EEE4113F Literature Review

Prepared by:
Karan Abraham
Lundi Mabasa
Mpilo Nxasana
Michael Van Staden

Prepared for:
EEE4113F
Department of Electrical Engineering
University of Cape Town

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May 10, 2024

Karan Abraham

Date

May 10, 2024

Lundi Mabasa

Date

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Mpilo Nxasana | Date

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Chapter 1

Introduction

> Philosophers have hitherto only interpreted the world in various ways; the point is to change it.
>
> —*Karl Marx*

1.1 Background

1.1.1 Problem Statment

Sally, a researcher at the FitzPatrick Institute, needs a way to weigh the red-winged starlings without startling them, because interestingly, they record their weight manually using a kitchen scale.

1.2 Objectives

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Literature Review

3.1 Introduction

Weight is an important metric for evaluating the overall health, behavior and ecology of a bird in ornithological research. However obtaining this weight data presents several challenges due to their size, fragility and often rapid movements. This literature aims to explore and evaluate the different techniques and technologies researchers employ to obtain weight data, the different ways this data could be transmitted and recorded, and the types of devices needed to power such a system. This literature review will also consider the challenges described above and, other environmental and ethical factors that must be taken into account when weighing birds in the wild.

3.2 The Importance of Monitoring Avian Weight Changes

According to Clark, "Weight summarizes the total biomass of an individual and is probably the most convenient standard of energetic comparisons." [2], which emphasizes how valuable the weight data of an individual bird can be. Baldwin and Kendeigh state that "The weight of birds and the variations and fluctuations of these weights furnish criteria of considerable importance in the understanding of the physiological and ecological reactions of the bird as a living organism [3], which further establishes how important the tracking of an individual bird's weight data can be. Both of these statements cement how valuable weight data can be for ornithologists studying individual birds.

Clark goes on to say, "Weights have been used in analyses of the factors that influence differences in species diversity between communities." [2]. They also state that "Weights and census data have often been combined to calculate the total biomass of a particular species or group of species in an area". These statements add that weight data could also be invaluable for the analysis of an entire community of birds as opposed to just monitoring individuals.

3.3 Current Weighing Methods

This section examines the different methods and tools used to obtain weight data in ornithological research today.

3.3.1 Spring Scales

Spring scales measure weight based on the extension of a spring when a force (the weight of the bird) is applied. Their main advantage, as described by Manolis [4], is that they are "relatively inexpensive and sufficiently portable to suffice for short-term field project[s]". However, within the same study, the scale was only accurate to within 0,5g and when smaller birds can weigh less than 50g, spring scales may lack the precision for such research applications.

3.3.2 Electronic Scales

Electronic scales utilize load cells or strain gauges to convert the weight of the bird into an electronic signal, which can then be displayed on a digital screen. These scales offer precise measurements as shown by Carpenter et al. [5], where they were able to improve the precision of their measurements from 0,05g to 0,01g, by simply replacing their spring scales with electronic ones. Another advantage over spring scales, is that they do not have to be recalibrated after moving [5] and they tend to come with features such as taring functions to account for the weight of the housing holding the bird.

3.3.3 Perching Scales

Perching scales integrate a weighing platform into an artificial perch or nest. In Poole and Shoukimas' [6] study, birds landing on perch would deflect a transducer (a metal beam with 4 strain gauges bonded to it), thus generating an electronic signal. Reid et al. [7] used artificial nests rigged with a load cell in much the same way. In both studies, these electronic signals would then be recorded via some kind of electronic storage medium. This meant the birds could be weighed remotely, which minimizes stress and reduces the risk of injury, making perching scales particularly useful for long-term monitoring studies or behavioural observations. However, for such long-term studies, researchers would need to keep track of a large number of birds, which would also result in a large amount of data that needs to be stored.

Manolis [4] provides a solution to these issues by urging other researchers to make use of telemetry. One such technology is Radio Frequency Identification (RFID) which enables researchers to track individual birds and record their weight automatically. Wang et al. [8] made use of RFID by attaching two transponders to each bird, which would be detected by antennas placed under the perches. When a tagged bird interacts with the RFID reader, its unique identifier and weight are recorded electronically, making the data much easier to organise. It also reduces the volume of data created as the weight is only taken when the birds are on top of the perch. This allows researchers to collect data on a larger scale but this data need not be stored locally.

