Purrfect Cat Care

Initial Project and Group Identification Document
Divide and Conquer

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Group 18

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2.1 Background and Motivation

Waking up every morning with small paws walking across the bed or a cold nose to the hand can be very rewarding if you are a pet lover. According to the 2017–18 National Pet Owners Survey approximately 84.6 million homes own a pet **?**. The friendly, playful, loving and independent qualities of cats make them a fantastic companion. While independent, cats rely on their owners to satisfy the basic needs of food, water, shelter, and welfare. Taking care of an animal can be a demanding job, but pet owners have a responsibility to keep the animals safe and healthy. Maintaining the health of one's cat can be an especially difficult task. Due to their independence, and subtle behaviors, it is often difficult for pet owners to notice the subtleties of their actions. Differences in eating, or water intake typically go unnoticed, and over time may lead to a trip to the vet. Hence, developing a product to track an animal's feeding, hydration, and liter box habits is the perfect avenue to blend convenience with functionality.

2.2 Objectives

The goal of our project is to provide cat owners a convenient and completely automatic way to track their cat's health, while also filling the role of other automatic cat chore systems. We want to create a reliable, autonomous, and easy to use monitoring system that handles many of the common chores associated with keeping cats. The system must also be able to detect small changes in the cat's behavior. In order to meet these goals, the Purrfect Cat[1] Care system will consist of four main subsystems: the feeding station, water station, waste station, and base station.

The feeding station will handle the food intake of the cat. To be autonomous, it will dispense a user-determined amount of food at regular intervals throughout the day, similar to off-the-shelf cat feeders. However, it will also measure the amount of food the cat eats. Changes in a cat's diet can be indicative of numerous feline diseases, including diabetes, digestive problems, and dental problems. By tracking the weight of food consumed each day by the cat, increases or decreases in appetite can be detected.

The water station serves a similar role. It will automatically pour the cat's water supply to keep the owner from having to provide fresh water each day. It will also track how much water the cat drinks each day to ensure that the cat is adequately hydrated. A lack of hydration can be a symptom of diseases like diabetes or kidney disease.

The waste station will consist of an automatic litter box that automatically cleans itself. We will add on to this litter box an array of sensors to detect how often the cat uses the litter box and what type of waste it is producing. Changes in litter box habits and waste production can indicate digestive issues, urinary tract infections, and other diseases in cats.

[1]"Cover image courtesy of Thingiver user AllCoffeeShop; `https://www.thingiverse.com/thing:2546710`

All the information collected from each station will be sent to a central base station for recording and processing. The base station will calculate statistics of the cat's behavior, such as mean and standard deviation, and can detect outliers that might indicate health problems. The base station will also present a simple interface to the user that shows their cat's history and current statistics as well as allow the user to control the feeding system.

2.3 Requirements Specifications

The requirement specifications for this project are broken down by system. There will be slight overlap between various systems, but we have included it this way to emphasize that each subsystem is independent from one another.

System	Description	Value	Unit
Food:	Dry Food Storage Capacity	7	Day
	Maximum Dry Food Storage	1	kg
	Maximum Dry Food Dispensal	80	g
	Sample Period	1	Hour
	Maximum Dispensing Delay	<2	Minute
	Weight Error	<±2	% of M.S.
	Minimum Serving	> 10	g
	Maximum Operating Power Draw	<20	Watt
	Minimum Feeding Interval	1	Hour
Water:	Water Storage Capacity	7	Days
	Maximum Water Storage	1.5	L
	Maximum Water Dispensal	60	ml
	Sample Period	1	Hour
	Maximum Dispensing Delay	<2	Minutes
	Volume Error	<±2	% of M.S.
	Minimum Serving	5	mL
	Minimum Dispensing Interval	1	Hour
	Maximum Operating Power Draw	<20	Watt
Waste:	Maximum Operating Power Draw	<20	Watt
	Minimum Cleanup Delay	1	Minute
	Maximum Cleanup Delay	10	Minute
Base:	Maximum Operating Power Draw	<5	Watt
	Data History	12	Month
	Communication Delay	< 5	Second
	Website Size	< 2	Page
	Onboard Memory	< 64	GB

Table 1: Requirement Specifications per subsystem.

2.4 House of Quality

The house of quality below has been adapted to focus on what is believed to be the key factors influencing this project.

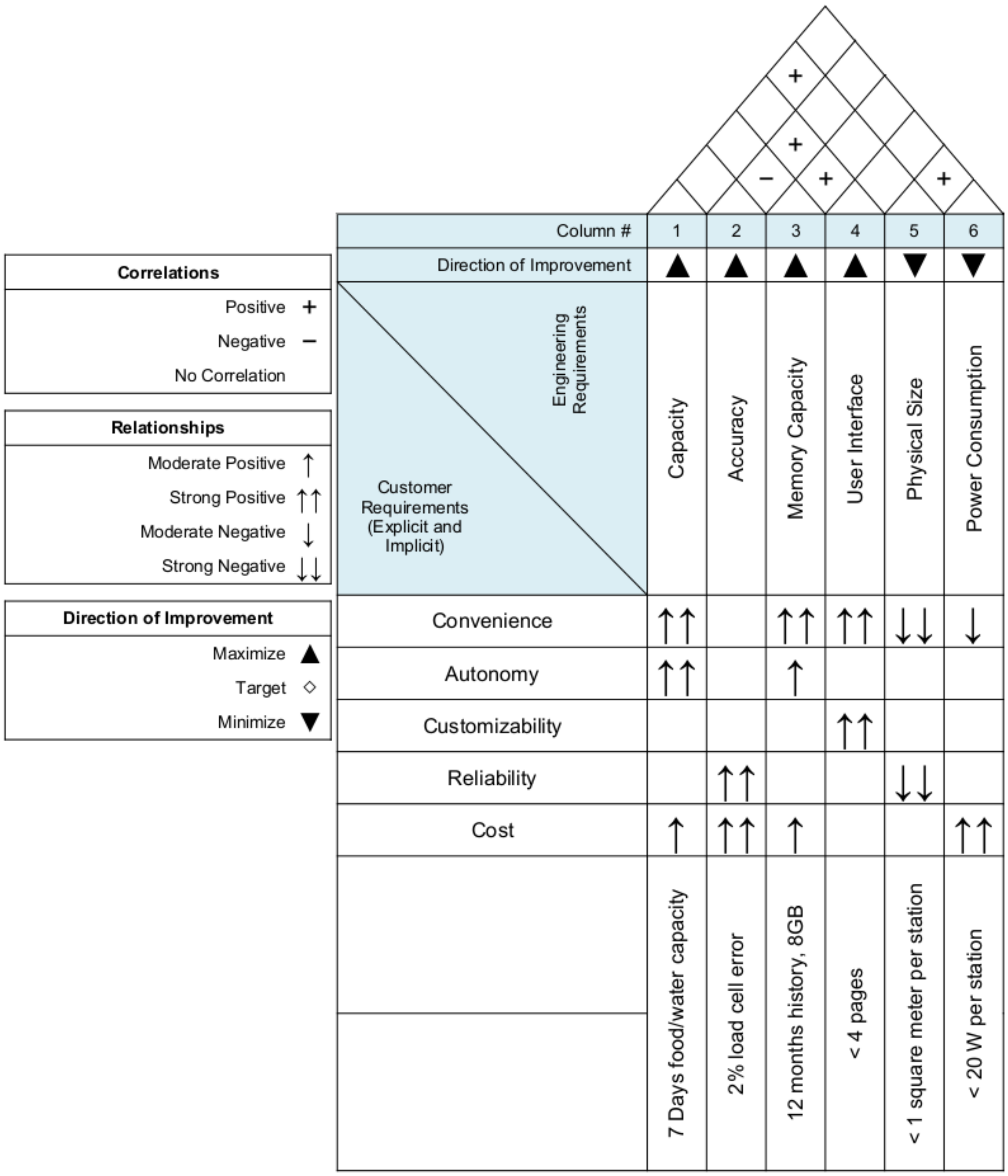

Figure 1: House of quality diagram

3 Research

3.1 Current Market

The current market of cat care automation favors cost and convenience above all else. For most use cases, these two parameters should be the primary concern. This has led to the overwhelming supply of automatic pet feeders, water bowls, and litter boxes on the order of

$30 to $300 to flood the market. Many devices offer week-long food and water storage, and up to 50 automatic litter box cleanings. These capabilities offer a convenient experience to the owner, however, they lack significant innovation across the market. Our implementation aims to take it a step further through our data collection capabilities. Tracking quantities such as food and water intake, as well as litter usage provides a breadth of information for owners and veterinarians. Hopefully our proof of concept may become standard practice in order to save the lives of cats whose ailment may have been caught too late otherwise.

3.1.1 Feeding Stations:

The current market of automatic dry pet feeders lacks significant innovation excluding the physical housing. For cats, a distinction is made between wet and dry feeders since automatic wet food feeders do exist, although uncommon. It is believed that most pet owners would prefer dry food as opposed to wet food for automation. Most wet food manufacturers place the food inside a closed, single-serving, container. Requiring a user to empty several of these wet food containers to fill the feeder introduces another layer of interaction from the user. Therefore, the scope of this project will focus on dry food within the feeding station.

Provided in the next column is a figure of a standard automatic food bowl. The figure is provided courtesy of Closer Pets and is the CatMate C3000®. The feeder may be broken into four main components: food storage, food bowl, the embedded system, and the mechanical dispenser. Some products may have a physical user interface for the user to adjust timing intervals and quantity, whereas other products may use a mobile app or website to remotely adjust these settings. The motor may also drive a different

Figure 2: CatMate C3000®automated feeder.

The food bowl and reservoir are relatively fixed from a design perspective. Hence, the bulk of the system design lies in the mechanism dispensing the food into the bowl and how complex the system controller is. This project is not intended at designing mechanical systems, so in favor of simplicity the design will be focused entirely on the system controller and how the system interacts with the user. These descriptions of the automatic feeder may seem redundant; however, the inaccuracies of the system will need to be dealt with. Designing an automatic feeder costing on the order of hundreds of dollars likely not be a popular product. Hence, the inaccuracies of each mechanical part will need to be addressed in the design of the controller firmware and hardware

3.1.2 Water Stations:

Technological investigation has revealed that automatic water feeders fall into two drastically different families: gravity bowls and fountains. Both types of bowls do not limit or control the quantity of water within the bowl. Several resources have claimed that water regulation is not necessary for cats. Due to their desert nature, cats are excellent at regulating their water intake and drink only when necessary. The water content from wet food also adds to their daily intake, making it difficult to accurately track how much liquid a cat intake throughout the day. Hence, to water a larger emphasis is placed on keeping the volume of water clean and encouraging the cat to stay hydrated.

Gravity Bowl:

The gravity part of gravity bowls hint at the use of gravitational force to dispense water into a bowl. A gravity bowl consists of three core components: a water reservoir, a water bowl, and a floating plastic disk. The disk is attached to the reservoir and regulates the flow of water to the bowl. The flow rate is determined by the volume currently in the bowl. If the bowl is full the disk experiences a buoyant force that pushes the disk away from the dispensing vent. While the disk experiences this buoyant force the disk will not touch the bottom of the reservoir, blocking the flow of water. The only moment when the flow is blocked occurs when the reservoir is empty.

Figure 3: PetMate Replendish Feeder with Microban®.

