July 11, 2020
Dr. Andrew Rawicz
School of Engineering Science
SImon Fraser University
Burnaby BC, V5A 1S6

RE: ENSC 405W/ENSC 440 Design Specification for Flud

Dear Dr. Rawicz & Dr. Scratchley,

Please find our ENSC 405W/ENSC 440 Design specifications for Varia Technologies' Flud. This document will outline the necessary project designs to deliver a successful product. Our goal for capstone is to use AI to detect lawn pests and to use sustainable and environment-friendly solutions in deterring the detected pests through water and light. Flud will use a camera as real-time lawn surveillance and a microcontroller to act upon unwanted pests.

This document's specifications will provide detailed designs for the course project which includes a timeline for the proof-of-concept, prototype and final product. This document will also cover the software, hardware, electrical, mechanical and system designs in Flud's development life cycle. It will also include the support test plans, and user interface and appearance appendixes.

Varia Technologies features six confident and hardworking senior engineering students: Clifford Fung, Josh Baltar, Justin Tsang, Desmond Trang, Eric Wang and Miguel Taningco. With a diverse background of technical skills and experiences, and a variety of engineering concentrations, our group has extensive knowledge in software and hardware systems that will guide us in realizing our goal to completion.

Our team would like to thank you for your time in reviewing our design specifications. Please do not hesitate in contacting us via our designated contact person, Joshua Baltar. For any questions or concerns, you can reach him at jbaltar@sfu.ca.

Sincerely,

Clifford Fung
CEO
Varia Technologies
Enclosed: Requirement Specifications for Flud

Design Specification:
Flud

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Abstract

For a majority of homeowners, landscaping activities consume a lot of time and money, with an average of two hours a day spent maintaining lawn work [1]. With all these resources expended into the lawn, it only requires a single pest overnight to ruin all this hard work. Varia Technologies has created a solution to deter any unwanted pests from the lawn to preserve all the efforts in lawn maintenance.

This document outlines the design specifications for Flud, the sentry device that uses AI to deter any unwanted pests from the lawn, while preventing any destruction of the lawn itself. We will discuss the different stages of the design specifications for each integral component of Flud. The goal of this document and the team is to provide effective designs to out-compete our competitors and to provide the readers with a strong justification of the design specifications made.

Flud is driven by three main components: a camera that uses AI to recognize different animals, a microcontroller to process recognition of animals and humans, and a nozzle system to direct water at a target pest. The user will interact with the device by way of a web application; thus, enabling the ability to monitor device status and configure any settings if necessary. The device and web application will have a simple user interface and provide a simplistic user experience.

This document will entail all the technical design details for Flud including the software, electrical, mechanical and system designs, with a justification and analysis of our decisions. This document will also include several appendices for our test plans, and the user interface and appearance. Our final proof of concept device will be presented and delivered by August 2020.

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Glossary

AI - Artificial Intelligence
API - Application Programming Interface
CPU - Central Processing Unit
CSI - Camera Serial Interface
FPS - Frames Per Second
GPIO - General-Purpose Input/Output
I2C - Inter-Integrated Circuit
IC - Integrated Circuit
IR - Infrared
LED - Light Emitting Diode
PETG - Glycol Modified Polyethylene Terephthalate
PIR - Passive Infrared Sensor
PoC - Proof of Concept
PWM - Pulse-Width Modulation
MCU - Microcontroller Unit
SFTP - SSH File Transfer Protocol
SPI - Serial Peripheral Interface
TPU - Tensor Processing Unit
UI - User Interface
URL - Uniform Resource Locator
USB - Universal Serial Bus
WiFi - Wireless Fidelity

1. Introduction

Flud is a smart lawn pest deterrent that is programmed to deter any pests using sustainable and environmentally friendly mediums; for example, water and light [2]. The primary features include an AI infused camera that will recognize pests, a motion sensor that will point the camera to the direction of the pest, and a microcontroller to perform the actions required. The product will also include a companion app that will allow the user to monitor product activity, view lawn surveillance and allow the user to customize which pests to deter.

Varia Technologies emphasizes providing an AI approach solution to solve a continuous problem homeowners face without having to harm the environment and wildlife. This system will provide users a cost-effective solution for removing unwanted pests from lingering around their lawn in comparison to the options in the market already. Flud will be a tool for all homeowners and will provide excellent out of the box functionality to enhance user experience.

1.1 Background

A major time-consuming aspect for all homeowners is maintaining their lawns [3]. Homeowners put a lot of time, resources and effort into producing a presentable lawn for their guests, a play space for their children, or simply for decorative pleasure. Nonetheless, there is a large potential of different pests exposed to their lawn; and within a few minutes, a pest could quickly cause unexpecting damage to their hard work.

Currently, the market offers solutions for lawn pests. A U.S. patent defines a water sprinkler based deterrent system, that deters entry of any unwanted intruders into a specific area [4]. The issue with this device is it uses sensors to detect intruders; thus, it will trigger on any visitors in the lawn. Another issue is the sprinkler system only targets a specific area, so to cover the entirety of the lawn, this system must be installed throughout every section of the lawn.

Another example on the market is the Scarecrow, a motion detector sprinkler system that shoots a burst of water when the motion sensor is triggered [5]. Similar to the U.S. patent's issue, this sprinkler system is only able to target one specific area, and will target anything in the line of sight. Alternatively on the market, there is also the Guardian, a deterrent system that emits sonic and ultrasonic noise frequencies to deter any unwanted wildlife [5]. The issue with this system is that the frequencies to deter different pests vary on this device; thus it requires the user to manually switch the dial every time they want to deter a different pest.

Therefore, after conducting market research on the current deterrent systems, Varia Technologies has decided to design Flud. The initiative of Flud is to deter any unwanted pests from the lawn using an eco-friendly manner, with a large range of view, and an AI recognition system to deter multiple pests while eliminating as much user intervention as possible.

1.2 Scope

This document outlines all the design specifications for Flud to adhere in accomplishing the overall goal of the product. It describes all the software, electrical, mechanical and system designs needed to carry out the completion of our final product. It will also include a supporting test plan, and user interface and appearance appendix. Moreover, some of these defined designs may withstand some changes as a result of unpredictable hardships/issues or due to system improvement. With the designs outlined in this documentation, Varia Technologies will have a strong reference in facilitating a prosperous solution for all homeowners.

1.3 Intended Audience

This document serves as Flud's design specifications for Varia Technologies' members, its potential clients/partner, Dr. Craig Scratchley, Dr. Andrew Rawicz, and teaching assistants. The core requirements for each stage in the product's lifecycle are precisely stated. Any future revisions will be accurately drawn from this preparatory framework.

1.4 Design Classification

For ease of reference and to prioritize each design requirement, the following convention will be used throughout this document:

[D. <Section>.<Subsection>.<Requirement Number>-<Priority>-<Stage of Development>]

<*D*> outlines design. <*Section*>*,* <*Subsection*> and <*Requirement Number*> are numerical values used to identify the current requirement in the documents hierarchical order. <*Priority*> defines the necessity of each requirement. <*Stage of Development*> illustrates the timeline of each requirement deadline.

Table 1 below highlights the priority encoding with one of three priority levels. The priority levels are represented by **H**, **M**, and **L** for high, medium and low. High priority describes definitive features and are necessary for the basic functionality of the product. Medium priority represents essential features that are preferred for optimal and complete performance enhancement. Low priority entails non-essential features that could be included towards product completion.

Table 1.4.1 Priority Encoding Description for Design Classification, Representative of High, Medium, and Low

Priority Encoding	Description
H	Definitive features. Necessary for basic functionality
M	Essential features. Features for optimal and complete performance enhancement
L	Non-essential features. To be included towards product completion

Table 2 below outlines the stage of development encoding for Flud. The encoding includes **prc**, **prt** and **prd** which are short form for proof of concept, prototype and production. The proof of concept describes the design deliverable date for August 2020, near the end of ENSC 405W, the prototype describes the design deliverable date for ENSC 440, and the production describes the deliverable checkpoint for when the product is marketable.

Table 1.4.2 Stage of Development Encoding Description for Design Classification to Outline the Different Checkpoint Deliverables

Stage of Development Encoding	Description
prc	Proof of Concept stage and onward
prt	Prototype Stage and onward
prd	Production Stage and onware

2. System Overview

Flud is a next-generation smart lawn pest deterrent that has the capacity to deter pests from your lawn by combining various electrical, mechanical, and software components. The system overview of Flud differs slightly from the PoC compared to the prototype and production stages. Figure 2.1 shows the system overview of the PoC stage and shows the components of each individual system and which other system they interact with.

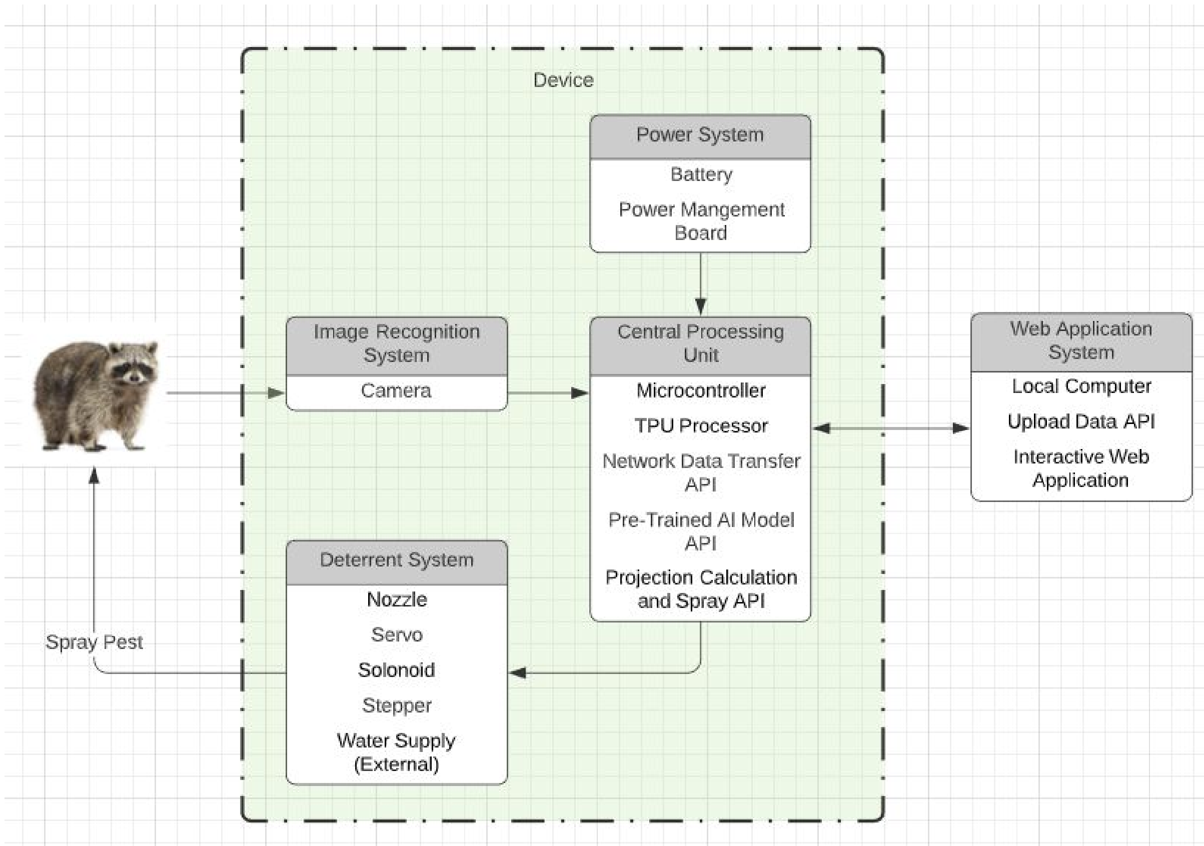

Figure 2.1 System Overview of PoC - Highlighting Components and Interactions

The later sections in this document will go into more depth about the components and their usage but the high-level overview, Figure 2.1 shows that the system first starts with identifying a pest through the camera in the *Image Recognition System*. The camera will feed this image into the *Central Processing Unit* where it will run the *Pre-Trained AI Model API*; the API determines if the image matches an image from its pre-trained model to determine if the image is truly a pest. If it is, the *Project Calculation and Spray API* will determine the exact angle to shoot and will control the components in the *Deterrent System* to do so accordingly. The CPU will periodically send data, everytime the AI API recognizes a pest, via SFTP to a local computer, where it will be manually uploaded onto the interactive web application in the *Web Application System*. The data being sent will be metrics about the system, such as how much water was used, and the consumer will be able to see these metrics on the web application. They will also be able to choose the targeted pests, which will cause the web application to send data to the local computer that will communicate with the device's CPU.