3.4 Data Transmission and User Interface

The method that the FitzPatrick Institute currently have for reading the bird weight is having one of the researchers go up to the scale and read off the screen. They then record the weight into *Cybertracker* [9], a mobile app that creates an Excel spreadsheet for them to analyze later. This highlights a need for a way to access that data remotely; or perhaps, a way to send that data directly to the Cybertracker app.

There are many communication protocols for transmitting data from a microprocessor. In a comparative performance study by Eridani et al., three protocols were compared: Bluetooth, Wi-Fi direct, and ESP-NOW ('a new protocol that allows multiple devices to communicate with each other without the use of Wi-Fi, with low power consumption' [1]). Five metrics were used in the tests: maximum range, transmission speed, latency, power usage, and signal resistance to obstructions [1]. A brief summary of the performance of each protocol is shown below in Figure 3.1.

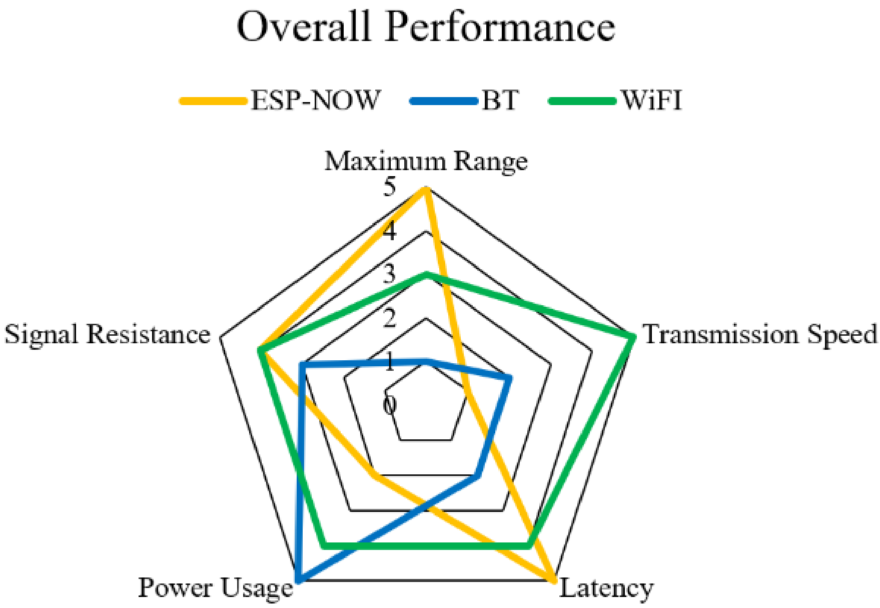

Figure 3.1: Overall Performance of each Protocol [1]

ESP-NOW performs best in range and latency; Bluetooth in power usage; and Wi-Fi in transmission speed. Since the scale must be portable, it is important to keep power usage to a minimum. Bluetooth seems to provide sufficient range and speed. The problem with this; however, is that connecting the system to the user's phone requires effort, and perhaps expertise that the user may not have. In this case, connecting the system to the internet may be a better option (that is if an internet connection is available, i.e. if *eduroam* is in range).

Budoyo and Andriana used the internet when designing a prototype of a digital scale to measure the weight of onions. [10]. They interfaced the microcontroller (an ATMega2560) to the internet using an ESP8266 Wi-Fi module. The weight data is sent to a website where it is stored in a database. A database is useful in creating an Excel spreadsheet with many fields which is the end product that the client requires.

3.5 Power supply

Traditional weighing scales have relied on either battery or electric power sources for operation. Battery-powered scales utilize internal batteries, commonly alkaline or lithium-ion, to supply the necessary electrical power. This section will discuss the different types of power supplies available for bird scales and the power limitations on what type of power source the final design can use.