Fountains:

Water fountains take a significantly different approach from gravity bowls, opting for constant circulation of water within the system. A dedicated filter is present to keep the water clean and in motion. Several sources, including a team member, confirm that some cats prefer their water to not be stagnant. If the water has been sitting for too long, the member's cat will physically move the bowl or slap the water with their paw. It is unsure why cats sometimes behave like this, but it provides an alternate design thought for the water bowl.

An example filter is provided in the next column. The product is the PetMate Fresh Flow II®water fountain. The Fresh Flow combines the reservoir and fountain into a single product.

The bulk of water sits inside of the bowl and the tiny vents allow water to be pumped through, filtered, and dispensed through the top of the pump. Various other products include a dedicated reservoir of unfiltered water. As the volume in the bowl decreases, unfiltered water is added into the system for filtering and a fixed volume is maintained.

Figure 4: PetMate Fresh Flow®water fountain.

3.1.3 Waste Station:

The autonomous nature of our project has restricted our scope to automatic litter boxes. The waste station is the most mechanically involved of the subsystems. This project will not recreate the mechanical automation. Hence, a choice is required in determining which litter box will be used in the final design. Refer to component selection for the litter box decision. The automated litter box market is divided into two categories: Rotating Platform or Comb Movement. This discussion is necessary to determine which devices will be most easily retrofit for the data collection modules.

Comb Movement:

The simplest of the two types, comb litter boxes have a motor which drives a comb-shaped piece of metal through the litter box. These systems typically use a propriety, high-absorption, litter which absorbs nearby moisture to dehydrate cat urine and excrement. The high-absorption litter quickly absorbs cat urine within minutes of the cat leaving the litter box. A proximity sensor is attached midway through the box to detect if the cat is within the box. Once the cat leaves, a user-defined timer counts down before activating the motor. A timer is necessary as to not scare the cat, giving it adequate time to leave the immediate vicinity. Once the motor is activated, the arm combs through the litter and the excrement either sticks to the bare metal or is pushed along the length of the box and the small litter crystals pass through the teeth of the comb. At the end of the litterbox is a small storage area which holds the dried excrement. Over time the excrement will dehydrate and detach from the metal comb.

The relatively detailed explanation above was gained from a group member who owns an automated litter box. A brief search of automatic litter boxes will result in several products by PetSafe®and Premier Pet®. An example of these types of litter boxes is provided below, with permissions of PetSafe®.

The litter box sits on top of a disposable container holding the litter. Hence, replacing the litter is as simple as picking up the housing, tossing the litter in the trash, and placing a new box underneath it. The front of the figure has a dark grey slope. Underneath this sloped section

Figure 5: PetSafe Ultra Self-Cleaning®Litter Box

is where the dried excrement and any other foreign objects are pushed leaving a clean area for the cat to conduct its business.

The last feature worth mentioning is a digital counter in the top right of the device. This counter tracks the number of times the motor has activated, corresponding to the number of times the cat has used the litter box. This feature is essential to let the user know when it is time to replace the litter.

Rotating Platforms:

The rotating platform takes an inverse approach to comb movement by rotating the entire litter box instead of one mechanical piece. These forms of boxes are typically round and are fixed on top of a rotating platform. The platform allows the litter to rotate and filtered through a slotted spatula-like material. The slotted material may be actuated to allow the filtered waste drop into either a trash can for manual removal, or a plumbing system. Products by Litter-Robot®opt for a trash can design whereas PetGenie®directly attaches to your home plumbing system for removal. Regardless of the waste's destination, the underlying mechanics are the same.

The market for rotating litter boxes is much less than that of comb litter boxes. A brief search resulted in prices on the order of $400-$500 for these products whereas the comb-based boxes are on the order of $80-$200. The drastic increase in price is likely due to the increased mechanical complexity associated with of rotating an entire litter box and ensuring the litter does not clog critical mechanical components.

Provided by PetGenie® are figures of their PetGenie A.I® product. It is beyond the scale of this document to discuss how the rotation of the platform is implemented. However, the filtration mechanism is present in Figure 2. The letters spelling out solid represent excrement which has landed on the scoop. While the platform is rotating the scoop moves vertically passing through the litter and capturing excrement. Once the scoop reaches its maximum height, the angle is such that the excrement slides into a hopper for disposal.

PetGenie® opted to direct the waste into the home plumbing system through the hose in the following figure. Whereas other produces oft for a trash can which the user may replace when it reaches capacity.

Figure 6: CatGenie A.I.®sifting mechanism.

Figure 7: CatGenie A.I.®complete installation.

Regardless of the mechanism, most automated litter boxes function on the same principle of moving the waste to another location to be dealt with by an external mechanism. With the mechanics not being the emphasis of the project, and cost being a pivotal constraint. These will play an emphasis on what automated litter box will be chosen for implementation.

3.2 Relevant Technologies

The software system will consist of three main parts. First is the device server, which will send "commands" and receive "updates" from each station. The device server sends updates

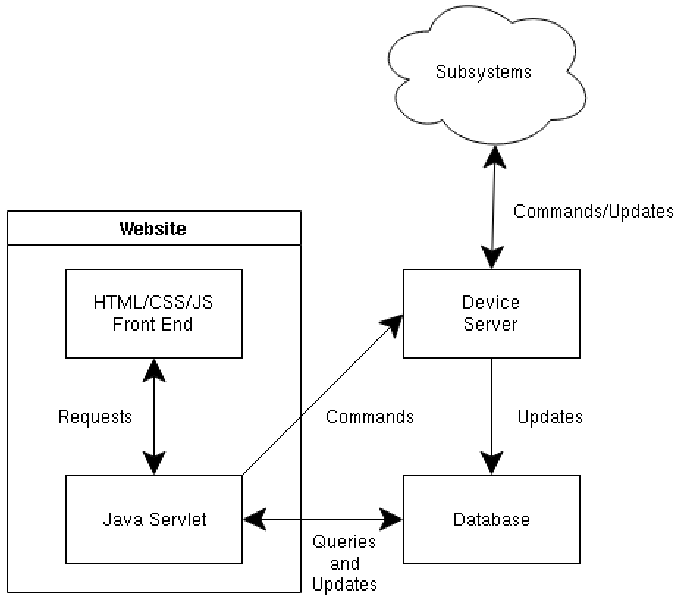

Figure 8: Block diagram for the software system

from the stations to the database. Second, the web server will provide a user interface that will show the current statistics for the cat, and will allow the user to request updated information, change the amount of food dispensed by the food dispenser, and change the schedule of the food dispenser. Finally, the database will be responsible for storing all the information gathered from the subsystems and the user's configuration info.

To create the web server, multiple options are available. Two major options for web servers are Apache and nginx. nginx is more well suited to large scale web use, since it has many functions to act as a proxy server. For our purposes, Apache will be more suitable since it is very well documented and is very good at serving dynamic content, which our project will require. Apache also provides Tomcat, a piece of software we could use to generate the dynamic content using Java. This could be helpful to us since we are familiar with Java already. If this is the software we decide to use, we would write Jakarta servlets to handle requests from the website frontend, and service the user.

The database can also use a variety of technologies. Two currently under consideration are MariaDB and MongoDB. MariaDB is a database system designed to be as similar as possible to MySQL, so it is very compatible and therefore well documented. MongoDB is a "NoSQL" database system that uses JSON-like documents to store data. It can be more flexible than SQL databases. Both MariaDB and MongoDB can integrate with a variety of languages like Java, C++, and Python.

For the operating system used in the base station, we will probably use a Linux distribution. Linux is the choice for web server applications, running the more than 3 out of every 4 web servers on the public internet. Linux is also compatible with personal computers, which would make development easier than using a less portable system. One of the most popular Linux distributions for servers is Ubuntu Server. Ubuntu Server has a number of features which make it an attractive choice. Ubuntu Server is extremely popular, so most software products have pre-built packages available for it or instructions on how to build for it. It has a powerful package management system in APT and Snap packages. It is also officially supported by Canonical, the large organization behind Ubuntu, and is designed for stability.

The user will interact with the system through a website. They will access this website on their personal device after connecting that device. Since they will be on a private wireless network, the DNS services provided by the base station will allow them to easily connect to the website with a simple URL such as "catcare.com" or some other memorable, simple phrase that can be printed on the physical station.

The device server can be written in any language that supports a TCP/IP stack and can interface with the database. Some possible languages would be Java, C++, Python, or Rust. The device server would have to be highly reliable, but it is also not complex.

The device server is responsible for receiving information from each station and then sending it in the proper format to the database. It also sends commands to each station, which can be requests for updated information, or commands for the food station to set its food amount and schedule. Additionally, the device server can communicate with the website, so that the user can initiate an update of all information, or set a new food amount and schedule.

3.3 Component Selection

3.3.1 Force Transducers:

One of the most important sensors used throughout the Purrfect Cat Care system is the force transducer. This seemingly simply piece of hardware measures an applied physical quantity at a point of contact and converts this to meaningful data for a user to analyze. Force transducers can measure mechanical force in a variety of ways, namely: compression, tension, torsion, shear, and bending. In this section, a discussion on how to measure the cat's food and water consumption using force transducers will be explored. A key argument to consider entails which mechanical force measurements will act as a medium to grant insight into project objectives and which type of force transducer may be reliably used to measure incremental changes in mass with minimal error.

The measurement of the cat's food and water intake is a key objective into detecting precursors to health abnormalities. In order to realize these objectives, the device must meet a few key requirements: must measure on a scale of hundreds of grams, must accurately measure small changes to the load, must maintain minimal drift in load accuracy due to prolonged sensor deformation, and must operate on the order that coincides with the power requirements of the specific module and the input into the Analog/Digital Converter.

There are two popular types of force transducers, strain gauges and load cells. The strain gauge is simply a force transducer that is the basis of the load sensor market. The implementation of this technology consists of a conducting foil distributed in a sinusoidal pattern upon a nonconducting substrate. Based on fundamental physics of resistor technology, the impedance of a signal transferred through a resistor segment may be modeled by R = $\frac{\rho L}{A}$ (Ω). The strain gauge arrangement enables a variation in voltage that changes with the change in area. This means, for a given circumstance in which the strain gauge is secured on the surface of a flexible beam positioned on a ledge and an applied force to the extended end is present, the surface area of the strain gauge increases resulting in changed resistance and by extension, changed voltage across the element. This useful technique enables other applications of strain gauges, which reveals a second type of force transducer, load cells.

Load cells require an array of force transducers in order to measure how the larger component deforms. This is useful in order to determine the magnitude of force applied at a specific point. When it comes to consumer and commercial use, measurements based on the mass of a product are often used based on the principle, F = m·a. A load cell in this sense, allows for the Purrfect Cat care system to determine the remaining mass of food or water after every interaction with the cat.

The Purrfect Cat Care system requires this change in food and water intake over a long period of time. In order to meet this objective, the project design required an objective comparison of the available technologies that operate on the order of grams, millivolts, low error per unit of time, etc. Given the functionality of a load cell, there are a number of sub-types to consider when attempting to meet these objectives. The most popular technologies come in the form of hydraulic, pneumatic, capacitive, strain gauge, and piezoelectric. A brief introduction of each sub-type will be explored followed by an explanation for the given selection based on each capabilities.