Figure 2.2 shows the slight changes to the system overview in the prototype and production stages - the changes occur in all of the systems of our device.

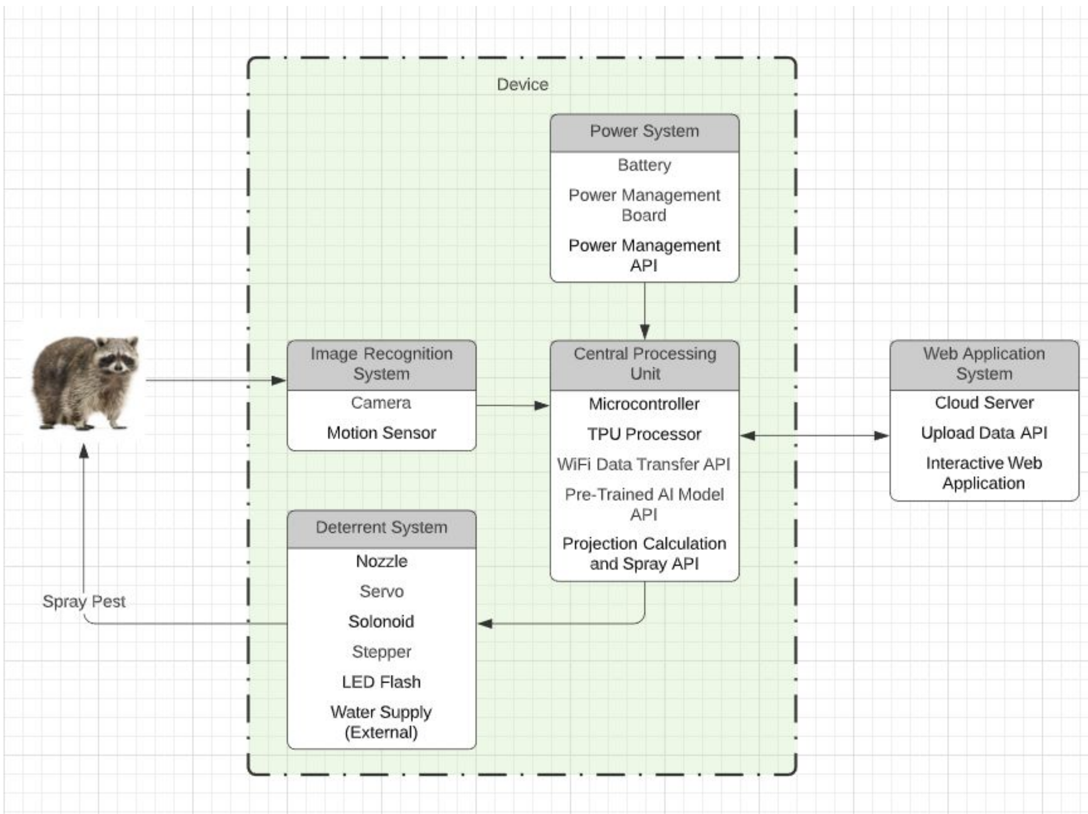

Figure 2.2 System Overview of Prototype/Production - Highlighting Components and Interactions

The image recognition system contains a motion sensor that will turn on the device only when it detects motion, otherwise the *Power Management API* will keep the device in an idle state. Also, there will be an LED flash that will deter pests, along with the water spray. The CPU will communicate directly to the cloud server using WiFi, without the need to go through an intermediate local computer.

Table 2.1 highlights the requirements of our system design throughout the different stages of development.

Table 2.1 System Design Requirements for Development Stages

Design ID	**Design Specification Requirements**
D.2.1.1-H-prc	The motion sensor shall detect movement and send data to the microcontroller.

D.2.1.2-H-prc	The CPU will track water usage and send data to the local computer via SFTP.
D.2.1.3-H-prd	The CPU will track water usage and send data to the cloud server via WiFi.
D.2.1.4-H-prc	The *Pre-Trained AI Model API* will be able to distinguish between trained pests and other images.
D.2.1.5-H-prt	The *Power Management API* shall be able to keep the device in an idle state until the motion sensor is activated.
D.2.1.6-H-prc	The user shall be able to modify the intended targeted pests through the web application.
D.2.1.7-M-prd	The device should have a battery life of up to 1 week.
D.2.1.8-L-prt	The device shall contain a button to power on and off the device.

3. Electrical Design

3.1 Central Processing Unit

The central processing unit subsystem interfaces with all the other subsystems as previously shown in Figure 2.2. By accessing and interpreting the data provided from the sensor and image processing subsystems, it can provide control signalling responses to satisfy all the functional specifications. It also influences some of Flud's performance characteristics such as latency, operating speed, device sizing and cost. Ultimately, it is the entity that dictates the object detection, wireless communication and movement of Flud. Table 3.1.1 specifies the design requirements for the CPU.

Table 3.1.1 Electrical Design Requirements for CPU

Design ID	**Design Specification Requirements**
D.3.1.1-H-prc	Processor is capable of running image processing and detection software
D.3.1.2-H-prc	Include enough GPIOs and connectors for all components used in Flud
D.3.1.2-L-prt	Microcontroller must easily fit in Flud's enclosure

3.1.1 Microcontroller

The microcontroller (MCU) is the principal subsystem responsible for housing all object detection and other algorithmic processes for Flud. It has various numbers of digital, analog, and output power ports and pins for electrical data communication. Three competing microcontroller products are the Raspberry Pi 4 (RPI4), Raspberry Pi 3 B+ (RPI3B+) and BeagleBone Black (BBB). The selected microcontroller is determined by satisfying the following metrics: Ease of implementation, number of non-multiplexed pins, processing power and cost.

Each metric is not desired equally but desired based on practical needs of prototyping. For instance, ease of implementation is the most desired metric to address one of the primary risk mitigation, system integration. The number of pins is one of the most desired metrics because it avoids over-complicating the system with multiplexers or shift registers. Although higher processing power improves the performance of object detection, power is proportional to power consumption therefore finding a balance between power consumption and power must be weighed. Finally the cost is the least desired feature because the microcontrollers in the market are very similar.

With the metrics in mind, RPI3B+ is selected for satisfying the overall metrics. RPi3B+ it provides many features to handle data communications and object detection, it satisfies ease of implementation metric. Moreover, it can be developed upon using the Python programming language. Furthermore, it has 40 pins (28 digital and 10 power) and provides many different functions such as I2C, SPI, Serial and PWM. The main specifications for the RPi3B+ that is important to Flud: 1.4GHz 64-bit quad-core processor, 1GB Ram, supports 2.4Ghz/5GHz Wi-Fi and contains a CSI camera port. Although the MCU is not the most powerful, the MCU measures the lowest power consumption of 500mA. Finally the cost is the cheapest at $47.95 (RPi4 at $69.00 and BBB at $63.24).

3.1.2 Google Coral USB Accelerator

The Google Coral USB Accelerator (Coral) adds an Edge TPU coprocessor to Flud [6]. This will assist the RPI3B+ for machine learning related work including our object detection. The usb can work with the RPI3B+ by simply connecting to the onboard usb ports and recommending to supply 500mA at 5V. The device can be modified to speed up or lower clock frequency to fit our needs.

3.2 Image Recognition System

The image recognition subsystem interfaces the world with the Central processing Unit subsystem. To assist the AI software in detecting the pests nearby we will be using a combination of a Camera Module and PIR Motion Sensors. Table 3.2.1, specifies the design requirements for Image Recognition System.

Table 3.2.1 Electrical Design Requirements for Image Recognition System

Design ID	**Design Specification Requirements**
D.3.2.1.1-H-pcc	Camera must be able to interface with the CSI port on the RPI3B+
D.3.2.1.2-M-prt	Able to capture images with low light levels
D.3.2.1.3-L-prt	Motion detectors must have a maximum detection of 5 meters.

3.2.1 Camera Module

The camera module will capture video of the area surrounding Flud and transfer the video to the AI algorithm and detect pests. The RPI3B+ contains a CSI port specifically for interfacing with cameras. Flud will utilize this to transfer images captured by the camera at high speeds. Furthermore the module must be able to capture clear images at low to no light for nocturnal animals. Hence, we selected the Smraza Camera Module. The module is able to interface with the CSI port on the MCU and capture clear images at little to no light. The module’s lens can mechanically switch off the IR filter and uses the IR leds to illuminate the dark. The sensor, OV5647 is a 5 megapixel sensor that is able to stream 1080p at 30 frames per second and has a field of view of 75.7°.

3.2.2 Motion Detectors

The motion detectors serve to detect pests outside of the camera’s field of view. If the motion detectors sense an object moving, Flud will turn and face the object and begin object detection with the camera. We selected DIYmall HC-SR501 Passive Infrared Sensor (PIR) motion sensor module. The sensor can detect 5m and contains a built in board using the BISS0001 motion detector IC. The IC amplifies and outputs a digital signal. Figure 3.2.2.1 shows the waveform of different signals of the module. The signals to focus on are V2,the output of the PIR sensor, VS, the detected motion, VO, the voltage output of the module. VO will be sent to the MCU to signal the motors to move to the direction.

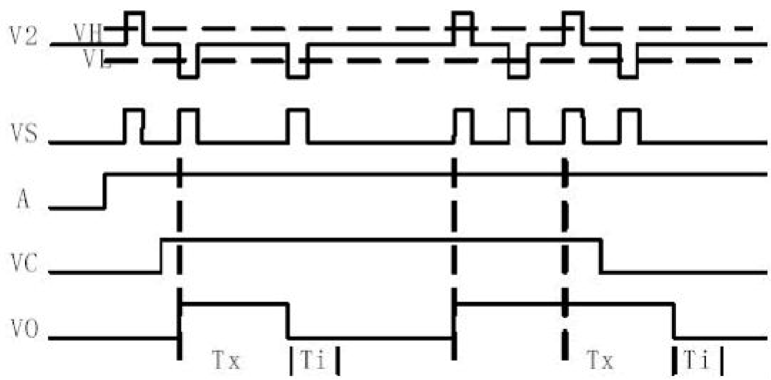

Figure 3.2.2.1 PIR Motion Sensor Module Waveforms

3.3 Deterrent System

The deterrent system is a critical subsystem that serves as the response of the combination of sensors and object detection that Flud provides. The main objectives of this system is to control the aiming (horizontal and vertical), use of visual deterrent and release a jet of water at the pest. This is being fulfilled by the stepper motor and driver, a servo motor, a solenoid valve and led lights. All devices receive commands from the MCU and act independently of each other. We will discuss the electrical components used to horizontally and vertically move the device, how to switch on the solenoid valve and how we can light up LEDs. Table 3.3.1 specifies the design requirements for the Deterrent System.