3.5.1 Wall Power

For indoor scales, which are in a fixed to one spot, the electric-type scales are directly connected to a power source via a cord, typically drawing from AC power provided by a wall outlet. These type of scales are used in laboratories and residential environments.

3.5.2 Energy Harvesting

One other method researchers use in low powered bird scales is Energy Harvesting. Energy Harvesting is used to extend the lifespan of the scale and sensing devices, however the process is not always effective [11]. An example of energy harvesting would be using wind or solar as a power source to the scale device. This concept is useful in situations where the scale is left in the field for data capture, and only accessed after a prolonged period of time. It is worth noting that low-power weighing scales are an existing topic, where in some cases there are scales and sensors that are able to take measurements, read and communicate the data in real time [12].

3.5.3 Limitations

The reliance on electrical power poses serious constraints, particularly in terms of mobility. This limitation becomes pronounced in specialized applications such as bird weighing scales, especially for very mobile birds such as the starlings. A better solution is to use a rechargeable battery source, such as the alkaline batteries mentioned above. Environmental conditions also pose a risk to the battery lifespan. Solar panels can pose collision risks for birds, particularly if the panels are highly reflective. Some birds may collide with solar panels while flying, leading to injury or mortality.

3.6 Challenges and Considerations

While modern weighing methods offer significant advantages in terms of accuracy, convenience, and animal welfare, researchers must consider several factors when selecting the most appropriate technique for their study.

3.6.1 Size and Species

The size and behaviour of the target bird species may influence the suitability of different weighing methods. Some birds may become skittish around researchers which would make measurements unreliable. In Manolis' case [4], they had to use binoculars to take readings of the scale from afar; an inconvenience that is entirely removed from the solutions presented by Poole and Shoukimas [6] and Reid et al. [7]. Smaller birds may require scales with higher precision, while larger species may benefit from perching scale systems capable of handling multiple subjects simultaneously.

3.6.2 Environmental Conditions

Field studies often expose equipment to challenging environmental conditions. For example, Manolis [4] had to keep swaying to a minimum to get accurate readings, hence spring scales would not be suitable in windy conditions. Rain can seriously damage electronic components so it was important for Reid et al. [7] to house the amplifier unit in "a small water-resistant case with a sealed connection to the data logger cable". Researchers must choose weighing methods that are robust and reliable under these circumstances, with weather-resistant features where necessary.

3.6.3 Material Considerations

An important consideration that our design would need to fulfill is that it is safe for use on birds. Given that they will be in direct contact with the scale, toxicity is a primary concern when considering the materials used to construct the scale.

In the design of an electronic scale, artificial materials such as plastics are an attractive option due to their naturally weatherproof properties. However, caution must be exercised when considering specific materials. Artificial materials such as polytetrafluoroethylene (PTFE) are a common source for airborne toxicity in avians [13]. However, in a paper by Kroshefsky [14] this material is only cause for toxicity concern when exposed under high temperatures. This is because PTFE begins to decompose in air at around 200°C. Even if the scale is place outdoors, the ambient temperature will be well under this temperature limit, making this material a viable choice in the housing.

Heavy metal poisoning is another important concern when it comes to our choice of materials. The most common occurrences of which come from the ingestion of lead [15]. When lead is ingested, it can be absorbed in the gastrointestinal tract and then taken up by soft tissues and eventually bone [15]. The paper by C. Pollock includes a list of common sources of lead in household items, the most notable of which is solder. Thus some kind of insulation is required around soldered circuitry to avoid any trace amounts of lead affecting the birds.

3.6.4 Ethical Considerations

Ethical guidelines emphasize the importance of minimizing stress and harm to the animals being studied. As such researchers should prioritize methods that avoid the need to handle the birds, as this will minimize the risk of injury to the researchers and the birds. This means that the red-winged starlings will need to be lured such that their weight measurements can be taken. This can be achieved using the many perching scale solutions described earlier, but for more traditional weighing methods, Manolis [7] provides a solution. In their study they used sunflower seeds to entice the birds to land on the scale, and since red-winged starlings tend to scavenge for food, this will prove useful for this application as well.