The use of hydraulic and pneumatic variants often span into mechanical engineering, mobile machinery, lifting gear, geo-technology, process engineering, power generation, and agricultural engineering. They generally apply the same physics, which incorporates fluid dynamics in order to develop readouts that measure force, however most sensors use mechanical means to report data through the use of spring gauges , diaphragm measurements , and valves. Although there exists technology for measurements within the realm of project goals, the tech is still relatively specialized and common sensors measure within the scope of a few kilo-newtons of force.

Load cells that take on the characteristics of a capacitor with variable plate distances allow for an alternative avenue for load measurements. Current implementations might incorporate one plate of the capacitor fixed, while another plate is connected to a load baring tray or beam. When a load is applied, this would decrease the distance between both plates resulting in higher capacitance. This change in capacitance would ultimately vary the voltage output. Based on a number of distributors, like Loadstar Sensors, Automated Process Equipment Corp., SMD Sensors, and Newark Electronics, capacitive load cells are extremely over-priced for project budget, they aren't accurate over long durations, and operate in the range of 10lbs or more.

Piezoelectric devices operate much in the same fashion as a traditional strain gauge load cells. The difference is the implementation of a crystal oscillator that outputs a voltage under compression. An important point to consider in the implementation of these sensors is how it measures applied force. When a static force is applied, electric charge is generated across the crystal. However, due to the fact that the materials used are not perfect insulators, charge tends to leak at the terminals and recombine. This indicates that this type of sensor is sufficient for dynamic measurements performed over a brief periods since the measurements tend to introduce error due to recombination.

Strain Gauges are a sub-type of load cells that operate as an array of strain gauge sensors arranged in a Wheatstone bridge configuration, where the voltage output is sensed across the bridge nodes. This allows two of the sensors to be in either tension or compression. When in either of these two states, the resistance changes, and thus changes the voltage across them. If the sensors are configured on the surface of a small beam, used to support the sensor and prevent permanent deformation, the end of the beam may measure the applied force at the center of the beam where the tension or compression occurs. The main advantage of this category of sensors, is the streamline implementation of the sensors, the support of the metal beam, and ability to maintain prolonged measurements of static force. This category of sensors are popular amongst high precision kitchen scales and chemistry equipment.

When it comes to a side by side comparison of the previously mentioned load cell sub-types, only one of them meet the criteria for accommodating the prescribed objectives of the project. Strain gauge load cells are adequate for the reasons already mentioned and all that remains is how the sensor will operate in order to track changes in mass. Additional considerations include how the specifications of potential load cells are broken down in order to render the expected output. Typical specifications may include but not limited to, Load cell capacity, Full Scale output, Rated output, and Combined Error. These are a few of the specifications that determine the final decision on which specific strain gauge load cell to select. When it comes to the actual strip that makes up the strain gauge, it was mentioned that the strain gauge is essentially a variable resistor that changes as the surface area changes upon a nonconducting substrate. This is a foil that contains the metal tracing of a wire that alternates in direction in a sinusoid patter from one soldered tab to another. These tabs are what connect to the next adjacent component.

When a network of them are connected in a Wheatstone configuration and four sensors are attached to a hollow beam, a sensor could be applied to the exposed surface above and below the beam in sets of two in order to measure the compression and tension applied to the sensor. This means that there are always two sensors measuring compression and tension. Additionally, the orientation of the sensor determines resistance spread of the max and min values. If the sensor is orientated orthogonal to the axis of incident, there will be a greater variance in resistance as opposed to the sensor being parallel.

Through the use of an excitation voltage, the circuit is provided with the necessary bias to the bridge and the output is measured across the bridge nodes. An adequate range for the systems excitation voltage, must fall in the range of approximately 10(VDC). Since the circuit is in a Wheatstone configuration, two branches of the circuit creates a voltage divider that is the output. This in turn adequately shows the change in voltage potential across one end of the output with respect to the other. This variation implies, that under a certain deformation value, an imbalance of the voltage potential will be present. When no force is applied, there is no deformation and by extension no variance in voltage potential and so the output will be zero.

When it comes to searching for the most suited load sensor for the correct application, there are a few terms that are identified within a typical load sensor data sheet. The first type is the capacity, which is the difference between the highest and lowest measurement the load cell can make. In terms of project objectives, the max dispensed cat food is about 500 (g). F_a is a constant that describes how dynamic a system is in terms of Full Scale (%FS) output indicates the percentage of the magnitude of the output voltage when the load equals capacity. This means, when the load cell is at capacity, the output voltage would be 100%. This is important because the %FS output depends on the magnitude of the excitation voltage, which is the input voltage coming from a power source. Data sheets provide information regarding the resolution of the measurements per unit of the input voltage. This is generally regarded as the Rated Output and are read in units of millivolts per input voltage (mV/V). Finally, the Combined Error may encompass a number of different considerations, like non-linearity, hysteresis, and creep error. This may be represented as individual fields, but for this project the measurements must be as precise as possible and must not change over long periods of time as a result of static loads.

One of the key considerations that is common to both systems of the food and water dispensers, is the life span of the sensor. It although it may be convenient to a shear-beam due to its high precision, this type of sensor form factor reveals that it has a relatively short life span. In terms of life span this could be considered as total time a load may be applied before failure. Additional considerations may include a button form factor, in which a flat button exists in order to measure a load. The inconvenience involved in this approach might include a scenario where the load is off centered which results in lower force at the point of incident. These considerations leads to the conclusion that the application of force should be consistently read regardless of position, for this a Single Point form factor may be the most reliable type for this system.

The implementation of force transducers within both, the water and food dispensers have been covered at length within the scope of this discussion. Important factors considered were types of force transducers, the most promising were piezoelectric and strain gauge load cells. After careful consideration, comparisons of both technologies revealed that strain gauge load cells offer consistent measurement readouts over a long duration, which is a main functionality of both modules. Additionally, the capacity of interest had to be on the scale of 500(g). The load sensor must operate just over this value since the 500 (g) is the amount dispensed at the beginning of the day. Given this, the sensor must be sensitive enough to resolve the minute change in remaining mass as the cat decides to eat throughout the day. The load cell, chosen ultimately falls to a single point strain gauge load cell, as it operates within the scale of 500(g), produce data with minimal error over time, and operates within the prescribed range for the rest of the independent modules.

3.3.2 Water Pump:

Water pumps are classified into two categories: positive displacement and dynamic pumps. A Positive Displacement Pump operates by trapping a fixed quantity of fluid and pushing, or displacing, the trapped volume into a discharge pipe or system.Dynamic pumps impart velocity and pressure to fluids as they pass through or past the pump impeller, and then transform some of the velocity into additional pressure. Kinetic pumps are another name for it. This pump works by increasing the velocity of the liquid and converting it to pressure in a diffusing flow channel. There are several different types of pumps within the two categories as fallows.[6]

Positive Displacement Pump:

Rotor Types Positive Displacement: requires very close clearances between the rotating pump and the outer edge, making it rotate at a slow, steady speed. If rotary pumps are operated at high speeds, the fluids can cause erosion. This eventually causes enlarges clearances that liquid can pass through, which reduces efficiency.

- **Gear pumps:** A gear Pumps are simple type of rotary pump where the liquid is pushed between two gears. (Hydraulic fluid power)
- **Screw pumps:** Screw pumps are the shape of the internals of this pump is usually two screws turning against each other to pump the liquid. (Irrigation and in agricultural machinery for transporting grain and other solids)
- **Rotary vane pumps:** these pumps are like scroll compressors; these have a cylindrical rotor encases in a similarly shaped housing. As the rotor orbits, the vanes trap fluid between the rotor and the casing, drawing the fluid through the pump. (high-pressure hydraulic pumps and in automobiles, including supercharging, power-steering, air conditioning, and automatic-transmission pumps)

Reciprocating Types Positive Displacement: move the fluid using one or more oscillating piston, plungers, or membranes(diaphragms), while valves restrict fluid motion to the desired direction. For suction to take place, the pump must first pull the plunger in an outward motion to decrease pressure in the chamber. Once the plunger pushes back, it will increase the pressure chamber and the inward pressure of the plunger will then open the discharge valve and release the fluid into the delivery pipe at a high velocity.

- **Plunger Pumps:** A reciprocating plunger pushes the fluid through one or two open valves, closed by suction on the way back. (This type of pump is often used to transfer municipal and industrial sewage)
- **Diaphragm pumps:** It uses two diaphragms in and out to fill the pump chamber with fluid and then push it out. When the diaphragms move away from the chamber, it lowers the pressure of the chamber and fluid rushes in. When they push back into the chamber, they increase the pressure and the fluid flows out. The fluids flow through one-way check valves, ensuring that fluid only flows in the proper direction through the chamber. (Diaphragm pumps are so versatile, they are used in virtually every industry that requires fluid transfer) https://pumpsolutions.com.au/characteristics-and-best-uses-of-diaphragm-pumps/

Linear Types Positive Displacement: the fluid displacement takes place linearly

- **Rope pumps:** A rope pump is a type of pump of wdhich the main or most visible component is a continuous piece of rope, in which the rope is integral in raising water from a well. Rope pumps are often used in developing areas, the most common design of which uses PVC pipe and a rope with flexible or rigid valves. Rope pumps are cheap to build and easy to maintain.

- **Chain Pump:** is a water pump in which several circular discs are positioned on an endless chain. One part of the chain dips into the water, and the chain runs through a tube, slightly bigger than the diameter of the discs.

Dynamic Pump:

Centrifugal Pump: is a rotating machine in which flow and pressure are generated dynamically. The energy changes occur by virtue of two main parts of the pump, the impeller and the volute or casing. The function of the casing is to collect the liquid discharged by the impeller and to convert some of the kinetic (velocity) energy into pressure energy.

For a centrifugal pump to work properly, you need to fill it up with water. Primary is required, because the pressure developed by the propeller of centrifugal pump, is proportional to the density of the fluid in the impeller. If the impeller is running in air, it will produce only a negligible pressure. This pressure will not suck water from its source through the suction pipe. [7]

- **Axial Flow Pumps:** are high flow, low pressure pumps which lift fluid in a direction parallel to the impeller shaft.
- **Mixed Flow Pumps:** are medium flow, medium pressure pumps which push fluid out away from the pump shaft at an angle greater than 90 degrees.
- **Radial Flow Pumps:** are high pressure, low flow pumps which accelerate fluid along the impeller blades perpendicular to the shaft.

Special Pumps:

- **Cantilever Pump:** are centrifugal pumps with long cantilever design used in sump pump applications.
- **Jet Pump:** are kinetic pumps with an ejector attached at the discharge outlet, utilizing the Venturi effect and motive fluid to generate pumping pressure.
- **Turbine Pump:** Turbine pumps are centrifugal pumps that use pressure in combination with a rotary mechanism with numerous small impellers and vaned to transfer energy to fluid.

Pumps specifications:

- **Pump design:** Type of pump
- **Voltage:** expected voltage for operation
- **Priming:** The preparation of something for operation.
- **Rated and Normal Flow Rate:** rated flow is the operating condition that the pump is designed for. The normal rate is often less than the rated flow and represents the conditions the pump is expected to operate at most of the times. [8]
- **Suction lift:** describes the distance from the pump center line down to the free level of the liquid source below the pump

- **Total Head or pressure:** The total dynamic head of a water system must be considered when determining the size of pumping equipment to be installed. It determines the various head losses that the pump must overcome. Total dynamic head = elevation head + friction head loss + pressure head. [10]
- **Pressure Switch:** a device that monitors pressure and provides an output when a set pressure is reached. The specific pressure that opens and closes the switch is called the set point. Many residential pressure switches are designed for a minimum of 30 PSI a maximum of 50 PSI. [9]
- **Ports:** Point of connection.
- **Housing:** the substance from which the most outer layer is constructed

4 Constraints

4.1 Realistic Design Contraints

Like any engineering project, the Purrfect Cat Care System is subject to certain design constraints due to some environmental factors and limiting factors placed upon the project. Below the economic, safety, social and time constraints are discussed.