Table 3.3.1 Electrical Design Requirements for Deterrent System

Design ID	**Design Specification Requirements**
D.3.3.1.1-H-poc	Motors for tilt and rotation.
D.3.3.1.2-H-poc	Electronic valve to release jet of water
D.3.3.1.3-L-prt	Light used as a visual deterrent.

3.3.1 Horizontal Movement

For the horizontal movement we will use a stepper motor and the corresponding driver. The stepper motor runs on pulsed current which turns the motor for some fraction of the turn [7]. There are two types of stepper motors, unipolar and bipolar. For Flud, a bipolar motor is selected because of greater power efficiency and higher torque. Hence, we selected the Nema 17 Bipolar Stepper Motor. The bipolar stepper motor contains 4 inputs shown in Figure 3.3.1.1 and shows how current can step the motor in a full-step sequence.

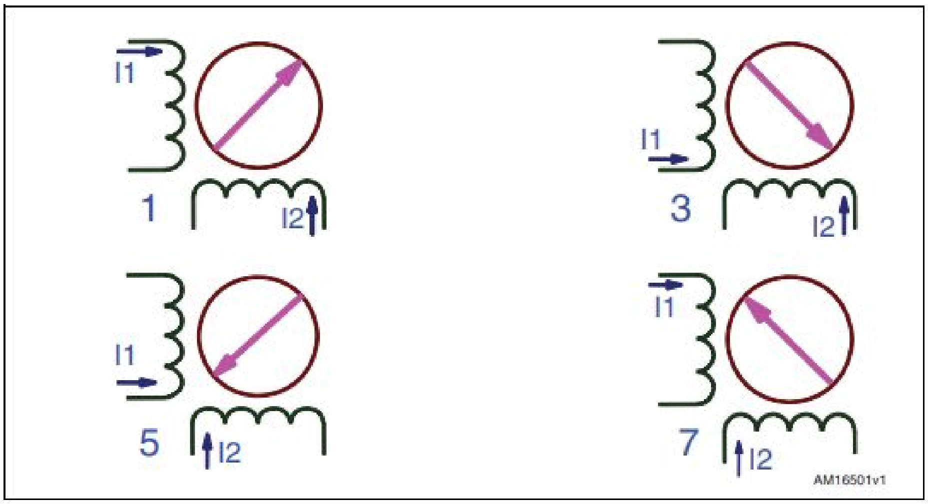

Figure 3.3.1.1 Bipolar Stepper Motor Full-Step Sequence

Stepping requires the combination of supplying and reversing current in each coil to step the motor. Driving the motor will bring forth problems because safely managing reversed current can be complicated. One solution is to use a motor driver IC to control the motor, thus we selected the DRV8825 driver board. DRV8825 features adjustable current limiting, over-current and over-temperature protection, and six microstep resolutions which will be beneficial for our design. It also can operate at 12V as needed for our motor.

Figure 3.3.1.2 below is the circuit that will be implemented in Flud. There is a 12V supply for the motor connected to the VMOT pin of the DRV8825 module. An additional capacitor, C1, is added in parallel to act as the local bulk capacitor, protecting the components from the in-rush current that occurs when current is initially drawn from the power supply. Next, B2, B1, A1, A2 are the outputs of the internal H-bridges and are connected to the motor.

Pin 2-8 are the control pins connected to the microcontroller. M0-M1 pins set the microstepping modes, !RST controls reset, and !SLP controls sleep and DIR controls the directions. Finally, STEP will control the stepping of the motor. According to the datasheet, the rising edge causes the indexer to move one step [8], thus the input to this pin is a pwm signal with varying duty cycles. Also an 1kΩ resistor is connected to Pin 2-8 to act as a current limiter to protect the MCU from voltage spikes. Figure 3.3.1.3 uses Ohm's law to calculate the current that is flowing through the path.

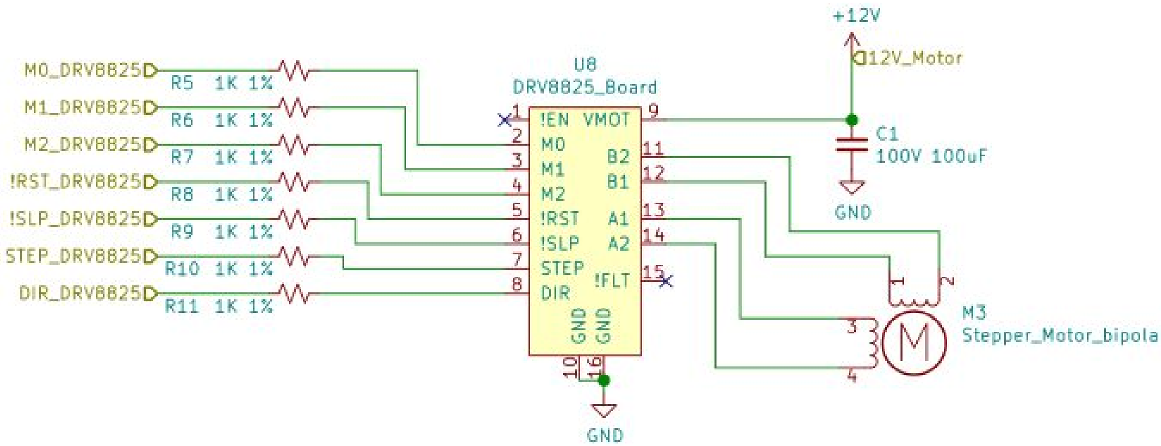

Figure 3.3.1.2 Circuit Design for the Stepper Motor

$$\frac{V_{in}}{R} = I \implies \frac{3.3V}{1k\Omega} = 3.3mA$$

Figure 3.3.1.3 Ohm's Law Equation Used to Calculate Current

Lasty, we want to control the motor's speed for quicker and accurate targeting. According to the datasheet, Figure 3.3.1.4 details the formula used to calculate the PWM frequency, f_{step}, needed to be applied to the STEP pin [8]. Where motor speed (v), microstepping level (n_m) and motor full step angle (θ_{step}) are the manual inputs..

$$f_{step}\,(\mu steps\,/\,second) = \frac{v\left(\frac{rotations}{minute}\right) \times 360\left(\frac{^\circ}{rotation}\right) \times n_m\left(\frac{\mu steps}{step}\right)}{60\left(\frac{seconds}{minute}\right) \times \theta_{step}\left(\frac{^\circ}{step}\right)}$$

Figure 3.3.1.4 Equation Used to Calculate PWM Frequency

3.3.2 Vertical Movement

For vertical movement, another motor must be chosen. In this case a servo motor is chosen for this design, however the explanation is entirely mechanical and thus explained in Section 4.3 under mechanical movement. Servo motors have a built-in driver and encoder, therefore a circuit does not need to be designed. To control the servo motor, the MCU must send a PWM signal to the motor to control speed and direction.

3.3.3 Solenoid Valve

Once the position of Flud is set and is ready to release a jet of water at the pest, there must be a valve that opens. For this implementation we will use a 12V solenoid valve. Figure 3.3.3.1 below, is the circuit implemented to turn on and off the solenoid valve.

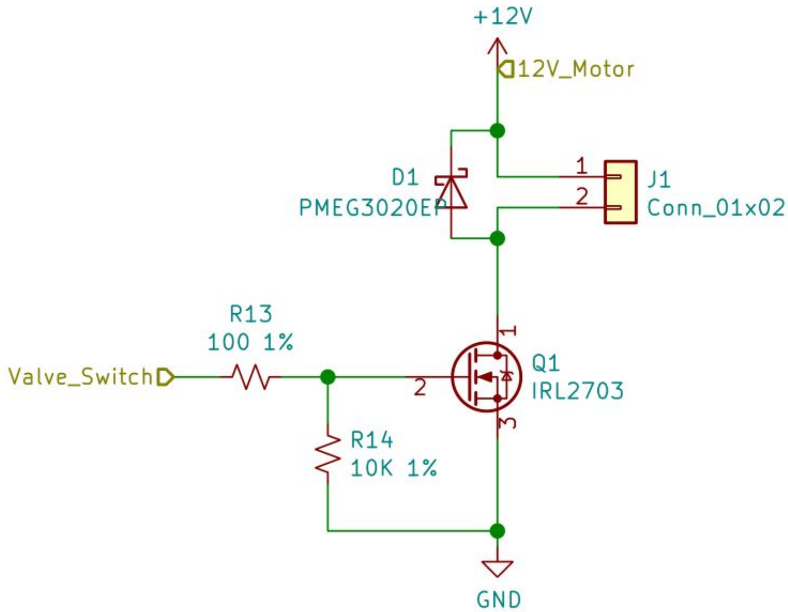

Figure 3.3.3.1 Circuit Design for Controlling Solenoid Valve

In this circuit 12V is connected to Pin 1 of the solenoid valve (J1). When Valve_Switch is high, the N-channel mosfet, Q1, reaches saturation mode and current flows from drain to source to ground, thus the valve opens. R14 serves two functions: first to keep the mosfet in the cutoff region; second, as the mosfet continuously turns on/off, capacitance increases at the gate, slowing switching speed. Hence, R14 is connected from gate to ground to drain the capacitance. R13 is chosen to limit current and also has voltage divider effect with R14. Figure 3.3.3.2 is the equation used to calculate the voltage after the divider circuit.

$$V_s \cdot \frac{R_{14}}{R_{14}+R_{13}} \rightarrow 3.3 \cdot \frac{10k\Omega}{10k\Omega+100\Omega} = 3.267V$$

Figure 3.3.3.2 Voltage Divider Equation Used to Calculate Input Voltage

Where Vs is the Valve_Switch voltage when it is high.

Lastly, the schottky diode, D1, serves as a flyback diode to protect the other components. The solenoid can be broken down into an inductor and resistor. Initially, when current flows through the solenoid, the inductor is storing current. When current stops flowing, all current that was stored in the solenoid is released and the potential at pin 2 of J1 increases high enough to break the body diode in the mosfet and destroy the component. Therefore the schottky diode is selected as a path for the current to flow in a loop with the solenoid until the current dissipates. The reason why the schottky diode is chosen instead of a normal diode is because the schottky diode has a lower forward voltage than a normal diode, therefore conducting earlier.

3.3.4 LED Flash

The LED Flash in a secondary method of deterring pests by using bright lights. Figure 3.3.4.1 details the circuit designed to power on the LEDs.

