the service for the Davra platform

Source: Davra Documentation [100]

4.4 Proposed Multi Sensor People Counting Technique

While looking through a number of files and previous work, it was clear to see that the utilisation of multiple sensors working together achieves a higher level of accuracy in comparison to a single sensor.

4.4.1 The use of Microcontrollers

Microcontrollers have been used throughout the project in various stages and tests, as they are electronic components that are for the purpose of small computation which can be used in a wide variety of applications that require decision-making or system monitoring. By using these devices, the capability and use of multiple inputs from sensors can work together to ensure that people's recognition and counting are accurate. In the end, this was conducted using Node RED, and the microcontrollers worked together with the information collected.

4.4.2 Why was a multi-sensor developed and what is its technique

A multi-sensor system was developed to ensure that the number of people counted was accurate by removing false positives, which was found in the initial testing of sensors. By using sensors together, they can work to ensure that a person is seen and counted; while single sensors can do this, they can lead to false positives. The technique through which it works is through Node RED, which is a flow-based development tool for visual programming. This was chosen due to easy and quick changes to the technique to ensure a higher level of accuracy. Moreover, given that multi-sensor monitoring typically detects multiple methods of counting people, they can assess if a person or people enter the location, which may not be fully captured by measurements via the use of only a single sensor.

4.4.3 Data Fusion

Data fusion is a process of combining collected data from multiple sources to build a more sophisticated outline to ensure that the information obtained will be more decisive, intelligent, sensible, and precise compared to using a single sensor. However, there is a limit regarding how many sensors can be plugged in and used with a specific device such as Raspberry Pi or Arduino.

This method of work with sensors working together helps with the creation of highly accurate information, low power sensors with little low accuracy can also be employed in IoT-based networks rather than high accuracy power hungry sensors. Throughout the testing, it is clear to observe that the benefits of utilising data fusion techniques outweigh the negatives such as the increase in cost.

4.4.4 Why is combined data better than other solutions

This method of sensors working together was developed to ensure a prominent level of accuracy is achievable. By looking through previous methods that have been conducted and comparing sensors and alternative methods that have been used, it was clear that a single device would still function and count people.

However, by using multiple sensors to work together, it will help reduce the number of false positives that will be obtained and ensure a higher level of accuracy. This technique will be beneficial to the company since it will help them ensure the information they have obtained and are displaying is accurate and will not infringe upon the overall cost of this project.

4.4.5 Novelty of Multi sensors

The novelty of the method that has been proposed is given by the multidimensional approach. This is achieved by the use of multiple sensors and by automatic counting methods from the sensors. If key characters are achieved, this being a size met with the PIR motion sensor, the ultrasonic retrieves a signal of a person, and if the IR sensor line is broken, it will count a person. The final novelty is the use of Node RED as a foundation to achieve the desired objective.

4.2 Infrared

Sensors using infrared come with many advantages, such as providing secure communication due to the line of sight or point-to-point mode of communication. Another major advantage of the 24-hour location is that the sensors can reliably detect motion in daytime and night-time, regardless of the light source. Compared to alternative sensors, infrared devices can measure the distance to soft objects, but this is not easily done by other devices such as ultrasound. Another major advantage is that they are smaller compared to other sensors of their kind, meaning they are more difficult to see, which minimizes the chance of theft. Along with this, they have a response time faster than thermocouples on average.

Due to its location in the wild, it will not suffer from corrosion or oxidation, which is beneficial for this device to be used for a long period of time. One of the final advantages is that it supports lower data rate transmission compared to wired transmission. This is an immense help due to the sensor's location and the limited availability of the network. However, this item does come with some disadvantages, such as the fact that infrared waves at high power can damage human eyes. It is more applicable at a shorter range, this being 10 mm, which means it has a lower level of use compared to other available sensors. However, due to the location of the sensor, it might never be an issue.

4.6 Ultrasonic sensors

This sensor type has a major advantage, which is that it is not affected by atmospheric dust, rain, snow, etc., and it can work in any adverse conditions. It has a higher sensing distance compared to proximity sensor types, meaning that it can work from a greater distance compared to other sensors. It provides good readings for sensing large objects, which means it has a good capability to recognize if a human passes the sensors compared to other animals.

A major problem it has would be with regards to where this sensor would be placed, as it is sensitive to variation in temperature. Another issue would be its difficulties with obtaining information from reflections from soft and curved objects; this means if someone is wearing certain materials, such as wool, the sensor will have difficulties identifying them since the material can interfere with the sound wave.

4.7 Laser sensor

The laser that is being used by this sensor cannot be seen by the human eye, and this will mitigate the potential theft or damage chances. These sensors are extremely accurate due to the method of counting people by having a laser line broken by a large mass. These sensors are small and discrete, meaning that it is hard for anyone to take notice of them, helping reduce the chance of theft. A major advantage of this sensor is that it works in both dark and light conditions since it does not require the ability to see someone. A final and crucial advantage is that, unlike other methods of data collection, laser sensors are not subject to any geometrical distortions.

It does, however, have problems that can leave it unusable, such as the potential of the laser being blocked by a hard or soft fabric or material such as paper. This will stop the laser from being usable until the obstruction is removed. Due to the limitation of knowledge about the location, if multiple people walk into the facility side by side, the laser will only be able to count one person. This can be a major issue since it can lead to miscounting and the information that is to be collected being inaccurate and unreliable.

4.8 PIR Motion sensor

By using a passive infrared (PIR) sensor, it can detect motion reliably both indoors and outdoors, regardless of whether it is morning or night. This sensor uses body heat signatures to recognize and count the number of people it sees. This device consumes a low amount of energy, which is from 0.8W to 1.0W. Finally, due to their size, they are good for electrical applications used in smaller and more compact premises, such as this toiletry facility, since they cannot be used to recognize people.

A major drawback of this sensor is that it does not operate at temperatures greater than 35 degrees Celsius. It will struggle if the heat is continuous and high, especially due to the location where it will be placed. This is a major issue. It works effectively in LOS (Line of Sight) but will have problems in the corner regions. Since PIR sensors sense heat signatures in a room, they are not sensitive if the room itself is warm.

Hence, PIR sensors are not able to detect human beings at key times in some Hence, PIR sensors are not able to detect human beings at key times in some countries. PIR sensors may turn off if there is little movement in occupied areas; this means the device is not keeping a 24-hour log unless active. The final major issue is that they are prone to false positives due to being sensitive to environmental changes like hot or cold air flow and sunlight. From the information collected, it is clear that a PIR motion sensor would not be practical to use, especially due to the temperature that SA normally has. The numbers are rounded up or down to the nearest whole number:

Table 2 Average Monthly Temperature

Average Monthly Temperature	
Month	**Average Temperate**
January	26 C
February	25 C
March	24 C

April	21 C
May	19 C
June	16 C
July	17 C
August	19 C
September	23 C
October	23 C
November	24 C
December	25 C

After finalizing the research of alternative devices, the results were discussed with Nick Williams of iPoint so we could reach an agreement on the revised approach to sensors.

4.9 Alternative sensor and device testing

Below is breakdown of alternative sensors that are available to use but did not meet the required needs.

4.9.1 Arduino

Arduino using Temperature and Humidity Sensor

The Temperature and Humidity Sensor was evaluated, and the information collected was found to be accurate, as long as key information and outlines are included such as the utilisation of temperature outlines. For example, a loop was required for the humidity sensor, and then all the information gained was accurate for the device. This at the time of writing is not useful to the overall project because the primary focus is people counting, however, this can easily be implemented if this information is needed at a future stage.

4.9 Alternative sensor and device testing

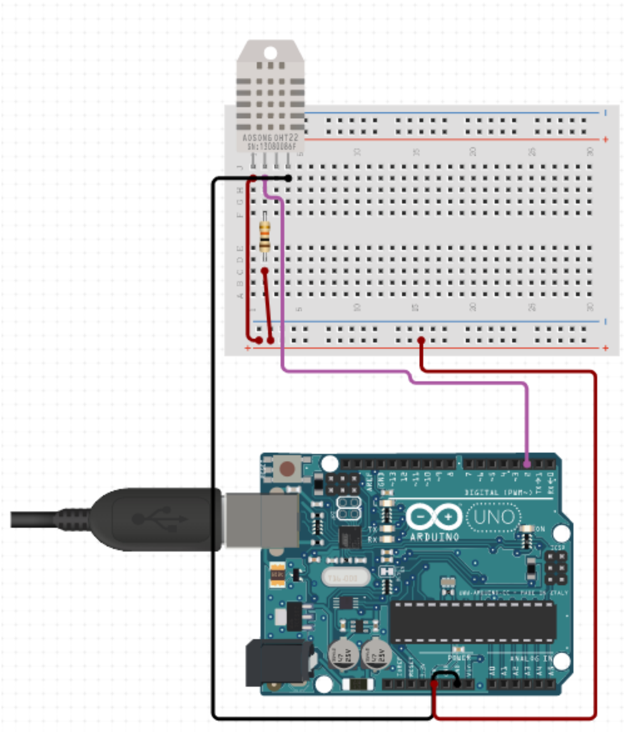

Figure 3.2 The physical set up for the Temperature and Humidity Sensor

By conducting this temperature tests, it was clear that the placing of the sensors is important. Since different sensors can be affected by heat this would be an ideal device to detect if heat or humidity were a key reason a sensor may not be sending information.

Arduino using Motion sensor

The motion sensor was evaluated as shown by the image below. The sensor detected humans by a combination of heat and motion. This could be used in combination with a camera, as the heat and motion signal could activate the camera from sleep mode. However, camera use was later withdrawn as an option and without an alternative sensor to collaborating with it; the motion sensor could recount the same person several times.

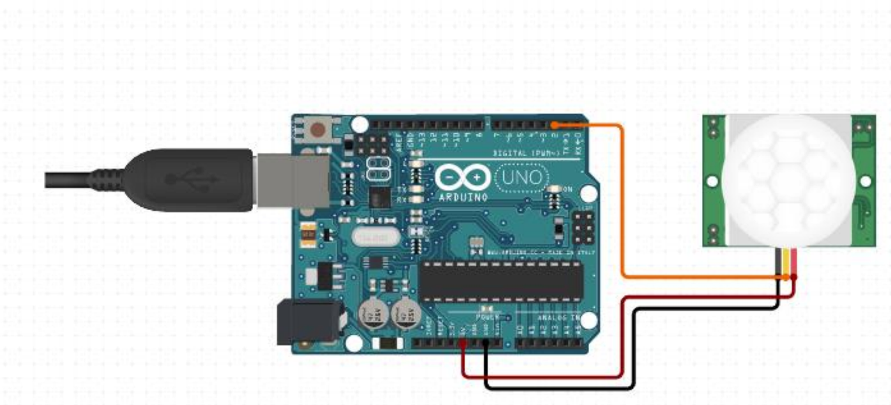

Figure 3.3 The physical set up for the PIR motion sensor

Whilst this sensor could detect whether a human is in the building, it would not be accurate since it does not log and identify users, meaning it can count the same person multiple time each time they are visible to the sensor. By having this sensor working along with another such as an infrared, it can count the number of people it sees more accurately.

Arduino using Sound sensor

The sound sensor was initially assessed by clapping, the sensors we able to detect the noise of a clap clearly enough from a total of 132cm or roughly 5 inches distance. A light indicator flashed on when a noise was detected. More tests were conducted afterwards such as by testing different audio files and seeing if there were methods to have the sound sensor listen for a particular noise for it to log a person.

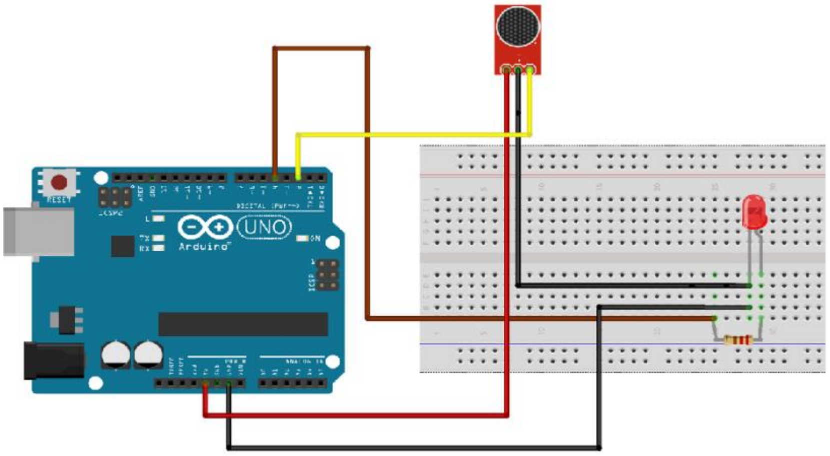

Figure 3.4 The physical set up for using a sound sensor along with a light

This sensor can detect the human voice and with training, could distinguish between genders. However, this would not be useful to the overall project since we are unsure how many people will be using the facilities at one time, the density of the building's walls and the layout, these key factors mean the sound sensor is impractical. Due too potentially too many sounds happening at once, meaning it is unable to distinguish one individual from another.

Arduino using Water level sensor

The water sensor or water level sensor is used to detect water leakage, rainfall, tank overflow, or to measure a water level. The sensor has a series of ten exposed copper traces. Five are power traces and five are sense traces. These traces are interlaced in parallel so that there is one sense trace between every two power traces. The output value of the sensor depends on not only the water level but also the water's conductivity.

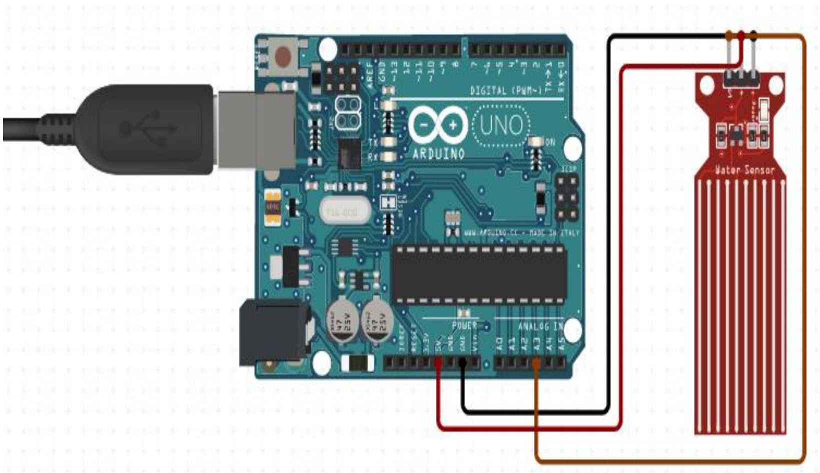

Figure 3.5 The physical set up for the water level sensor

By following this simple layout, it was possible to assess and ensure the efficiency and practicality of the water sensor. This is not needed at the time of writing but for the overall project and the purpose of measuring the water flow and the fullness of the septic tank is particularly useful, meaning it is highly likely to be used in later stages of work.

4.9.2 Grove Kit

The Grove kit as a standalone item is not functional and needs to be used along with the Raspberry pi board. Thus, the Grove requires another item. However, due to the robustness of the cable connection, the chance of loosened connection is dramatically reduced. This will be helpful since it will minimize how much maintenance and observation the devices need.

Grove Buzzer

The Grove buzzer was assessed for both learning how to us the device and to see how sturdy the connection is whilst the buzzer was set to the maximum level. It remained quite secured and gave no sign of loosening the connection regardless of where the device was connected. This remained the case while being held upside down for 5 minutes.

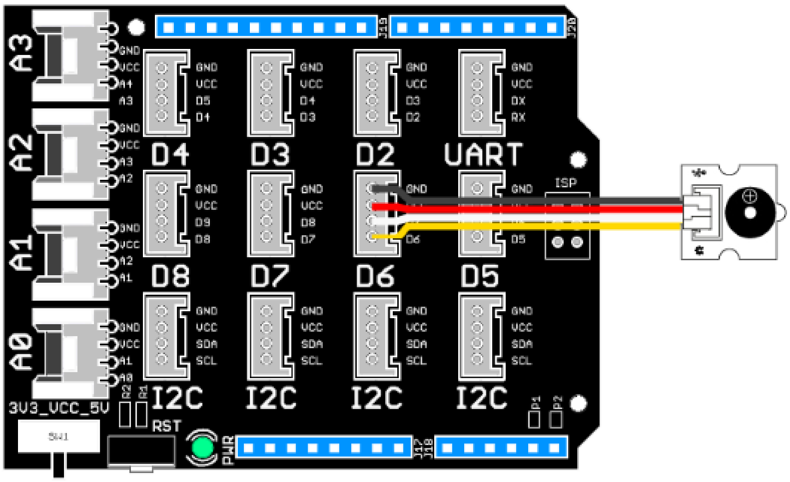

Figure 3.6 The physical set up for a buzzer which is using the Grove kit

Source: [103]

By conducting this simple test, we were able to gain more understanding of the Grove kit and ability to see and evaluate how secure the connection would be for a prolonged period. It was dramatically more secure regarding device connection and cables security than either Arduino or Raspberry pi standard connections.

Grove Light Sensor

The light sensor was assessed to see if it could detect the change regarding the variable amount of light in a room. It was able to accurately and show changes in the value regarding how much light was in the room at one time.

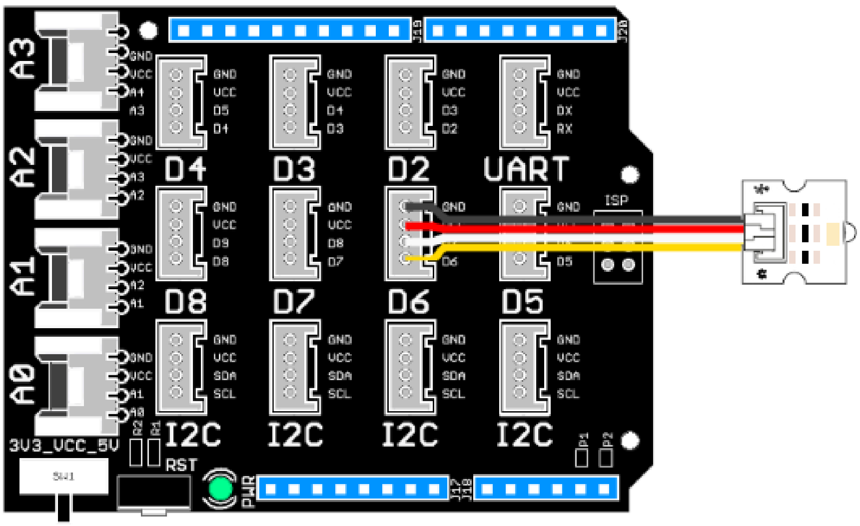

Figure 3.7 The physical set up and connection for a Grove light sensor

Source: Adapted from [103]

The Grove kit tests showed how quickly information could be seen in comparison to using an Arduino board alone. From this, it was easily visible that any difference regarding the speed of information that has been obtained. From this it is viable that buying a Grove kit; even though it would still cost more, it would not damage or lessen the speed or accuracy of the information that it obtains, and its connections would be more secure than other options.

Grove Temperature Sensor

The Temperature sensor was evaluated by connecting to the device as follows:

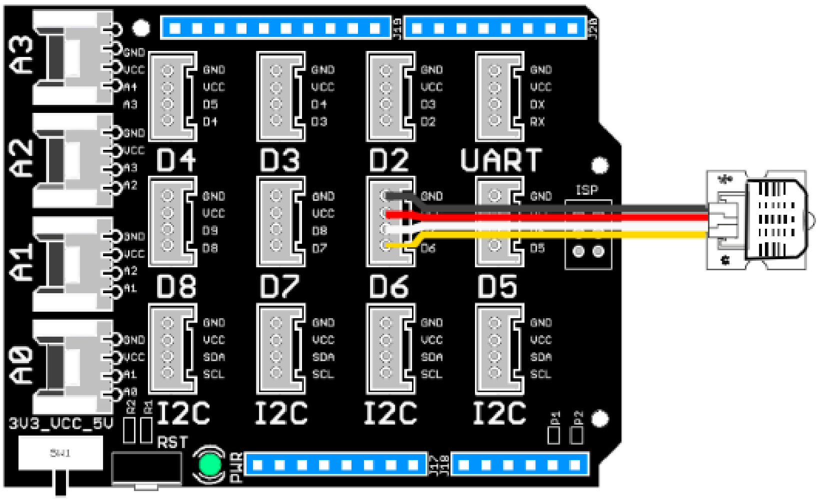

Figure 3.8 The physical set up for a Grove temperature sensor

Source: Adapted from [103]

In past communications with iPoint it has been mentioned that the need to use information of temperature for gauging the number of people using the toilet facilities. Additionally, by detecting the heat inside the location we can prepare and plan on what to do to keep gaining information instead of it being lost such as if we use the PIR motion sensor as mentioned before; chapter 2.5.

4.10 Summary

This chapter has identified the issues and problems faced with the project, such as its location. It has then clarified the project requirements, considering how information could be sent and shown from the Davra cloud platform.

Through comparing sensors working individually to sensors working in tandem, we were able to compare the level of accuracy achieved by these sensors. It was evident that, despite the increase in price, the extra sensors can help ensure the validity of the information collected. This is achieved by combining the collected data from the different sensors in a form of data fusion, the distinct types of sensors available offer different limitations and advantages each of which has been examined in this chapter and its different sections.

The closing section of this chapter was focused on alternative sensors that were not used in this project. It is, however, important to take notice of them for future stages of this project, such as a water level sensor that can be used inside a bio-waste collection tank to help minimize the chances of overloading the tank, which may lead to spillage and potential outbreaks. Overall, this chapter enabled the selection of sensors and devices that will be assessed in the following chapter.

Chapter 5 Testing

This chapter is focused on tests that have been conducted and on which device. iPoint has stated that they will potentially use multiple sensors, ranging from a people-counting camera, a door opening and closing sensor, an IBM acoustic sensor, and a water flow meter. In key scenarios, both sensor and data redundancy are important since it can help us ensure a high level of accuracy from the collected information by having multiple devices count the same input. If the information collected is the same, then we can easily work out the practicality and accuracy these devices have.

5.1 Arduino

By using an Arduino set, testing, and using sensors that seemed relevant to the overall project to conduct tests as well as accumulating data that has appeared relevant. We were able to see if any of these sensors would be relevant or beneficial to the overall project if used.

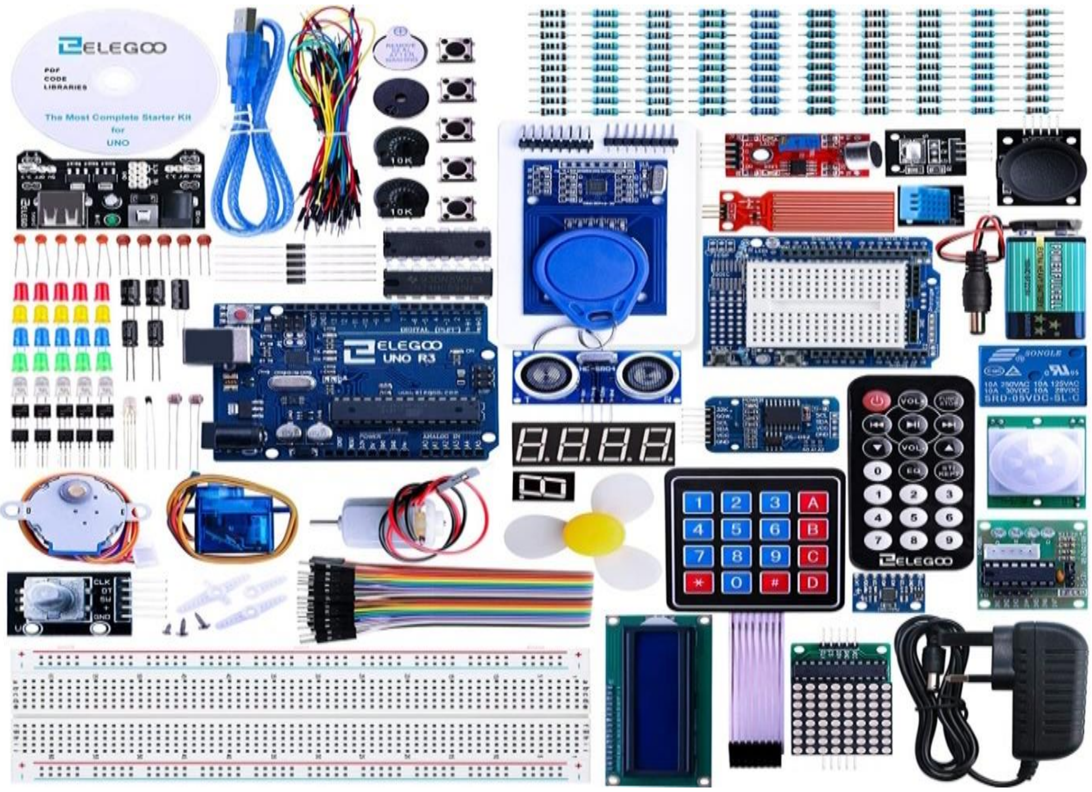

Figure 4.1 A collection of different sensors and pieces of an Arduino kit.

Arduino using camera

A camera connected to the Arduino device was evaluated and it is clear to see that using this device would need a large number of wires. The camera that has been used for this test has been AZDelivery OV7670 Camera Module 640x480 300KP VGA.

Due to this means, an increase in the likelihood of a cable falling out and it stop working. The camera picture quality was good however meaning it was able to observe and detect people with ease.

However, the wires were loose and prone to coming out of the Arduino board, this is a major issue since of the location it will be based it can come too loose and stop working from movement vibrations alone; we have assessed this by walking “hard” and stamping feet to make some vibration near the device.