An automatic feeder device could be implemented as a way to streamline this process. However, researchers have found that the introduction of automated feeders tend to reduce species variety in a given area [16]. Automated feeders are also highly inconsistent with seasonal change, which would result in it being a highly inconsistent form of luring birds [16]. The introduction of an automated feeding strategy would have a noticeable effect on the ecological and weight cycles of local birds, especially those that would be studied.

3.7 Conclusion

Based on the reviewed literature, it can be seen that accessing data remotely is very much feasible using accessible technology such as Wi-Fi. The importance of gathering weight data was established and how it would be of benefit to ornithologists was explored. Various challenges and considerations have been presented in the reviewed literature and the importance thereof will be taken into account going forward.

Chapter 4

Sensing Subsystem (NXSMPI001)

4.1 Introduction

The aim of this subsystem is to translate the force from the bird's weight on the scale into a digital reading. It involves designing and constructing the circuitry needed to change the weight into a analogue voltage, developing the algorithms in the micro-controller unit (MCU) used to process this signal and change it into a weight reading of the bird. Another component to this subsystem is to have accurate timekeeping so the weight data is timestamped.

4.2 Requirements Analysis

Table 4.1: Non-functional Specifications of the Sensing Subsystem

User Requirement	Specification Description	Specification no.
Portable	The final circuitry must be able to fit in a box that is 100x100x50mm.	SS1
Long battery life	The final circuitry should consume less than 30mA.	SS2

Table 4.2: Functional Specifications for Sensing Subsystem

User Requirement	Specification Description	Specification no.
The scale must measure weights of up to 500g.	The weight sensor must have a maximum capacity greater than 750g (1.5 times safety factor).	SS3
	The sensor and amplifier must output a voltage proportional to the weight force applied up to a weight of 500g.	SS4
The scale measure weight accurate to 0.1g.	The ADC must be able to resolve voltage changes from weight changes that are less than 0.1g.	SS5
	The ADC must have a gain and offset error less than a voltage change resulting from a change in weight of 0.1g.	SS6
The scale must have a tare function.	The microcontroller must have a digital input pin to read the users inputs from a push button.	SS7
	The microcontroller must subtract the current weight from all subsequent measurements when the voltage on the digital pin receives an input.	SS8
	There must be an LCD screen that outputs the current weight to give the user feedback.	SS9

4.3 Design Process

4.3.1 Microcontroller Unit (MCU)

The Arduino was chosen as its Integrated Development Environment (IDE) has ample support and libraries which will make interfacing with all different modules simple and straightforward. Within the Arduino family the Arduino Nano was initially chosen as it was one of the cheapest Arduino and it came in a small form factor. However, the User Interface subsystem required a WiFi or Bluetooth module so the Arduino Nano 33 IoT was chosen instead. Although BLE and BLE Sense also meet these requirements, they come with additional sensors that are unnecessary.

4.3.2 Weight Sensor

A strain gauge is an electrical component whose resistance changes when a force is applied to it. Strain gauges work on the principle that when the resistance of a conductor is proportional to its length, as shown in the equation below.

$$R = \rho \frac{L}{A}$$

One solution for meeting requirement WR2 is to put a strain gauge in series with another resistance, then place the strain gauge on a beam. When the beam deflects under the bird's weight, the change in voltage across the strain gauge can be measured. The issue with this setup is that the change in resistance, and thus the subsequent change in voltage, will be very small. This means a very high resolution ADC will be required to resolve these small changes in voltage. The resolution required could be reduced by amplifying the signal, however this would also amplify the DC offset introduced by the voltage divider, quickly saturating the output.

A better solution is a load cell which has 4 strain gauges in a Wheatstone configuration. This means that when the load cell has no load on it, the voltage will be zero, and when the device deflects, there will be a slight voltage difference between it's 2 output terminals. As discussed above, this output can be sent through an amplifier thus reducing the resolution required for the ADC. To meet requirement WR2, a 1kg load cell should be used.

The specifications for HKG 1kg load cell that will be used is shown in Table 4.3 below.