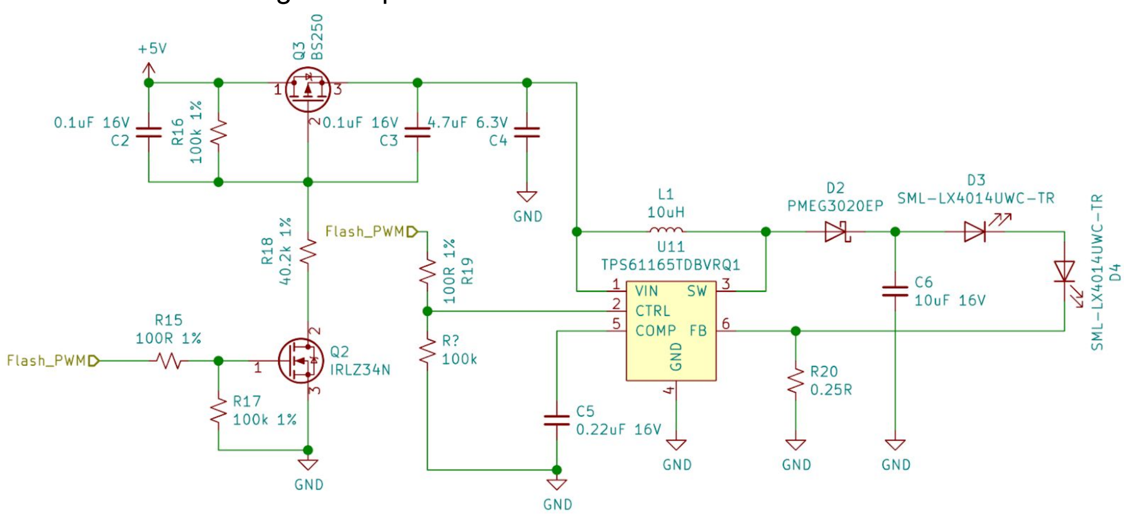

Figure 3.3.4.1 Circuit Designed to Power on LEDs

Firstly, Q2 and Q3 are designed to be used as a load switch. In the case that the signal, Flash_PWM, is high, the N-channel mosfet, Q2, will start conducting and shorting the gate of P-channel mosfet, Q3 to ground thus will also be conducting. Supply is now flowing to the second section of the design. The design decision to use a load switch with 2 mosfet instead of one simple mosfet switch is that the load switch provides more protection for high load applications. Capacitors C2, C3, C4 are used as in-rush current protection and filtering. R15 and R17 will perform the same function as mentioned in section 3.3.3. R16 and R18 will perform in a similar fashion as well.

The second section of this design involves the boost converter TPS61165TDBCRQ1, U11, and the SML-LX4014UWC-TR, D3 and D4. D3 and D4 are high powered white LEDs with 113 lm/W with 3.1V forward voltage. The forward voltage needed to power 2 LEDs in series is 6.2V which is higher than the supply. Thus we will use U11 as a boost converter designed to drive LEDs. U11 also provides a dimming option by sending a PWM to the CTRL pin of U11. Figure 3.3.4.2 and Figure 3.3.4.3 are provided by the data sheet and used to calculate the inductor selected and the maximum output current.

$$I_P = \frac{1}{\left[L \times F_s \times \left(\frac{1}{V_{out} + V_f - V_{in}} + \frac{1}{V_{in}}\right)\right]}$$

where

- I_p = inductor peak to peak ripple
- L = inductor value
- V_f = Schottky diode forward voltage
- F_s = switching frequency
- V_{out} = output voltage of the boost converter. It is equal to the sum of VFB and the voltage drop across LEDs.

Figure 3.3.4.2 Equation Used to Calculate Inductor

$$I_{out\_max} = \frac{V_{in} \times (I_{lim} - I_p / 2) \times \eta}{V_{out}}$$

where

- I_{out_max} = Maximum output current of the boost converter
- I_{lim} = overcurrent limit
- η = efficiency

Figure 3.3.4.3 Equation Used to calculate maximum output current

3.4 Power System

The Power System is a critical system in our design. This system will supply necessary power for all the components of our system, thus requiring careful considerations. Table 3.3.5.1 details the requirements for the power system.

Table 3.4.1 Requirements for the Power System

Design ID	**Design Specification Requirements**
D.3.3.5.1-H-prc	Power supply enough current to all components
D.3.3.5.2-H-prt	Battery supplies enough power to last 1 week
D.3.3.1.3-H-prc	Power supply enough voltage to all components
D.3.3.1.3-L-prd	Light to show device is on

3.4.1 Battery

Battery choice is one of the most critical components for a wireless system. With the requirements in mind, we selected the portable battery charger by Anker. This battery features a 20100mAh and 4.8A output (2.2A for each port). This meets supplying current to all components. We are also designing the battery to be hot-swappable and reduce down time of the device.

3.4.2 MT3608 Step Up Boost Converter

One issue is that the battery does not support 12V components, therefore a solution needs to be created. A solution using a MT3608 step up boost converter module. The module is capable of stepping a 5V input to a 12V output with a maximum output current of 2A. This will cover the voltage requirement that we need for all components.

3.4.3 Sleepy Pi 2

Battery life is an essential component to our device. We require the device to be powered on for longer and reduce the number of times that the user changes batteries. Thus, we selected using the Sleepy Pi 2 expansion board for the RPI3B+. This board provides power management features such as providing an input voltage range from 5.5 - 30V. The board also features an ATMEGA328P microcontroller which we can program for power management.

For power management we can turn off the RPI and only power on ATMEGA328P. This is beneficial for us because as mentioned in section 3.1.1, the current draw of the RPI is typically 500mA. When only the ATMEGA328P is powered, the power consumption can be as little as 180uA, as specified in the datasheet. With this feature, Flud will turn off when no pests are around, thus saving power. To turn on the RPI, we can use the PIR sensor as mentioned in section 3.2.2, to trigger on the ATMEGA328P to wake up the RPI.

The battery life can be calculated using the equation in figure 3.4.3.1.

$$Battery\ life = \frac{Battery\ Capacity}{Load\ Current}$$

Figure 3.4.3.1 Equation to Calculate Battery Life

When the RPI is always off, the device will have a battery life of 111666 hours. When the RPI is always on, the battery life is 40 Hrs. We aim to reduce RPI on time to maximize battery life of Flud.

3.4.4 Power On LED

To physically show the user that the device is powered on, Flud has an LED that will light up. Figure 3.4.4.1 is the circuit used to power on the LED. The LED requires a 2.15V forward voltage and a 20mA forward current, thus a BJT is used to amplify the input current, i_b . LED_ON_RPI is a 3.3V GPIO from the RPI from that we can calculate i_b ,. Next we multiply by the minimum DC current gain of the BJT, 30, to calculate i_c , which is 40.5mA. 40.5mA ensures the LED is fully saturated and lights up. Figure 3.4.4.2 shows the calculations in detail

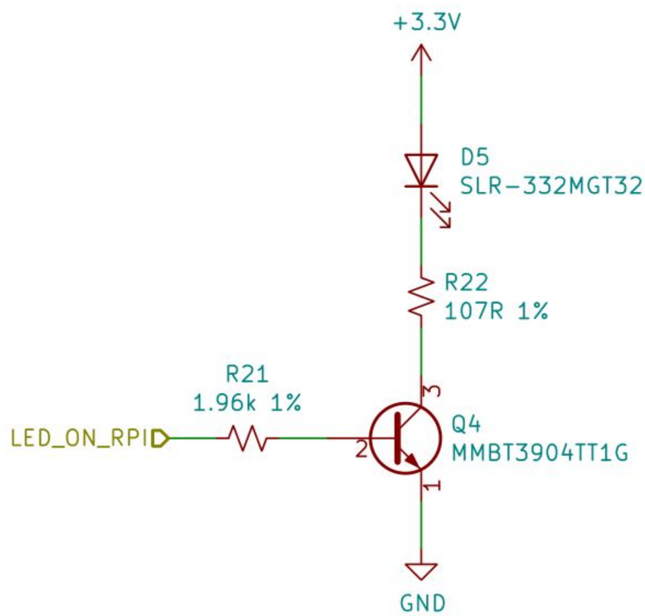

Figure 3.4.4.1 Circuit Designed to Power on LED

$$i_b = \frac{V_{in} - V_{be}}{R_{21}} = \frac{3.3V - 0.65V}{1.96k} = 1.35mA$$

$$i_c = 1.35 \cdot 30 = 40.5mA$$

Figure 3.4.4.2 Equation Used to Calculate Current Strength to Power LED

4. Mechanical Design

The Flud is a pest deterrent device that detects and sprays pests that appear in lawns and gardens with 360° of horizontal coverage. As the device is designed to be placed in the user's lawns and gardens, it needs to withstand the environmental conditions found in those locations with little in the way of maintenance. Furthermore, to fulfill the device requirement of full horizontal rotational coverage with nozzle adjustments to adjust to target distance, the mechanical movement is designed to allow for continuous movement with little load on the actuators. The following subsections discuss how the mechanical design addresses these considerations.

4.1 Material Selection

Table 4.1.1, details the requirements that our device materials must fulfill. The requirements mainly describe the environmental conditions the materials must withstand.

Table 4.1.1 Material Requirements for Durability and Environmental Sustainability

Design ID	**Design Specification Requirements**
D.4.1.1-M-prt	The device must be able to typical outdoor temperatures
D.4.1.2-L-prt	The device must be resistance to rain, dust, and wind

The Flud is designed to be placed in outdoor environments such as lawns and gardens. For our prototype, we designed the device to withstand the environments that are typically found in the lower mainland of British Columbia, Canada. According to Vancouver Weatherstats [9], Vancouver, BC between July, 2019, and July, 2020 had a maximum temperature of 29.2 °C and a minimum temperature of -8.0 °C. In addition to temperature, the Flud device also needs to be resistant to water from rainfall, wind, and dust typically found in outdoor environments. We also chose materials with considerations to minimize the environmental footprint of the device.

The Flud prototype external and structural components are designed with 3D printed parts. To meet our environment requirements and consideration, we are printing the components with PETG filament. The PETG printable plastics can typically handle all temperature up to 75 °C [10] which meets our temperature requirement. PETG plastics are also ideal for outdoor use as they are very durable with low shrinkage, no warping, and are not brittle. Moreover, PETG plastics do not absorb water, and do not degrade in water. [11]

While PETG plastics are not degradable in water, it is still recyclable. Therefore, the environmental impact of disposing the material is minimal.

4.2 Environmental Protection

Table 4.2.1 details the environmental protection requirements for the Flud device.

Table 4.2.1 Environmental Protection Requirements

Design ID	**Design Specification Requirements**
D.4.2.1-L-prt	The device must be resistance to rain, dust, and wind

To protect the electronics and other internal components, the device is designed with a protective shell that extends internally to shield non-water resistant parts from water, wind, and dust. The shell has a cylinder body and a dome cap. The camera and motion sensors are also mounted on the protective shell for maximum visibility. A visualization of the Flud exterior can be found in Figure 4.2.1.

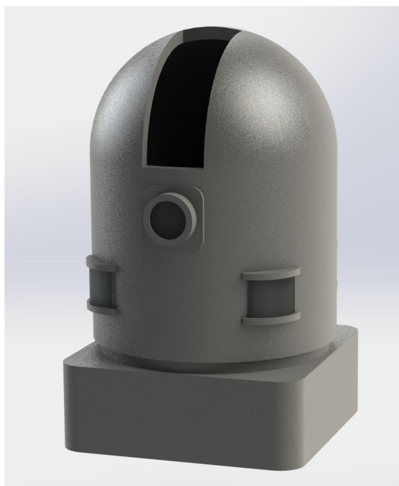

Figure 4.2.1 Flud Exterior Shell 3D Rendering

As seen in Figure 4.2.1, a cutout is made on the dome of the Flud exterior to allow for water spray from inside the device. The device is designed with further shielding extending from the cutout into the opening in the center of the device, preventing water and dust entering the cutout from reaching the electronic components of the device.