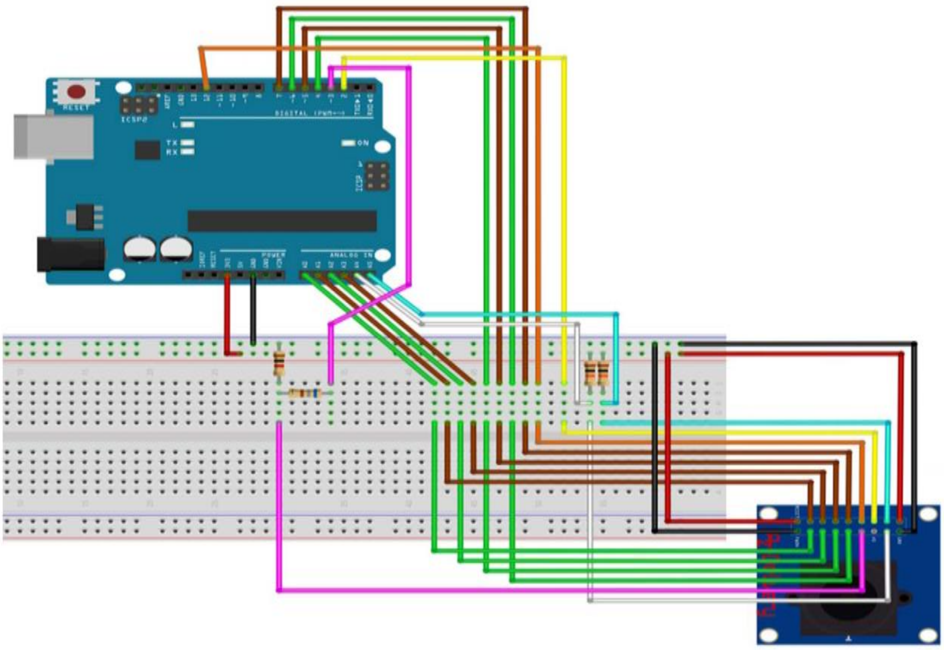

Figure 4.2 The physical set up for an Arduino using a camera

By conducting this physical test, key information such as identifying a person would be possible. However, the current quality of the image that is captured is not to a high standard and slightly blurry, depending on distance and speed of travel, the image could be drastically worse which would make it near useless so a higher grade of camera would be needed. Yet, due to SA stating cameras were no longer to be used, this test was to see the practicality of this denied method.

We used TensorFlow, which is an end-to-end open-source platform for machine learning. This has allowed the Arduino to use a camera to recognise a male or female person that enters a room and have that logged into a notepad file.

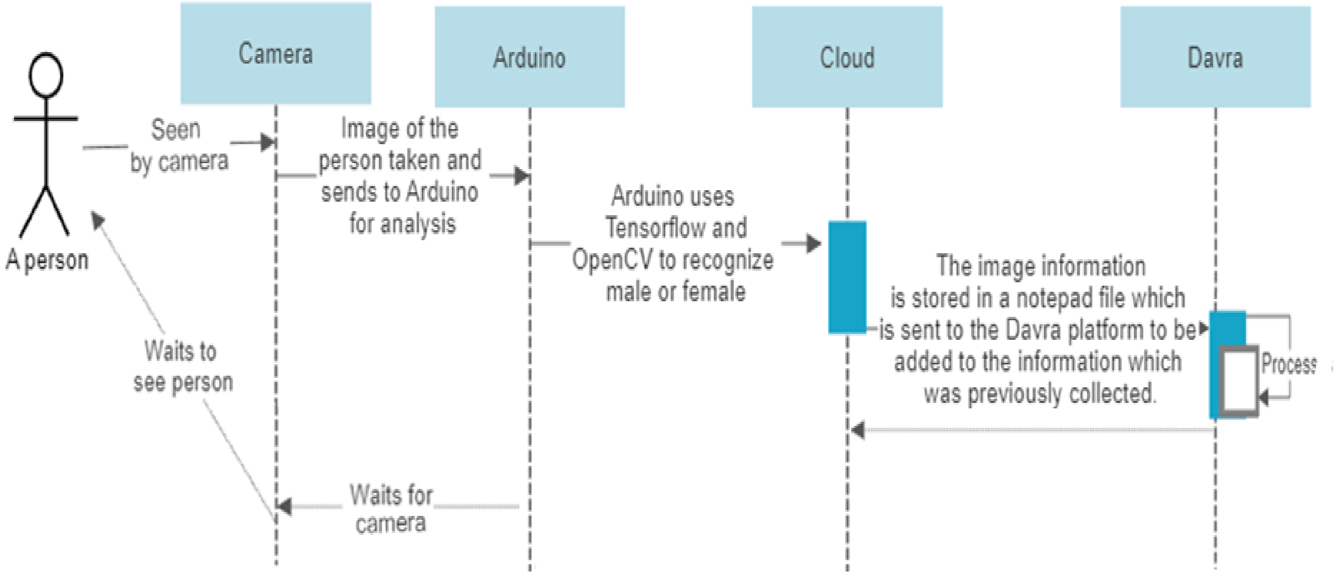

Figure 4.3 Arduino with Camera UML diagram

Due to this test, being conducted in the initial stages of the project, prior to cameras not being allowed, the making and finalising this method of people counting was not finished. This is why the messages are quite vague and over explanative.

Arduino using ultrasonic sensor

Evaluating the ultrasonic sensor, by having the sensor in place it was measurable to see how close someone was to the sensor. This can be useful for helping different sections of the device accurately count how many people are in the bathroom at one time. Since, after testing proximity a user is to the sensor has made a user's counter from it.

This could count the number of people entering a room from the ultrasonic sensor yet, it was unable to count the numbers that have left. From watching videos and reading forums a single sensor is needed to count people but, by having two, this can help ease what is needed to continually capture data since, if one of the devices breaks the other one would remain counting people.

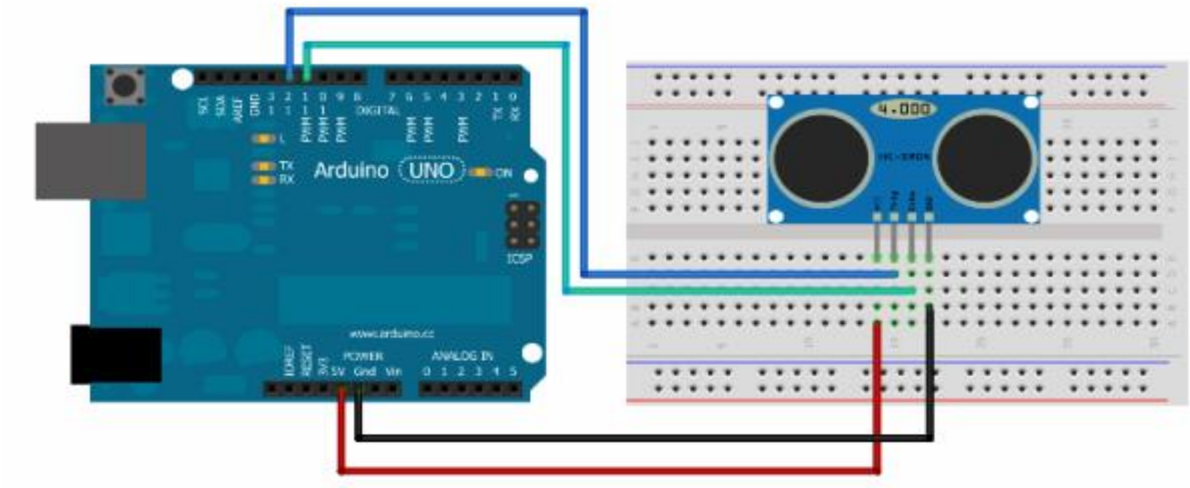

Figure 4.4 The physical set up for an Arduino using an ultrasonic sensor

By conducting this test, the ultrasonic sensor can be used either alone or by having multiple working together. By having this, it helps add a level of redundancy to the information, which can help clarify if another sensor has counted the correct number of people.

The equation that the ultrasonic sensor uses is **Distance = (Time x Speed-Of-Sound) / 2** by using this it can detect the distance between it and anyone that comes near it. This test was conducted after cameras were not to be used.

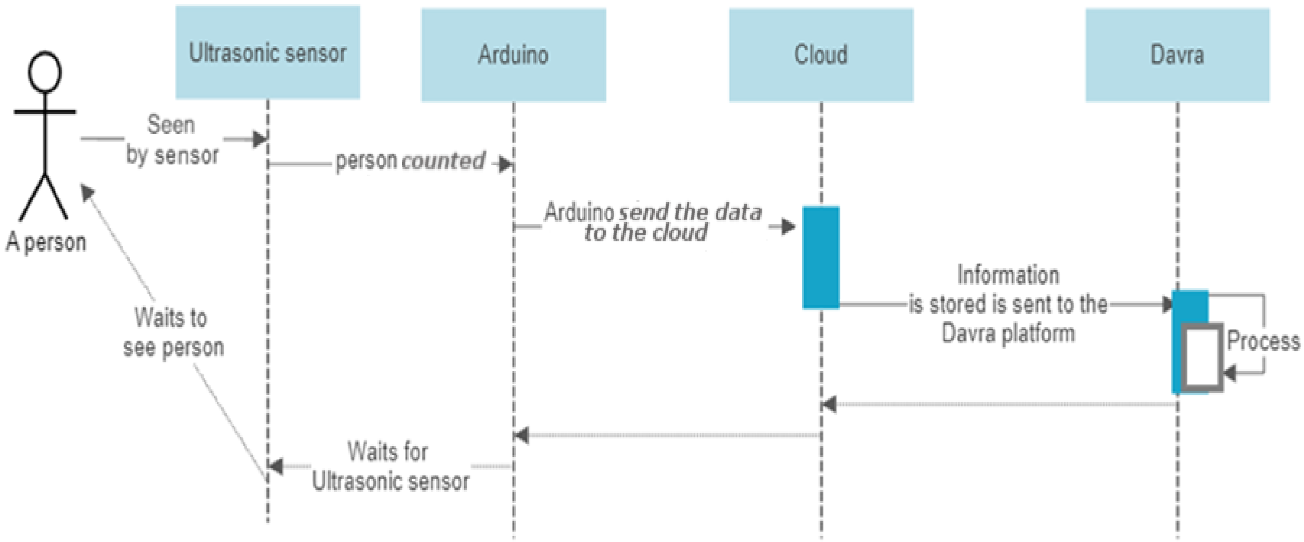

Figure 4.5 Arduino with Ultrasonic UML diagram

5.2 Raspberry PI

Raspberry PI alone

Minor tests have been conducted to see how usable and applicable for the Raspberry Pi. Some of these tests conducted were:

- Testing how tasks are distributed throughout the device since if it is unable to handle many different tasks at once for the project we may need multiple or different devices to work together.
- Testing how the Raspberry Pi device would operate for multiple days with different tasks, to gain an understanding on how the heat is distributed. This was conducted since it is useful to know the practically of the device for it being placed in SA.

It found that after a brief period the USB ports will get quite hot, this could lead to a major issue if they are placed near a wooden palisade or other flammable material due to the amount of heat and how long the heat will be generated. After these and a few other basic tests were conducted, it was followed by researching, utilising videos and forums to gain more of an understanding and use of the device.

Figure 4.2 1 This shows a Raspberry Pi by itself

Raspberry PI Using Camera

In this test, we used a camera along with a raspberry pi to create a gender identifier using OpenCV. Whilst this method appeared simpler to implement due to the limitations imposed by SA this method was no longer viable. By doing this and using pre-established code that was able to quickly, easily, and relatively accurately tell someone's gender when the camera sees them.

Figure 4.2 2 The image shows the physical set up for a camera with the Raspberry Pi

Source: Adapted from [102]

Tests were conducted from different areas in current residence to see how well it works from different angles and distances, it was able to work well regardless of camera location however, the amount of light and distance makes the process for the camera harder to pinpoint age and gender accurately. However, from what was evaluated with the camera it was shown that it was able to see the person clearly, and without quick movement it would be able to estimate the age relatively accurately.

5.2 Raspberry PI

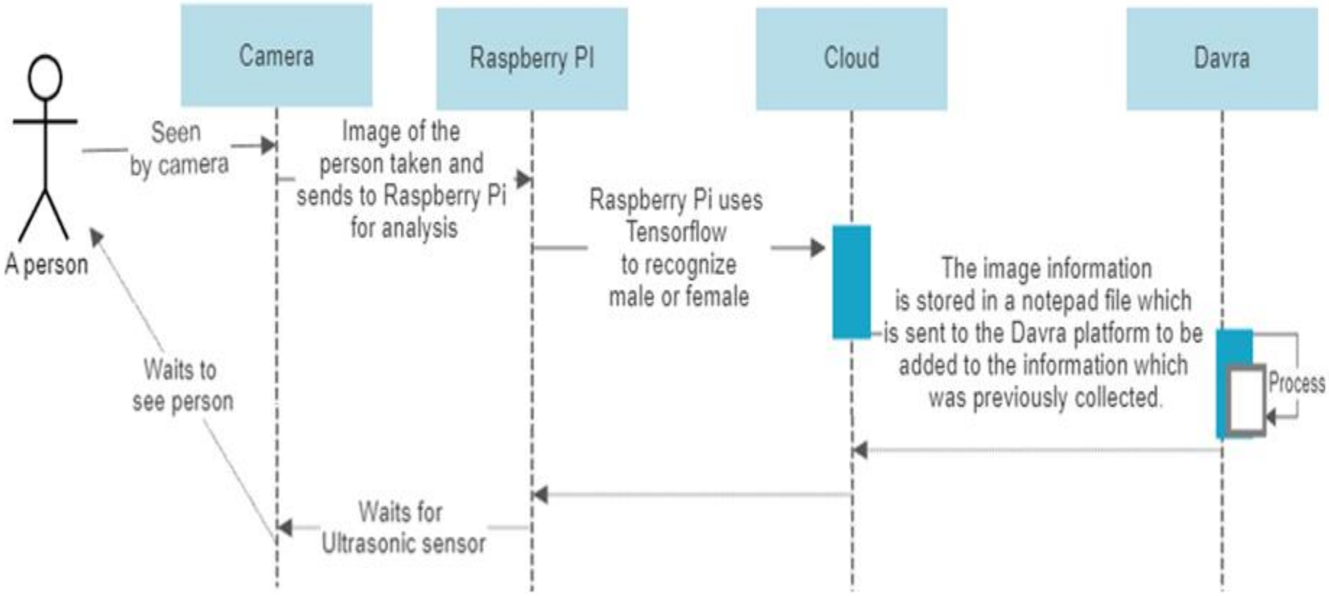

Figure 4.2 3 Raspberry Pi with Camera UML diagram

Like the camera test conduct on the Arduino, this test was never finalised, yet it is important to think about the practicality and the usability of it in this scenario.

Raspberry Pi Using Ultrasonic sensor

An ultrasonic sensor has been connected and used with both Arduino board and Raspberry Pi at various stages of this work. This was done as an attempt to see which device gave the best level of accuracy with the information captured. By comparing these two there is no visible difference of the two forums this sensor could be in regard to the device to which it is connected.

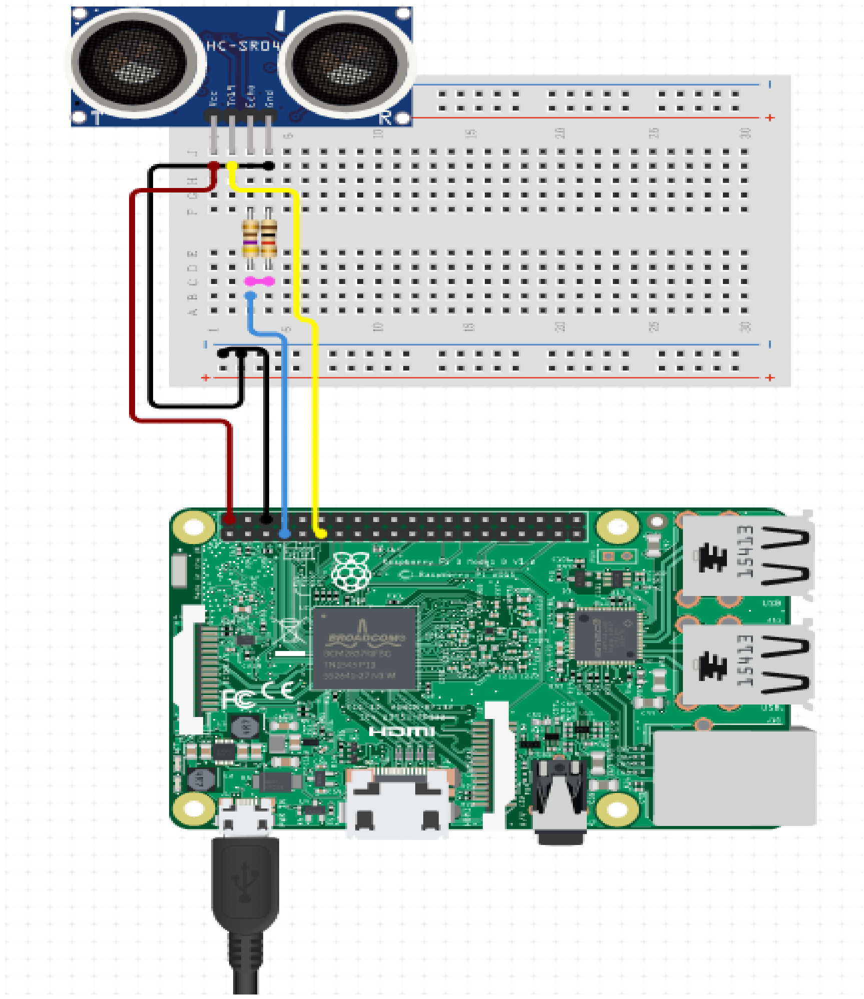

Figure 4.2 4 Physical set up for a Raspberry Pi with a breadboard to use a Ultrasonic

As mentioned earlier when looking and evaluating an ultrasonic sensor with the Arduino board; it was clear and visible during these tests that it could only count people entering a room instead of both counting people entering and leaving. The device was only able to count people entering regardless of direction. Due to this, it is clear that two ultrasonic sensors are needed to count people coming in and out of the bathroom. The equation for this is the same as the Arduino using an ultrasonic sensor **Distance = (Time x Speed-Of-Sound) / 2**.

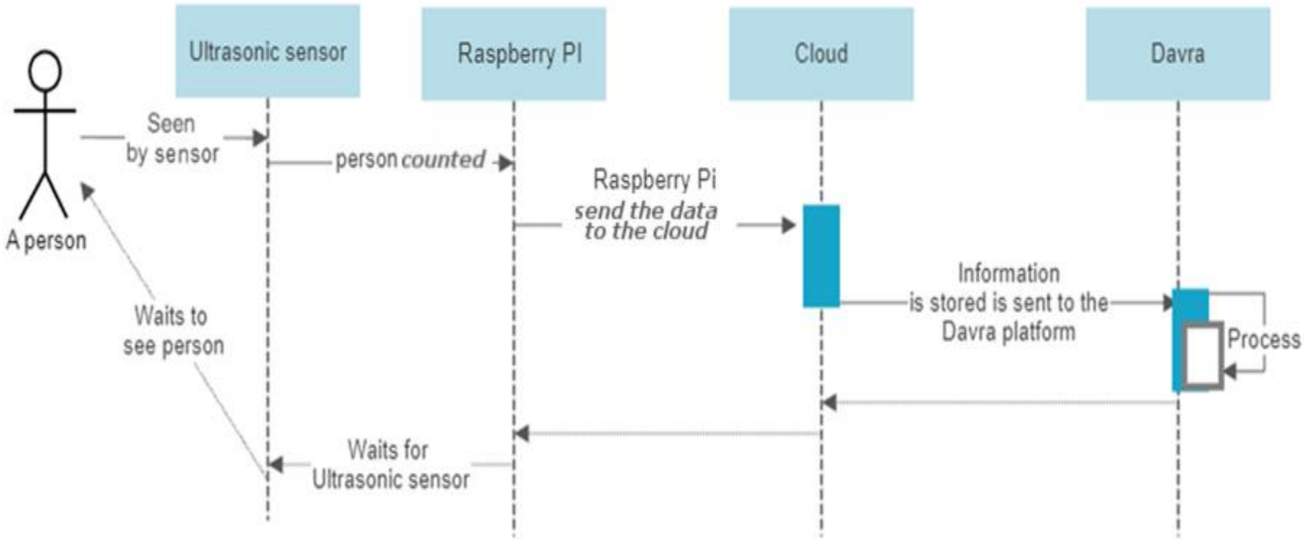

Figure 4.2 5 Raspberry Pi with Ultrasonic UML diagram

Raspberry Pi Using PIR motion sensor

This was a test for the utilisation of a PIR motion sensor, it has been shown that the beneficial purpose of the device is to detect people by viewing and identifying their body heat signatures to register them. In comparison to the Ultrasonic sensor that simply detects something by sending out and receiving an ultrasonic wave. By doing this we can ensure that people are being counted instead of counting anything that passes the sensor such as if we used Ultrasonic sensors. By using the PIR sensor, we would require only one sensor to count people, yet there is no method via using this sensor alone or as a set to count and inflow and outflow of people.

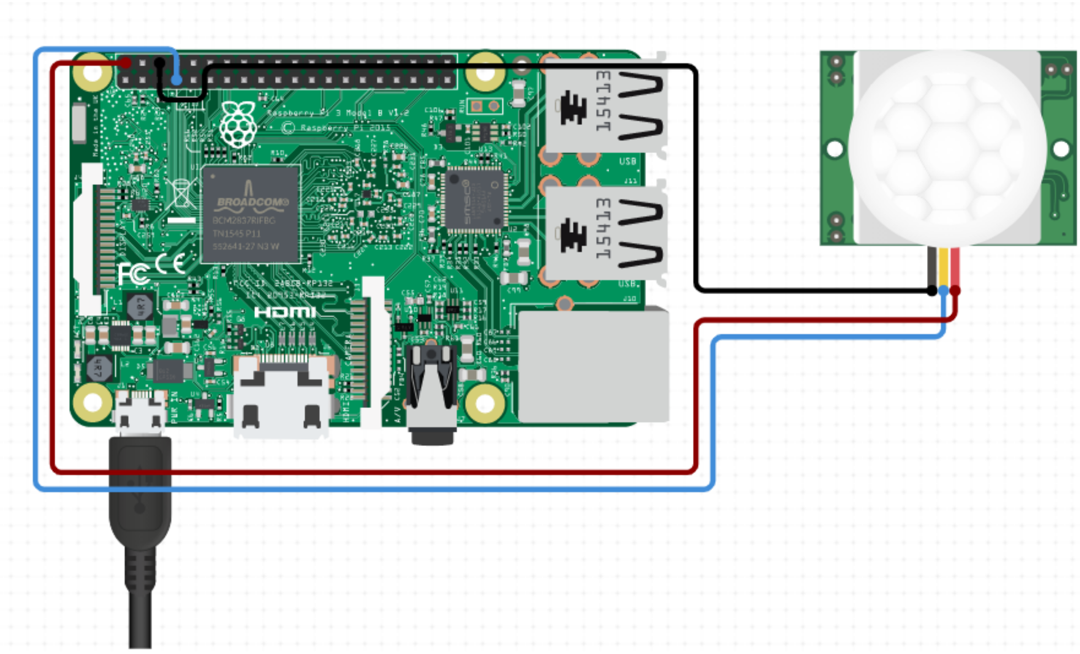

Figure 4.2 6 The set up for a PIR motion sensor

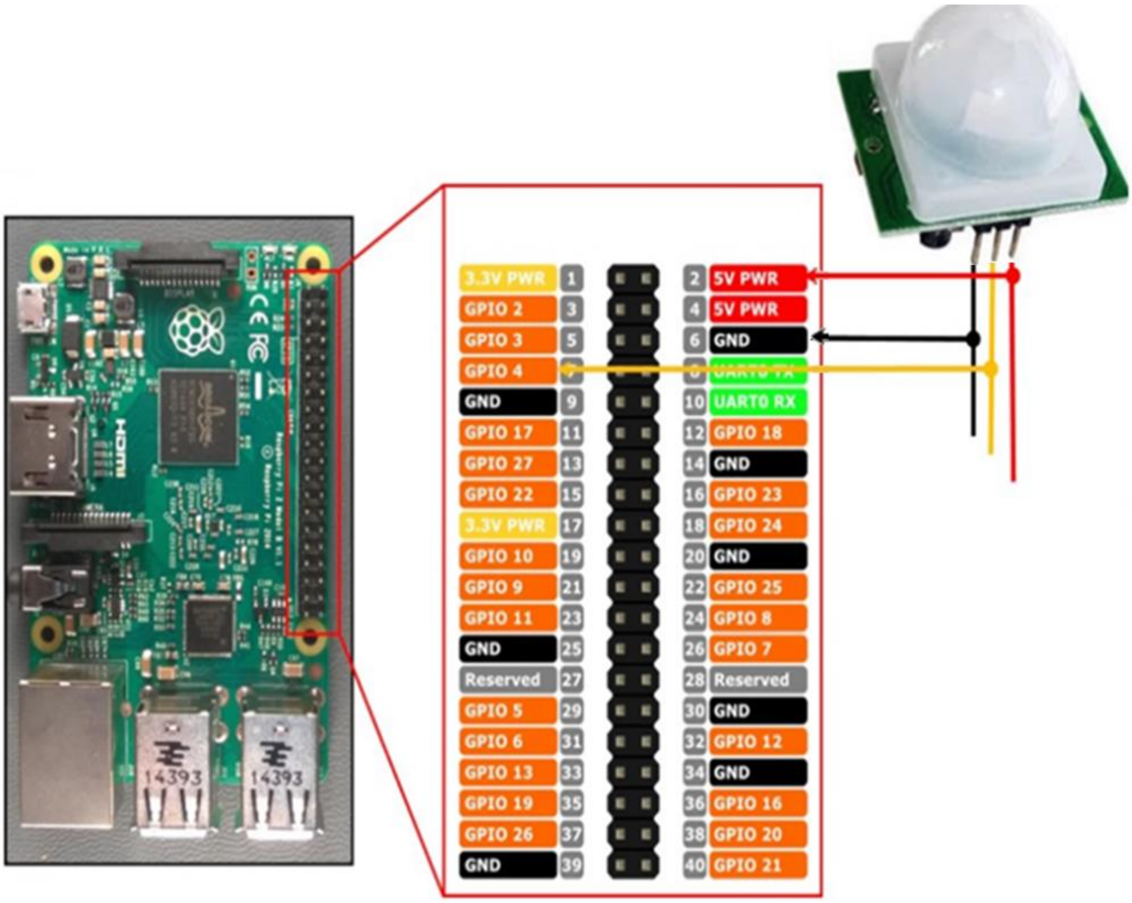

Figure 4.2 7 PIR sensor connects to the Raspberry Pi and to what pins

Source: Adapted from [101]

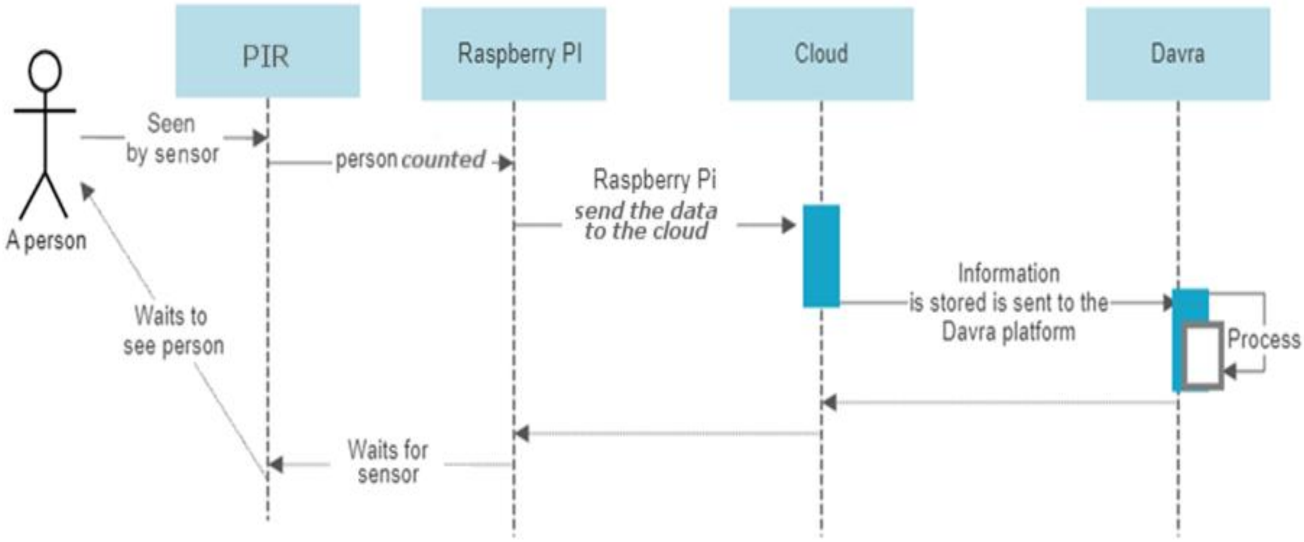

Figure 4.2 8 Raspberry Pi with PIR UML diagram

Raspberry Pi Using Infrared Sensor

This test has used a Sharp GP2Y0A02YK0F sensor with the purpose of detecting people by them moving through a laser which, when the line is broken, is able to identify movement and count people. In comparison to the PIR which simply detects a person by their heat signature.