4.2 Economic

The Purrfect Cat Care System did not obtain any sponsorship, and therefore will be fully funded by the group members. According to the estimated cost of parts from the initial research, the aim was to stay under $600.00 for design parts and testing.

Due to the budget limitations, when selecting parts there may be some trade-offs between cost and precision. For example, in the initial research, there were load sensors which provided the precision needed for the Purrfect Cat Care System's feeding and water stations, however, the price of some of the parts found alone were more than half of the total budget and therefore a different solution was needed. Considering the trade-offs of cost and precision, the use of a mid-range cost and precision part could be used and supplemented with software offsets during testing. In the same way, the water pump parts initially researched for the water system were not cost effective, however the selection of two mid-range parts could be used in tandem to increase the precision to a level appropriate for the system such as a water pump supplemented with a flow sensor could be used to obtain the precision levels needed for the system. Specifically, the comparing a high precision water pump with a cost of about $50 with a mid-range water pump with a cost of $12 combined with a flow sensor with a cost of $12 is about a 50% savings but can still produce a desired measurement.

In addition to the budget limitations, because the group members' focus is on the electrical components, any mechanical parts must be purchased for the project. In turn this limits the amount of the budget available for purchasing the specific design components such as the sensors, microcontrollers, and the other modules needed for the system. To lower the costs associated with some of the mechanical parts, the use of a previously owned automatic cat litter box is being used for the project. However, due to its high cost, if damaged, replacement would drive the cost up and further reduce the amount available to use toward design parts.

Finally, the goal is to make the system low cost enough to make marketable. Therefore, parts need to be selected in a way that limits the total cost of the system.

4.3 Time

As common with many projects, one of the major constraints facing the Purrfect Cat Care System is the time available to complete the design and implementation of the system. As a required capstone project for graduation consideration, this project needs to be completed before the end of the second semester of the senior design course. This imposes a hard deadline on the team to complete all of the milestones listed in this document. Within this time period the team is required to research, design, purchase parts, document the entire process and then build a prototype.

Due to the team being a larger size of five people rather than the normal four, the amount of pages required to be submitted is also greater. This requires the project to be of a larger scope and complexity to fit the five person team. However, if the project is too complex, the team risks not finishing the project in time. Due to this time constraint, the design was actually limited to exclude the original plan to have an activity station to track playing behaviors of the cat as well as provide play time automatically.

Furthermore, the procurement of parts may impose time constraints if purchased from outside of the US. To avoid this, the team is aiming to purchase the parts as soon as possible and avoid any parts that cannot be shipped within the allotted timeframe. There should be enough time to complete the prototype and begin testing on the completed system well before the end of the second semester.

Personal time constraints can also affect the total time constraints on the project. Specifically, some team members who live further away may have less time to put in work toward the project due to more time spent commuting if the team meets regularly in person. Some team members are also working while completing the project which reduces their window of availability to meet with the rest of the group. Therefore scheduling times when the whole group can meet together will be difficult. On top of these time constraints, the group members also have other courses they must dedicate some of their time to further adding to the constraints against the project.

4.4 Safety

Because the system will be providing services to a live animal, there are some safety constraints needing attention. It is important that the parts that will be in contact with the cat are food grade and do not use any materials that could be poisonous or hazardous to the cat. For example the food and water bowls should be made of a material that will be resistant to bacteria and easy to clean such as ceramic or stainless steel. It is a possibility the bowls may go longer without being cleaned due to the automatic operational nature of the system. The containers for the food and water storage should also be absent of any hazardous and poisonous materials as they will hold the cat's food and water supply for seven days minimum as a specification.

Due to the electrical components and communication modules used in these systems, it is important that they follow IEEE and FCC standards. Especially those being used around the water station should be properly shielded, fully encased and not easily accessible to the cat to reduce risk of electric shock. Since cats are exploratory in nature, all moving parts should not be easy to access by a curious cat. These parts should have safety features in place that react to exogenous events. For example, the cat should not be able to get its paw inside the opening where the food dispenses as there will be moving parts. Finally, the automatic litter box should function as previously purchased. Because additional sensors, such as the humidity sensor and wireless communication module are going to be added to this system, they should maintain the safety level of the original product.

4.5 Sustainability, Sociopolitical, Manufacturability

The goal of the Purrfect Cat Care System is to provide cat owners a convenient and completely automatic way to track their cat's health. To do this, the system will need to interact with the cat directly. The system will automatically dispense food and water to the cat, as well as track certain statistical data from the cat's eating, drinking, and litter box habits. Some social constraints to consider for this project are related to that interaction with the system and the cat. By specification, the system is designed to handle interaction with only one cat. This constraint limits the usage of this system by those who have multiple cats. Also, the system is designed to learn the cat's behavior based on usage rather than preprogramming statistics about specific cats with certain age or health backgrounds.

Another social constraint to consider is the system should not cause the cat any harm during interaction. This includes the ability to accurately record any monitored behaviors so that the user can accurately make health determinations about their cat based on the data provided from the system. The user interface should be easy to use such that the user does not improperly use the system. Improper use of the system such as forgetting an input to the system via the application can affect its functionality and performance. This could cause it to not operate as expected and can have detrimental consequences. For example, forgetting to refill the water reservoir when alerted that it is empty could result in the cat getting dehydrated. In the same way, not filling the food dispenser could affect the cat getting fed while the user is away.

One major constraint to consider is the user friendliness of the application. The application must provide statistics of the cat's eating and drinking habits as well as alert the user if anything deviates greatly from the norm. The system should also alert the user when the containers for the water and feeding station are empty. This poses a constraint on the design of how often the system should alert the user without being overly intrusive.

5 System Hardware Design

5.1 System Block Diagram

At the top-most system level, four subsystems will operate independently. Each subsystem will communicate with the base station through a wireless communication protocol such as WiFi or Bluetooth. Included in the figure below is a fairly straightforward diagram, however, each system will be discussed in further detail. The legend in the figure below will be used across each subsystem. There will be several common blocks throughout each subsystem, while redundant, they have been included to provide an accurate subsystem diagram.

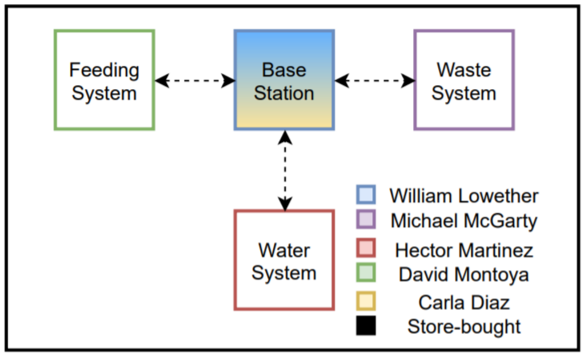

Figure 9: System overview and color key

5.2 Feeding Station

There is some significant mechanical contribution within this project. A motor will be necessary to drive a certain weight of food into the bowl. It is planned to purchase the motor, attachment hardware, any proprietary motor drivers, the food dispenser, and a bowl. The emphasis of this system is in controlling and accurately measuring the amount of food delivered to the cat, and how much the cat has ingested over time; not the mechanics.

A force, or pressure, transducer will be necessary to determine the weight of food currently in the bowl. Preliminary research has led us to strain gauge load cells as a reliable choice, hence its inclusion into the block diagram. However, research is still being done into alternative devices. WiFi is currently the working decision of wireless protocol, but some wireless module will be needed to transmit recorded data back to the base station. An on-board system controller will facilitate the data collection, data transmission, and driving of all mechanical components.

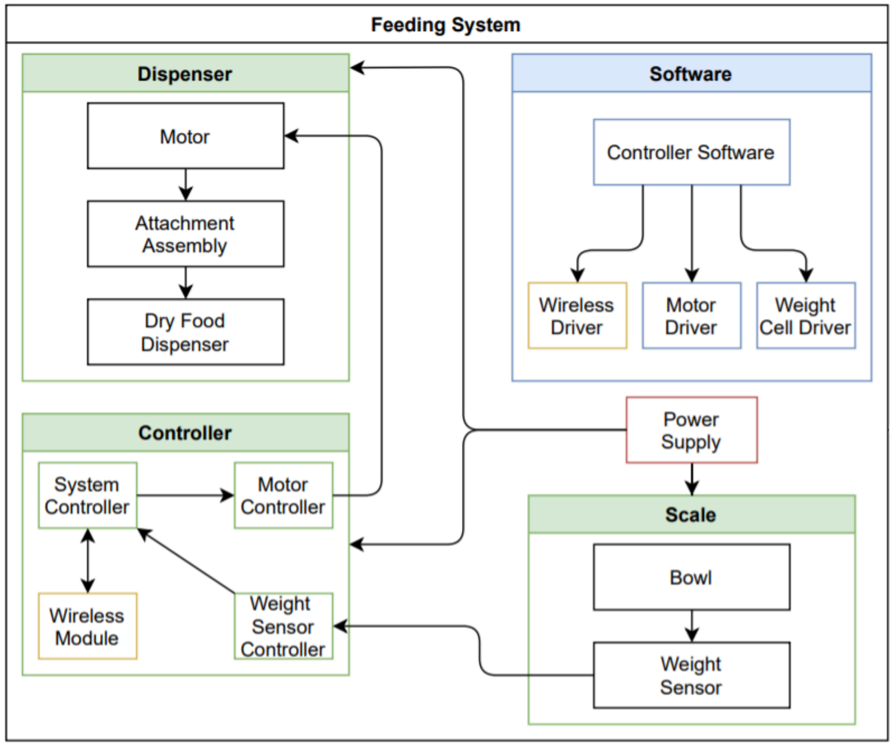

Figure 10: Feeding station block diagram

5.3 Water Station

The water system functions very similar to the feeding station. The system currently relies on two measurements to determine water intake, weight and volume. A water flow sensor, and load cell will be used in tandem to measure both the weight and flow rate while dispensing the water. This redundancy is needed to ensure the proper quantity of water is dispensed. Using purely the load cell would introduce a delay, resulting in more water being dispensed. Integrating the flow sensor with pump will minimize this delay, increasing the accuracy of the system to dispense water over a specific duration.

The load cell may seem redundant, however, it will be necessary to track long-term water changes. The flow sensor provides short-term accuracy on how much water was dispensed, but is unable to track how much the cat has ingested. These two data points will allow continuous replenishment of the water in the bowl to ensure that a cat is never without water. A surprising benefit of this design is encouraging the cat to drink more water. Studies have shown that cats prefer to see the bottom of their water dish, and will be sometimes hesitant toward drinking from deep bowls.