4.3 Mechanical Movement Design

Table 4.3.1 outlines the requirements in the mechanical movements of the Flud device. The requirements are based on the requirements of the Flud's ability to cover entire lawns and gardens.

Table 4.3.1 Mechanical Movement Requirements

Design ID	Design Specification Requirements

D.4.3.1-H-prc	The device must be able to rotate 360° in the yaw axis
D.4.3.2-H-prc	The device nozzle must be able to pitch 45°

The Flud is intended to have 360° of horizontal coverage. To achieve the full rotation requirement, we designed the internals to eliminate water pipe bending and twisting. Our design avoids twisting the water pipe by using swivel joints, incorporating ball bearings and having the pipe pass through the centre of the device. This design requires our horizontal movement system to have an opening in the centre which leads to the use of a spur gear drive system for rotation in the yaw axis of the device. The spur gear drive system can be seen in Figure 4.3.1.

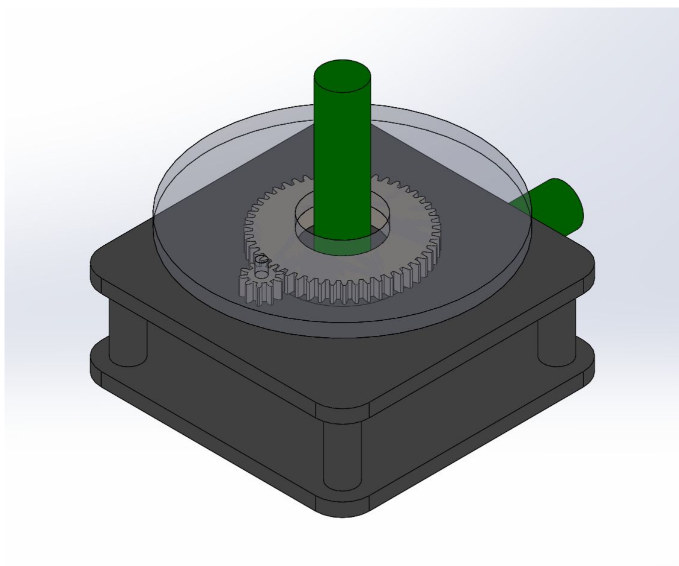

Figure 4.3.1 Flud Spur Gear Drive System

By installing a stepper motor to the smaller spur gear in the outer circumference of the drive system, we are able to control the horizontal rotation of the device while allowing for an opening in the center of the device for the water pipe to pass through. The water pipe is represented by the green tube found in Figure 4.3.1.

The drive system in our design has a gear ratio of 1:6. By driving the small gear in the with 1:6 gear ratio, the torque of the system would be six times the torque delivered from the stepper motor. This allows us to drastically reduce the torque requirements of the stepper motor. With this in mind we chose the Nema 17 Stepper motor, which can deliver up to 26Ncm of torque. Using this motor, our drive system has a maximum torque of 156Ncm torque.

To maximize the range of our device, the nozzle of our device must be able to pitch 45°. To drive the pitch of the nozzle, we have chosen to use a servo motor from ZOSKAY, which has an 180° control angle. The servo motor is chosen for its high efficiency of 80 to 90% efficiency and high torque of 25kg/cm. The placement of the motors and other components can be seen in the Flud internal assembly in Figure 4.3.2.

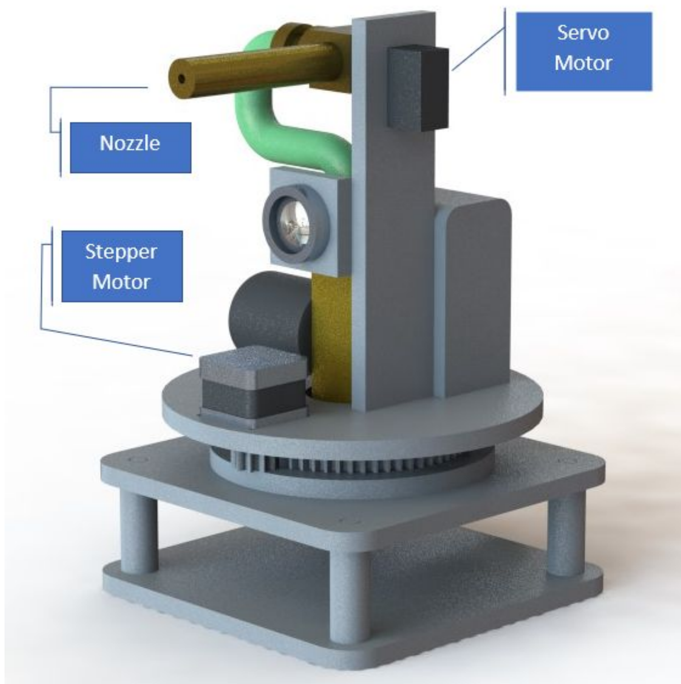

Figure 4.3.2 Flud Proof of Concept Internal Assembly 3D Model

In Figure 4.3.4, the assembly with the placement of the servo motor and the stepper motor driving the gear drive system, the device is able to rotate 360° in the yaw axis and the nozzle is able to pitch 45° in the pitch axis as per the requirements.

4.4 Device Dimensions

The Flud device is designed to be subtle and out of the way when placed in a garden. The device is designed to be just large enough to fit all the components with enough space left over to fit the wiring and water piping. Table 4.4.1 details the dimensional requirements for the device.

Table 4.4.1 Device Dimensions Requirements

Design ID	Design Specification Requirements

D.4.4.1-M-prc	The device must be large enough to fit all the components
D.4.4.2-M-prc	The device must have space for water piping

With the components assembled in the internal configuration seen in figure 4.3.2, we designed the device dimensions to be 20cm wide, 23cm long, and 33cm tall to fit everything in the configuration. At 33cm tall, the device height profile would be comparable or lower than to our competitors like the Orbit Enforcer motion activated sprinkler. Figure 4.4.1 displays a drawing of the Flud exterior with the dimensions labelled in centimeters.

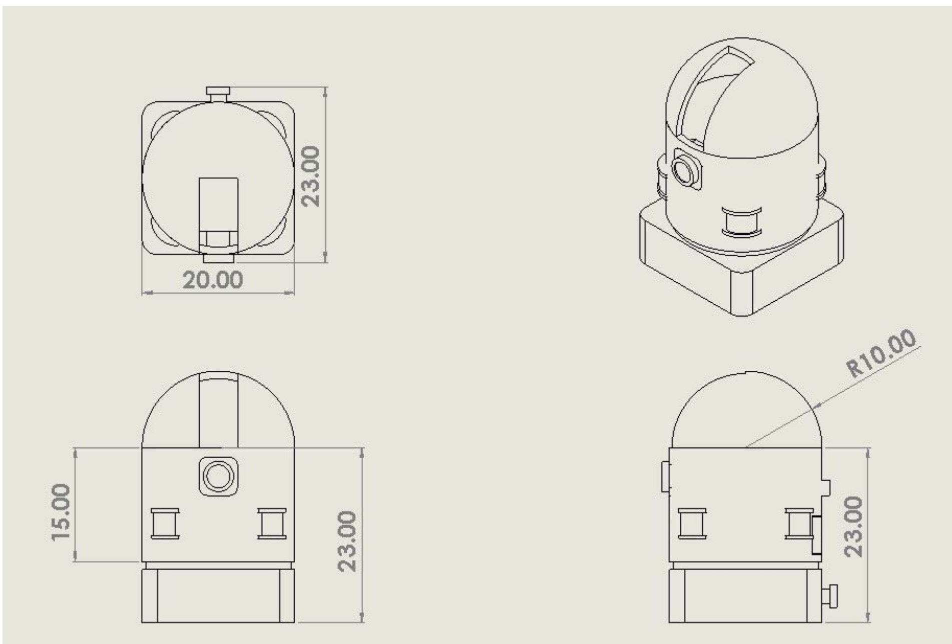

Figure 4.4.1 Flud Exterior Drawing with Dimensions in Centimeters

5. Software Design

Flud is composed of 4 software components where the first of these components is the image recognition using Google's TensorFlow Object Detection API and TensorFlow Lite. There will also be a mobile web application that will provide the user with a list of features to provide more utility. Our technology stack will be made up of PostgresQL, Express, Node.js, and React.js because of the active community and support surrounding these technologies especially for Model View Controller architecture.

5.1 Image Recognition AI

With this API Flud can make use of existing pretrained models from TensorFlow's Model Zoo [12], already containing our main target pests recognizing raccoons, crows, and squirrels. TensorFlow Lite models contain optimizations that enable less powerful computers, such as a Raspberry Pi, to reach performance usable in real-time applications. The models used are trained Quantized SSD-MobileNet Models. The quantization lets us use these models with the Google Coral TPU Accelerator and converts 32-bit parameter data to 8-bit representations [13]. With all of these optimizations, we are hoping to evaluate images streamed from the camera at a minimum of 5 frames per second (fps). From reported usage of a Raspberry Pi 3B+, using TensorFlow Lite instead of TensorFlow increased from 1.37 fps to 2.11 fps, and adding the Coral USB Accelerator increases it to 13.18 fps . More design specification requirements are in Table 5.1.1. A box will be drawn around each recognized pest as well as a confidence level as shown in Figure 5.1.1

Table 5.1.1 Image recognition design requirements

Design ID	**Design Specification Requirements**
D.5.1.1-H-prc	The device will recognize raccoons
D.5.1.2-H-prc	The device will recognize crows
D.5.1.3-H-prc	The device will recognize squirrels
D.5.1.4-M-prt	The device will recognize skunks
D.5.1.6-H-prt	The device will recognize humans and not shoot them
D.5.1.7-H-prc	The device will process the images at minimum of 5 FPS
D.5.1.8-M-prc	A box around each detected object will be shown
D.5.1.9-H-prc	A label to identify the object will be shown
D.5.1.10-M-prt	A confidence level in percent will be shown as in Figure 5.1.1

Figure 5.1.1 An example of a squirrel being identified by the image recognition

5.2 Web Application

The mobile application accompanying Flud will give users access to stored recordings of Flud deterring pests with sprays of water in an easy-to-use format. This feedback assures the user that Flud is working as intended. The recordings will be stored in a SQL database initially in the proof of concept, which is not ideal since the database can quickly grow too large. This will be minimized by only saving videos in a set time frame, but to fully resolve this, the videos will later be stored on Google drive and fetched with PostgresQL. React was chosen as our frontend to ensure the web application code will be reusable and maintain high coupling and low cohesion. More design specifications of the web application can be found in Table 5.2.1.

Table 5.2.1 Web application design requirements

Design ID	**Design Specification Requirements**
D.5.2.1-L-prt	The web application must have enable and disable options for what pests to deter
D.5.2.2-L-prt	The web application will fetch videos for playback of deterred pests of

	the last 24 hours from the database
D.5.2.3-L-prt	The web application will fetch videos for playback of deterred pests of the last 24 hours from Google Drive
D.5.2.4-M-prt	The user must log into the webpage to uniquely identify their device

5.3 Flud Movement and Aiming

For the Flud to properly function as a prototype, one of its requirements is to be able to aim its nozzle at the target and reliably hit the target. Two types of movement is necessary to achieve this requirement expected during the prototype stage, which is to move in its yaw (horizontal rotation) and pitch (vertical rotation). Figure 5.3.1 shows a visualization of which type of movements yaw and pitch are to clarify what kind of movement is required.