This means by using a laser sensor there is still a chance that it may count creatures and items, instead of solely counting the number of people that pass the sensor. By using this sensor, we could use just one sensor to count people, however, we could use two so we can log both the incoming and outgoing number of people. Compared to using the Ultrasonic sensor or PIR motion sensor, we would need to use an Arduino breadboard to be able to use this device.

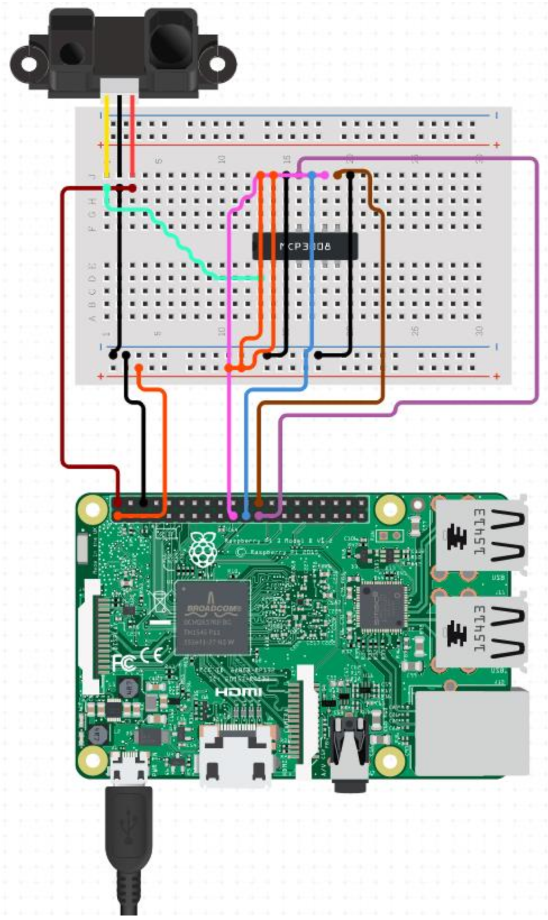

Figure 4.2 9 Physical set up for a Raspberry Pi to infrared sensor using a breadboard

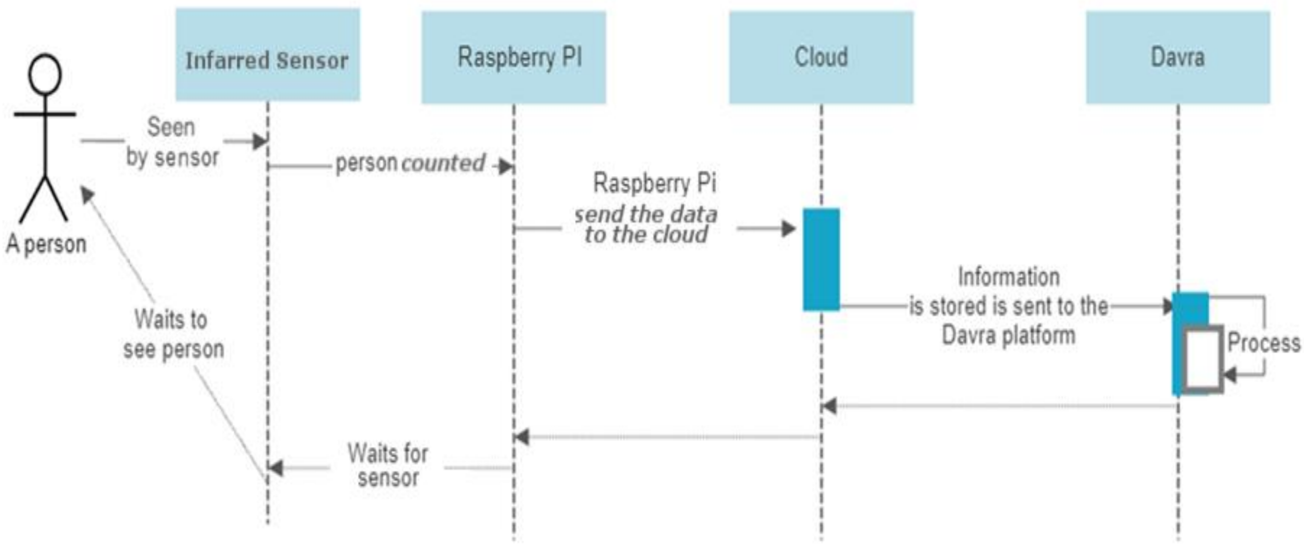

Figure 4.2 10 Raspberry Pi with IR UML diagram

5.2 Raspberry PI

Raspberry Pi Using Node-Red

Over the time working on this project, different methods for meeting the requirements have been evaluated in an attempt to find the best method to have information collected and sent to the Davra platform. With the use of Node-RED, multiple tests have been conducted to meet a conclusion that is supported by iPoint; the use of Node-Red, which is a programming tool for wiring together hardware devices, APIs, and online services in simple and easy to conduct methods.

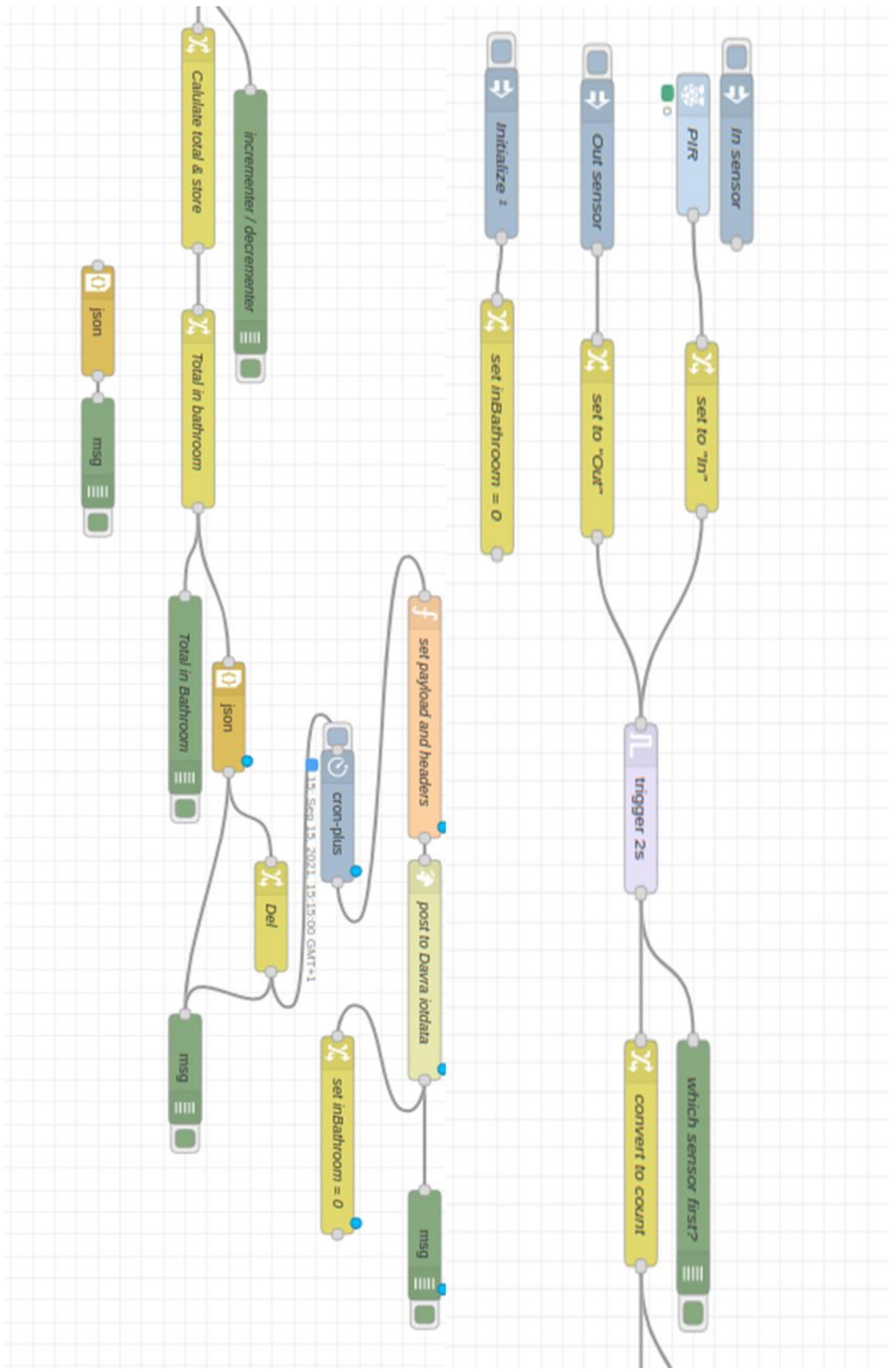

Figure 4.2 11 The image shows an example of a Node RED project for detecting and counting ingoing and outgoing number of people

This is beneficial since it speeds up the required time needed for testing. Using Node-Red with the PIR motion sensor it was able to quickly and effectively obtain information by the sensors and have that information sent to the online platform, Davra.

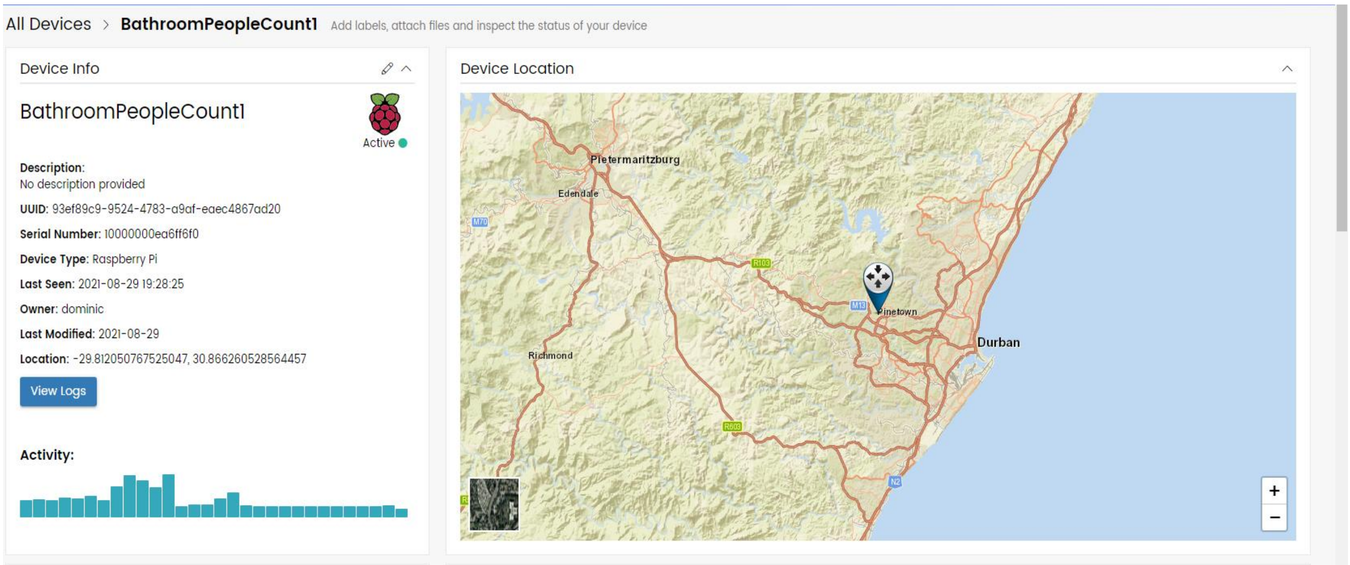

Figure 4.2 12 The image shows the Davra platform, showing where the location of the device will be, key information such as the serial number and number of activates

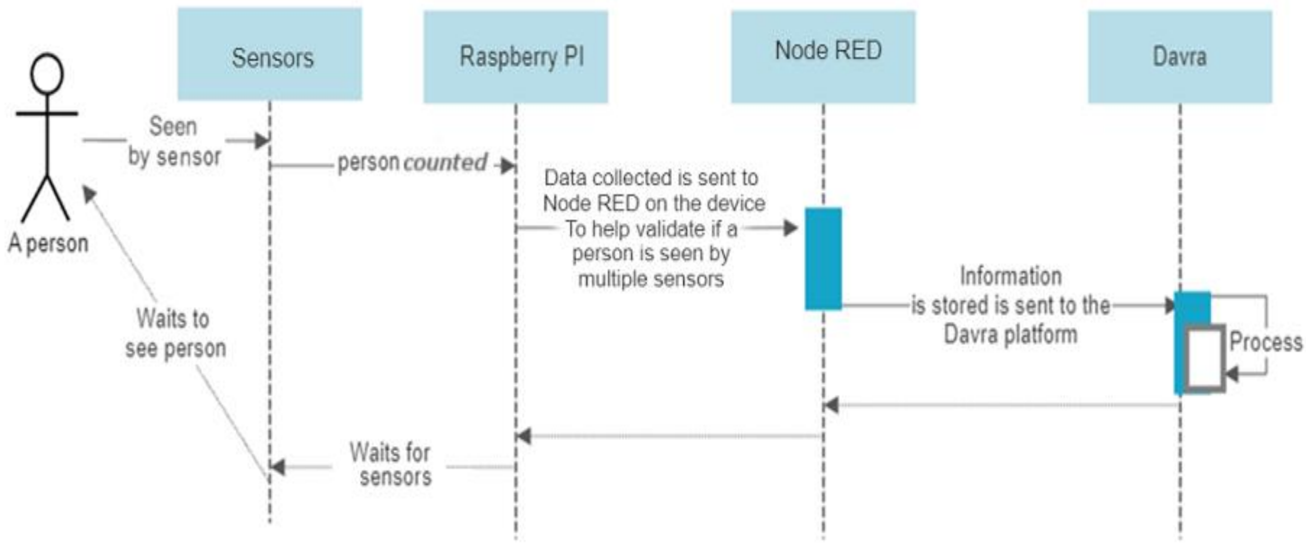

Figure 4.2 13 Node Red being used on a Raspberry Pi

5.3 Existing Architecture from the Cloud

By knowing and selecting the device and sensors, which are best fitting for this work, there is a need to know where the information that will be collected is stored. By looking into the Davra platform, which is the cloud service, that iPoint has selected. A large amount of pre-existing architecture has been made which can help ensuring that the information is easily understandable.

Table 3 Existing Architecture

Item	Description
Jira Kanban board	Jira is the providing company that allows us to use a Kanban board which is an agile project management tool designed to help visualize work.
Application UI Builder	The application builder is the editor used to compose an application primarily at the UI (user interface) stage.
Custom Widgets	An application can be made from widgets which are wired to API calls from standard Davra services; however, it is usual that applications will require a custom presentation of data, or the combination of data gathered by Davra along with that from another system in a single widget.
Custom Services	The Davra platform allows the creation of custom background server-side services, which functions as micro services.
Custom Rules	The Rules Engine allows a developer to define rules, which watch the data as it comes into the system and trigger an action if the conditions are met.
Device Management	The Davra platform supports a large variety of IoT device types. A device can represent an IoT gateway or an abstraction of a data source. From the point of view of the platform, a device is just a unique id of a data source.
Time series Database	All sensor data sent to the Davra platform is stored in the time series database. The API to the time series database allows the data to be queried. The API allows the filtering, grouping and aggregation of data.
Database backups	This platform has is self-hosted can be backed up to various locations using the backup mechanism meaning the loss of all data is mitigated.

5.4 Devices working together

Due to the location and previous conversations with iPoint regarding the devices that may be used, we have talked about using multiple devices working together to gather and utilize the information that is collected.

The original device combination that was agreed upon was the Raspberry Pi, using the images and information that is collected from the Arduino board via a LoRaWAN. By utilising both Arduino boards and Raspberry Pi's to both collect data and analyse, it would allow the data that is collected to be more accurate by having both devices however, this could be an issue for the network and LoRaWAN since this means more collected data will need to be sent to the cloud.

By allowing a surplus of collected data to be sent to the cloud, it would help to ensure that the information that is collected is accurate since both devices should show the same information. This would help drastically since if the devices were implemented together the collect information would be more accurate.

The devices can work together in separate tasks as shown in a test that was conducted, by having an Arduino board with a camera to take a picture once a person is seen from the device it would then send the images to the Raspberry Pi for analysing to gather information of age and sex independently, without affecting the Arduino.

By doing this it will help the overall project by allowing the devices to analyse the collected data, which will then be sent to the cloud to be finalised and logged. There are multiple methods for sensors fusion to be possible. This project has been primarily focused on entity assessments this can be seen by the detection and recognition of a human coming into line of sight of the devices. [56]

Figure 4.4 1 The above image shows the two main sensors used, a Ultrasonic sensor and a PIR motion sensor

As mentioned prior in the thesis due to SA stating cameras were not to be used, by having multiple sensors working together such as the imaged devices above. We can count the number of people that have used the facility whilst ensuring accuracy by the devices working together to minimize false positives and ensure accuracy.

5.4.1 Data Fusion

Data fusion: also known as sensor fusion, is the process and focus of combining collected sensory data or data derived from disparate source of using multiple sensors together. This is to ensure the information that is collected is accurate and relevant since it ensures for this scenario that both sensors agree that a person has been seen.

The purpose of data fusion also is beneficial in further development of this project such as the use of determining the location of specific boating vessels using low-cost sensors. However, it is important to take note there will be an increase in the overall cost since another sensor or more would be needed.

Since there is a large variety of sensors that have been used it will bring a wide range of overall benefits such as, some sensors might add to the data greatly whilst some may not help in anyway and just be a waste. In the next section some tests that have been conducted using multiple sensors for data fusion. Due to the devices remaining on, the flow diagrams start with the first sensor being activated.

Raspberry Pi Using PIR and Ultrasonic

By using an ultrasonic sensor along with the PIR motion sensor, we were able to use the PIR sensor to detect physical movement of a person via their body heat along with the ultrasonic sensor to detect if a person is entering or leaving the toilet facilities.

By having the two devices work, together we were capable of ensuring the information obtained is accurate and relevant regarding an entrance or exit of the area that they are placed. However, by evaluating these devices together misinformation can be obtained.

5.4 Devices working together

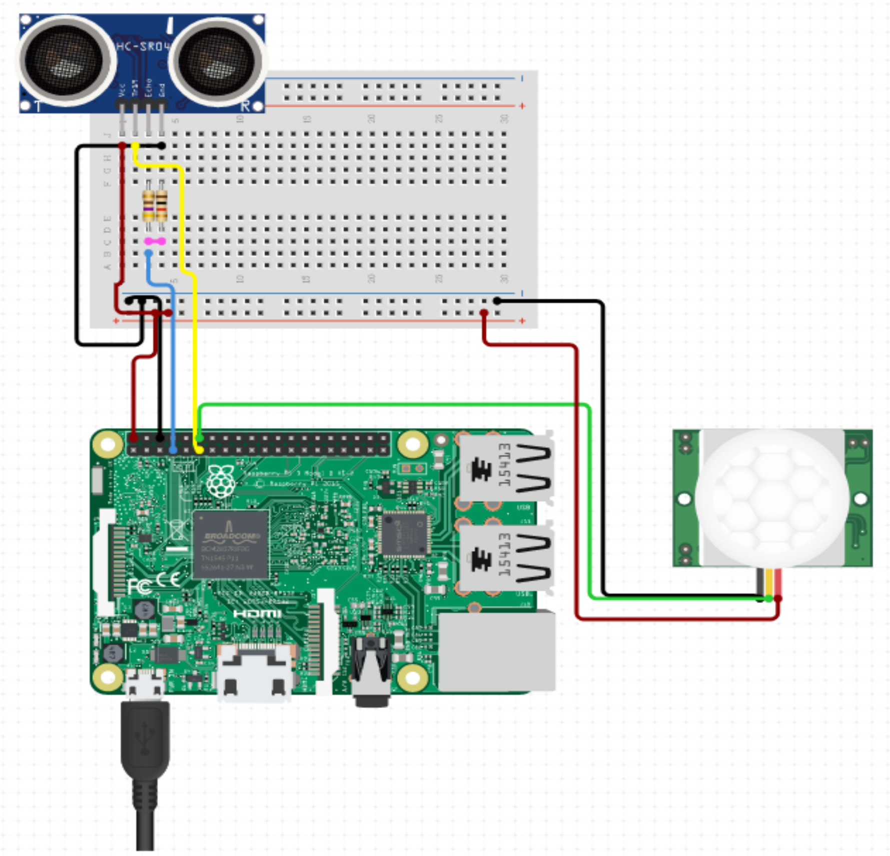

Figure 4.4 2 The image above shows a visual representation of how the PIR sensor and Ultrasonic are connected on the Raspberry Pi

By placing a body part near the sensor whilst holding an item, a person can be counted twice depending on the heat of the room and size of the item in question. This is an extremely unlikely event to happen however, it is a key fact to consider. Whilst using data fusion, it helps eliminate inaccuracies. Depending on the number of people who are using the facilities, there is still a potential risk of miscounting.

A method to mitigate this risk is by lessening the sensitivity of the PIR and/or the ultrasonic sensor, by doing this it can mitigate and lessen the chances of incorrect data will be obtained whilst at the same time lessening the chance for accurate and relevant data being caught. The following is a flow diagram showing how this data fusion method works together.

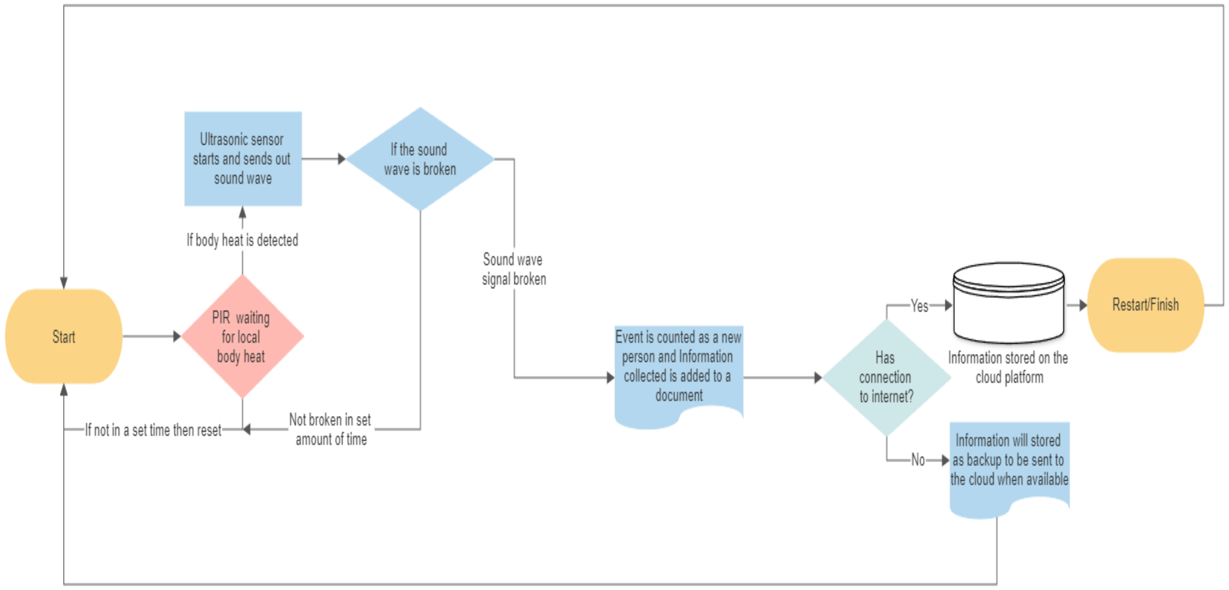

Figure 4.4 3 flowchart of PIR and Ultrasonic sensor

Raspberry Pi Using PIR and laser sensors

By using the laser sensors, Sharp GP2Y0A02YK0F, along with the PIR motion sensor the devices were capable to work well together. By having the laser see movement by a person breaking the laser line and then having the PIR sensor run and looking for that person, it was able to count people with a high level of accuracy.

By placing the laser sensors next to the PIR sensor and having a timeout of only 0.3 seconds; 300 milliseconds, the level of accuracy has been raised to a higher level that in this case is 9.8/10.