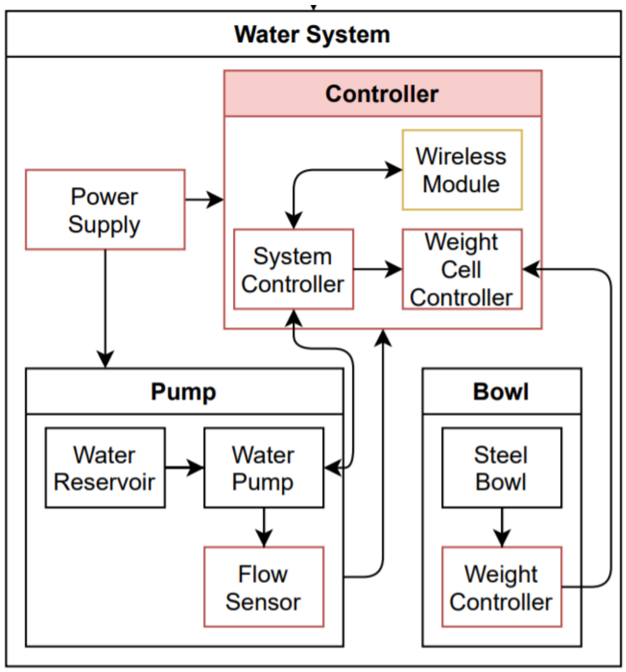

Figure 11: Water station block diagram

As mentioned in the introduction, Purrrfect Cat Care will provide cat owners a convenient and completely automatic way to track their cat's water consumption throughout day. Water intake is critical in both health and disease in cats. Unfortunately, felines are known to be fussy when it comes to water consumption, making encouraging water consumption difficult. Cats may not drink enough water for several reasons, including evolution, physiology, anatomy, instinctive behavior, and preferences.

Dehydration is frequent consequence of chronic kidney disease (CKD), and it can culminate in inappetence, drowsiness, weakness, constipation, and an increased vulnerability to uremic crisis. It may also trigger pathophysiology reactions that are hazardous to the kidneys. [2.3] While dehydration is the most frequent water balance problem in CKD patients, overhydration can also be a problem. As the kidneys deteriorate, their capacity to eliminate water from the body is impaired, making overhydration a danger that can have harmful repercussions. Excessive hydration can cause clinically visible symptoms such as third-spacing and can be harmful to the renal parenchyma. [2.3]

A recent study found that cats fed a wet food containing 70% moisture had lower urine specific gravity, less weight gain, and greater physical activity than cats fed a dry diet containing 10 moisture. Furthermore, research examining water balance in cats found that cats fed canned food had considerably higher water consumption per gram of dry matter than cats fed dry food.[3] Many cat owners would rather assume their cat is drinking enough than to know how much they drink. While 79% of cat owners feel their cats drink enough water each day, just 37% realize how much water their cats need to consume daily. [2.1]

With a better understanding of how important it is to keep track of the amount of water cats should drink on a regular basis, the team was able to come with a solution. Our team decided to implement an autonomous system that can provide fresh water up to seven days without human intervention. The system would have a reservoir with a capacity of 2L. Furthermore, the reservoir would have a senser that would detect when water is running low. When the sensor is activated, it would send a signal to the controller that would then trigger a flashing red-light that would in indicate that the reservoir is 10% full. Moreover, the reservoir would have a water pump connected to one of the outside walls that would be responsible for delivering accurate amount of water as needed. The pumped water would pass through a water flow sensor that would serve as a check point to determine the consistency of flow rate of the water pump. After, the water will flow into stainless still bowl where it would be sitting on top of a load cell that would be in charge to measure the amount of water is dispense and consume throughout the day.

The water station would include a controller that would be interconnected with the water pump, flow sensor, liquid level, and the load cell.

5.4 Waste Station

While arguably another mechanics-heavy system, the waste station may arguably be the simplest component of the project. A group member currently owns an automatic pet feeder which will be used as a base. Implementing the mechanism from scratch would place this project beyond the scope of a senior design project. Hence, we have opted to use the prebuilt liter station and append data collection capabilities to it. The designed system will not interface directly to the litter box. While a simpler implementation, it is very likely that the driver PCB will be broken in the process. With most automatic feeders on the order of $100-200$, having to purchase another litter box due to accidental shorting, or other electrical mishaps is not an option.

The additions to the waste system will be some sensor to detect if the cat has entered the litter box. Upon detection, a counter is updated within the system controller and a humidity sensor is activated. The humidity sensor will detect an increase in humidity if the cat is urinating. Therefore, the sensor allows the system to determine if the cat is urinating or defecating. The system will not need to drive the motor due to the litter box's built-in detection. As for the firmware, implementation will be simple. An internal counter keeping track of the number of uses, a way of encoding usage type will be needed, and the information will be sent to the wireless module.

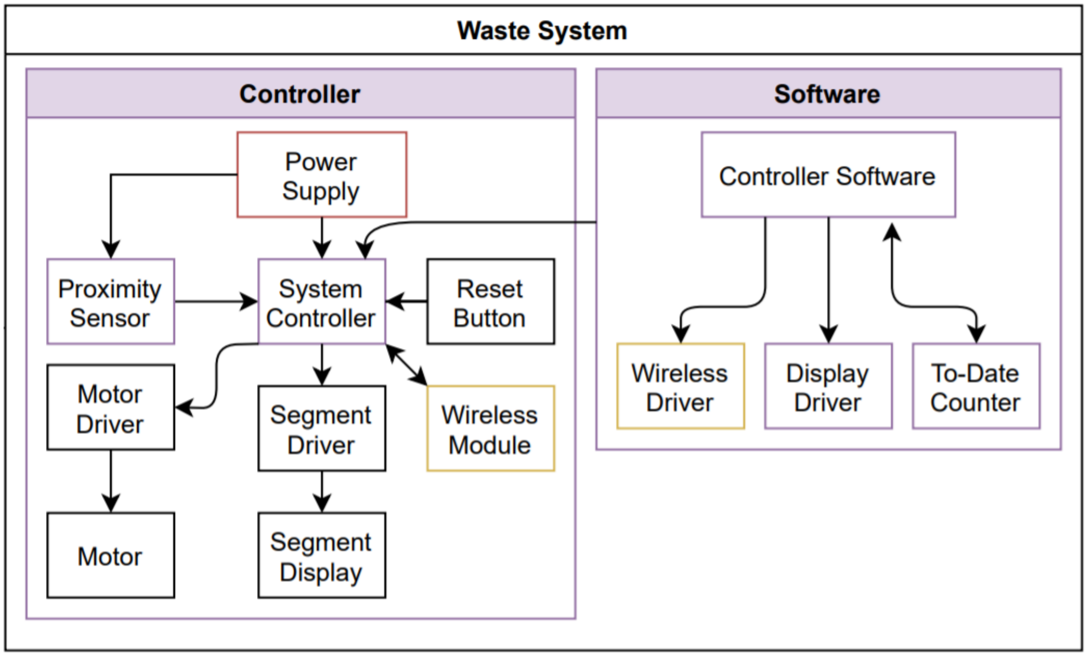

Figure 12: Waste station block diagram

5.5 Base Station

The base station will be the heart of the entire system. It will host a database to store recent data from the several subsystems, issue commands to each system, and host a web server for the user to access their pet's health information. On the web site will be recent data of the pet and inputs to change the feeding schedules and amounts.

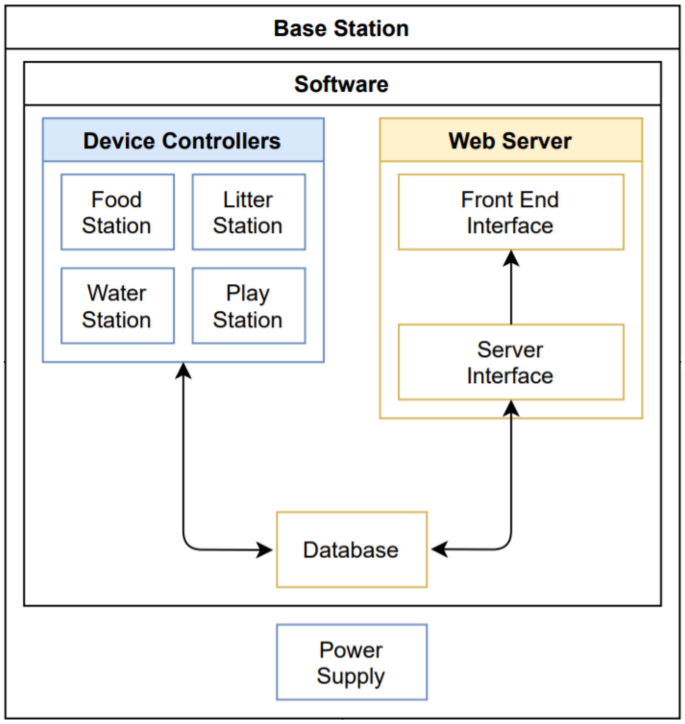

Figure 13: Base station block diagram

5.6 Power System

Within each of the subsystem diagrams, the power supply has been left as an abstract block. Each system will utilize home wall outlets to provide power. Depending on the power rails necessary for various ICs and mechanical components, this section of the project will be designed last. For a rough idea, a DC wall jack and buck regulators will provide efficient DC/DC conversion for the various power rails.

6 System Software Design

To develop these systems, we will choose software that can run on ordinary PCs, so that we can develop the software in a familiar environment and quickly iterate and fix bugs. To test the protocol, we will design software simulations of each subsystem, that send realistic data to the base station software and respond to commands appropriately. We can also run the web server and database on an ordinary PC, so the whole system can be developed in a prototype environment before moving to real hardware.

6.1 Base Station Server Architecture

The user interface will consist of two main pages. The first will be a dashboard page which shows a graph for food consumption, water consumption, and litter box usage. The graphs will be able to show history for 7 days, 1 month, and 6 months. Each section will be accompanied by the average and standard deviation, and if there are any alerts they will be highlighted to

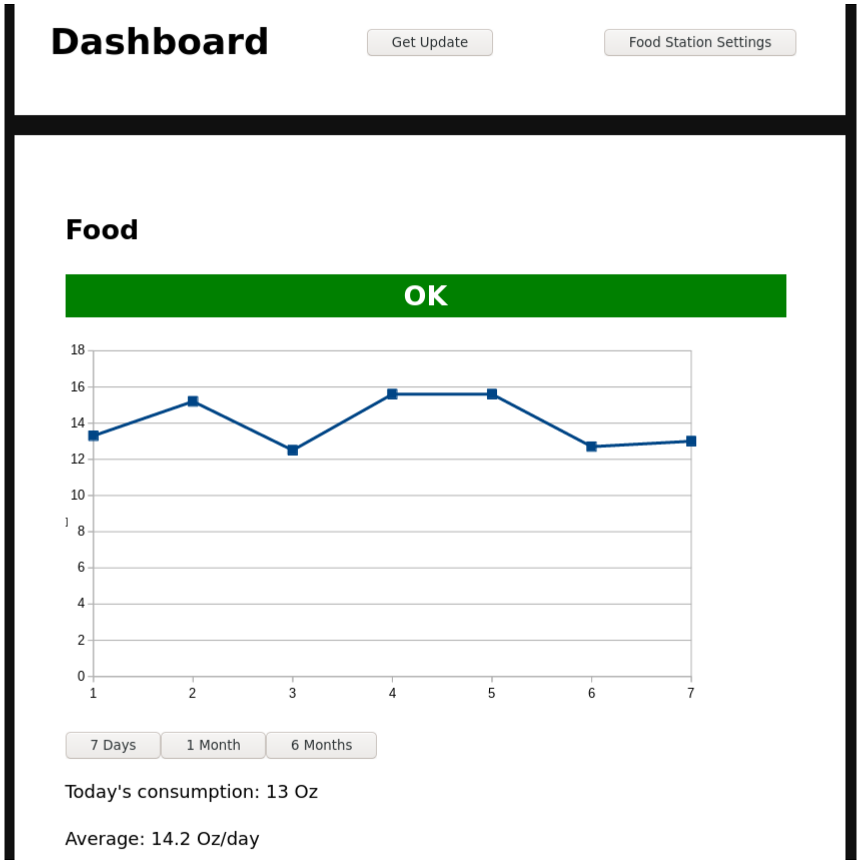

Figure 14: UI mockup for the dashboard

show them to the user. Each section will also show today's amounts, and the user will be able to press a button to request an update.