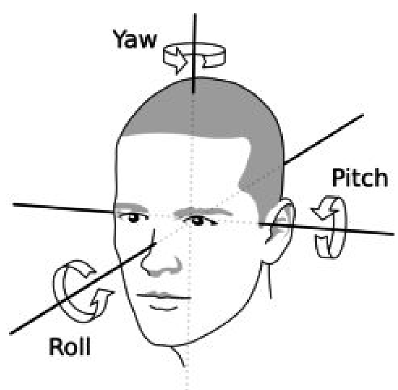

Figure 5.3.1 Radial coordinates used for positioning the Flud.

5.3.1 Input and Constants

The values that are fed into the yaw and pitch calculation are important to properly approximate where the pest is. The two categories of data fed into the algorithms are the inputs and the constants.

The input of the algorithm that varies depending on the scene are the bounds of the pest, the expected height of the pest, and the current initial water pressure of the system. The bounds of the pest and expected height of the pest is determined by Artificial Intelligence. As the Flud detects a pest in its camera, it passes the bounds and expected average height of the pest. Specifically, it uses the top bound, bottom bound, and average height to determine the pitch angle needed, and uses the left and right bounds to determine the yaw angle needed. Further explanation will be covered in the sections specifically regarding the two algorithms. Finally, the water pressure is also received to properly calculate for the pitch as it will affect the range of the water projectile.

The constants of the algorithm are the predetermined values and those that are expected to remain constant. Such constants are the kinematic forces, the dimensions of the sensor, the apparent center of projection of the sensor, the length of the nozzle, and the resolution of the camera. These constants play a crucial role in determining the robustness and accuracy of the Flud, so these must be accurately measured for proper use.

5.3.2 Yaw Calculation

The yaw calculation allows the Flud to correctly aim its nozzle in a direction that is facing the pest. It breaks down to two parts which is initial detection and angle refinement. After the algorithm finishes successfully, the outcome is that the Flud would be directly facing the pest head on.

Initial detection assumes that the Flud is not facing the pest. In the worst case, the pest would not be within the range of the primary camera. This problem however can be solved with 4 120° motion detectors equally spaced around the Flud. Figure 5.3.2.1 shows that each motion detector is spaced in such a way that it accurately rotates the Flud with the object in motion in the camera's field of view. However, the pest may still not be centered in the image which leads to the second part of the yaw calculation.

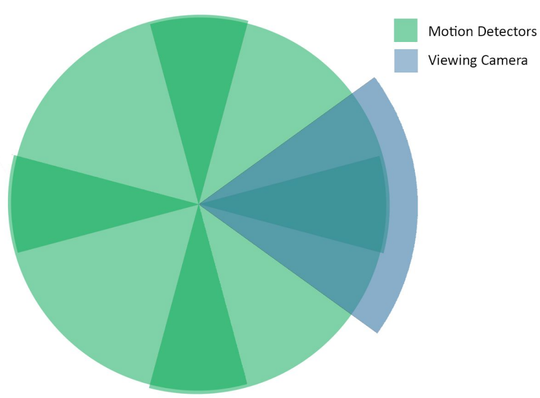

Figure 5.3.2.1 Approximate motion detector and Viewing camera coverage, showing that 4 motion detectors is enough pinpoint region of the pest for the viewing camera to see.

Angle refinement is the stage at which the pest is centered horizontally on the screen to align with the nozzle of the Flud. Figure 5.3.2.2 shows a model of a sensor, its apparent center in its perspective, and the left and right bounds of the pest detected. The angle refinement is an iterative approximation as the apparent center of perspective is assumed to be at the yaw axis of rotation. Under the worst cases where the pest's image is at the edge of the camera screen, the pest is not centered on the screen in one correction of the yaw. Figure 5.3.2.3 shows the feasibility and convergence of the algorithm under many iterations of the correction. Under realistic conditions, the algorithm converges to looking at the pest directly.

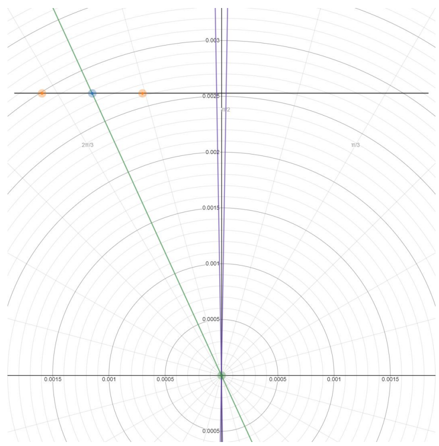

Figure 5.3.2.2 Sensor model used for the yaw calculation of the Flud. The angle is taken from this model as an approximation of where the pest might be.

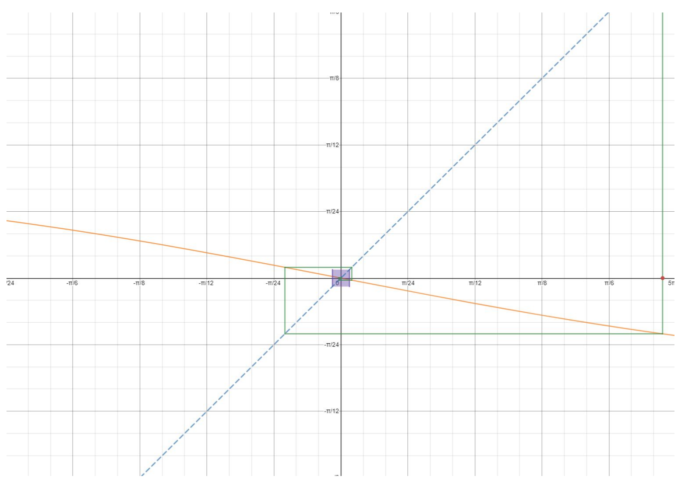

Figure 5.3.2.3 Visualization of the yaw angle refinement approaching a correction of 0° from the worst case. A maximum of 4 iterations needed to approach this region.

5.3.3 Pitch Calculation

The pitch calculation allows the Flud to correctly aim its nozzle which takes into account gravity. The calculation only requires one pass as it directly calculates the angle given the inputs it needs. It is not iterative like the Yaw calculation as the pitch angle cannot be measured solely with the pest's bounds without any further information. The expected height of the pest along with the current water pressure allows us to compute the expected depth coordinates of the pest and compute a solution respectively.

Figure 5.3.3.1 shows a model of how the image is projected onto the screen. Figure 5.3.3.2 shows how this projection is used as the image along with the expected height of the pest is extrapolated into a space coordinate that can be plugged into a projectile motion equation. Directly solving for the angle is not possible as the equations used are not linear and contain trigonometric functions, so Newton's method is used with 2 iterations to solve for the angle. We can see that the figure also shows that the targeted pest is hit under ideal conditions.

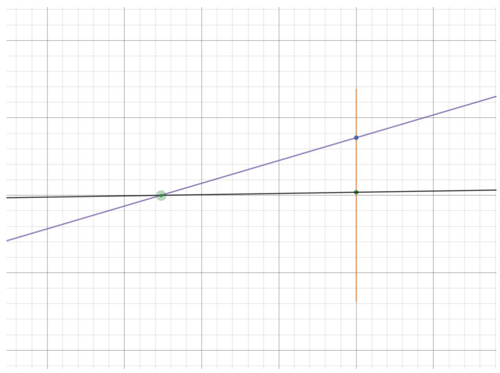

Figure 5.3.3.1 Model of the sensor used for the pitch calculation. The upper and lower bounds of the pest is projected onto the sensor.

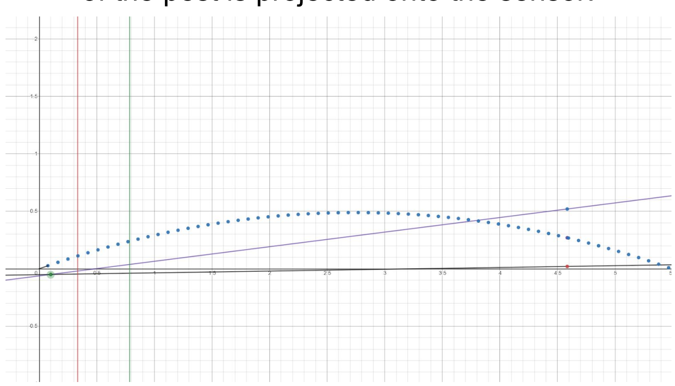

Figure 5.3.3.2 Model of the projectile motion of the water with the calculated angle. Under the conditions that the water can reach the pest, the calculation is able to hit the pest with accuracy.

5.3.4 Assumed Conditions

Although the equations of the pitch calculation is seen to be precise, the constants and the environmental conditions assumed may drastically affect the outcome. One constant that must be precisely measured is the apparent center of perspective of the camera. This constant is not a predefined specification for the camera, so this must be manually calculated. Also, an important assumption to be clear about is the absence of air resistance. This condition is assumed as the average weather is assumed to have negligible wind, as well as the fact that the velocity and cross section that the water is expected to have also has negligible air resistance. Regardless, the equations are now defined, however the accuracy of the pitch calculation is still inconclusive as real world measurements must still be made.

5.4 Connection

As mentioned in the system overview, the PoC stage will involve sending data from the CPU to an intermediate local computer via SFTP. This will be done by pre-configuring the WiFi settings of the Raspberry Pi to share the same network as the local computer, allowing the user to access the Pi's data through SFTP. Once the data is retrieved, the user will run a script that will push the data onto the Heroku server, where the web application is hosted. If the user decides to modify the pests that they want to target, the web application will push the changed data onto the local computer, where the user will be required to manually transfer the data onto the Raspberry Pi through SFTP. Figure 5.4.1 shows a preview of a possible implementation of the SFTP process.

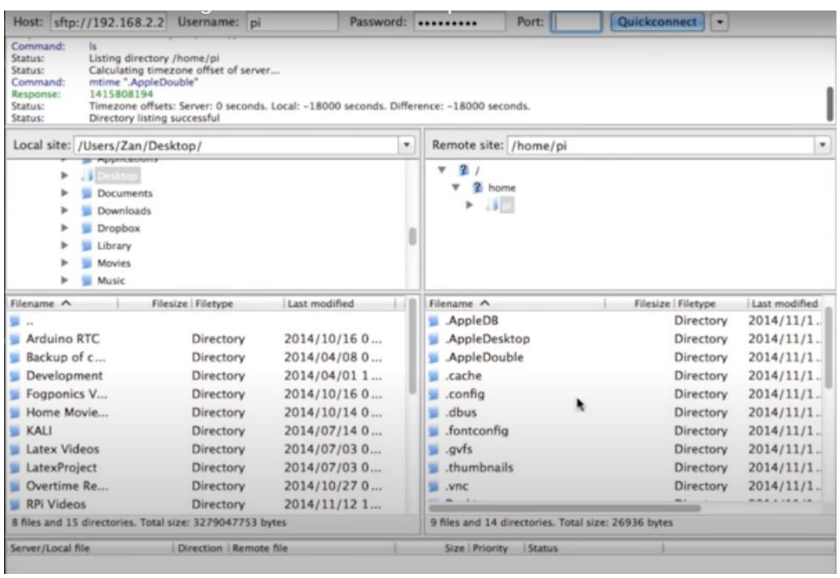

Figure 5.4.1 Possible Implementation of SFTP Between Pi and Local Computer

For the prototype and production stages, the CPU will be using WiFi instead to transfer data directly to the Heroku cloud server. This will eliminate the need of an intermediate local computer and manual user intervention, making the whole process autonomous. If the user decides to modify the targeted pests, the server will directly push the data onto the Raspberry Pi. We will use *Socket.IO* to allow for communication directly between the Raspberry Pi and Heroku application, using the internal port number that is provided with every Heroku container.