The potential reasons for inaccuracy would be due to events such as two people breaking the laser sensors at the same time. To improve accuracy further, by placing thin pieces of plastics to block the PIR sensor from seeing a 360-degree angle to be only 90 degree the level of accuracy is also raised by ensuring that the sensor will only see the person who broke the laser sensor's line.

5.4 Devices working together

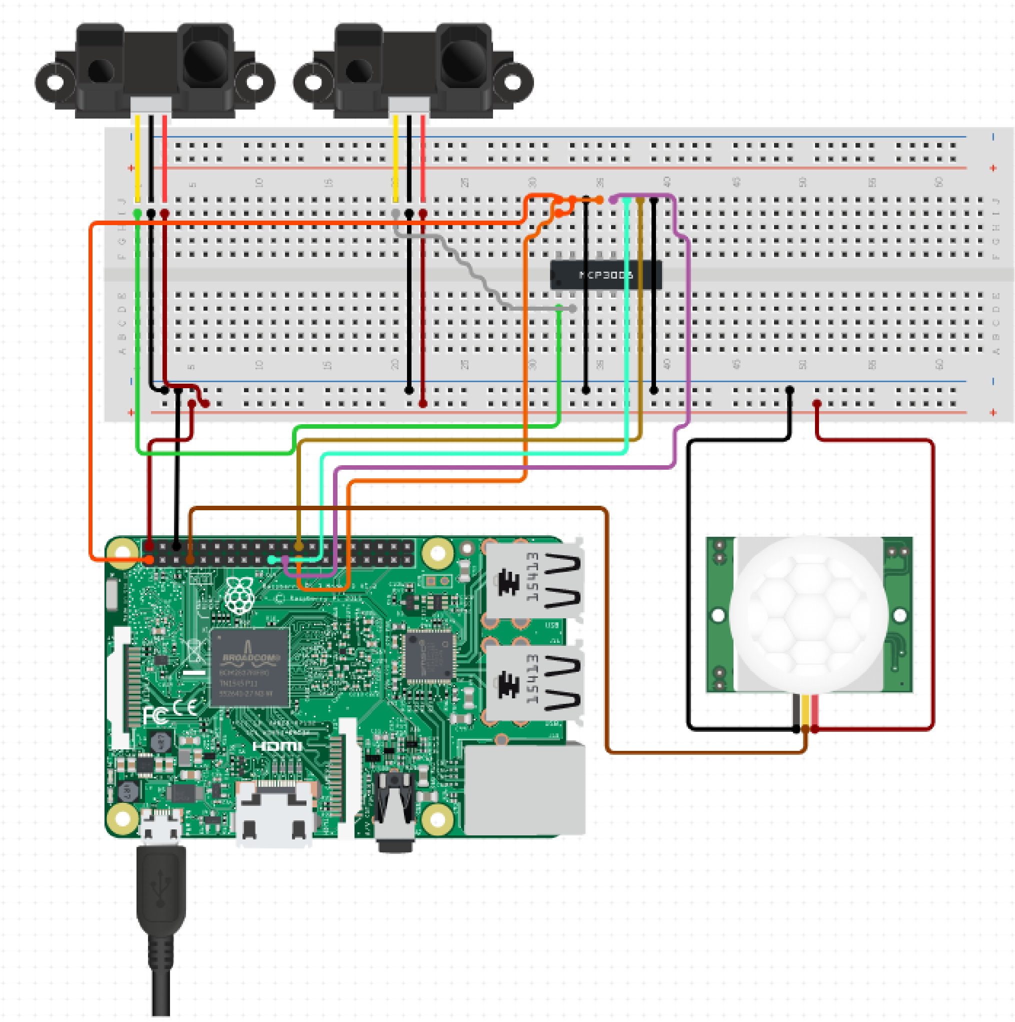

Figure 4.4 4 How we would be able to use two IR sensors and a PIR motion sensor together on a Raspberry Pi, the purpose of this one would be to detect and count the current number of people in a building by counting ingoing and outgoing separately.

Multiple resources such as Raspberry PI tutorials have been used to help gain more understanding of the device. Using these videos information was obtained regarding using an Infrared distance measurement with the Raspberry Pi and by using this information that was obtained along with the information that is already known for the PIR sensor and Raspberry Pi it is clear that using multiple sensors in tandem added an extra level of validity.

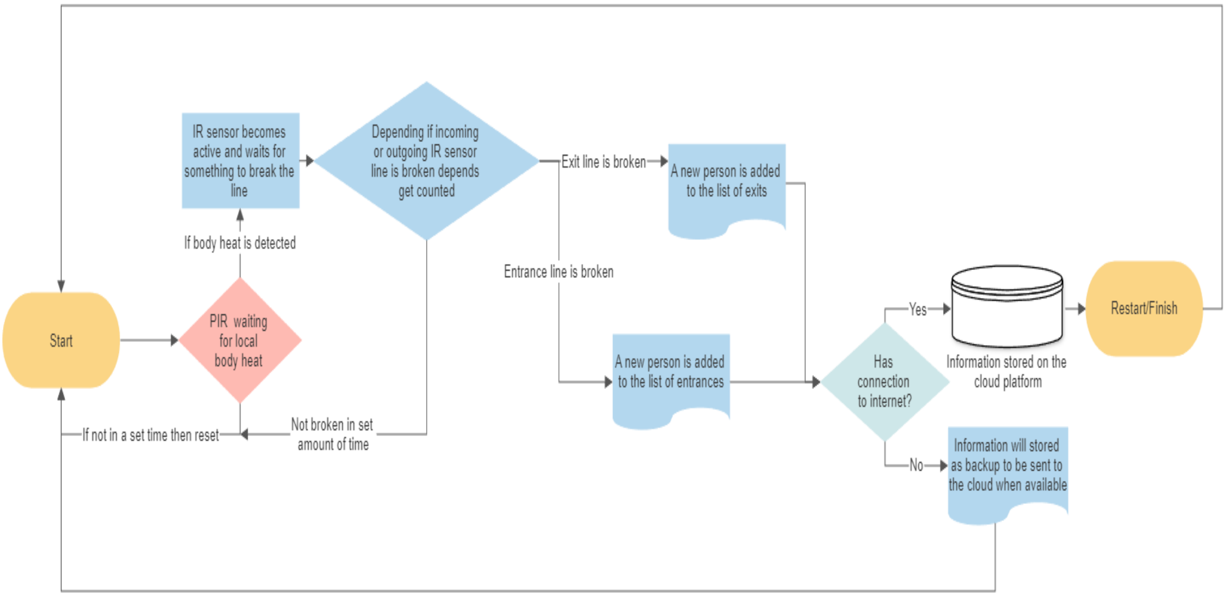

Figure 4.4 5 flowchart of PIR and 2 IR sensors

This flowchart shows how three sensors can be used to count both incoming and outgoing people in separate numbers by using multiple sensors.

Raspberry Pi Using PIR and sound sensor

By using the sound sensor along with the PIR motion sensor. It was capable and enabled the ability of using a PIR sensor to detect physical movement of a person by their body heat, whilst the sound sensor will listen for any noise that it detects to show movement has happened. Using both sensors, it helps to ensure that people have been counted correctly.

5.4 Devices working together

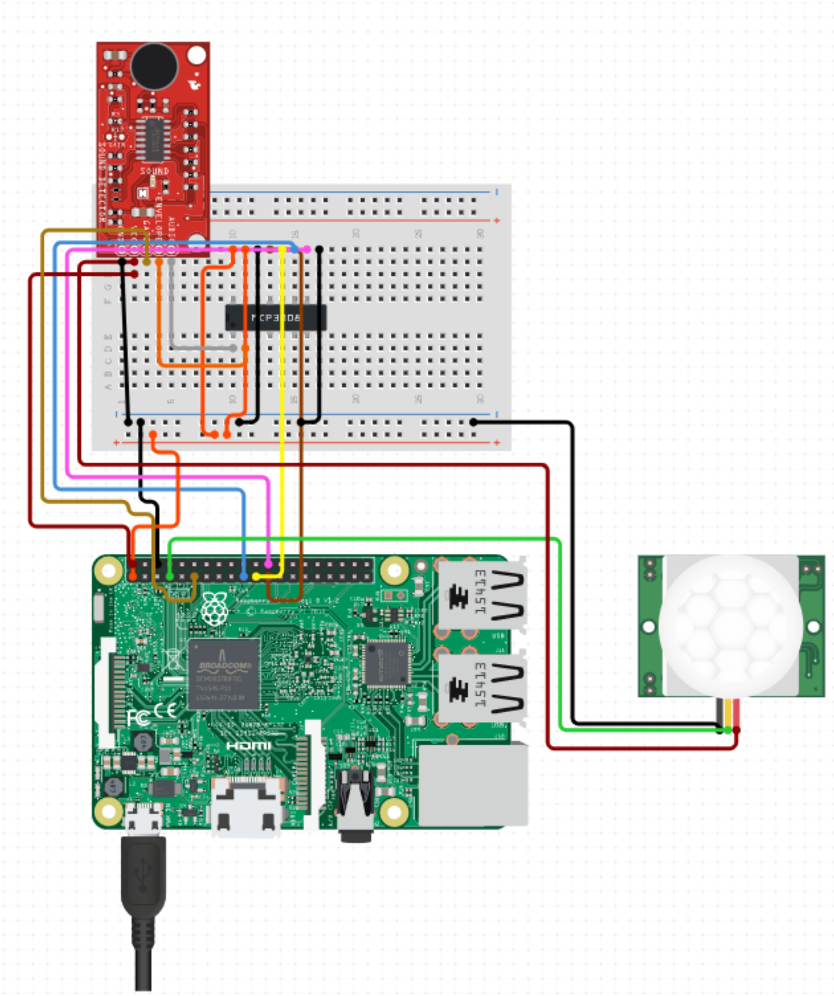

Figure 4.4 6 The image shows a PIR motion sensor working with a sound sensor that will activate when it hears a key noise such as a door opening following by the PIR detecting body heat

However, by further testing, logical inspection, and planning, it can be stated that these two devices could work together but there are more practical sensors that could have been used with the PIR sensor.

Since the sound sensor, would need to be able to detect loud enough noises and depending on the location's footfall and an individual's shoes, weight, and other matters the noise could be too soft or loud for the sensor. In addition, regarding placement of the sensor, it could be placed near the floor but that will increase the chance of damage and need of replacing.

The following is similar to the initial flow diagram at 5.4 3 however, due to variables such as the number of people in the area and conversations this seems impractical.

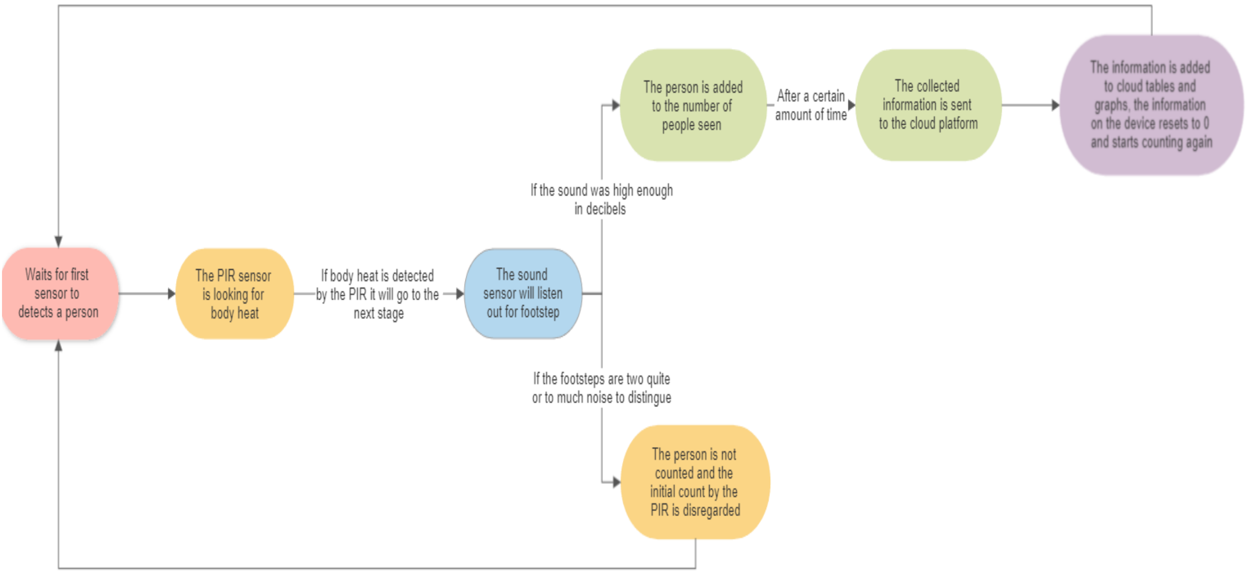

Figure 4.4 7 Flow chart of PIR and sound sensor

Raspberry Pi with PIR, ultrasonic and IR

By using these three different sensors together, we can ensure a human is entering a room by an ultrasonic sensor awakening trigger ensuring that the other two sensors are turned on once it sees movement.

This will allow the other two sensors to work as validators by ensuring that they agree the movement was human by the PIR detecting the body heat produced and ensuring it is to a human level. Followed by the IR sensor to ensure the movement has entered the location to finalise being counted. By doing this we can ensure of a higher level of accuracy.

5.4 Devices working together

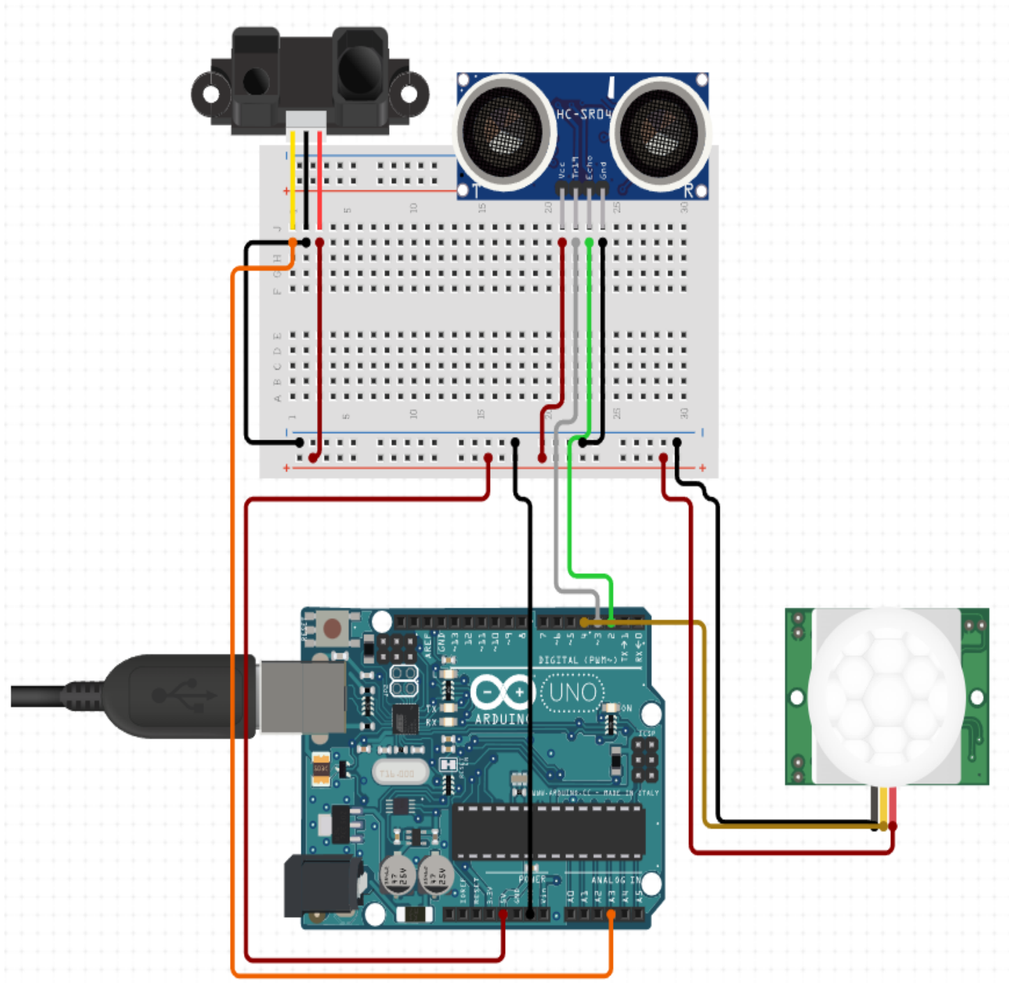

Figure 4.4 8 the image show three different sensors working together, this being Ultrasonic, PIR and IR sensors

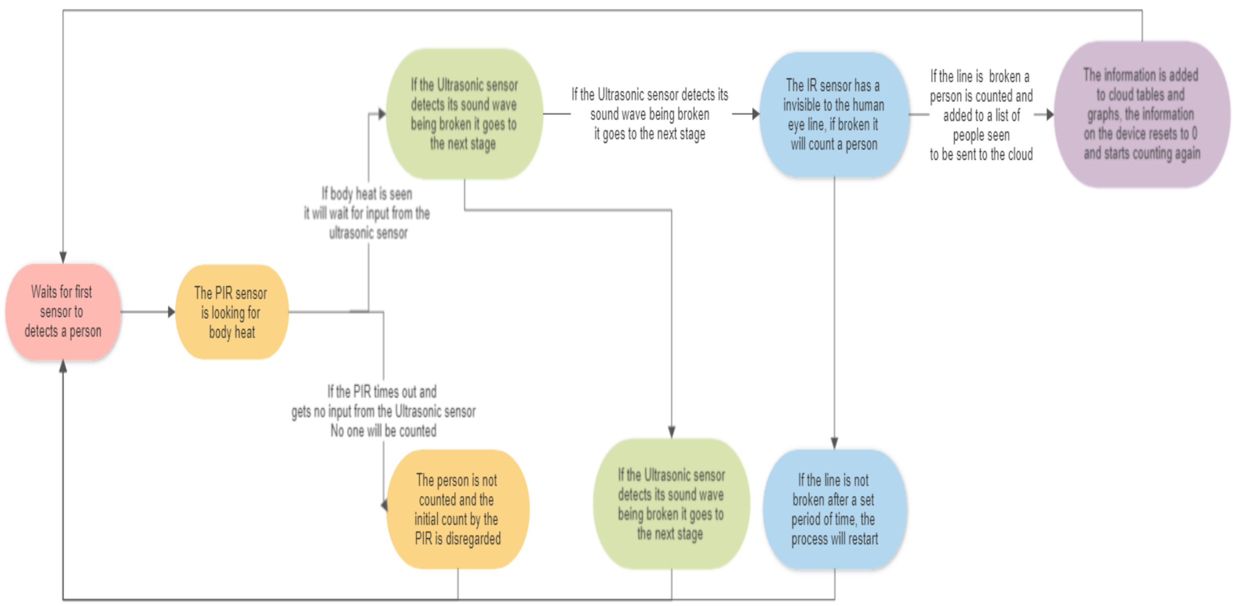

Figure 4.4 9 Flow chart of Ultrasonic, PIR and IR sensors

Outcome

Overall, from assessing it was found that using laser sensors and a PIR motion sensor would be predominantly beneficial since we could use that layout to see how many people have entered and left the bathroom facilities with a much higher level of accuracy. This could be by using a single laser to count the total number of people along with a PIR sensor to work along besides it. However, all the devices that are working together will need to use a breadboard meaning the device will take up more room and will cost more.

As beneficial as this would be, for the purpose of counting the number of people that are using the toilet facilities. By talking to members of iPoint it was clear that this format will not be used since the main goal of the project is to find how much water is being used. Followed by finding which group; male or female is using the most, and, if there is any potential, bacteria found in the collected bodily excrement.

However, from conducting individual tests with different sensors for the three different devices, it has been concluded that the raspberry Pi would be the overall best choice for this project. There is a multitude of reasons; the initial and main negative would be the increase in price. However, from the research that has been conducted it has been found that the device can be accessed from a distance by using application such as remote desktop connection.

In the situation, that information has been obtained but cannot be sent at that specific time, by using Node-Red on this device, the information will be held for a prolonged period and information will not be lost. Yet, overall, by the positive factors it is felt and seen that a Raspberry Pi would be best for this job regardless of the slight increase in price, the usability, accessibility from a distance and overall capability has shown that it is the best choice to use.

5.4.2 Evaluation of the proposed technique

When reviewing the collected information obtained from the use of data fusion, in comparison to the use of a single device, it is clear that using multiple sensors to work together would mean slightly higher power consumption. There may also be an increase in regard to devices breaking simply due to the cause of there being an extra sensor. However, by having the extra sensor and having two or more sensors working together it ensures that information is accurate. Using a PIR motion sensor alone there is no practical method to count incoming and outgoing people, and a person can be counted multiple times.

By using multiple sensors together such as PIR and Ultrasonic or Laser sensors together, it is possible to count people easily and accurately. The device in question; Raspberry Pi using Node-Red, is capable of determining if a person has entered or left the specific location. Since the two sensors need to agree that a person has left or entered, it helps remove inaccurate data that the PIR may have got from counting the same person multiple times.

An important note to remember is the limited number of inputs on the device. When planning which sensors will be used, a focus on the number of inputs available will need to be planned around since this leads to a limit of how many can be plugged in and used with a specific device, Raspberry Pi, or Arduino. Throughout the testing, it is clear to observe that the benefits of utilising data fusion techniques outweigh the negatives such as the increase in cost.

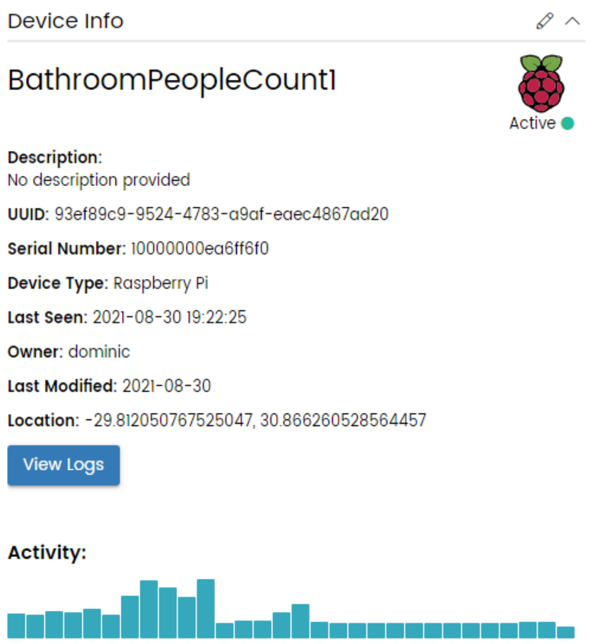

Figure 4.4 11: The above image shows the collected data of the people counting system information that was sent to the Davra platform

5.5 Summary

This chapter is focused on specific tests that were conducted to help find what particular sensor can achieve and how they impact the device. Data redundancy was found to be important since it helps ensure a high level of accuracy.

The most beneficial sensors have been identified in the previous chapter, so we were able to examine in depth at the different devices and sensors could be used in combination. Using the two main devices, Arduino, and Raspberry Pi it was simple to look at the three main types of sensors that are to be used in this project.

Having a deep look at the already existing architecture that will be on the cloud platform has helped us gain more of an understanding on how information can be displayed and how the information will be stored. Due to the architecture already being made a key factor for this project, understanding how to use it effectively was needed essential.

This chapter concluded by analysing the devices working in tandem. By conducting tests for each combination of sensors working together, we can see the amount of information has been made smaller, but more accurate which is the main aim of this project.

Chapter 6 Scenarios

This section is focused on creating logical, evidence-based scenarios regarding the overall project and how different sensors and cameras would be able to collect data. Below is the general design and layout that will be working with these theoretical scenarios:

6.1 Theoretical location and sensor placement

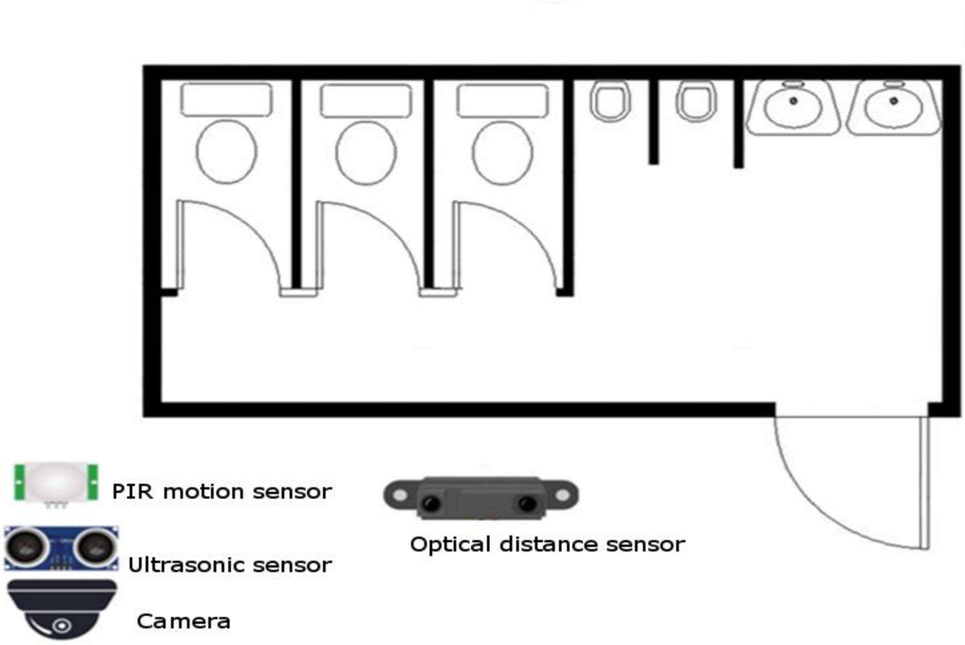

Figure 5.1 1 A template design of the location in South Africa with the sensors that will be used to help visualise how and where each sensor would be beneficial

To help illustrate the different methods the objective could be met by a visual media, there will be multiple layouts on all potential scenarios. Due to the multitude of objectives and items that could be used the main focus will be with regards to counting people entering and leaving the toilet room with a total of three different layouts. Due to working on both male and female toilets, these theoretical diagrams will focus on male toilet rooms since it both has urinals and cubicles.

Scenario 1

This scenario is focused on using a camera; prior to SA stopping it being used, in an ideal location. The camera would need to be placed in a location that a person’s face is easily visible and in a location that would allow the camera to count people both entering and leaving the bathroom. If there is only a single access point, a single camera would only be needed to count people and identify their sex.