The second page will be for controlling the amount and schedule of the food dispenser. The user will be able to set at most 5 dispensations per day, and must have at least 1 set. They will be able to set how much food to be dispensed, and at what time of day it is dispensed. Once they complete their changes, they will be able to press a button to submit the changes to the food station.

6.2 Communication Protocols

To facilitate communication between each subsystem and the base station, the base station will provide a private Wi-Fi network that each device will connect to. The user will also connect to this network to access the front end. This means we will need to configure the base station as a router, and it must be capable of handling DNS requests. This can be done in a Linux operating system. Each substation will have a hard-coded IP address that it will have when it connects to the Wi-Fi network, and the base station can run a DNS server that allows names to be resolved to those IP addresses.

The device communication protocol stack looks like this:

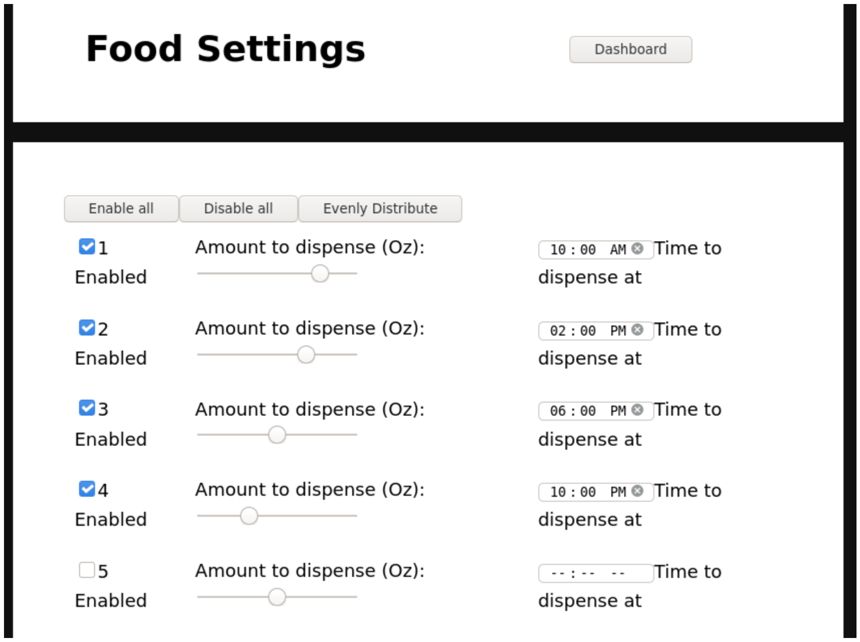

Figure 15: UI mockup for the food settings

```
+------------------+
| Commands/updates |
+------------------+
| TCP              |
+------------------+
| IP               |
+------------------+
| WLAN             |
+------------------+
```

We will use TCP/IP for reliable communication over a short network distance via the wireless connection. This way, we do not need to worry about error correction or reliability, since TCP is a very robust protocol. The command/update protocol is a simple protocol that can either deliver commands or updates over a single connection session. It is based on a client/server architecture, but the base station and devices will alternate between acting as the server and the client based on whether an update or a command is being transmitted. This is much simpler than designing a P2P architecture, which will not be necessary since our system is not going to scale to more than a handful of client devices [8]. The protocol will consist of one connection per command and update.

The device server can accept multiple updates, and issue commands to devices. Updates are sent from devices and contain processed information from the sensors

Updates:

- New food weight

- New temporary food weight
- New water weight
- New temporary water weight
- New litter event

Commands:

- Request temporary update
- Set food amount
- Set food schedule

The food station will regularly report the current count of how much food the cat has eaten. Upon a “Request temporary update” command, it will make a measurement and respond with a temporary weight, which will not be stored. The water system works similarly, regularly reporting how much water the cat has drunk, and it can respond to a temporary update request. The litter system is different in that it only updates on litter box events, so it does not need to continuously update the base station and will not respond to temporary update requests.

The device server can also send commands to the sub systems. The “Request temporary update” command will prompt the subsystem to immediately read its sensors and send an updated count to the base station. This is used for when the user wants to see a “real-time” update of their cat’s behavior. The “Set food amount” command tells the food station how much food to dispense during the day in total, and the “Set food schedule” command tells the food station how often and at what times to dispense food. The device server will also be able to accept commands from the website, in which case it will forward those commands to the devices

A typical series of communications between the base station and a device might be when the device server forwards a “Request temporary update command to a subsystem, and then the subsystem responds with a temporary update. The device server then sends this to the database once the update is received.

6.3 Feeding Station Design

The firmware design of the feeding station is split into two processing sequences. Regardless of the sequence, the feeding station will only activate when a request from the base station is received. This decision to make the feeding station an agent of the base station was made to simplify timing mechanisms.mIf both the base station and the feeding station were to have independent timings then there is a possibility for the two devices to desynchronize. A desynchronization could be fixed by initiating a request of the time from the base station, however, this approach is redundant since the base station will override the local time of the feeding station regardless.

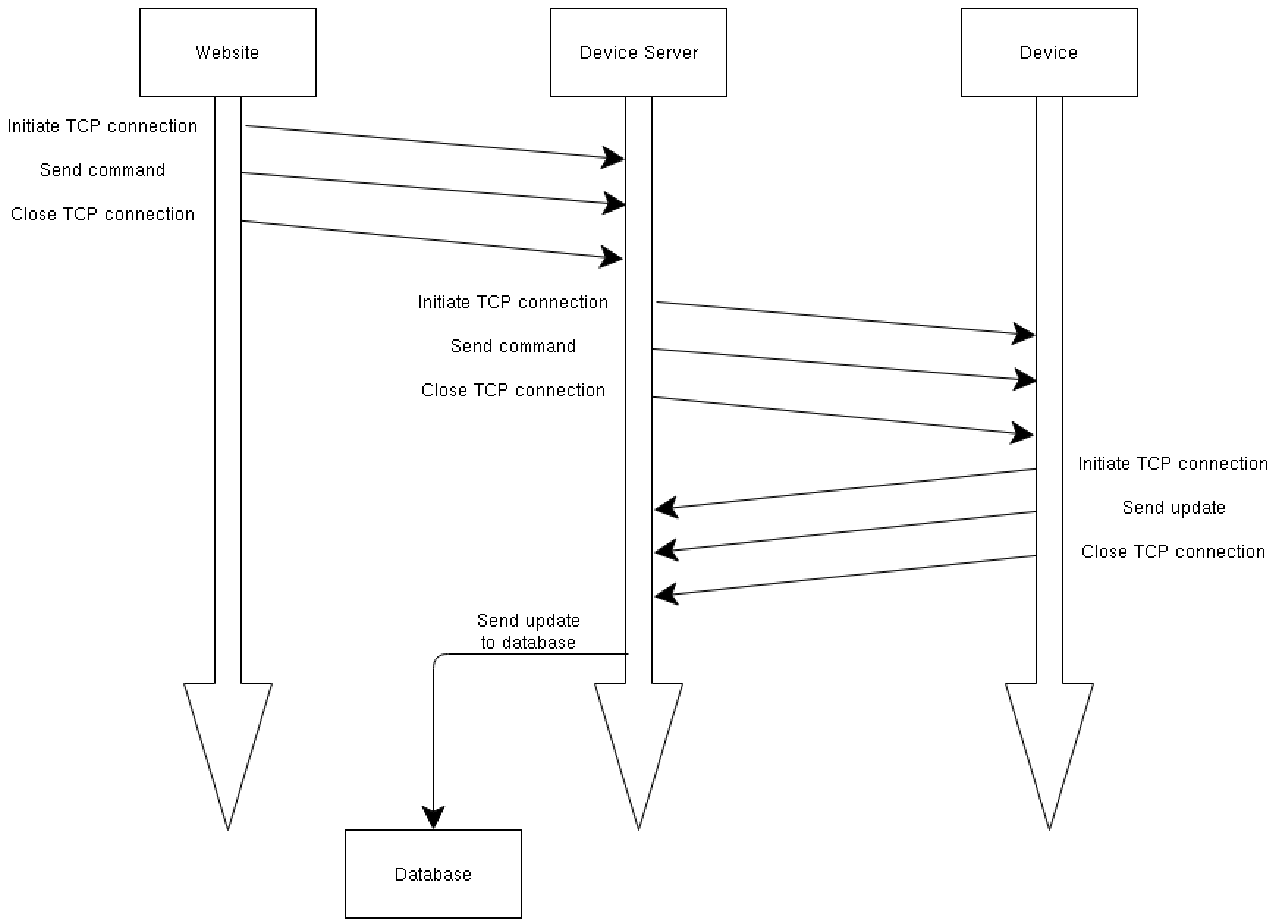

Figure 16: Example communication between the base station and a subsystem

Once a request is received, it is checked to be a dispensing command. The right process sequence in the figure below will send the current weight of food and the total amount of food ingested to the wireless module. A check is made if the device is currently dispensing. This verification is likely unnecessary since the base station should not send a dispense and read weight command to the device. If the device is dispensing, the device will loop and wait for the dispensing to finish. Once the station is finished dispensing, the weight is measured from the sensor.

Whenever the weight is measured a check of bounds occurs on the weight measurement. Bounds refers to the expect range of weights that should be in the bowl. For example, one group member has a cat which drops their toys into the food bowl. If the weight in the bowl drastically increases over sampling periods, it is likely that something has been dropped into the bowl. If so, the measurement is faulty and an alert will be sent to the user. If an alert is not thrown, the measured data and to-date value is sent to the wireless module.

The alternate process sequence describes the food dispensing process. The dispensing flag is triggered to prevent a measurement while dispensing. Afterwards, an iterative loop of dispensing predefined servings begins. The weight is measured, the amount to dispense is calculated, and an overflow is checked. Assuming no overflow, the motor will dispense one interval of food. See Section 6.2 for a definition of one food interval and dispensing limitations. This process of dispensing, measuring, and repeating will occur until the total serving has been dispensed. Afterwards, the motor is deactivated, the dispensing flag is reset, and the success flag has been sent to the wireless controller.

The overflow mechanism was mentioned in the paragraphs above. For the given bowl chosen, it should be able to hold 2-3 ounces of dry food. The groups experience with automatic feeders in the past has shown that many of them do not prevent overflows. Hence, given the current weight of food in the bowl, either the volume may be approximated or the raw weight for a full bowl may be found. This feature is aimed at the user's quality of life. However, it is likely not needed since it is incredibly unlikely the cat will not eat for several servings. In the rare occurance something has happened, it as well as the other subsystems will alert the user.

6.4 Water Station Design

The water station firmware is extremely similar to the feeding station. The primary difference between subsystems is the dispensing of water as opposed to dry food. The weight sensor is a core component of the design but not as influential in the water pump. A water flow sensor is used to assist the weight sensor in determining the real-time flow entering the bowl.