Table 4.3: Table on load cell specifications

Rated Load	1kg
Rated Output	1.0 ± 0.15mV/V
Zero Output	± 0.1mV/V
Input Impedance	$1115 \pm 10\Omega$
Output Impedance	$1000 \pm 10\Omega$

At the rated load the output will be $0.001V_{cc}$, hence the amplifier needs a gain of 1000.

4.3.3 Sensor Amplifier

From Table 4.3, the output impedance of the load cell is quite significant, meaning there will need to be an input buffer between it and the amplifier to avoid loading. The instrumentation amplifier is thus ideal circuit for achieving this and it is shown in Figure 4.1 below.

The circuit has three stages. The first stage has two input buffers which also amplify the input signal. The second is a differential amplifier which is a circuit whose output is proportional to the difference between the two inputs. The final stage is a low pass filter. The final output voltage is related to the input voltage by the expression below.

$$V_{out} = (V_2 - V_1)\left(1 + \frac{2(R_2 + R_3)}{R_1}\right)\left(\frac{R_9}{R_6}\right)$$

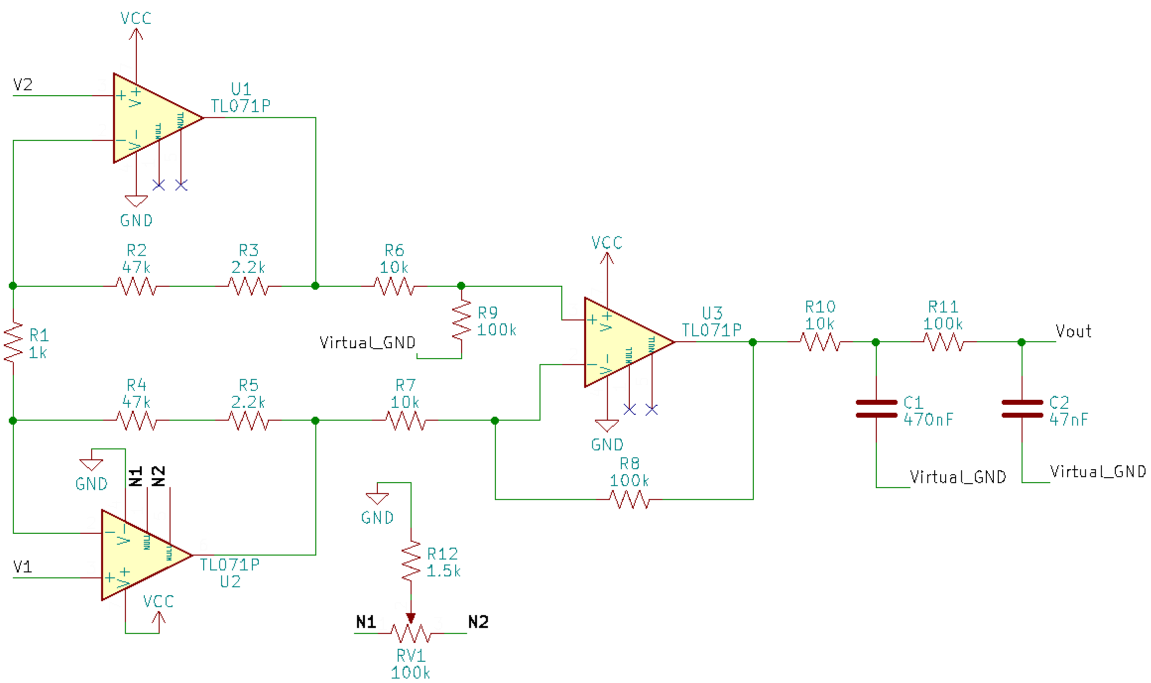

Figure 4.1: Circuit Schematic of Instrumentation Amplifier

From the expression above, when the load cell is connected to the two input terminals, its output will be amplified by a factor of 994, which is close to the gain required. The amplifier have such a large gain presents two issues.