A sensor would be needed to calculate water usage, via water flow and tank level; having sensors in a water tankard to calculate how much is used. This would be of immense help regarding the process and need to create an associated water usage by mathematically calculating which of the two sexes are using more water; due to the limitation of water in SA, this is needed and sought after. As mentioned previously this will no longer be allowed via a camera hence why the other scenarios focus on using sensors.

By having both a camera and sensors talking and being able to send data to the cloud via a LoRaWAN system that is in place, information can quickly be obtained and received. In an ideal location, changes and manipulations to the plan would not be needed. This can be seen in the image below:

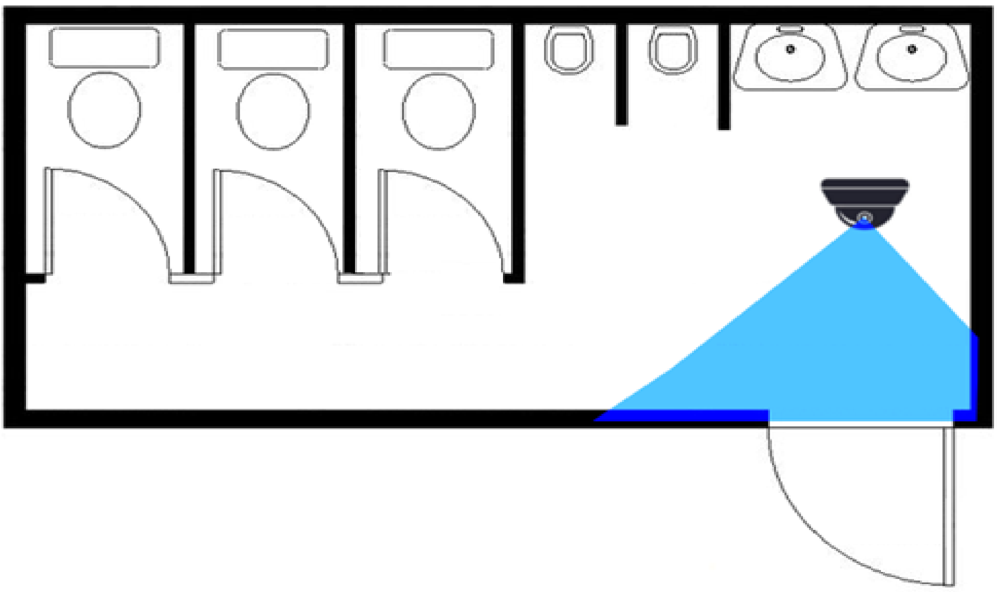

Figure 5.1 2 The above image shows the scenarios base layout with a camera in use

From the image above it is clear to see that one camera would be capable of seeing people thus identifying them and being able to count them accurately.

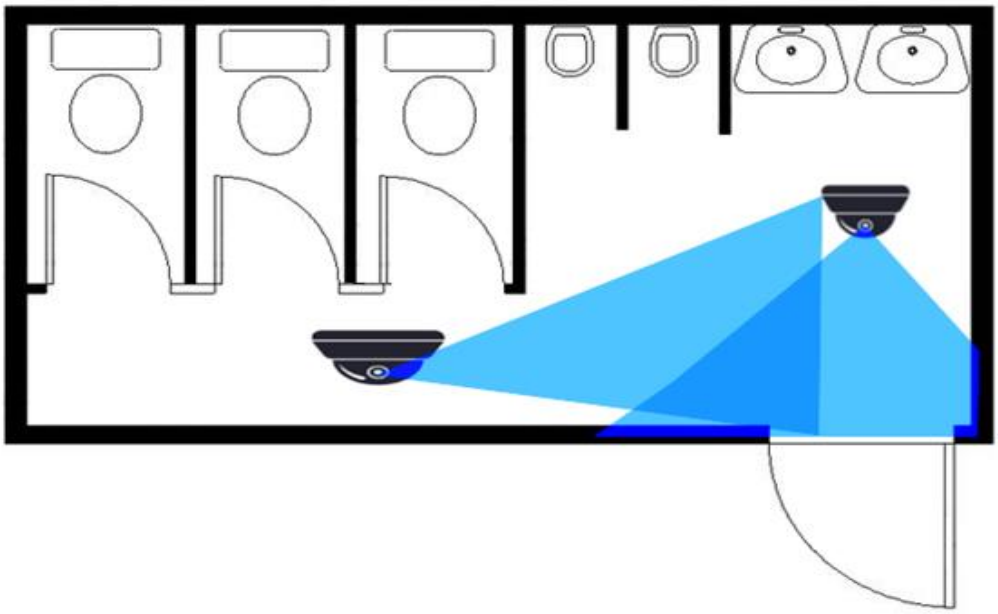

Figure 5.1 3 How the utilization of two cameras

By having two cameras looking at the same location, it can help collect more data to help accuracy and if one camera fails, the other will be able to keep working and collect data. The more cameras that are used the more data that can be collected but that will increase the cost also which would be a major negative so the use of different sensors such as an ultrasonic sensor as shown in the diagram below would be advisable.

By having these two devices work, together we are able to ensure that that relevant and accurate information regarding the number of people is using the bathroom and help us mathematically state how much water each person that comes to the facility is using.

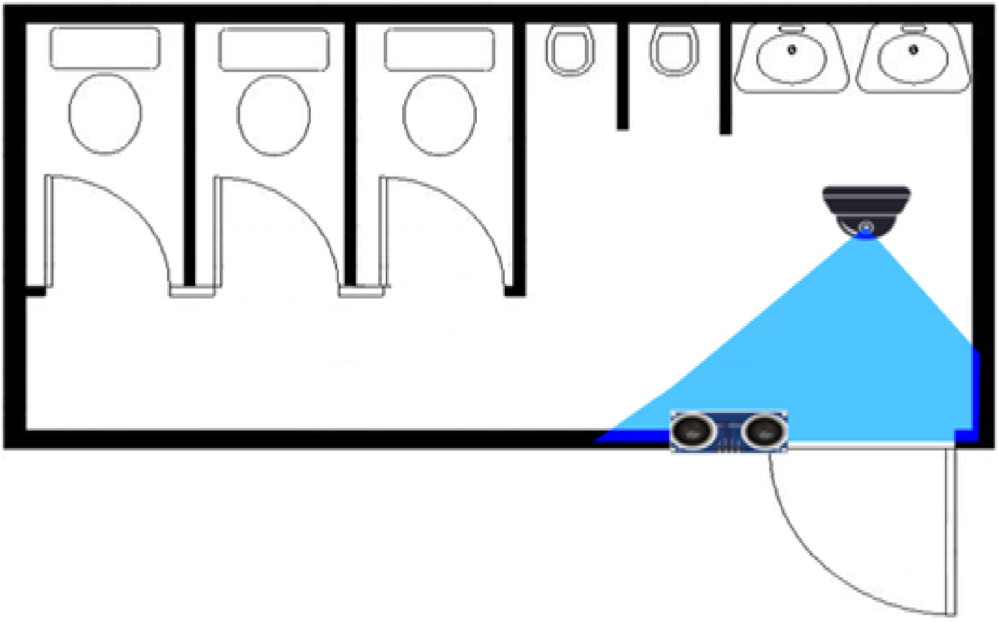

Figure 5.1 4 Image shows the use of both a camera and ultrasonic sensor

By using a camera along with an ultrasonic sensor, we can have the camera activate if the ultrasonic sensor detects something/someone. By doing this it helps lessening the chance of the camera burning out and can ensure a higher level of accuracy.

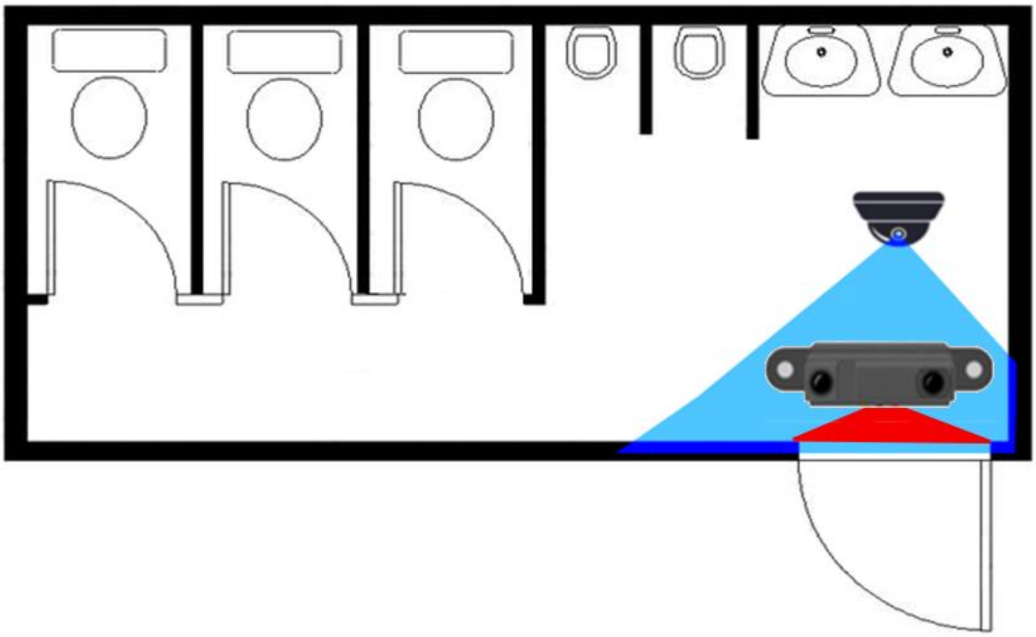

Figure 5.1 5 The image shows the use of both a camera and IR sensor can work

By using both a camera and laser sensor/sensors, we could activate the camera once the laser from the sensor is broken by movement. By doing this it helps lessening the chance of the camera burning out, on top of this, by having two lasers, we could have a relatively active method to count the number of current users at any time. By having both devices aimed at the only entrance we could achieve a highly accurate result of people and when they are using the location.

Scenario 2

This scenario is focused on using one or multiple sensors listed beforehand, items that we are currently allowed to use. These devices will be used in an ideal location and method to see how practical they would be. As listed previously in chapter 6, there are multiple types of sensors that can be used, depending on the location, building material and room layout different sensors could be used to ensure their overall practicality.

In this scenario, there is only one entrance and exit meaning we could use two ultrasonic sensors to count people entering and leaving the bathroom easily. Due to this we could use multiple sensors to collect more data, it may seem redundant, but it helps with ensuring and finding accuracy. Due to it being overall ideal, there are multiple methods and locations to place sensors and collect relevant data. This can be seen in the images below:

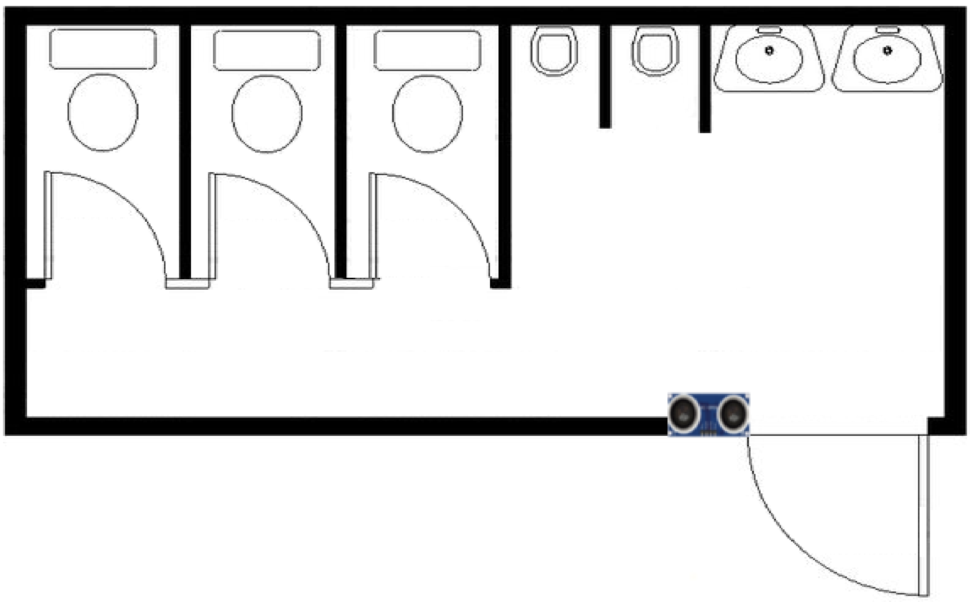

Figure 5.2 1 How an ultrasonic sensor alone could work

As shown in the diagram above, by having a simple set up of having an ultrasonic sensor at the entrance we can have a highly accurate method of counting the number of people who have used the bathroom however, as mentioned prior, due to it being sensitive to variation in the temperature it may struggle with the fluctuation of heat.

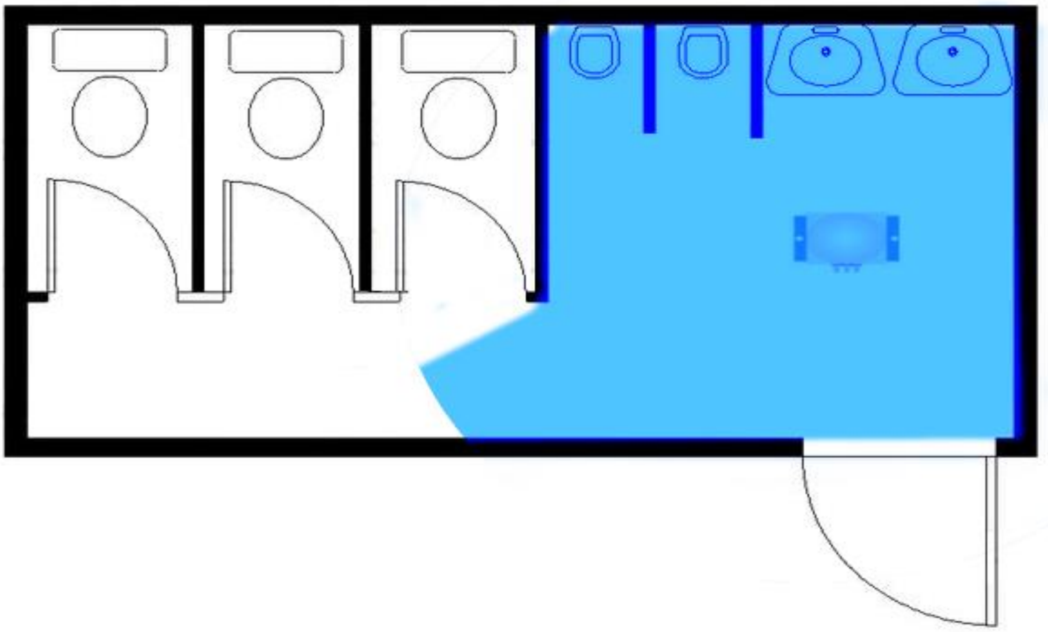

Figure 5.2 2 PIR motion sensor alone could work

As shown in the diagram above, by implementing and using a PIR motion sensor, a large area of the toilets are visible and information ranging from how long a user spends washing their hands to counting people that have entered the toilets can happen. However, Since PIR sensors sense heat signatures; they are not practical if the room itself is warm. The use of PIR sensors would have difficulties, with recognizing and detecting human beings in the summer times.

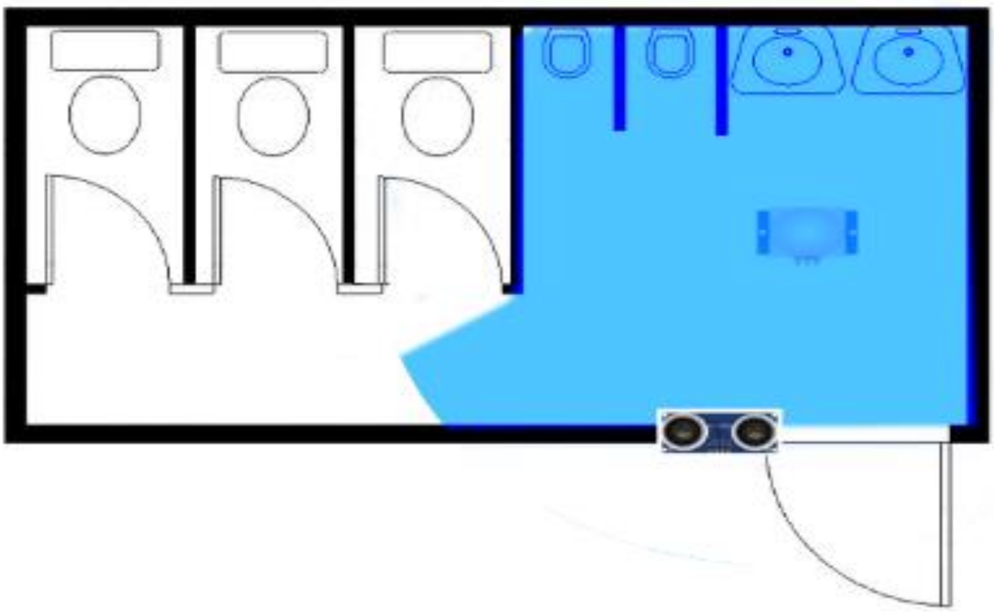

Figure 5.2 3 How a PIR motion sensor would work along with a PIR sensor

As shown in the diagram above, by incorporating and using both of the sensors shown prior, there would be a slight increase in cost and code that is needed to capture and format relevant information captured from both sensors. However, due to these two scenarios working together that means more information can be collected and with the chance of one device being damaged or if it stops working than the other would still be functional since they do not need each other to function.

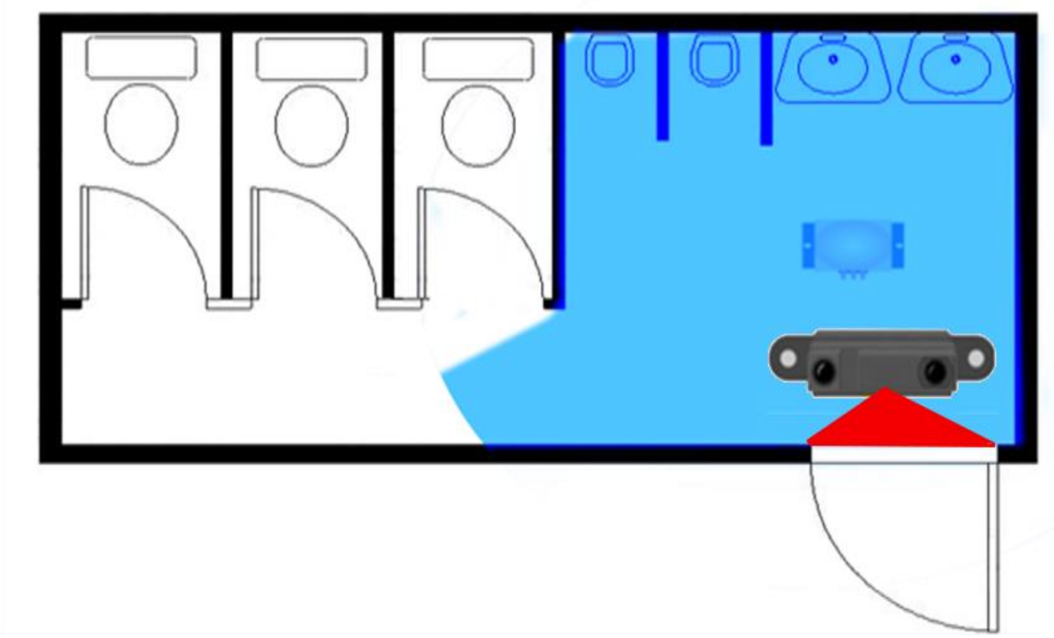

Figure 5.2 4 How a PIR motion sensor would work along with an IR sensor

As you can see in the diagram above, the laser sensor will be looking at the entrance to the toilets, by having this the PIR can be activated once the laser sensor has been tripped; meaning it has detected someone. By having this it will lessen the chance that the PIR burns out from overuse. Also, by having this we can also have a more accurate number of people using the location instead of simply counting every person the device sees.

Scenario 3

This scenario is focused on using the sensors, and items that we are currently allowed to use however, these devices will be used in a non-ideal location and method. In an attempt to see how practical they would be by allowing us to compare and contrast scenario 2 to 3. Due to the multitude of locations in SA where this project can be placed in later stages and due to this, each implementation of this project would need information to be gathered and planned around, especially if the location is not ideal.

In this hypothetical location, there is multiple access points either it being doors or potential holes this would need to be planned around, we can place multiple laser or ultrasonic sensors at all the access points to attempt and ensure accuracy when counting the number of people who are using the bathroom.

We could attempt to have one overall data field regarding the number of people that have used the bathroom, which would be ideal. This might lead to more issue's especially if a sensor stops working; by having different lists of collected information regarding how a person leaves or enter the facility, we can be fairly confident that if one sensor stops working the information that is collected would be reliant and semi-accurate.

Depending on the room layout and once again the condition of being able to hide the sensors and other device may be difficult and need more planning around to help limit the chance of theft or damage. In this scenario the overall project will still be achievable however, in-depth planning and information will be needed to help ensure that the information collected is both accurate and has not been manipulated in anyway, i.e. through damage or interference. This general room layout can be seen in the image below:

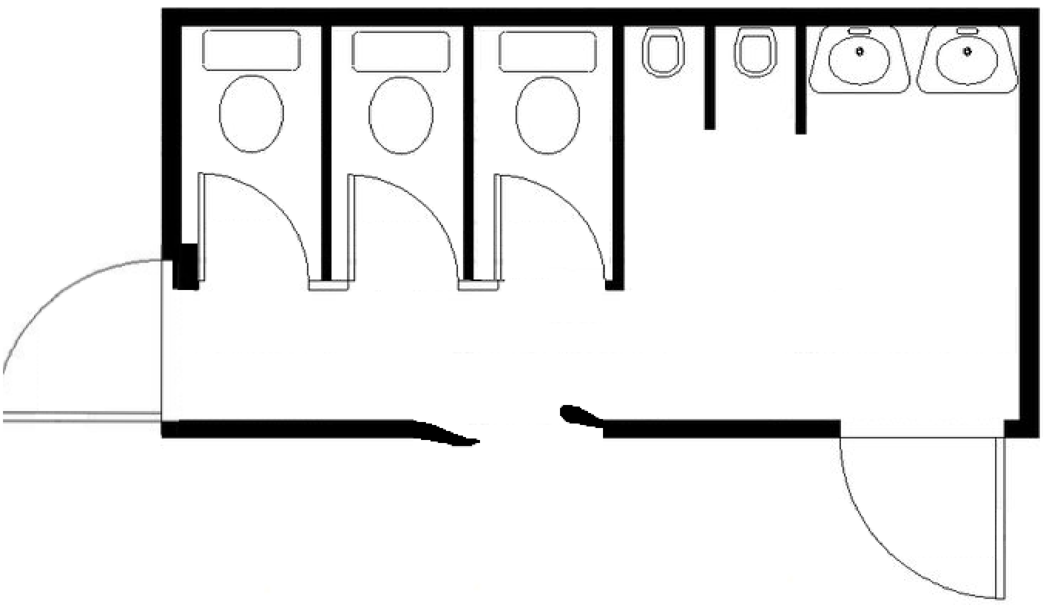

Figure 5.3 1 Scenario where there is a hole in the wall that can work as an entrance

6.1 Theoretical location and sensor placement

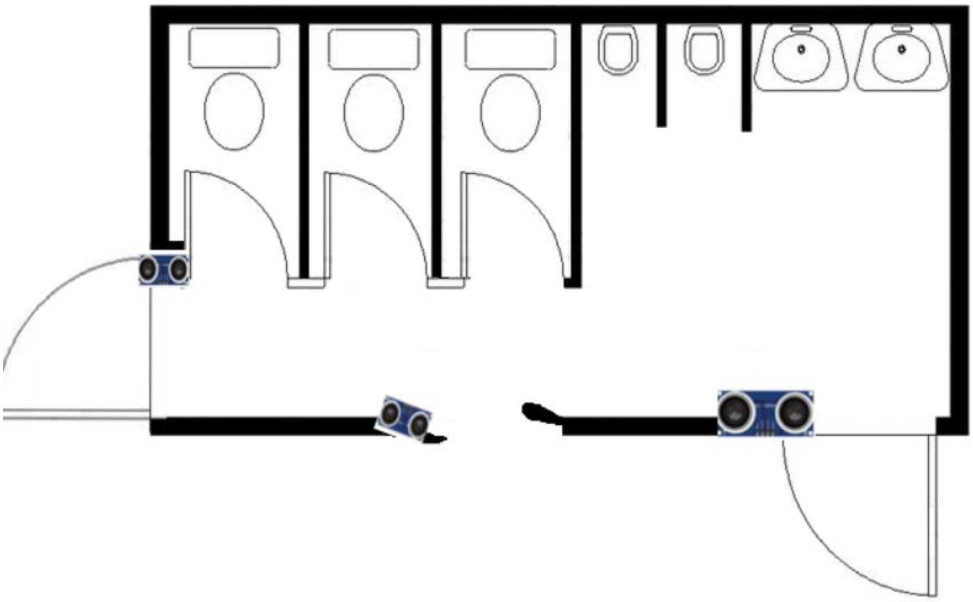

Figure 5.3 2 How an ultrasonic sensor along with a PIR sensor could work in this scenario

As it can be seen from the image above, regardless of the buildings condition or the number of entrances available by using ultrasonic sensors they can count entrances and exits from all directions, regardless of if a person enters from one direction and leaves at another the overall calculation of users will be relatively accurate and relevant.