The base station volume request behaves identically to the feeding station. The water station will refill more often than the food bowl since overhydration is not often with cats. The request type is determined, verified that the station is not currently dispensing, and the weight is measured. With the measured weight a bound check is determined. Yes, the same group member's cat tends to throw their toys into the water bowl as well. If a drastic increase in volume occurs an alert is thrown, if not, the volume is calculated and sent to the wireless module.

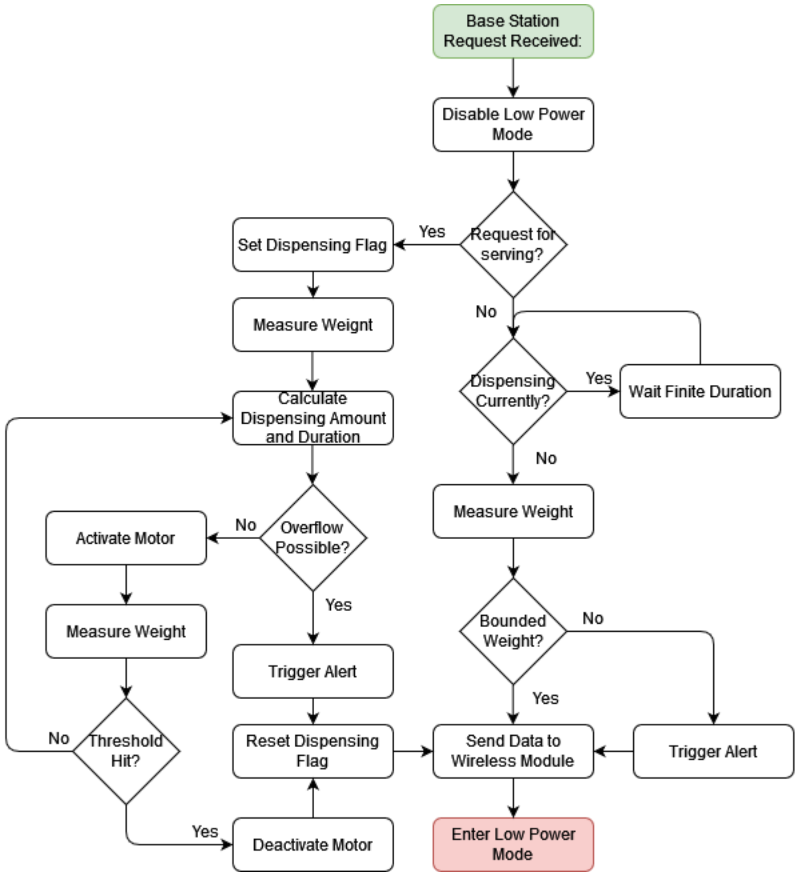

Figure 17: High-level feeding station firmware block diagram.

The first difference between modules is the conversion of weight to volume. The density of pure water is approximately 1 gram per milliliter. According to the United States Geological Survey (USGS) the density of tap water is dependent on temperature. From 40 deg F to 90 deg F the density varies by half a percent. For our purposes, a density of 1 g/ml will be assumed. Therefore, the conversion from volume to weight is automatically done. The weight sensor will output the weight of the bowl in grams which indirectly measures the volume in the bowl.

For this implementation a threshold volume is preset. Ideally, the threshold should be a user-input so a user can switch to a different bowl. For the sake of simplicity this decision was made to simply the design of the interface between the weight sensor and bowl. While the fixed bowl may seem like a disadvantage many products have a built-in bowl. It is also very unlikely for a cat to fully empty the bowl which negates the need for a large volume bowl.

With a predefined maximum volume, the amount of water to dispense is determined from the difference in maximum volume with the current volume in the bowl. If an overflow is imminent, the pump is turned off and an error is thrown to the base station. Otherwise the pump is turned on for a fixed duration and water begins to flow. The flowing water produces a signal in the flow sensor which may be analyzed to produce the current flow rate. Paired with a relatively constant flow pump, the volume of water entering the bowl may be verified almost real time.

Once the threshold is hit the pump stops, data is sent to the wireless module, and the device enters low power mode.

There is a loop in the dispensing of the water for the time being. Until we receive the pump and flow sensor and respectively characterize their behavior this diagram is tentative. If the pump is relatively accurate, the flow sensor is not necessary. Inversely if the flow sensor is accurate and the system controller is fast enough to stop at the threshold volume then an iterative approach is not necessary. Lastly, it is implicit that an overflow error will deactivate the pump. It is unlikely that such an event should occur in the first place that including it in the diagram would be redundant.

6.5 Waste Station Firmware

The firmware design of the waste station is relatively simple. Due to the retrofitting of an already operable automatic litter box the motor driving control is not necessary. Refer to Section 6.4 for a more explicit hardware overview, but the core components interacting with the system controller is a proximity and humidity sensor. If the proximity sensor is triggered, the system controller will emerge from a low power mode, update counters for total use, urination, and defecation. A humidity sensor is sensed for a finite duration of time to detect whether the cat is urinating or defecating. If the humidity increases significantly, it is likely that the cat has urinated. External testing with the chosen humidity sensor is needed to verify and characterize the urination threshold.

The litter box may also be triggered by a base station request. The base station could either request the usage count, or to reset the count. Reset functionality is necessary since most litter is disposable, however, some are reusable. Hence, when the user replaces the litter the counters need to be reset externally. Sending the current count just requires the data be sent to the wireless module for transmission. **Note** that the wireless transmission will involve an associated handshaking, transmission, and verification which is not explicitly stated in the block diagram.

6.6 Database Design

Data storage: The purrfect cat care system supports a few functionalities, particularly changes in cat behavior. This presents the designers with a few challenges, how the data should be tracked, how much space should be considered for a prolonged duration of data persistence, and what is the most efficient mode of data management. We look at a couple of options for storing and manipulating possibly large quantities of data. The choices available for logging input data are file system storage, or database storage. We discuss the differences for each and decide which one is the best to use for this application.

File System Storage: Data can be stored in files and saved onto the hard disk. These files can be updated, deleted, or moved in the hard disk by users. The files live in a directory, which can have other files or other directories. Storing data in a file can provide fast and easy access to the data if limited to small amounts of data and organized in a way that the data can be sorted through efficiently. No additional overhead or software is required for using this form of data storage, making it an ideal low cost solution and easy to use [1]. The problem occurs when the data grows in complexity and size. The issue of redundant data can occur when the same data is repeatedly used in related elements [2]. For example, the purrfect cat care system will need to keep track of how many times the cat uses the litter box and how much food and water is consumed within one day. For every day when one of those values needs to be added, the date will be recorded in every data element. As the data grows, this redundant data can use up precious memory space. Also, as these files become larger, the data will use more system resources to access and therefore become slow. Furthermore, the file system does not have any type of change history and therefore if the files are moved or deleted by accident or malicious intent, there is no record of the original file [1].

Database: Rather than storing data in files, a database stores data in a collection of organized structures. A database can be visualized as a set of tables containing rows and columns or as a collection of key-value pairs. This structure allows for data to be searched, or queried, easily. Databases are generally ACID compliant, where ACID is an acronym for atomicity, consistency, isolation, and durability [3]. ACID compliance means that the database will contain all four properties and that is that the data will be reliable, validated (i.e. the data can be rolled back if something went wrong), and the system can be scalable, and if it fails, nothing will happen to the data. A database can be either relational or non-relational.

Relational: A relational database is organized as a set of tables, where each can contain a relationship to the other tables in some way. Most relational databases use structured query language (SQL), which is a programming language, to access the data elements in the tables [4], which is why the terms SQL and relational are interchangeably used when discussing these types of databases. Relational databases are generally designed to be normalized, meaning any redundant data is removed and the tables will be split into smaller tables based on the relationships between the data to optimize disk space. The organization also allows data to be inserted, deleted and updated more quickly. SQL databases prioritize consistency and reliability in the data over availability and speed [5].

Non-relational: A non-relational database is organized in documents or objects containing key-value pairs. Unlike relational databases, non-relational databases are designed to be denormalized, which is why they are also called noSQL databases. This means the data is combined and often redundancies are added for faster querying [6]. Because of this redundant data, non-relational databases may require more disk space to store the data. However, since the data is organized as more of a document, the databases are more scalable horizontally. Also, non-relational databases prioritize availability over consistency and therefore may lose data integrity.

Database management systems: A database management system (DBMS) is the software that interfaces with the database and allows users to set up and manage the database. This makes the database upkeep more manageable and provides the ability to monitor performance and database metrics [14]. Two DBMSs considered for this project are MongoDB and MariaDB. MongoDB uses a noSQL non-relational database and organizes the records into structures called documents which can be accessed from any language that they are written in [15]. MariaDB uses a SQL relational database and uses SQL to query the data. MongoDB will have faster access, but Maria DB will have faster insertion, deletion and updating of the records. One of the decision factors is the tradeoff between speed of access and total disk space needed with the data and overhead.

Comparison and analysis: To decide on which type of data storage to use, we must first look at the requirements of the system. The purrfect cat care system base station should run autonomously. The inputs from the other systems (i.e., the water, food and waste stations), should be handled by the base station software automatically. The data should be readily available by the base station software to do statistical calculations and report the daily results back to a user via a web application. Since the data will need to be accessed efficiently by a software program rather than manually, the file system storage is not the optimal choice. Then comes the choice between the database designs. When looking at the types of databases, we need to see how the data will need to be organized. For each of the systems connected to the base station, the data will be mostly log data as shown in figure [1]. Considering the few relationships between the tables, the data may benefit from being organized in a non-relational database. The next factor to consider before choosing the best database design structure for this project is whether speed or space is more important for the purrfect cat care database management system. We look at the individual stations and their data that will be transmitted to the base station.

Feeding station: The feeding station will be configurable to have up to a maximum of six scheduled dispenses of food to the bowl per day, set by the user on the application. These configurations will be stored in the database. For each time the food station dispenses food, the system will also send an update to the base station database of how much food was dispensed and how much food was consumed from the last time it checked in, at the same time. Therefore, the total values being sent to the base station will be twelve double precision float values per day, plus the initial configuration values which will be a combination of time-date values and double precision float values.

Water station: For the water station, there will be a set total of six samplings per day which reports back to the base station database how much water was consumed by the cat from the last check-in and the dispensed amount. The water station will keep the bowl filled up to a maximum amount and will not have any configurations from the user stored in the database. Therefore, the total values being sent to the base station will be twelve double precision float values per day.

Waste station: The waste station will track how many times the cat enters to use the litter box and whether the cat defecated or urinated. The update to the base station database will be the count increase for litter box usage each time the cat enters the litter box and a Boolean value that determines whether the cat defecated or urinated. To determine how many updates this translates to in the database, we need to look at how often the average adult cat visits the litter box. Generally, an adult cat will go to the litter box to urinate two to three times per day and will defecate about once per day. Therefore, taking the ceiling of these values, the system will potentially send up to eight updates per day to the base station, four Boolean values and four integer values.