6. Conclusion

Flud is the future of pest deterrents that utilizes an AI-based solution and is marketed for all homeowners with lawns. Flud is meant to be an efficient all-in-one solution for deterring lawn pests while eliminating the majority of user intervention. Our device will provide an intuitive and user friendly experience while using unharmful methods in deterring unwanted pests.

Varia Technologies strongly believes that AI is a powerful tool that will eliminate and automate tedious tasks, enabling consumers to maximize their productivity. To ensure product success, Varia Technologies will work closely with users to collect test results and feedback to enhance system improvements; thus, enables the components to be efficiently designed to provide a cost-effective product for all lawn owners.

The company's ambitions and objectives are to solve real world problems with permanent solutions. Our dedicated team of engineers will strive to deliver an impressive product that contains prominent design specifications held at a high standard.

7. References

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Appendix A: User Interface and Appearance

A.1 Introduction

The user interface is a crucial part of almost every hardware and software system because poorly designed user interfaces could be blamed to cause consumer disasters, and an increase in cost and error [1]. With this key concept in mind, Varia Technologies exercises to create a thoughtfully designed user interface to allow the users to navigate, deploy and operate our product with ease. Our product is meant to be an everlasting and irreplaceable solution; hence, the user interface must be catered for all users.

This user interface and appearance appendix provides a detailed analysis of how Flud's user interface will be designed, constructed and tested with user feedback. All UI design choices will be justified and explained in depth through Don Norman's design principles, "Seven Elements of UI Interaction" [2].

A.1.1 Purpose

The purpose of this appendix is to demonstrate Flud's hardware and software user interface designs, and to provide a meaningful analysis of the UI components. Varia Technologies' overarching goal is to provide the user with an intuitive and simplistic user interface to enhance consumer productivity and comfortability.

A.1.2 Scope

This user interface and appearance appendix primarily focuses on the user interface of Flud's prototype phase because the proof-of-concept will mainly focus on the embedded components. All of the UI testing sections are for the prototype phase and onward. The main topics discussed in this section include user analysis, technical analysis, engineering standards and usability testing. This appendix also includes graphical representations to emphasize the deep analysis of the user interface and how the user interacts with our device.

A.2 User Analysis

When people without a strong technical background run into a technical difficulty, they tend to conclude a relationship between two unrelated events [3]. With this in mind, Varia Technologies has designed Flud's user interface to avoid our users from drawing these conclusions. Our user interface will not require the user to have a strong technical background as our user interface will be simplistic and intuitive.

For the hardware portion of the user interface, the user will need to physically push buttons (mainly to turn the product on) and must be able to insert their hose into the twist nozzle of our device. To replace the batteries of the device, the opening will be similar to a television remote, where the user will just need to pop it open and replace the batteries inside.

For the software portion of the user interface, we have designed the web application to minimize the amount of user intervention. The user will need to access our website which is provided with the unique device ID that is accompanying the product. The user will need to have an email address, and then required to create a password with their new account on our website. Once the user has logged in, only mouse clicks will be required to navigate our website, as we used button elements for all the user input.

A.3 Technical Analysis

This section encompasses a comprehensive analysis of Flud's user interface influenced by Don Norman's, "Seven Elements of UI interaction", and will provide a deep analysis of the following principles: discoverability, feedback, conceptual models, affordances, signifiers, mappings, and constraints [2].

A.3.1 Discoverability

Discoverability describes how intuitive the device's user interface is when seen for the first time. For our prototype, we plan to place all user input elements on the one side of the device, so the user is able to view all their options at once. Figure A.4.1 below provides an image of the device where all the user input elements will be placed. We currently only have one button for the user to push, and that is for the power. In the image, the button is placed in the centre, battery pack opening.

Figure A.3.1.1 Flud's user interface from the hardware perspective, including the power button, hose opening, and battery casing

For the website, the UI elements will be centered to provide ease to new users and allow them to be able to find everything they are looking for. Figure A.3.1.2 provides a snapshot of the dashboard for when the user's login. The web design is made to be simplistic by including a background image on the sides of the web page to indicate that no UI elements will exist there.

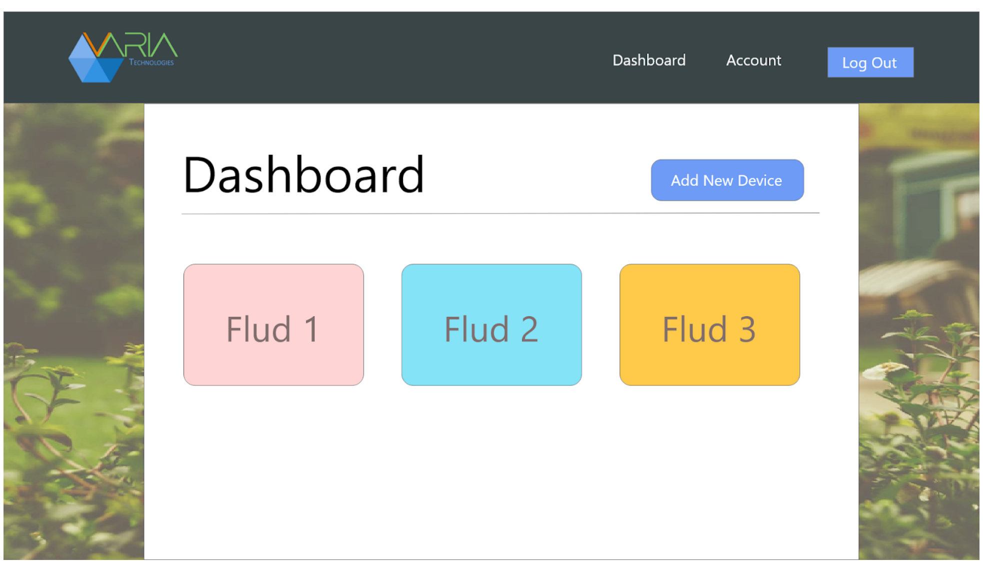

Figure A.3.1.2 Snapshot of dashboard webpage, with pre-existing devices to show the ease of selecting and viewing their devices

A.3.2 Feedback

The feedback of a user interface is to provide the user with information on any changes or issues with the device. For the prototype, since our device does not have many hardware UI elements, the majority of the feedback is from the web application. When the user changes a setting in the web-app, the user will be notified with a pop-up to alert that the changes have been saved and reflected on the device. Figure A.3.2.1 illustrates the pop-up alert the user will receive when a setting has been changed and reflected on the hardware device. The web-app will produce one of the two pop-up alerts dependent if the hardware has received the modification.

Figure A.3.2.1 The image on the top illustrates a setting configuration received by the hardware device, and the image on the bottom illustrates that the setting was unable to be changed

A.3.3 Conceptual Models

Conceptual models are utilized to allow users relate our device with similar devices and to provide conceptually similar experiences. For the prototype, the web-app will have a login page/create account page similar to Facebook’s UI. Facebook is a common website that a majority of people log into everyday, so creating a similar style will provide ease to the user. Figure A.3.3.1 illustrates the login page for our device that mimics Facebook with a navigation bar on the top of the page, company remarks on the left of the page, and an account creation form on the right of the page.

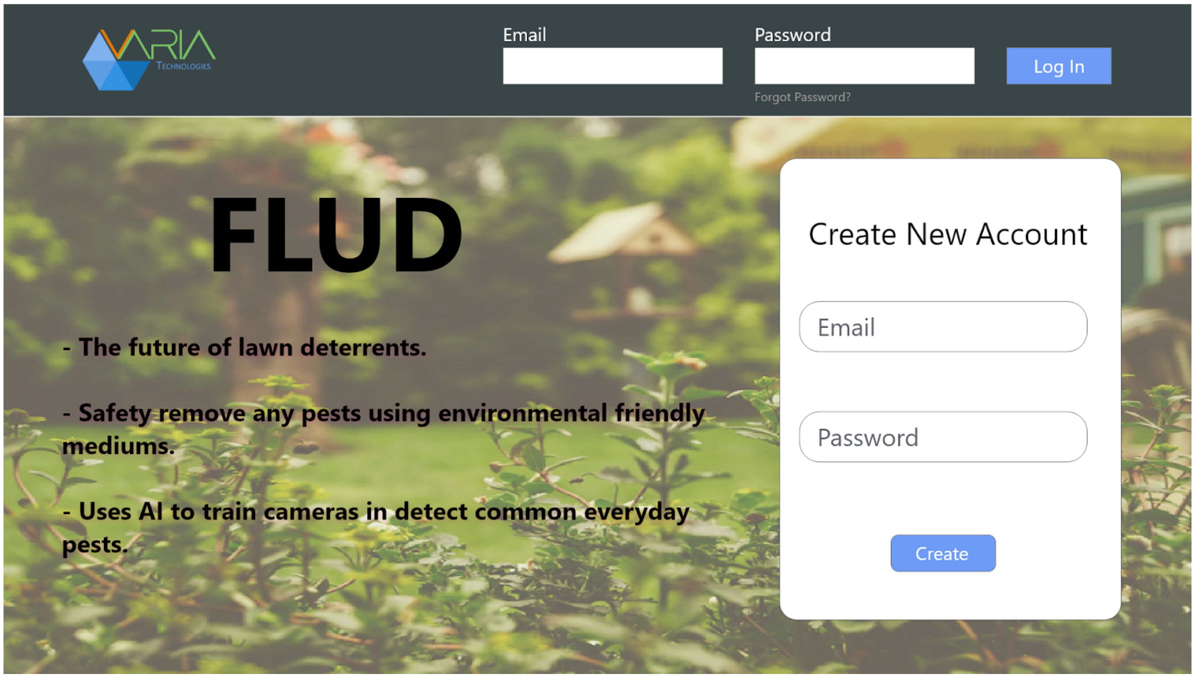

Figure A.3.3.1 Flud's login page and account creation page that mimics a similar style like Facebook

A.3.4 Affordance

Affordance demonstrates the clarity of how an object should be used with respect to the quality of the elements. For our prototype, our web-app will provide a brief summary of the device and its functionality. The hardware of the device has also been designed to provide ease of comfortability. Figure A.3.4.1 demonstrates our hardware user interface, and provides intuitive direction on how the device should be used. The device will have a flat base plate, and will only be stationary if placed on that base, as the rest of the device has rounded edges. There are also four sensors surrounding the device, so it does not matter which direction the device faces, as it has a 360° field of view.

Figure A.3.4.1 Hardware mockup of the prototyped version of Flud

A.3.5 Signifiers

Signifiers are similar to feedback items, in the case where signifers are meant to provide information to the user about the main elements. For the prototype, the power button will signify the user by emitting a constant red LED light when the device is in an active state/turned on. For when the device is powered off, the power button will not emit any LED light. When the reset to factory defaults button is pressed, the power button will flash red LED light and then become constant to notify that the device is now in an active state.