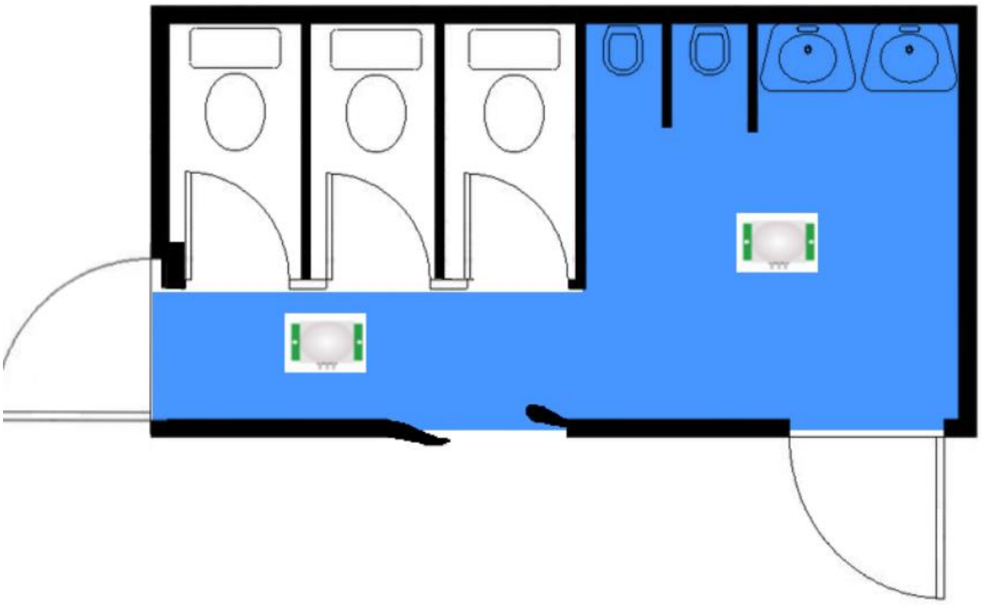

Figure 5.3 3 The above image shows how having two PIR motion sensors could work in a worse scenario since it would cover the needed area

With using primarily PIR motion sensors we would need to have full active monitoring of the bathroom from all entrance points, this means we would need a minimum of two to ensure that all information of the number of users have entered and exited the bathroom location. Due to having two of these devices talking to each other we would need to ensure that they are sharing information they collected to each other to combat the chance of counting the same user multiple times.

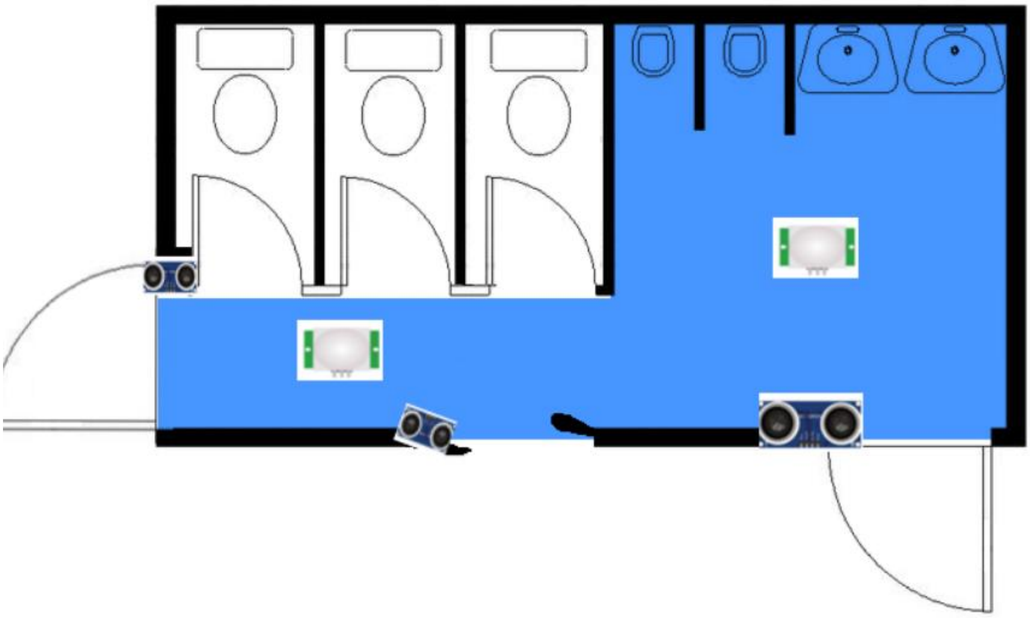

Figure 5.3 4 How having two PIR motion sensors along with three ultrasonic sensors could work in a worse scenario since it would cover the needed and give accurate readings of movement

Similar to the two prior scenarios this figure shows the room with two of the previous sensors working together: this being PIR, and Ultrasonic sensors. Similar to the previous figurers like this, this would be ideal since if a sensor were no longer functional or stolen the needed information could still be collected from another sensor. The data these devices collect can be containerized and placed into different sections to allow human interaction to help manage and monitor to find relevance and accuracy of the data collected.

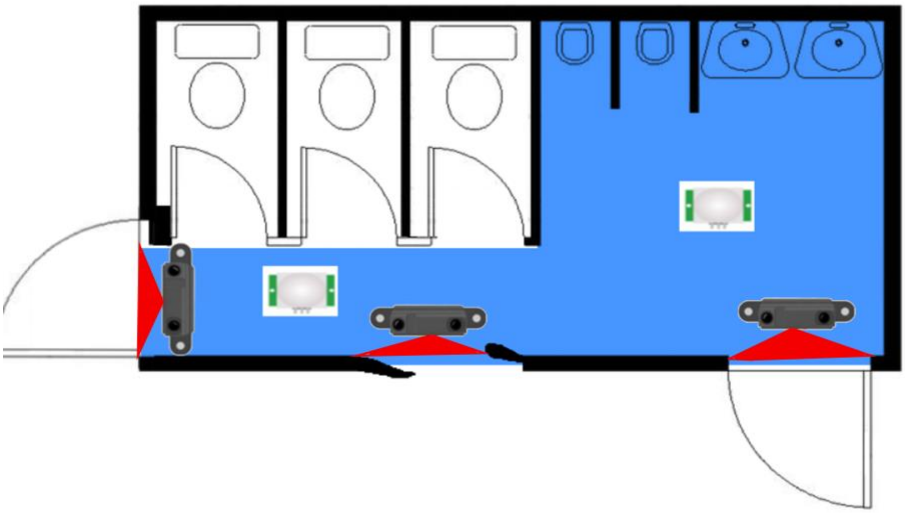

Figure 5.3 5 Two PIR motion sensors along with three IR sensors could work in a worse scenario since it would cover the needed and give accurate readings of movement

In this figure of the room, two of the previous sensors are working together in unison; PIR and Laser sensor, to help collecting data even if it is repetitive. By utilising all of the key components of the devices, such as the IR laser, we can for example have it function as activation for the PIR. If we could place two lasers on each entrance, we could have an accurate count of people using the location and see when it is most busy. This will help in later work regarding the amount of water used and when.

6.2 Summary

This section was focused on creating a total of 3 theoretical building scenarios and using the previously chosen devices and sensors in an attempt to gain insight as to how these scenarios with different levels of structural integrity would impact the sensors and vice versa. This was beneficial especially with the different scenarios of building structural integrity and methods to enter and exit the building. Due to the variables shown in these scenarios it was clear that multiple sensors would be the most appropriate method to count the number of people, especially with multiple access points.

Using multiple sensors would stop sensors miscounting or counting a person multiple times which can easily happen without the inclusion of data validation. Although these tests were not conducted in a physical location is has helped us gain an understanding of how a sensor would work alone and how utilising validation from other sensors helps ensure that the collected information is correct.

Chapter 7 In The Wild Evaluation

7.1 Preparation and device information collection

By the information collected by the previously conducted tests on the different devices, sensors and created theoretical scenarios this has led to the initial decision to focus primarily on a PIR motion sensor that is connected to a Raspberry Pi using Node Red. This automatically sends the collected data to the Davra platform, iPoint agreed with this approach. A 3D printable case for the items was created, for them to be contained and placed on ceilings, out of line of sight, whilst they capture information.

Once the device was fully working, it was placed inside of the made container. The device was placed in different areas of the researcher's accommodation, to find the best location such as on a wall at different heights, on the floor, or on the celling. More information was captured regarding people once placed on the celling instead of anywhere else. If it was to be placed on a wall or floor, there is a heightened chance of theft or damage.

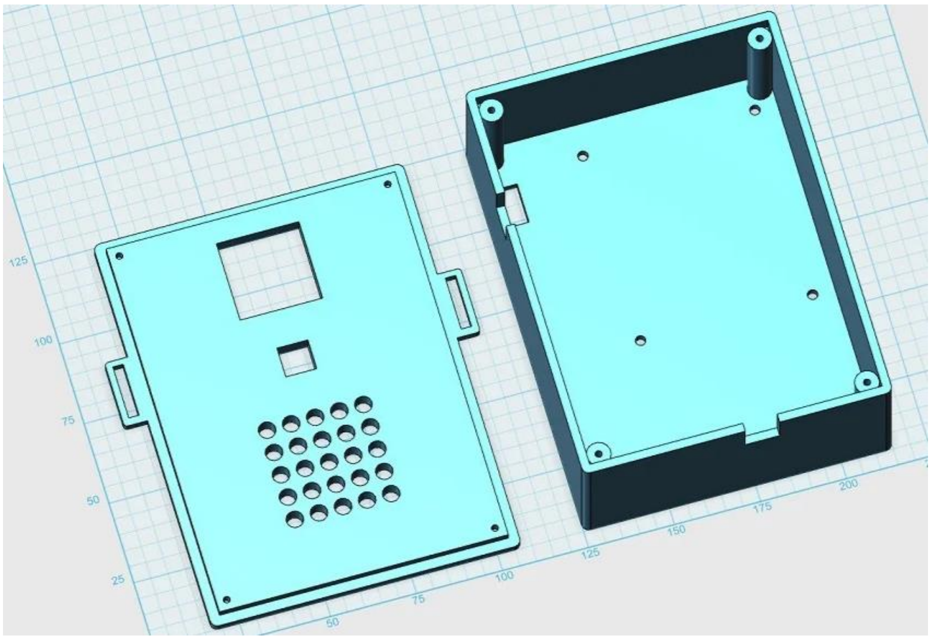

Figure 6 1 The image shows an initial design that was created to hold the devices and sensors

Above is an image showing the device in design, prior to printing. Once the device was in place and information was captured and sent to the Davra platform, it was possible to monitor activity on a graph or other visual output.

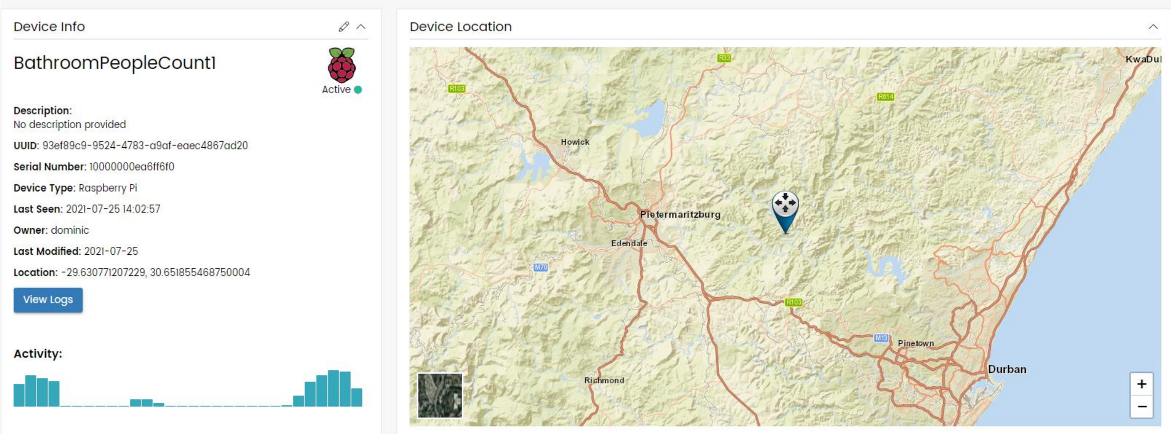

Figure 6 2 The image shows the activity the device has recorded

7.2 Implementation and Location testing results

For the purpose of conducting tests, Cardiff University agreed to have the device/devices implemented in their new building named Abacws however, prior to deployment in the Abacws building preliminary tests were conducted in the researcher's accommodation.

This enabled an assessment of the level of practicality and usefulness this device would have. The Committee from the university gave a favourable ethical opinion of the above application on the basis described in the application form, protocol and supporting documentation, subject to the conditions. One of these conditions was signage that was used to inform users of the buildings of the presence of sensors.

Due to the restrictions on building access across the Covid period, there was a lower amount of footfall, which means less information. Prior testing conducted in the researcher's residence with guests, placing the sensor inside, looking out through a window. This window had a reflective coating that may have caused some variability in results. Finally, the sensors and Raspberry PI were placed at the end of a hallway adjacent to the researchers' residence. This was done to gain an understanding of the practicality of certain devices.

The sensors used were, the PIR motion sensor, the PIR with the laser sensor, PIR with ultrasonic sensor, PIR with the sound sensor and finally PIR with both ultrasonic and a laser sensor. A diagram of the hallway to the researchers' residence is shown below with a red box to show where the device was located:

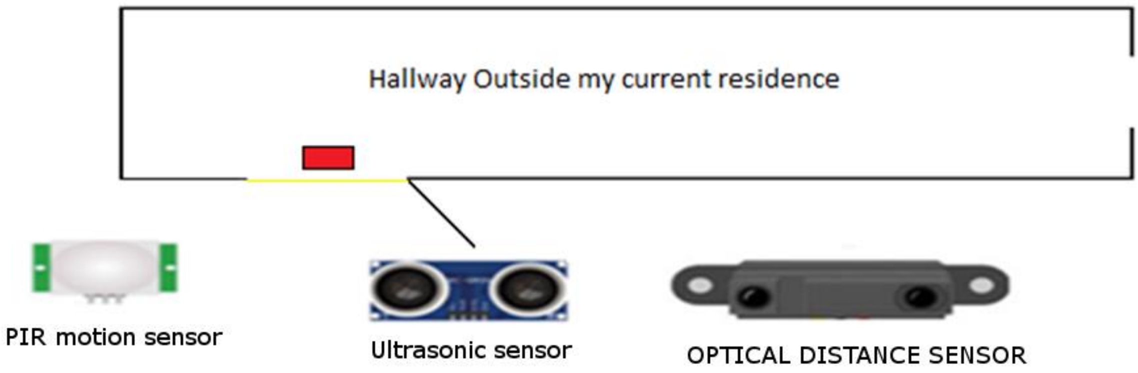

Figure 6 3 The image shows a rough guide of where the devices were initially tested, undercover in a public hallway

Testing the device in a local public location ensured that no damage or theft could have occurred. Tests of Remote Desktop Connection were conducted to see if this application would be beneficial to the project and if any electronic changes were needed.

These tests followed GDPR (General Data Protection Regulation) practices and The Fair Use Act, since it complies with two of the main principles, non-profit and educational. Tests confirmed that the devices would not harm anyone in this position. Majority of the time the sensors in this test only counted me entering and exiting the residence. This test was conducted in two methods, one being top down and the other being side on. These tests revealed that it would be more practical having the sensor-facing top down, since this minimised the threat of theft, damage and people being concerned.

After all preliminary tests were conducted; the device was placed and deployed in Cardiff University's Abacws building. The implementation of the solution utilising Node-RED and various IoT sensors were used to create a seamless and efficient system. Meaning the primary base of software was conducted through Node-RED, which is a flow-based development tool that was chosen for its ease of use and powerful integration capabilities making it ideal for orchestrating interactions between the IoT devices and processing data.

7.2 Implementation and Location testing results

When placing the device in a real world location we were able to ensure the device was fully functional whilst minimising potential issues such as device breakages. The real world testing also involved addressing significant complexities, such as building layout, number of footfall and the sensors limitations. By using lightweight software libraries such as Node-RED we were able to minimize the system's resource footprint.

Before placing the device in the real world location the selection of components was paramount to ensure these tests were conducted effectively and efficiently. This included choosing devices, sensors, and potential storage solutions that would be needed for this task efficiently. The integration of hardware and software was managed through a systematic approach, using middleware and APIs to facilitate seamless communication between different devices and sensors.

Once the device was put in place, an internet connection was needed for the information to be sent to the cloud platform. This was done by connecting to the University Wi-Fi. During the test, we used Node-Red along with a Remote Desktop Connection named VNC viewer, which allowed access to the Raspberry Pi device as long as we were on the same network and inputted the correct password.

The software tests have been conducted in previous chapters; this was done with a robust architecture design. This design choice was driven by the need for accuracy and maintainability. The use of micro service architecture found in Node-RED was particularly innovative, enabling independent deployment and variability of sensors that could be used. This significantly improved the system's robustness and fault tolerance by minimizing potential issues by overcomplicating.

As mentioned in chapter 4, Node-Red is "a programming tool for wiring together hardware devices and APIs to online services in a simple and straightforward flow-based program". By using Node-Red we were able to make changes to the sensors that were to be used, ensuring that it is functioning correctly by the knowledge we gained from previous tests. Making these internal changes was made simple by the utilisation of VNC viewer, allowing the ability to make any changes to the code or to the sensor combination. Changes could be easily and quickly made without unplugging and physically changing the device. From the initial tests done at the researchers' residence, the choices for the devices and sensors used were in place and ready to be used in real world testing.

The tests were conducted using the following sensors, either alone or in combination; PIR, ultrasonic, laser Infrared sensors and a camera. These were chosen for their accuracy and ability to function in various lighting conditions. During all of these tests the sensors were placed in the same location with the camera having the same viewpoint on all iterations, this was done to minimize the chance that collected information was infringed regarding sensor placement.

Throughout the previous chapters and tests on specific sensors and throughout implantation, we were able to ensure a simple level of innovation along with creativity was achieved. For example, to minimize the chance of burn out of the devices by not having them active constantly, we had a key sensor working as an activator to the other sensors.

Finally once the information was collected, it was placed into a text file stating only timestamps for activity ensuring that anonymity was achieved, whilst still having useful information sent to the Davra cloud platform. From the cloud platform this information was placed in a readable graph to ensure practically and usability of the information obtained.

In conclusion, implementation of these different outlines for tests conducted required and involved a detailed and thoughtful approach to hardware and software integration. Key decisions were made with a focus on innovation and creativity, addressing complexity and constraints to develop a high-quality solution.

7.2 Implementation and Location testing results

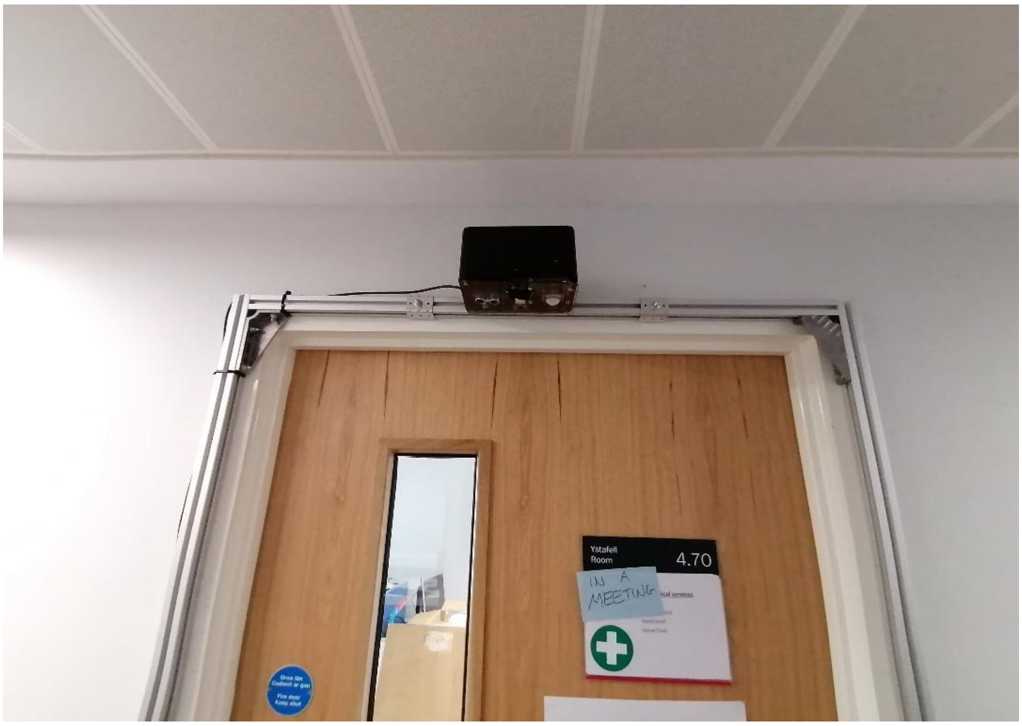

Figure 6 4 The above image shows the placement of the device in Cardiff University Abacws building.

Figure 6 5 The above image shows the viewpoint that the sensors and cameras can see

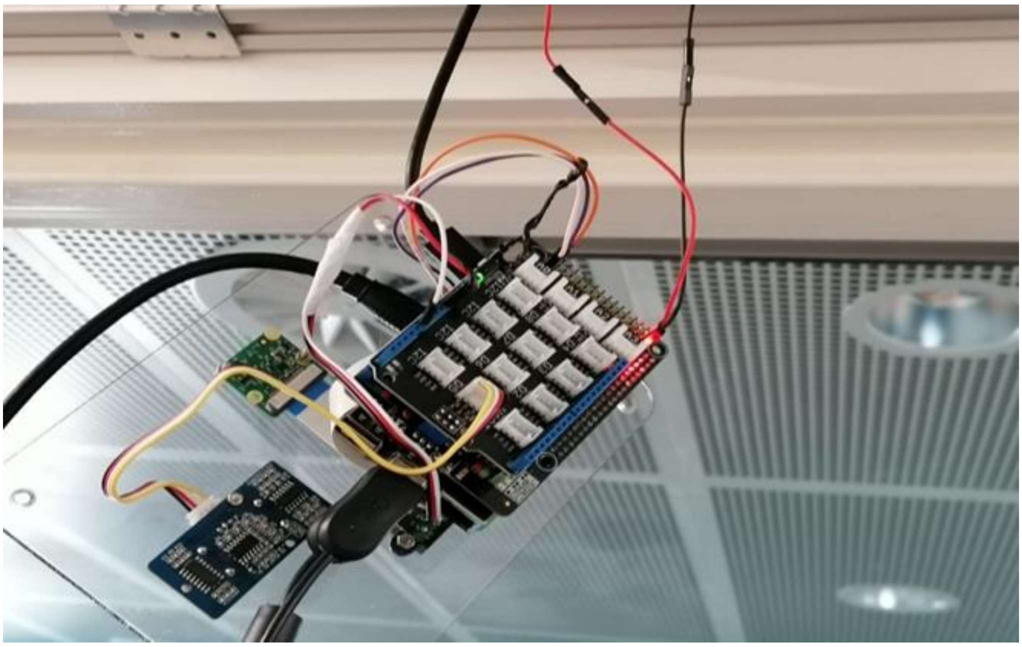

Figure 6 6 The above image shows the inside of the previous image, and the devices and sensors are connected

Test 1, Single sensors

Test duration, 1 week 18/04/2022 - 25/04/2022

For the initial test, three different sensors were working independently for the purpose of collecting independent data at the same time. The purpose of this test was to gauge how accurate and similar the results would be from each sensor. As can be seen below, there is a wide level of fluctuations. This happened due to multiple factors such as, the sensors themselves, location, and speed of a person, proximity, and casing for the Raspberry Pi.