Choice of data storage system: Using these values we can determine the total number of updates needed per day to the database which will be used to determine how much space will be needed on the base station system to retain the data for twelve months before being purged. Considering the requirements discussed, the database should expect to have about 8,766 double precision float entries, 1,460 integer entries, 1,460 Boolean entries, and 6 configuration entries if only set once for a twelve-month period. Looking at the data alone without any overhead from the database management systems installation, the amount of storage space needed for these records when considering how much space is needed for each one, we need about 76 kilobytes of space for the data. Comparing the space needed to the available disk space on the base station, which will be at least 64 gigabytes, the space is not a significant factor, therefore speed of access would be the better option to maximize user experience. The best option for this would be a non-relational database management system like MongoDB.

7 Administrative Content

7.1 Budget

A large focus of this project is cost. Each automatic system can cost in the ranges of $30-$300. It is not the goal of this project to make a better, or more competitive priced automatic system. The goal is more in elevating the current feeder to provide data a pet owner, veterinarian, or animal shelter owner would want. This additional information cannot be free, sadly. The current budget is $500. The price breakdown is provided below. Note that a significant percentage of the budget is reserved to mechanical components. As more technological discovery is done, it is hoped that more cost-effective components may be found.

Part	Quantity	Price
Load sensor	2	$50
ADC	2	$20
Humidity sensor	1	$5
Water pump	1	$25
Flow sensor	1	$25
Food dispenser	1	$20
Steel bowl	2	$10
Motor	1	$40
Wi-Fi module	3	$45
Power supply	3	$15
Microcontroller	3	$5
SBC	1	$50
PCB	3	$100
Miscellaneous		$50
Total		$460

Table 3: Budget breakdown.

7.2 Milestones

Provided in the table below is the current milestone schedule. Note the parallel nature of the schedule. Updates to the milestone will be made alongside challenges and progress.

Milestone	Task	Start	End	Status	Responsible
1	Brainstorming	6/22/2021	7/12/2021	Complete	Group 18
2	Project selection	7/21/2021	7/28/2021	Complete	Group 18
3	Block diagram development	8/23/2021	8/30/2021	Complete	Group 18
4	Role assignment	9/6/2021	9/6/2021	Complete	Group 18
5	Initial divide and conquer	9/10/2021	9/17/2021	In Progress	Group 18
6	Component research	8/23/2021	9/17/2021	In Progress	Group 18
7	Schematic development	10/1/2021	10/22/2021	Pending	Michael
8	PCB design	10/1/2021	10/22/2021	Pending	David
9	Base station development	10/1/2021	11/1/2021	Pending	Will
10	Firmware development	10/1/2021	11/1/2021	Pending	Carla
11	Power supply development	10/1/2021	11/1/2021	Pending	Hector
12	Food station development	11/1/2021	12/1/2021	Pending	David
13	Water station development	11/1/2021	12/1/2021	Pending	Hector
14	Waste station development	11/1/2021	12/1/2021	Pending	Michael
15	System integration and testing	11/14/2021	12/3/2022	Pending	Group 18
16	Prototype testing	1/10/2022	2/28/2022	Pending	Group 18
17	Finalize product	3/1/2022	3/31/2022	Pending	Group 18
18	Peer presentation	3/15/2022	4/1/2022	Pending	Group 18
19	Final report	4/1/2022	4/8/2022	Pending	Group 18
20	Final presentation	4/8/2022	4/22/2022	Pending	Group 18

Table 4: Senior Design milestone schedule.

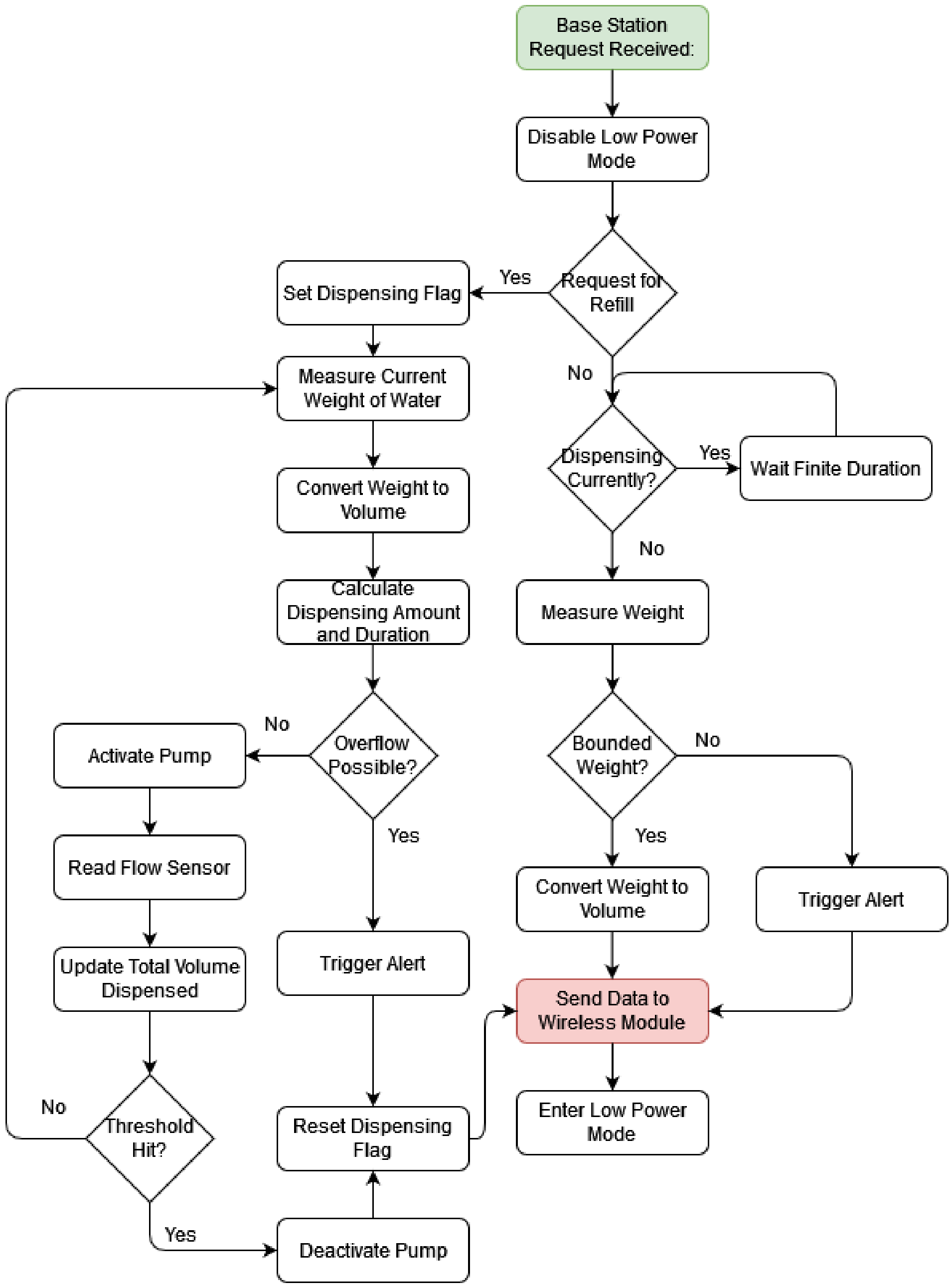

Figure 18: High-level water station firmware block diagram.

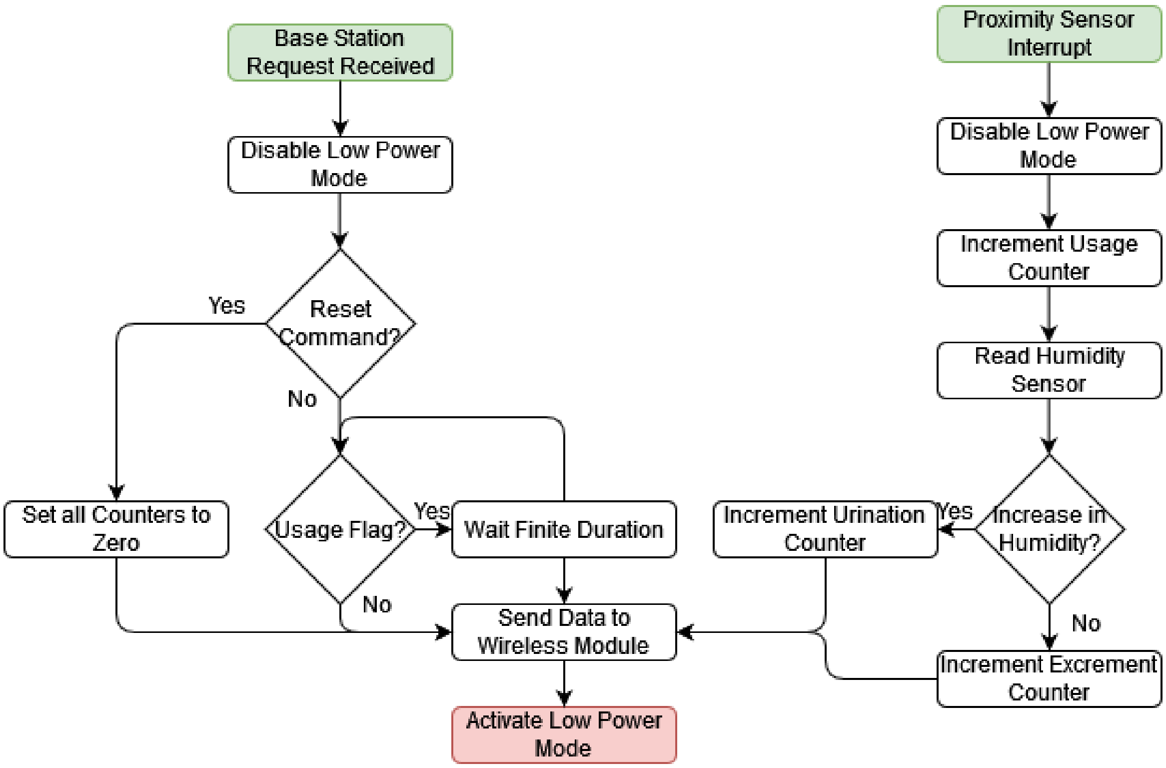

Figure 19: High-level waste station firmware block diagram.

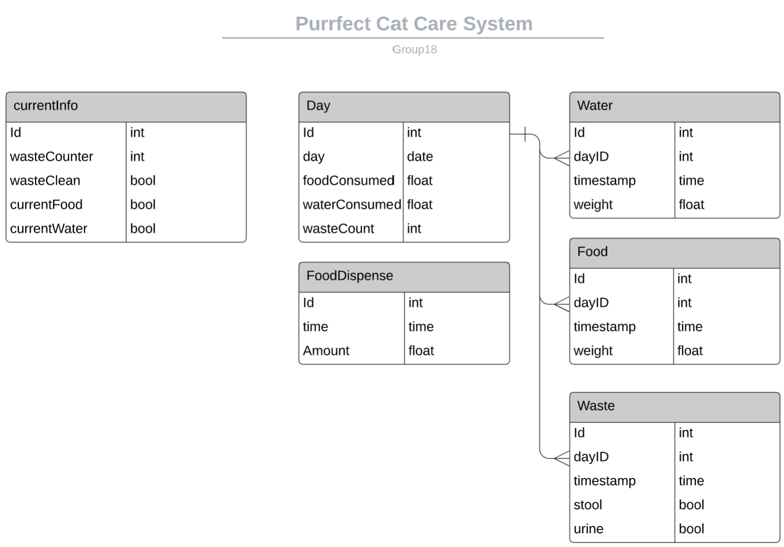

Figure 20: Entity Relationship Diagram