The first is that real op-amps have an input offset voltage. As the offsets from the input stage propagate through the circuit, they are amplified resulting in the output having a large bias and saturating for very small weights, hence the op-amps used were the TL071P. These are JFET op-amps meaning they have a very low input offset voltage, in this case, of 1mV. This is still large in comparison to the input, but they also come with two NULL pins which allows the input offset to be adjusted, and thus reduced to 0. The is the purpose of potentiometer RV1 in Figure 4.1. Another reason for choosing TL071P is that their minimum recommended supply voltage is 4.5V which means unlike other JFET op-amps they can operate at lower supply voltages. This advantageous since the scale will be battery powered so there will not be a large supply.

The second is that noise from the input will also be amplified as it propagates through circuit, making the final output difficult to measure. The low pass filter in the final stage addresses this. Since output is a DC voltage, ideally the cutoff frequency should be as low as possible to attenuate the most amount of noise, but this would have a negative impact on the rise time. A lower cutoff frequency would also require larger capacitors. The sample rate for final system will be 10Hz (discussed later). This equates to a period of 0.1s and ideally the output should settle within half that time. It takes 5 time constants for the output to settle to 99% of its final value. This means that $5RC = 0.05s$ or $RC = 0.01s$. If a 100kΩ resistor is used then the capacitor would need 100nF. The filter also needs a steep roll-off to ensure a clean output, so a second stage can be added at the input, to make it a second order filter. The input stage of this filter needs to have much lower impedance than output stage to avoid loading, which would resulting in the filter having a larger cutoff frequency than was calculated. This could be avoided using an op-amp but another op-amp would just to the power consumption and cost of the circuit unnecessarily. Using a 10kΩ resistor, the capacitor needed would be 1uF. The equates to a cutoff frequency of 16Hz. It is difficult to know the exact rise time for higher order filters from calculation alone, as such, this filter was simulated in LTSpice. The circuit diagram is shown in Figure 4.2 below.

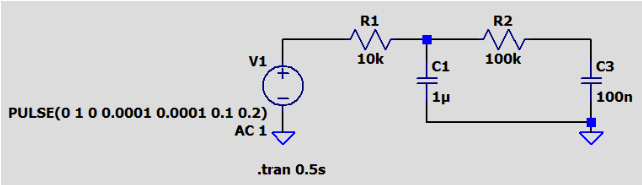

Figure 4.2: Circuit Schematic of Low Pass Filter

The input was set to a $1V_{pp}$ square wave with a frequency of 20Hz. Figure 4.3 below shows the input and output of the circuit.

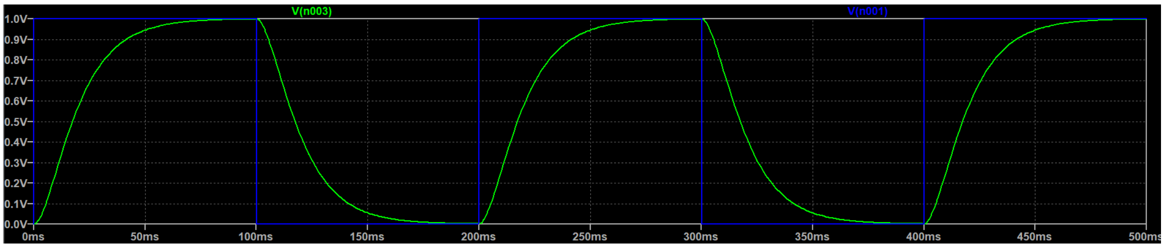

Figure 4.3: Input and Output Waveform of Filter

From the waveform above it can be seen that the rise time is too large, as the output (in green) is barely settling in time for the next half-cycle. This can be rectified by halving the size of the capacitors to 470nF and 47nF, as seen in Figure 4.1. The new output is shown in Figure 4.4 below.