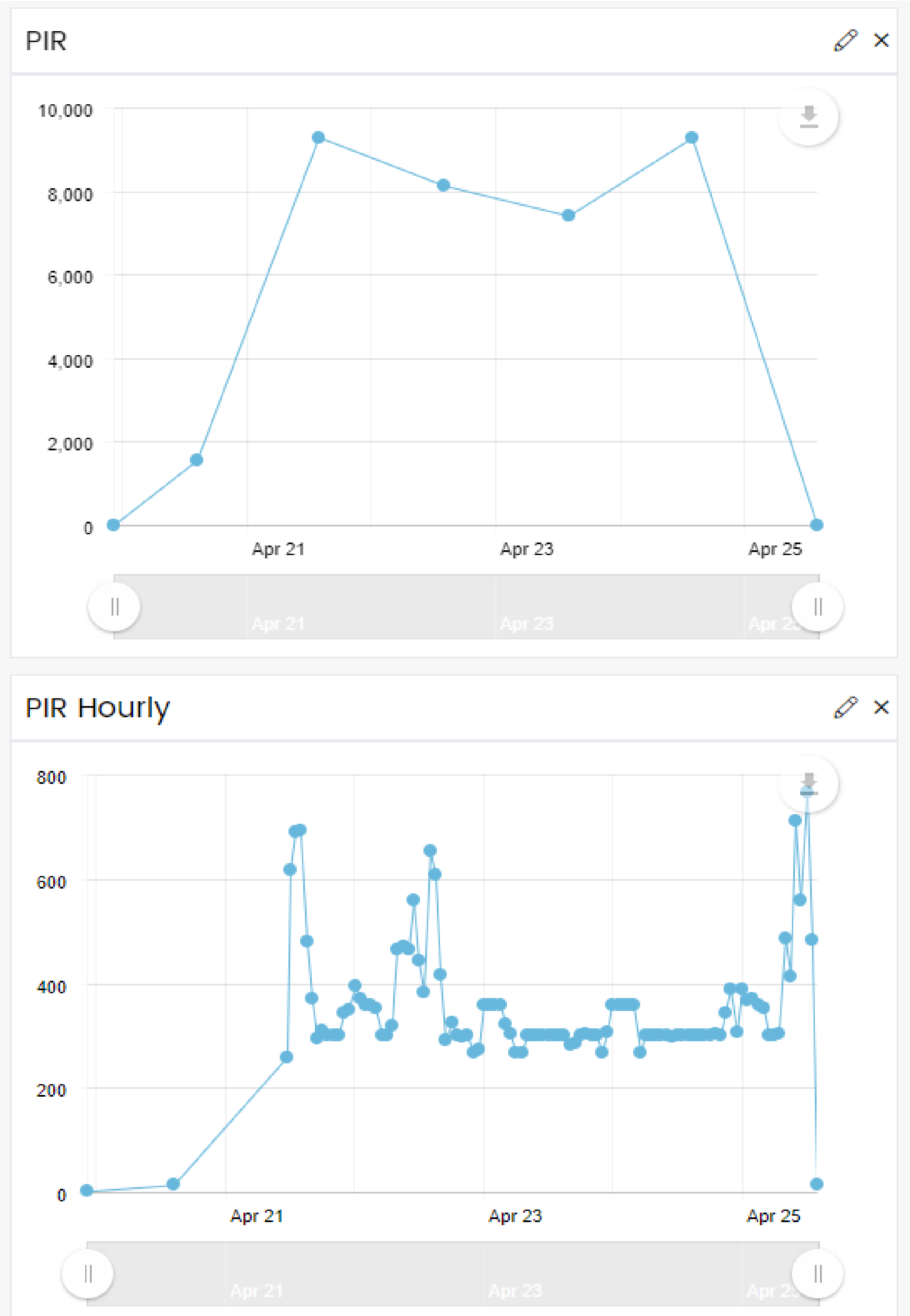

Figure 6 7 How much data has been captured and sent to the Davra platform via PIR 18/04/2022 - 25/04/2022

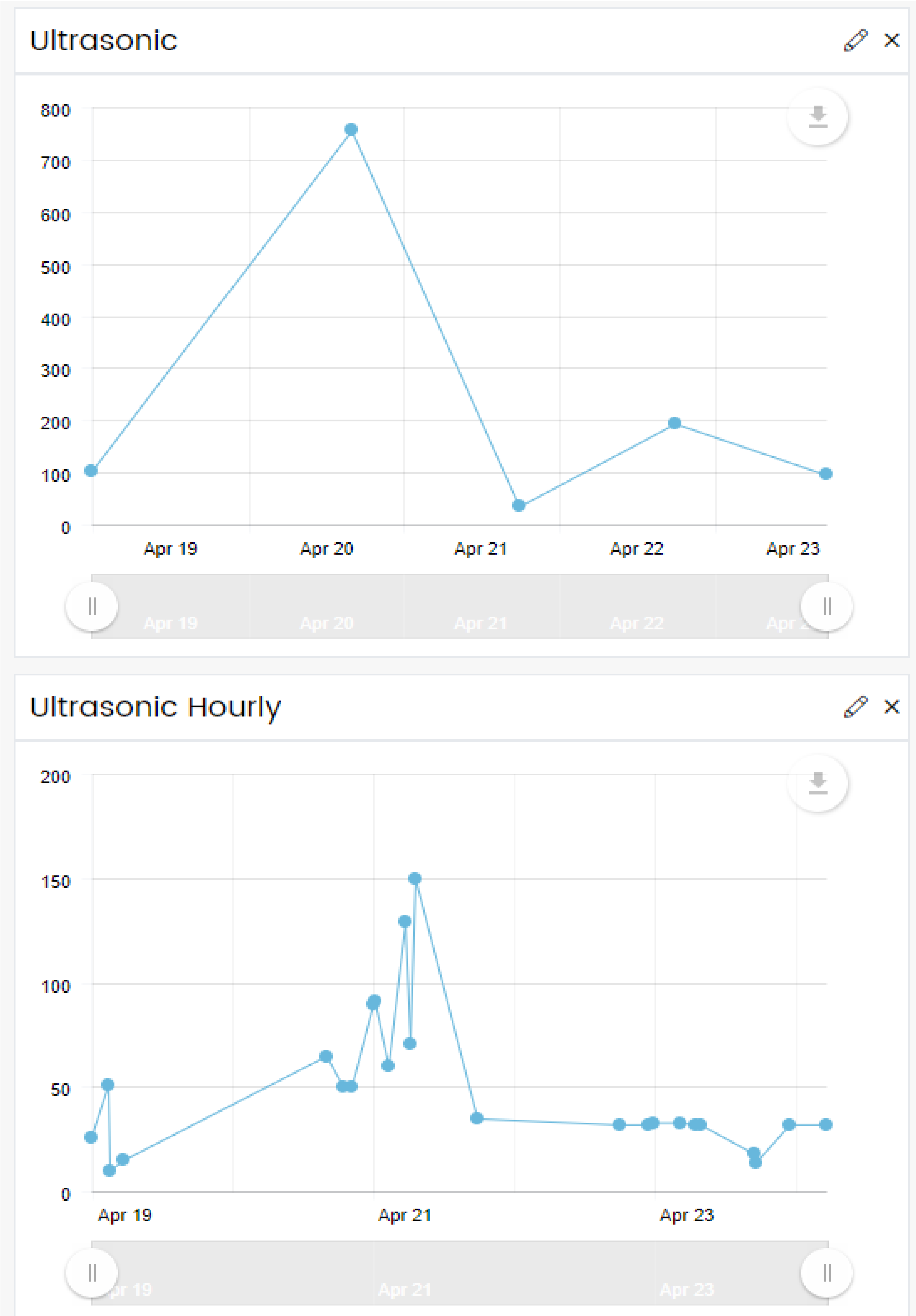

Figure 6 8 How much data has been captured and sent to the Davra platform via ultrasonic 18/04/2022 - 25/04/2022

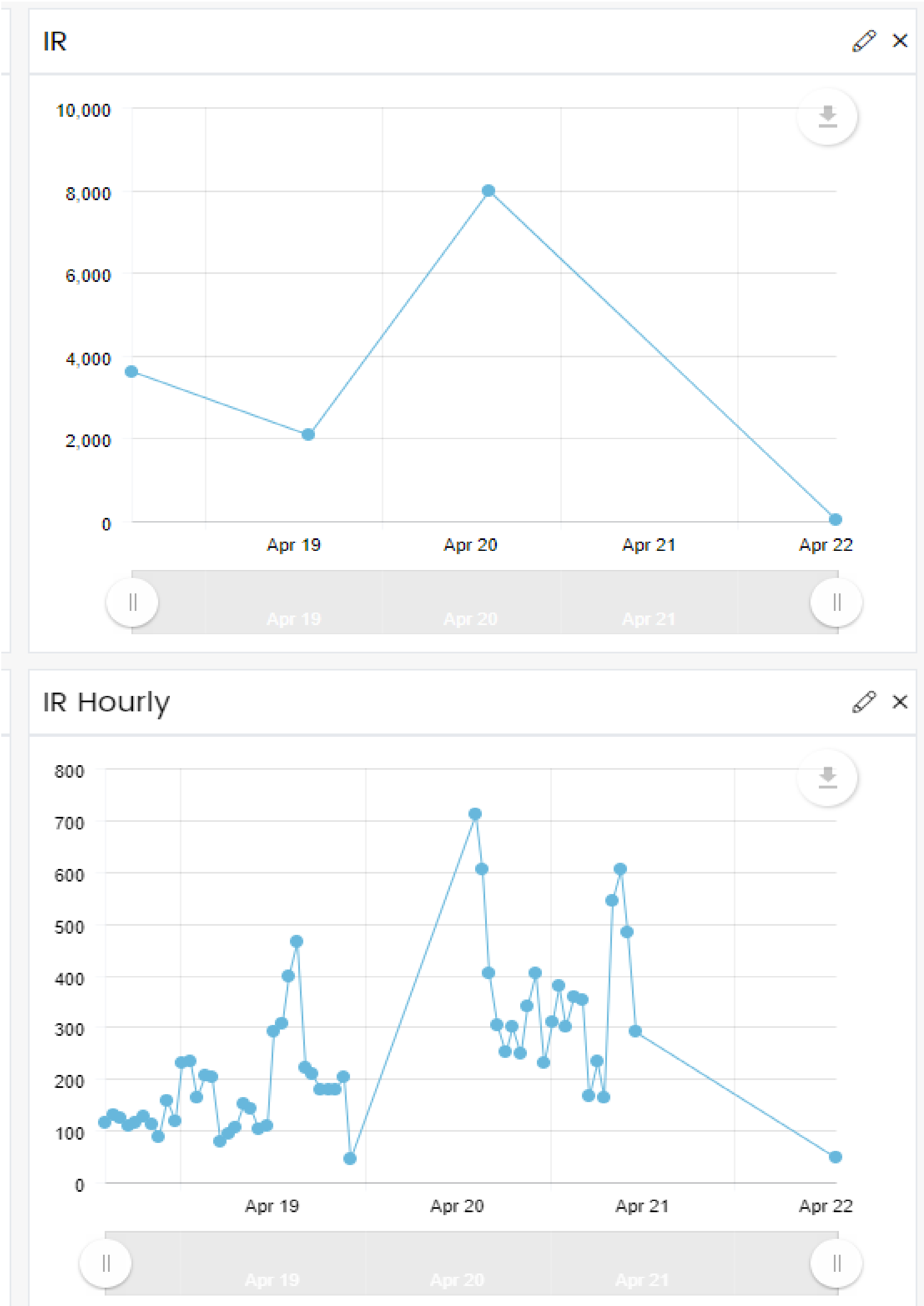

Figure 6 9 How much data has been captured and sent to the Davra platform via IR during 18/04/2022 - 25/04/2022

Looking through the collected and stored information from the sensors that counted the number of people by each individual sensor, it is clear to see that each sensor counted a drastically different amount of people:

PIR: This sensor was connected to the Raspberry Pi directly and using individual's body heat it was able to detect and log everyone that it saw. The highest result of people seen was nearly 10,000.

Ultrasonic: To conduct the ultrasonic test, unisannio-node-red-contrib-grovepi node was added to Node RED to work along with the Grove kit to allow the devices to talk to one another and ensure that the information was captured and obtained. The highest result of people seen was nearly 800.

Infrared: By attaching a Dfrobot, DFR0327, Arduino Shield, to the raspberry pi we are capable of using sensors such as infrared due to this sensor not using a digital input, instead it uses an analogue input. The highest result of people seen was 8000.

Highest count combined: 18,800

A camera was used in these tests to take pictures once a sensor has been activated, such as having the infrared sensor line broken by movement. With these pictures, we could find the level of accuracy each sensor was achieving, since each image has been saved with a timestamp and to a specific folder. Due to the unknown factors such as a person speed and if they were entering or exiting the room, a majority of these images were not beneficial for counting people. Another factor was how images were taken using libcamera. This system of image capture does not simply take one image, as a standard camera would, but instead, it takes multiple images in a brief time span and merges the images into one file.

Results

The information that was captured and uploaded to the Davra platform shows that each sensor counted a substantially different amount of people. This could be due to multiple factors such as the location and the restricted view of the sensors, allowing them to count people that they should not have, such as people using the corridor but not entering the room.

Each sensor counted and sent data to the cloud platform whilst also capturing images. Although the image data was not of value it was possible to find the individual sensors levels of accuracy and identify what is the beneficial and overall, most accurate.

Test 2, Two sensors working together

Test duration, 1 week 26/04/2022 - 03/05/2022

When two different sensors work together, they must agree if a person is seen and is to be counted. This agreement was achieved in a time span of one second to ensure a higher level of accuracy than was achieved in test 1. For this test, three alternative setups were deployed to show their practicality and usefulness. The purpose of these tests was to gauge how accurate and consistent the results would be from each combination.

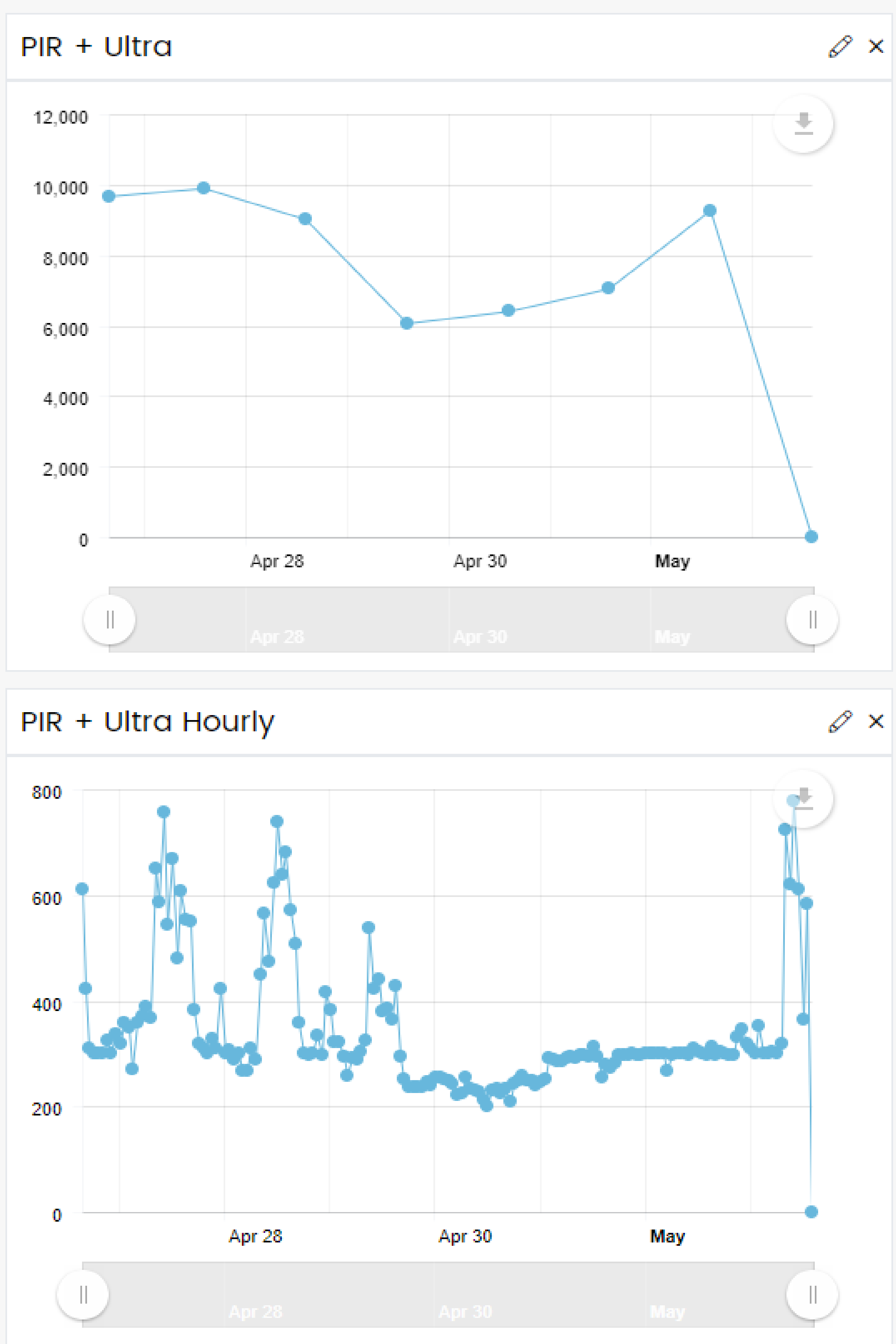

Figure 6 10 How much data has been captured and sent to the Davra platform via PIR + Ultrasonic during 26/04/2022 - 03/05/2022

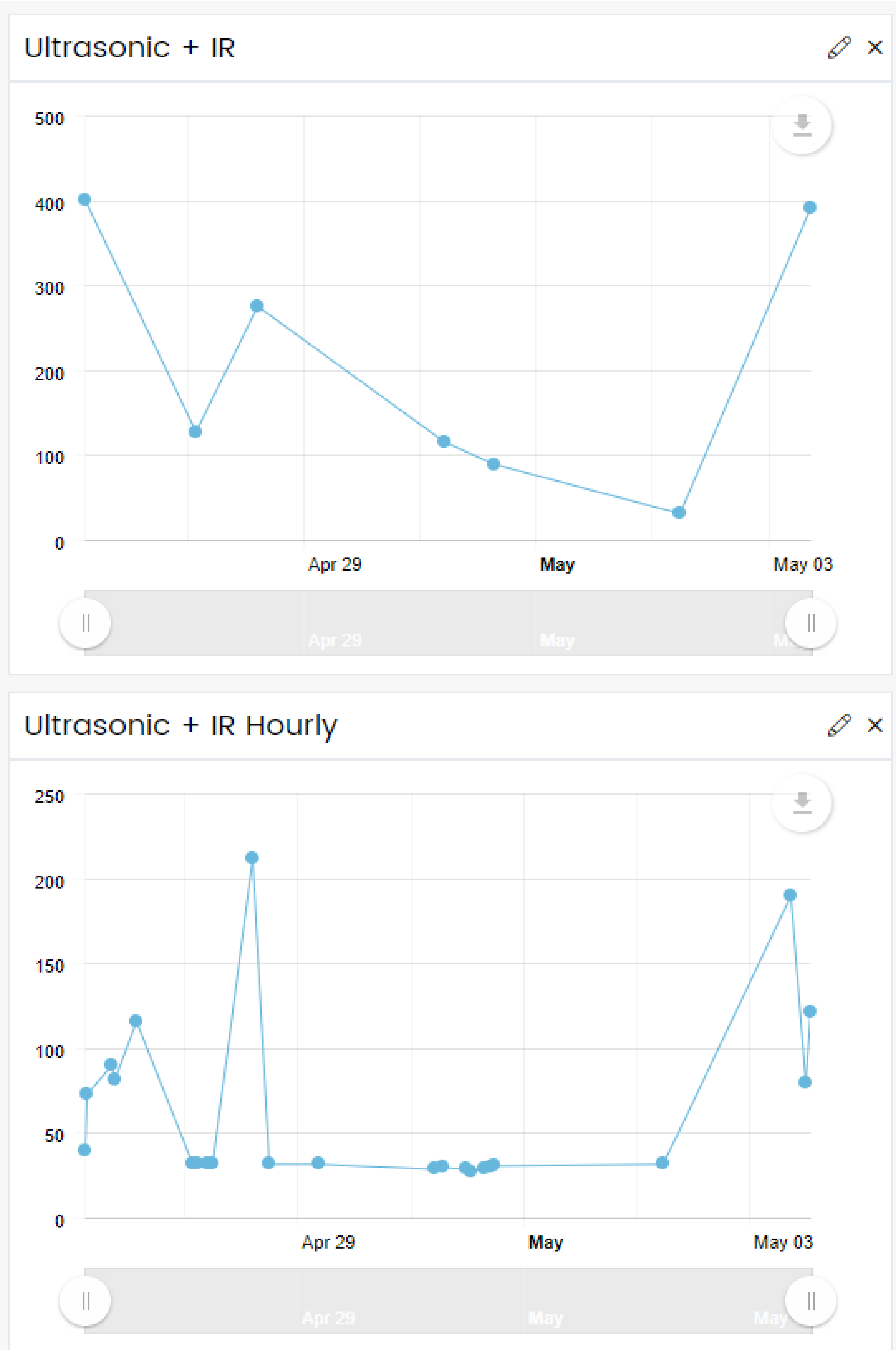

Figure 6 11 How much data has been captured and sent to the Davra platform via Ultrasonic + IR during 26/04/2022 - 03/05/2022

Figure 6 12 How much data has been captured and sent to the Davra platform via IR + PIR during 26/04/2022 - 03/05/2022

Looking through the collected information and people counted by each individual sensor, it is apparent that each sensor counted a different number of people:

The highest result for people seen hourly was:

PIR with Ultrasonic, nearly 10,000

Infrared with Ultrasonic, nearly 400

PIR with Infrared, was 34.

The PIR image also shows that information was not sent hourly, as was done with the other tests. This could be an issue regarding the device or the structure of the tests. This shows that information was not collected when a person passed nearby.

Highest count combined: 10,434

Results

Looking at the information that was collected and uploaded it is clear the devices are counting a different amount of people. By using multiple sensors, working together the information corresponds closer with the images that were taken. Looking at PIR working with the Ultrasonic and the IR working with the ultrasonic, it is clear that the IR and PIR section should have a higher number of people counted; either the information collected was not correct, or there are issues are with one of the sensors.

Test 3, All sensors together

Test duration, 1 week 04/05/2022 – 10/05/2022

This time all the sensors will be working together in an attempt to achieve a better level of accuracy. We have done this test to compare the level of accuracy achieved against the previous results and a single sensor, this being a PIR motion sensor recognizing a person by their body heat alone.

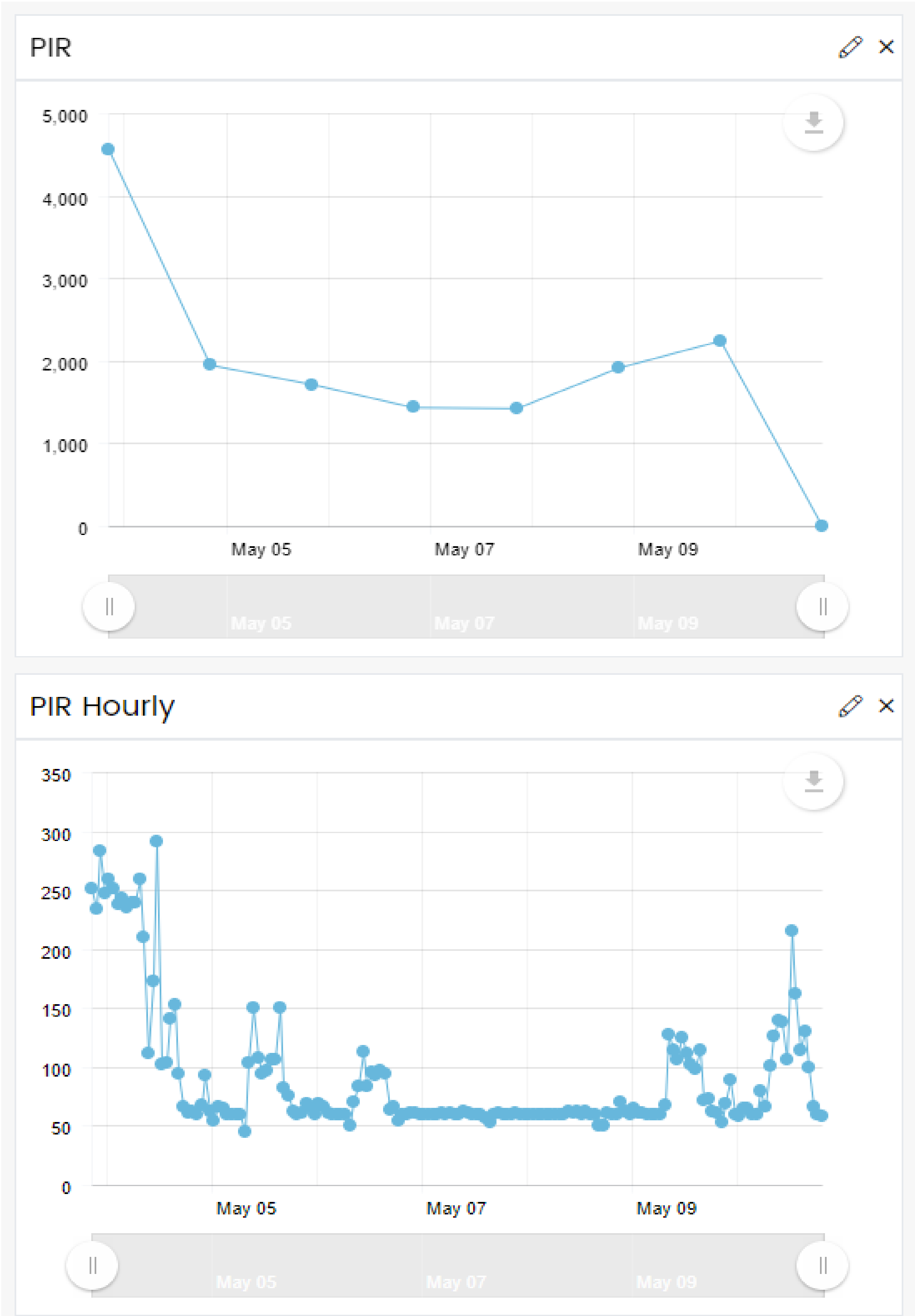

Figure 6 13 How much data has been captured and sent to the Davra platform via PIR during 04/05/2022 – 10/05/2022

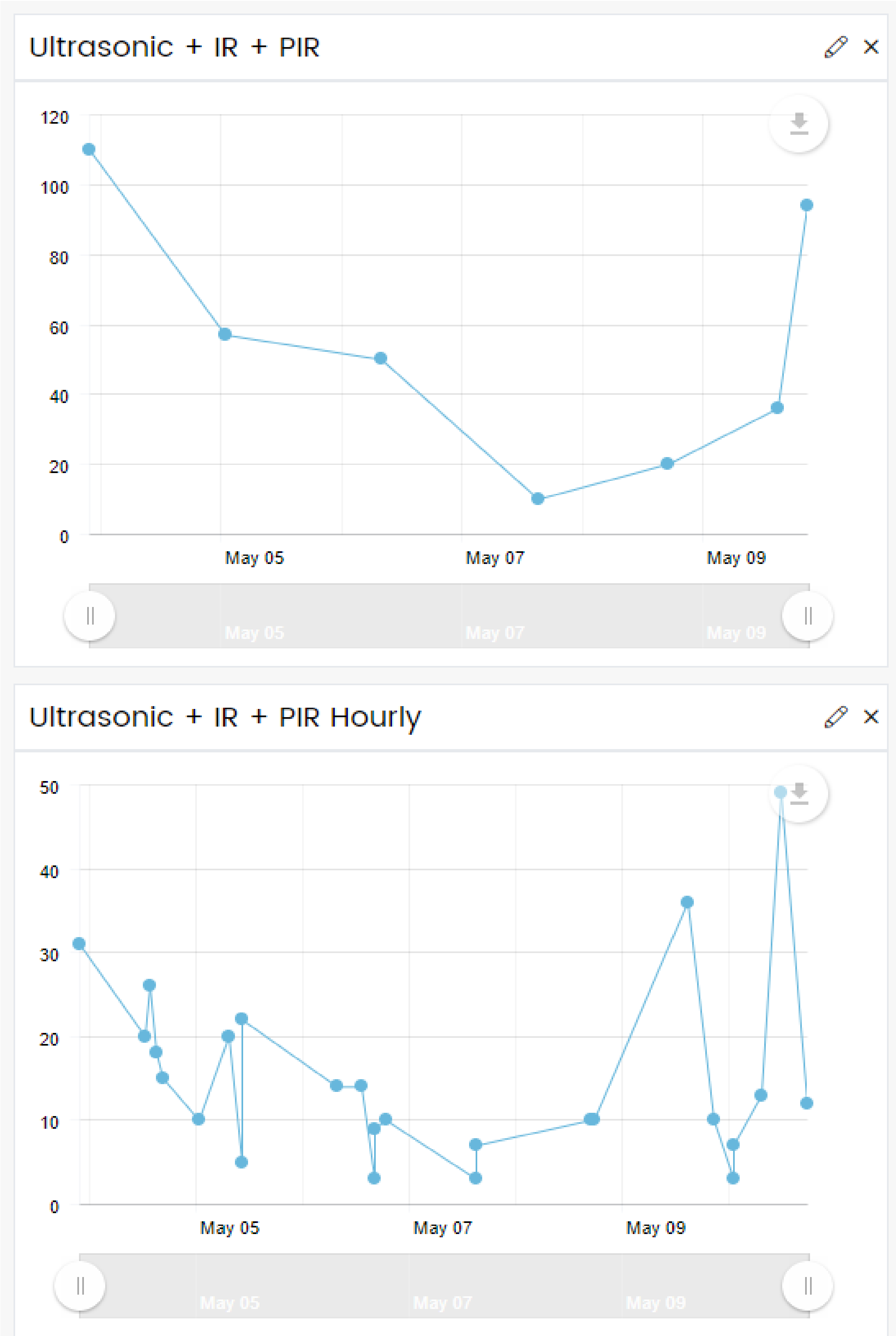

Figure 6 14 How much data has been captured and sent to the Davra platform via all three sensors during 04/05/2022 – 10/05/2022

Looking through the collected information and people counted by each individual sensor it is evident that each sensor counted a highly different number of people:

PIR, highest count was near 5000, during the 04/05

PIR, Ultrasonic and Infrared, max counted on one day was 115

From this, we can see the issue of relying on a single sensor instead of using multiple to ensure accuracy.