The camera also will have a signifier for the user. When the camera has recognized the pest to deter, there will be a flash of light from the camera first before it shoots water. This flash of light will signify to the user that the camera is working and is triggered.

A.3.6 Mappings

Mappings are considered to identify how intuitive an UI element is relative to where it is situated. For the prototype, the button on the hardware device will be clearly engraved with a power symbol. For the buttons on the web-app, all the buttons will be of the same shape, so the user has familiarity of what is clickable and what isn't.

A.3.7 Constraints

Constraints are the limiting factors that disallow the user to perform any inappropriate actions. For the prototype, the web-app will primarily use button elements to navigate through the pages, so there won't be many different types of user input that could render the website to an unexpected state.

For the hardware, the insertion hole for the hose will be shaped to only twist in one direction to lock the hose securely into the device. For the hot swappable battery case lid, it will evidently close the encasing if placed the proper way every time, so it minimizes the concern of not properly closing the battery case.

A.4 Engineering Standards

Since Flud will be accompanied by a web-application, Varia Technologies will ensure that the user interface will follow several engineering standards in both the proof of concept and prototype stages. These standards are detailed in Table A.4.1, which detail how we will show important information to our users, general purpose guidelines for camera video, and an enhanced experience interacting with Flud.

Table A.4.1 User Interface Engineering Standards

Standard	Description
IEEE/ISO/IEC P26514	ISO/IEC/IEEE Draft International Standard - Systems and Software Engineering--Design and development of information for users [4]
IEC TR 61997:2001	Guidelines for the user interface in multimedia equipment for general purpose use [5]
ISO 9241-210	Ergonomics of Human-System Interaction [6]

A.5 Analytical Usability Testing

During the analytical usability testing stage of Flud, our team will review the user interface design, and test for any errors or annoyances in the user interface. After conducting these tests, we will compile all the data together to commend any changes if necessary to ensure that the user interface is fully functional and intuitive. All of the findings will be discussed as a team before making the adequate changes to the UI. We will be conducting multiple iterations of analytical usability testing which include the initial interaction and subsequent iterations when the UI is modified. The testing will be conducted for both the hardware and software UI, and a comprehensive step-by-step list is provided below.

Hardware:

- Open the hot swappable battery encasing and insert batteries
- Close the encasing; if closed correctly, there should be a snapping sound and lid should not move if closed securely
- Insert hose into the nozzle opening of the device and twist fully to secure
- Depress the power button to transition the device to an active state
- Confirm the red LED emittance on the power button is constant in active state
- Make movement in front of the device's sensor and ensure the camera point towards the movement
- If human recognition is turned on via the web application, then ensure the spray is activated and targets the human's location
- Open the battery encasing, and push the reset to factory default button
- Observe the power button flash red LED emittance and then stay constant to indicate the device has reset and is in active state
- Depress the power button and the red LED emittance should be turned off to indicate that the device is turned off and in an inactive state

Software:

- On a computer, follow the website URL given with the device on any browser
- Create an account using an already existing email address and create a password for the account
- Observe the website is redirected to the dashboard creating an account
- From the dashboard, click the "add new device" button and enter the device ID given with the product
- The new device button should be displayed in the dashboard
- Click the device button to open the statistics and options for that device
- In the options, toggle the pest recognition for humans and observe if the device still shoots at human movement

A.6 Empirical Usability Testing

To begin the empirical usability testing, the team members of Varia Technologies will start testing in a controlled environment to ensure proper system functionality. Initial feedback of the team members will be used to make any minor adjustments and note any areas of improvement. Some of the main objectives are ensuring the AI trained camera only triggers to target recognized pests, the sensor rotates to the required field of vision, and the spray system accurately aims towards the correct target.

For the safety and reliability of the device and its surroundings, we will also test the device after a few days of sitting in various climates to ensure the product encasing is fully waterproof and no moisture is produced inside the device. We will also test the base of the device to ensure it is stationary under any weather conditions. We will also ensure the reset to factory default on the device itself functions properly in the event that the device renders an unusable state or achieves an unforeseen deadlock situation.

Afterwards, we will bring the product towards our target market, and family and friends as a sample group to collect their user feedback. The sample group will have no prior knowledge of this device and will be asked to use this device over the span of a few days. We will collect their user feedback and draw any necessary improvements to progress the development of Flud. Figure A.6.1 below illustrates a sample feedback form that we will provide the users with to ensure each user is asked the same questions. The feedback form is meant to gather information about the overall ease of usability in the product, design, and setup of both the hardware and software deliverables.

User Feedback Form

This feedback is for Flud, the AI pest deterrent.

Please answer each question honestly, as it will help improve the development of our device.

Please checkmark the box that applies.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
This product was easy to setup out of the box.					
This product required no prior knowledge.					
This product did not require a lot of user intervention.					
This product was able to target the entire area of my lawn.					
I noticed less damage towards my lawn since I installed this device.					
I would recommend this device to all homeowners with lawns.					
This product deterred all the pests I was looking for.					
The website was easy to navigate.					
The website was visually appealing.					
Overall, I am very satisfied with this product.					

Additional Comments:

Figure A.6.1 Flud's user feedback form provided to all field trial users

A.7 Conclusion

The user interface is a vital component of Flud; thus, Varia Technologies devotes many efforts in designing a simplistic user interface. Our user interface will be intuitive and is designed for users of all backgrounds while eliminating tedious user intervention. After analyzing the seven fundamental principles of UI design, our device will provide a minimal design to enhance user experience, to aid in lawn maintenance, and to enable users to maximize their productivity.

The UI appendix illustrates the essential UI components to ease product usability and comfortability. Moreover, Varia Technologies will work closely with users to collect test results and feedback to enhance system designs; thus, enables the hardware and web application to be efficiently designed to provide a cost-effective product for all lawn owners.

For the proof-of-concept, we focus on providing a primitive design to showcase the basic functionalities of the system. The proof-of-concept deliverables are primarily the embedded component design; hence, the only user interface work remaining for this state is the overall system design diagram for the user's perspective. For the prototype, we will intend to provide a fully functional device that showcases all the key features while withholding a minimalistic and intuitive user interface and appearance. The current state of the prototype has the web application mockups, and the work remaining includes the actualized web application interface and the physical device interface that encompasses all the embedded components.

A.8 References

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Appendix B: Supporting Test Plan

B.1 Proof of Concept Acceptance Test Plan

Date of Acceptance Testing:

The test plan provided verifies the functionality of Varia Technologies' proof of concept, Flud. The test plan measures the subsystems of the product like its electrical parts, mechanical parts, and its software system. Each test looks over a particular behaviour of the system and is categorized to either Pass or Fail based on the expected and observed outcome.

B.1.1 Electrical Parts Acceptance Test

Electrical Parts are defined to be all components of the proof of concept system which do not have any moving parts as part of its overall functionality. Table B.1.1.1 describes the tests for each of the high level electrical components of the system where the engineer must check off the verification of this sub system.

Table B.1.1.1 Electrical Parts Acceptance Table

Component	Test	Description	Procedure	Expected Outcome	Pass/Fail
Batteries	On Capability	Device must turn on.	Press the power button.	Device has turned on.	❏ Pass ❏ Fail
Camera	Operationality	Camera must be outputting data.	Observe output signal when the device is active.	The output of the camera is displaying a signal.	❏ Pass ❏ Fail
Motion Detectors	Operationality	Detectors must activate to any stimulus.	Observe output signal when visual stimulus is applied.	The output of the detector is displaying a signal.	❏ Pass ❏ Fail
	Maximum Detection	Detectors must have a minimum detection of 5 meters.	Apply stimulus outside of range and approach until an output signal is observed.	The output signal activates when the stimulus is at a minimum of 5 meters.	❏ Pass ❏ Fail

B.1.2 Electrical Parts Acceptance Test

Mechanical Parts are defined to be all components of the proof of concept system which have any moving parts as part of its overall functionality. Table B.1.2.1 describes the tests for each of the high level mechanical components of the system where the engineer must check off the verification of this sub system.

Table B.1.2.1 Mechanical Parts Acceptance Table

Component	Test	Description	Procedure	Expected Outcome	Pass/Fail
Motor	Maximum Horizontal Rotation	Device must be able to rotate fully at 360°.	Allow the device to rotate counter clockwise until it has reached the initial position. Repeat going clockwise.	The angle observed clockwise or counter clockwise is 360° or more.	❏ Pass ❏ Fail
	Maximum Vertical Tilt	Device must be able to tilt a maximum of 45°.	Allow the device to tilt down completely and measure the angle it takes to tilt up completely.	The total angle observed is at a maximum 45° with the tilt down boundary as the reference.	❏ Pass ❏ Fail
Nozzle	Non-active Nozzle	The nozzle must be shut when no electrical signal is input.	While the device is active, apply no electrical signal into the nozzle.	The nozzle remains shut.	❏ Pass ❏ Fail
	Active Nozzle	The nozzle must be open when an electrical signal is input.	While the device is active, apply an electrical signal into the nozzle.	The nozzle opens.	❏ Pass ❏ Fail

B.1.3 Software System Acceptance Test

Software System is defined to be all components of the proof of concept system which is functional but does not take on a physical form. Table B.1.3.1 describes the tests for each of the high level software system components of the system where the engineer must check off the verification of this sub system.

Table B.1.3.1 Software System Acceptance Table

Component	Test	Description	Procedure	Expected Outcome	Pass/Fail

MCU	WiFi Connection	The user must be able to manually change the WiFi connection of the device.	Set the WiFi connection and view that the connection is set through the command line.	The expected WiFi connection should be the same as the intended WiFi connection.	❏ Pass ❏ Fail
	Transfer Data	The user shall be able to manually send data from the device to the local computer via SFTP.	Connect to the device using SFTP via the local computer and send a file.	The expected file that was sent should show up in the file system of the local computer.	❏ Pass ❏ Fail
	Upload Data	The user shall be able to manually upload data from the local computer onto the web application.	Run the script that will send the intended data onto the web application.	The intended data should be viewable on the web application.	❏ Pass ❏ Fail
Companion Application	Estimated Water Usage Status	The estimated water usage must be displayed in the application.	Access the application and view the estimated water usage status.	The estimated water usage should be consistent with the water used by the device.	❏ Pass ❏ Fail
	Estimated Battery Percentage	The estimated battery percentage must be displayed in the application.	Access the application and view the estimated battery percentage	The estimated battery percentage should be consistent with the battery percentage of the device.	❏ Pass ❏ Fail
Pest Detection	Inactivation to Humans	Artificial intelligence must avoid activation on humans.	Face the camera in front of humans for artificial intelligence to determine if it is a pest or not.	Artificial intelligence does not activate on humans.	❏ Pass ❏ Fail
	Activation to Selected Pests	Artificial intelligence must activate to selected pests.	Face the camera in front of a pest for artificial intelligence to determine if it is a pest or not.	Artificial intelligence activates on pests.	❏ Pass ❏ Fail
	Inactivation to Unselected Pests	Artificial intelligence must not activate to unselected pests.	Face the camera in front of a pest for artificial intelligence to determine if it is a pest or not.	Artificial intelligence does not activate to unselected pests.	❏ Pass ❏ Fail