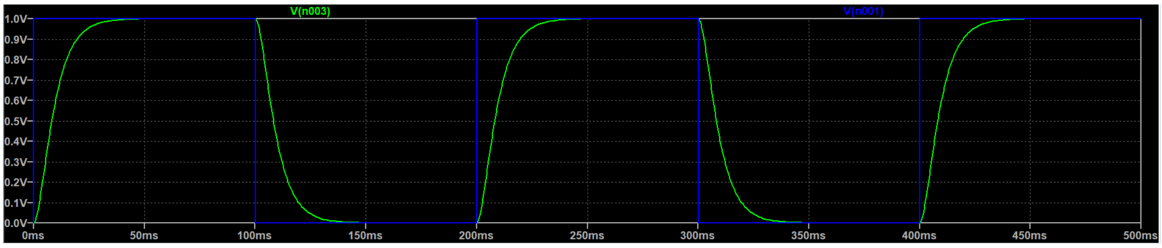

Figure 4.4: Input and Output Waveform of the Final Filter

As seen above, the filter now meets the speed requirements.

Since the instrumentation amplifier has op-amps, it needs 2 rail voltages, a positive and a negative. Unfortunately there is only a single supply, however this supply can be split in two with a simple op-amp circuit, as shown in Figure 4.5 below.

If the new reference point is made to be 'Virtual GND', then two rail voltages equal to $\pm\frac{V_{cc}}{2}$ are obtained. This does mean that output of the amplifier will have an offset of $\frac{V_{cc}}{2}$, but this can be stepped down using a voltage divider as to not damage the input to the micro-controller. In testing, a 5V supply was initially used but this resulted in the op-amps saturating. Any voltage above 6V

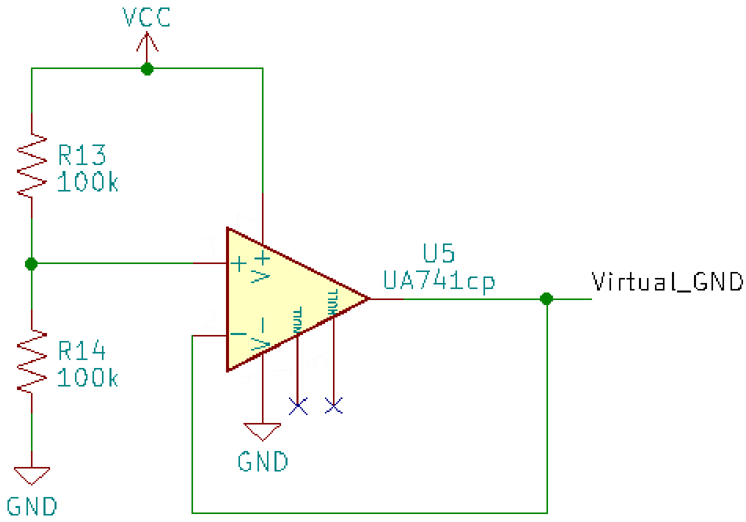

Figure 4.5: Schematic of Split Supply Circuit

seemed to work thus in the end a 6.6V supply was chosen. This will be the supply voltage required from the Power Subsystem.

4.3.4 Analogue to Digital Converter (ADC)

Chapter 5

User Interface

5.1 Introduction

5.2 Design Process

5.2.1 User Requirements

1. Display weight data on app.
2. App must have interface for manual data.
3. Other data should be automated (time, location).
4. Data must be saved to Excel spreadsheet (and stored on cloud).

5.2.2 Functional Requirements

1. Establish connection between smart scale (Arduino) and phone (via Bluetooth or Wi-Fi)

5.2.3 Acceptance Test Procedures

5.3 Design Process

5.4 Final Design

5.5 Testing

5.6 Conclusion

Figures/Starling data block diagram.drawio.pdf

Figure 5.1: Block diagram of subsystem

Chapter 6

Conclusions

> The same rule holds for us now, of course: we choose our next world through what we learn in this one. Learn nothing, and the next world is the same as this one.
>
> —*Richard Bach, Jonathan Livingston Seagull*

The purpose of this project was to...

This report began with...

The literature review was followed in Chapter...

The bulk of the work for this project followed next, in Chapter...

In Chapter...

Finally, Chapter... attempted to...

In summary, the project achieved the goals that were set out, by designing and demonstrating...

Chapter 7

Recommendations

> It is for us the living, rather, to be dedicated here to the unfinished work which they who fought here have thus far so nobly advanced.
>
> —*Abraham Lincoln*

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