Highest count combined: 5,115

Results

Looking at the information that was captured and uploaded to the Davra platform and the images obtained, it is clear that using all sensors together reduced the number of people counted to a more realistic level especially in comparison to the amount the PIR sensor alone was showing. By looking at the images that have been captured we can see a total of 102 people, but some images were either too blurred or late, so no people were captured in the images in question.

Test 4, 2 images taken every second

Test duration, 1 day 09/05/2022 - 10/05/2022

This test has been conducted to collect the ground truth; this has been done by having 2 images captured in every second and storing them on the Raspberry Pi device. The focus is an active time of an 8-hour trial to allow the examination of the images collected, personally work out the level of accuracy via counting the number of people seen in the images collected and compare that to the graphs that was used in the previous tests.

After conducting this test, it was clear that the DFrobot IR sensor was no longer functioning correctly; it was intermittently capturing and sending information to the cloud platform. Whilst this is an issue, it was also beneficial since from that, we can see how dependable the device would be in a real-world scenario.

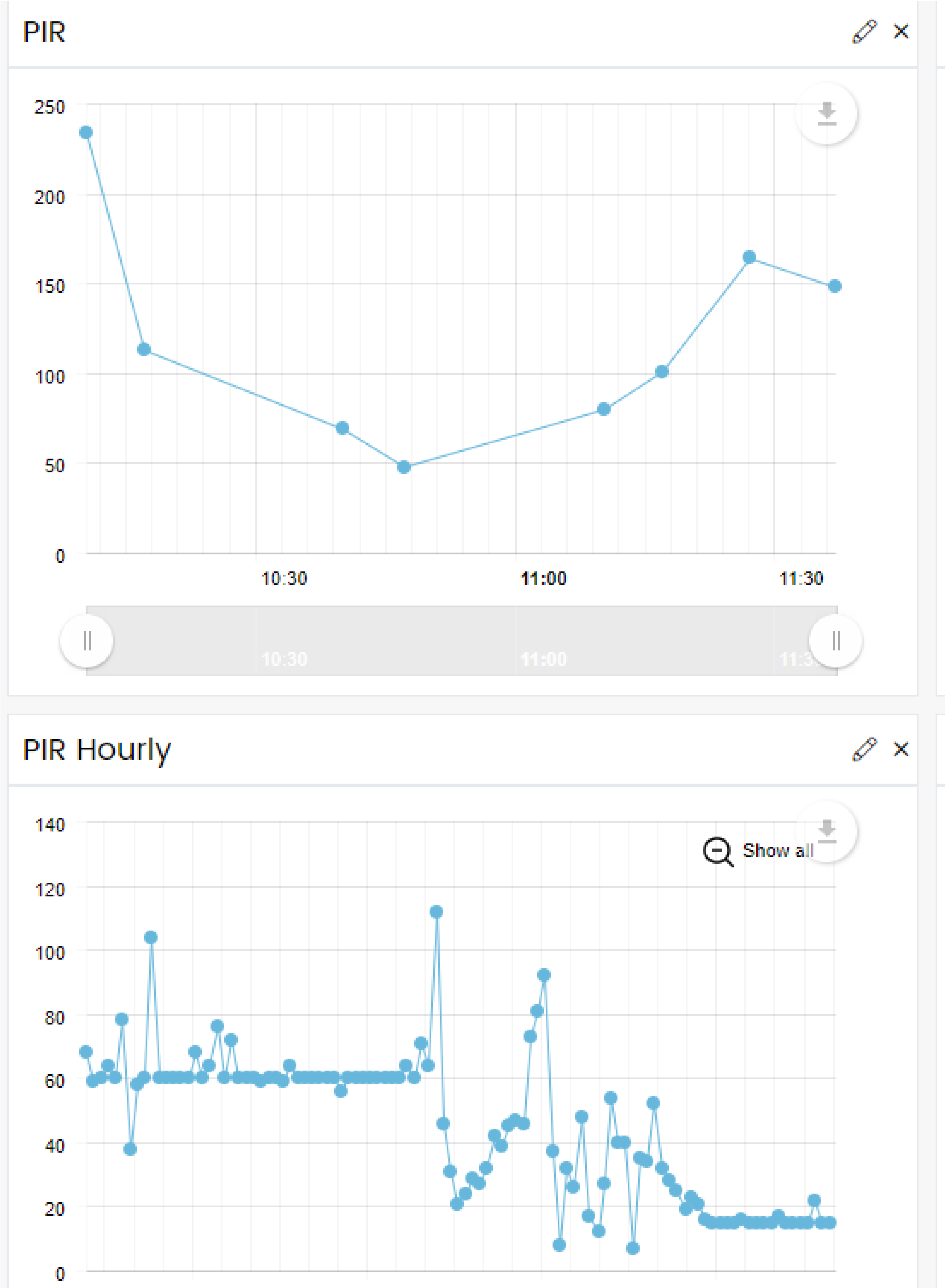

Figure 6 15 How much data has been captured and sent to the Davra platform via PIR 09/05/2022 - 10/05/2022

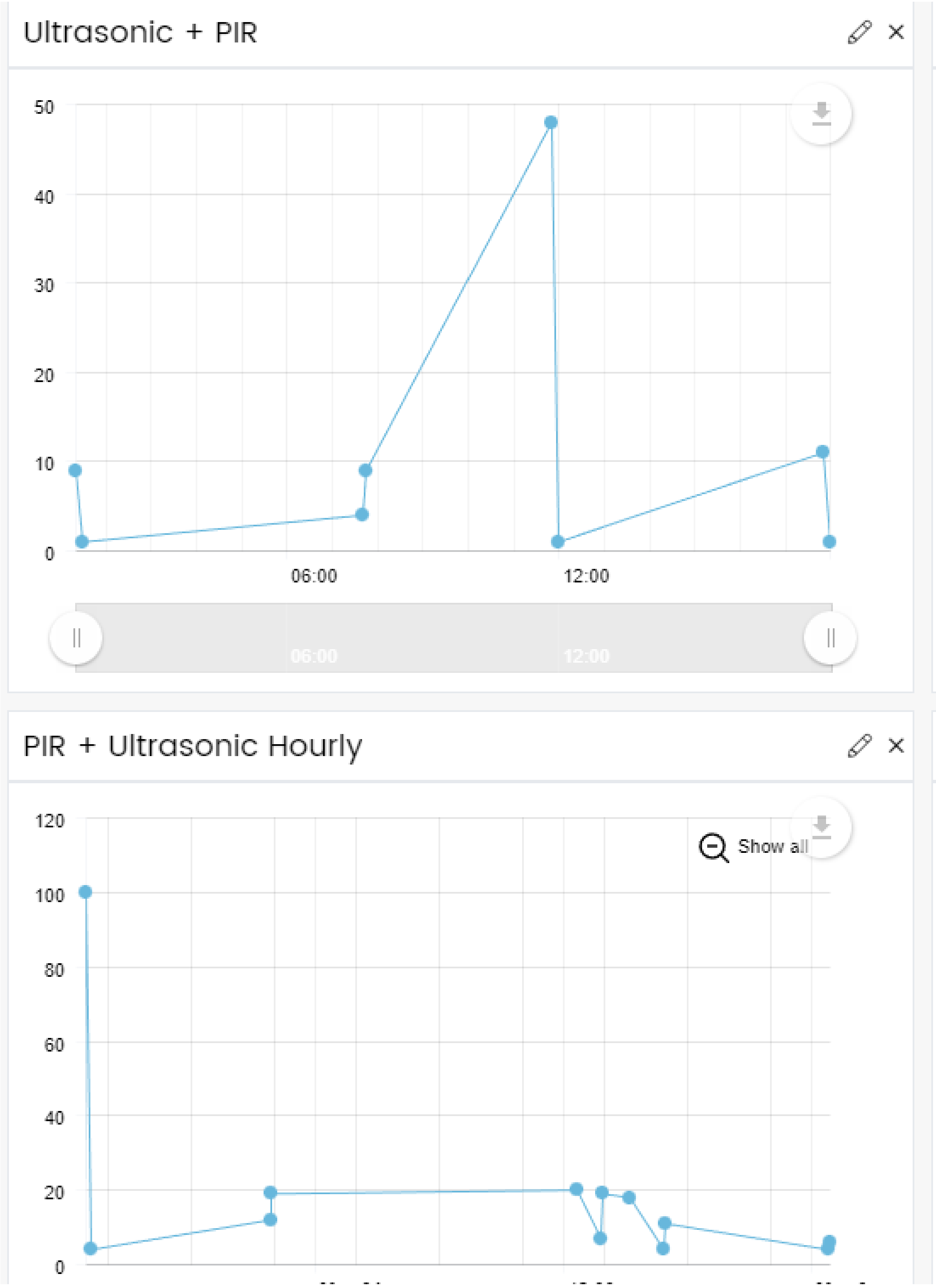

Figure 6 16 How much data has been captured and sent to the Davra platform via ultrasonic 09/05/2022 - 10/05/2022

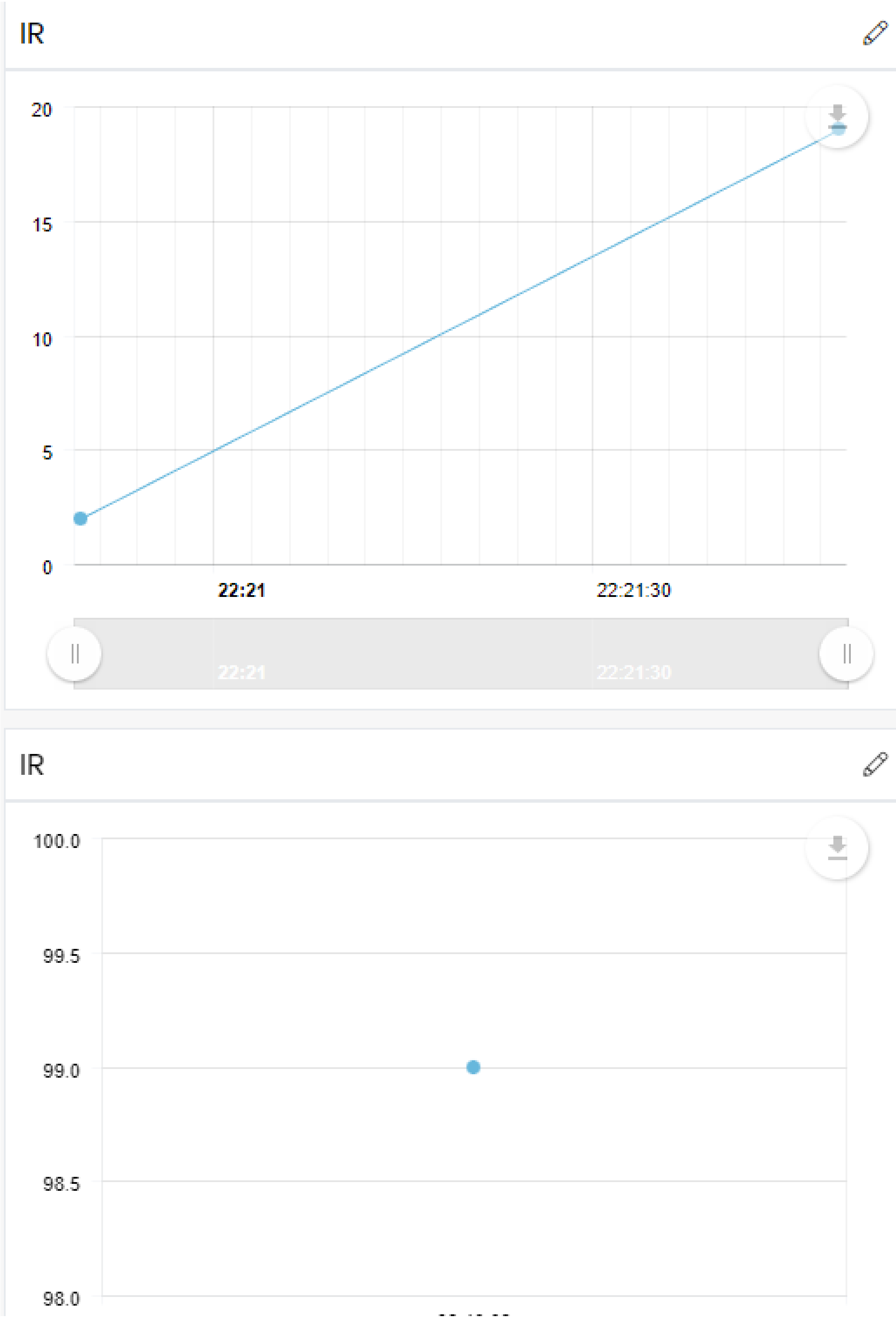

Figure 6 17 Data captured and sent to the Davra via IR 09/05/2022 - 10/05/2022

Each of the collected camera images were examined to gauge the level of accuracy to the sensors. The highest number counted in the eight-hour period:

PIR, 242 people

PIR with Ultrasonic, 48 people

Infrared, due to the issue with the sensor not counting or sending information to the cloud, did not properly collect information.

Highest count combined: 290

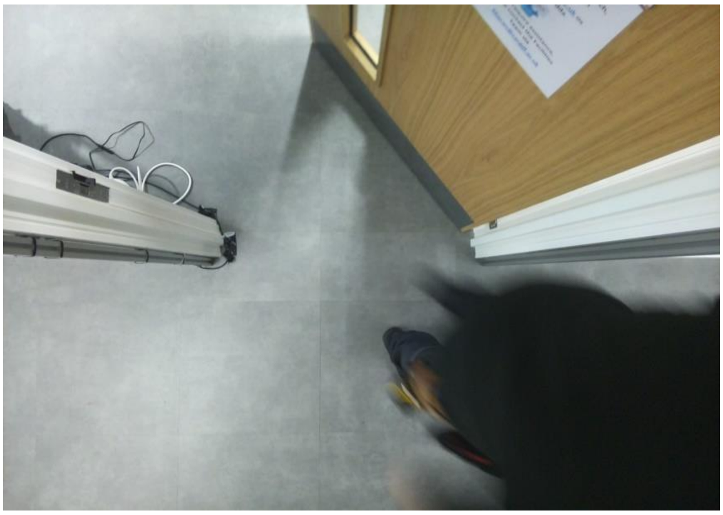

Figure 6 18 Image showing a person moving this caused a blur effect.

Some of the images show a vague body or part of a person such as their leg; this is normally due to the speed that they were moving which also makes a blurred outline of their body.

All the clear images that have been taken totalled 32 people.

Results

The test lasted in total for over 24 hours, however the focus will be on 8 hours where the majority of activity happened, and, during this time we have gained a total of 57,600 images to look through to see how accurate the findings are. By looking at the images that were captured and the information held on the cloud platform it is clear that Ultrasonic + PIR was highly accurate in comparison to a PIR sensor by itself which was also visible in the previous test.

Data Analysis

Looking through all the information that has been collected in multiple testing periods, it is clear to see that different sensors would collect a varied amount of information with a different range of accuracy. In relation to different situations, scenarios, and distinct types of sensors it is clear that utilising sensors together help ensure a higher level of accuracy.

7.2 Implementation and Location testing results

In later stages and tests, pictures were taken when the sensor was activated or every second. We were able to get an accurate level of accuracy by physically counting the number of people seen and comparing that to the number counted by the sensors. When all sensors were working together, it was able to achieve the level of accuracy of 96.2%. This was a satisfactory result within the limitation of a fairly low footfall environment.

Test results Issues found

During these tests at multiple stages, we have observed the physical devices and surrounding area to count the number of people that could be seen in an attempt to compare how accurate the devices were at counting. Through testing, we have noticed that due to the PIR motion sensor having an unrestricted view, it could see in 360 degrees meaning that it was counting people who walked near the device but did not enter the room. This showed even though the device was able to easily identify and count people its observation would need to be limited to ensure accuracy.

The image below shows the cone shape of the Ultrasonic sensor. Sound waves are sent off and expands, this means that the area of focus needs to be limited with this sensor. It is clear that the location and placement must be planned prior for placing this sensor in an advantageous position.

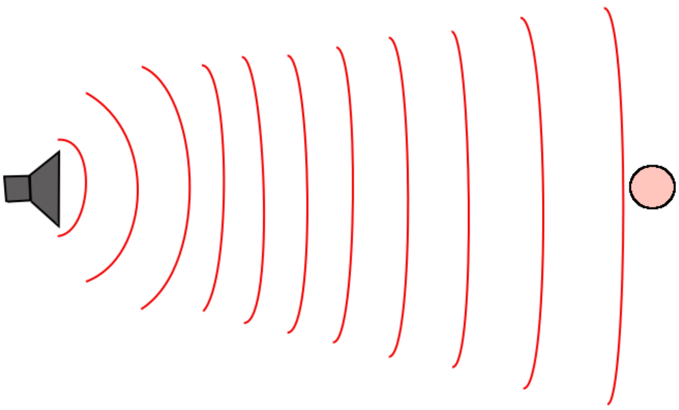

Figure 6 19 Diagram shows how ultrasonic sensor works by sending out sound wave.

The IR sensor; as mentioned prior, would not work on a Raspberry Pi, so either the utilisation of a breadboard or a hat board such as DFRobot would be needed, this is an increase in price and sadly can lead to potentially more problems. A method around this is by using an Arduino board along with the Raspberry Pi.

7.3 Summary

This section of the thesis was focused on completing a number of “in the wild” tests to overlook the collected information and ensure that a high level of accuracy was achieved regarding people counting.

Through testing single sensor vs multiple sensors, we were able to easily see a difference in the number of people counted, proving that using multiple sensors together to validate each other helps ensure a high level of accuracy. Evaluating the level of accuracy was mostly achieved in test 4 by utilising a camera to take pictures every 2 seconds and going through the images to count the number of people that have been seen by the sensors.

Using single sensors recorded a drastically different number of people seen which helps shows a high chance that false positives could be added to the collected data. Multiple sensors helped validate the data collected.

By conducting these tests, it has helped prove that the theoretical scenarios from chapter 5 have credence and that location and placement of the sensors can help reduce the chance of false positive.

Chapter 8 Conclusion and Reflection

8.1 Conclusion

The primary objective of this thesis was to discover a solution for accurate people counting in a remote and secluded location. Numerous experiments were conducted using various sensors either individually or in combination, in an effort to determine the most practical approach to utilizing IoT technology for counting the number of individuals entering this location. After reviewing existing literature, it became evident that people counting can be achieved through multiple methods, and several potential combinations would require testing.

From the initial stages of this study, it was decided to employ the Davra platform, as it was deemed the most suitable cloud platform for this project. Node RED was identified as a faster and simpler programming method using a visual interface. This aided in expediting the progress of this project, as it enabled communication with the connected sensors and transmission of collected data to the cloud platform.

Three key devices were selected for thorough evaluation and eventual deployment: Raspberry Pi, Grove Kit, and Arduino. The Raspberry Pi proved capable of efficiently collecting, storing, and transmitting information to the cloud at a reasonable cost. The Grove Kit served as an add-on that facilitated secure connection of specific sensors in a quick and straightforward manner, allowing for rapid adjustments and testing. Arduino was chosen as a basic and versatile electronics platform that could read inputs and provide flexibility through its compatible sensors. The sensors for each device were listed, and their relevance to the project was assessed. PIR, Ultrasonic, and Infrared sensors were chosen as a combination to offer the most robust and accurate data.

Throughout the course of this MPhil, numerous factors and changes have arisen. Concerns regarding anonymity led to the exclusion of cameras in the wilderness, necessitating further tests of alternative methods for people counting.

This paper proposes that the most reliable method for people counting is achieved by utilizing the following combination of multiple sensors: IR, PIR, and Ultrasonic sensors. We worked on a Raspberry Pi system utilizing both a Grove kit and later added a DFrobot.

Our system can count the number of people accessing a room. Experimental results demonstrated that we could achieve up to 96.2% accuracy in people counting.

Due to the speed and advancement in modern day technology, there is a chance that a better system, method, and hardware for the purpose of people counting could be developed. However, the current solution has achieved a level of accuracy and practicality appropriate for this project.

Additionally, if alternative devices to Raspberry Pi or Arduino were to be used the information collected and accuracy achieved could theoretically be maintained.

Finally, by conducting a cross-reference with this thesis to the research challenges listed in chapter 1 section 3. It is clear that the product and thesis has addressed the research challenges set. These were:

- To find the most appropriate sensors combination to capture data regarding the number of people using a facility.
  - This was achieved in chapter 7 with multiple real-world testing with different sensor combinations, by doing this we were able to ensure a higher level of accuracy was achieved.
- Determine the optimal method to achieve a high level of data accuracy.
  - This was demonstrated in chapter 7 by the use of graphs displaying the number of people counted. Due to the different tests and sensors used a major change in the information obtained is clearly visible.
- Ensure the security and anonymity of all data collected.
  - Due to the sensor, types and the information collected key information such as a person's sex and personal characteristics could not be obtained thereby ensuring both the security, and anonymity of the person counted was achieved.
- Ascertain the best method to efficiently transmit the quantity of information required.
  - The information only sent a time stamp when it was collected. It was captured from the sensors in a plain text format, meaning the overall size of the information sent to the cloud platform was minimised.

Designing and developing the IoT infrastructure has helped to meet the targets. Working with multiple layers such as edge computing enables the system to work in unison with the IoT Davra platform, which is capable of moving analytics across different nodes.

We have developed and worked on a robust framework that other researchers can use to further explore this area of work, for various rural world people counting, by having this time could potentially be saved for another research in this field.

The contributions of this thesis provide a foundation for people counting and sending information to a cloud platform whilst working within limitations of signal strength and speed. By addressing key challenges, this research offers insights and practical solutions for both academic researchers and industry practitioners.

8.2 Limitations

Whilst the device is functional and tests have been conducted, there are limitations found in its current form, such as but not limited to.

- Replicability:
  - Due to variability in installation, there were differences in how and where sensors were installed which can lead to inconsistent results. Minor changes in the angle, height, or location of the sensors can significantly affect their accuracy, and by not restricting the "view" of the PIR sensor it can begin counting people from too far away.
  - Environmental differences cause changes in the physical environment, such as different lighting conditions, varying temperatures, or the presence of reflective surfaces, which can affect the performance of sensors. What works well in one setting might not perform as well in another.
  - Crowd density can influence the accuracy of this system. In a low density and flow of people scenarios, this system might work well, but in high-density situations, the performance can degrade due to occlusion and overlapping people.
- Accuracy Issues:

  - Infrared and ultrasonic sensors can struggle with obstructions. Objects or people blocking the sensor can result in missed counts which gives an inaccurate.
  - This system in its current form is unable to determine the direction of movement. Thus ideally, a person would be counted twice only, on entry and exit, but there is no method of guaranteeing this.
  - External conditions such as lighting changes, temperature fluctuations, and noise can affect the accuracy of infrared, ultrasonic, and thermal sensors.
- Limited Data Collection:
  - Unlike camera-based systems, these tools cannot provide demographic data such as age, which is something that may be required in later stages, since this can be used to see which sex is using the most water in this rural location.
- Range and Coverage Constraints:
  - These sensors often have a fixed directional focus, which can miss people moving outside the designated path. If there are multiple access points to be monitored this can be a problem.
- Scalability and Deployment Complexity:
  - Installing multiple sensors to cover large or complex areas can be challenging and costly. Additionally, the locational difficulties make changes and management burdensome.
  - Many non-camera systems, such as this device relying on infrared, PIR and Ultrasonic, can be affected by environmental factors like temperature, humidity, and lighting conditions, limiting scalability and ease of deployment.
- Interference and Signal Issues:
  - The accuracy can diminish with distance, and signal strength can vary based on the environment and obstacles, meaning that this device would need careful planning and placement.

8.3 Potential enhancement

The tests could be developed further by re-conducting in various locations and scenarios. This could include the use of different sensor angles with limitations put in place in an attempt to emulate the location to a higher degree. A wider test of different real-world variables can be conducted in an attempt to give this research a higher level of validity and reliability. In future, the sensor combinations suggested could be deployed to achieve more specific data may be required. Some of the main focus for the next stage of this project is as follows:

- Determine sex whilst preserving privacy.
  The original aims of this project included having methods to detect a person's sex and count the number of males/females using the bathroom facilities. This was intended to identify if males or females used a greater amount of water. Privacy issues and disagreements between stakeholders led to the removal of this requirement. Adaptations could be made to make this possible.
- As mentioned in the limitations, the systems struggle with determining the direction of movement, which is crucial for distinguishing between people entering and exiting an area, this could be extremely useful for real world information gathering to know how many people are using the area at a point in time.
- Monitoring and measuring the fullness of a septic tank.
  Due to the location of these toiletry facilities, there are no pipes that will directly take waste to a plant for the purpose of cleaning. As SA has limited water, they attempt to reuse as much as they can, so they use septic tanks to capture and contain the waste. If the tank is overloaded or damaged, it could release a surplus of waste into the local ground, which can lead to an outbreak of disease. Thus, a method to measure the fullness of a tank could be valuable. The sensors could also be programmed to broadcast this information to local waste vehicles to ensure collection prior to a potential issue arising.
- Utilisation of sensors to collect data from body waste from toilet pipes.
  Knowledge of possible disease outbreaks in the local areas would be valuable to prevent widespread outbreaks. This has been considered by the SA government and is an

ongoing area of research in disease management and mitigation. Especially since Covid-19, more focus has been placed in locating and managing potential outbreaks.

These future applications for the sensors have been discussed with iPoint at various stages of the project and may be developed after people counting systems have been established.

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8.3 Potential enhancement

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