Conceptual Design Report
Automatic Pet Feeder

By AutoBotics

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1.0 Analysis And Identification Of Appropriate Sensors

1.1 Load Cell Sensor

Regarding weight measurement, the team chose the SENS-5 5Kg Load Cell Sensor over the FSR 402 Force Sensing Resistor Pressure Sensor and A201 Flexiforce Sensor Pressure Sensor since the Load Cell is more suitable for accurately measuring the weight of pet food, which typically does not exceed the 5 Kg compared to the force sensing resistors and piezoelectric sensors. The load cell also has more linearity and repeatability ensuring consistent and accurate weights are measured over its entire range.

The Load Cell Sensor accompanied by the Load Cell Amplifier seen in Figure 1 is made from an aluminum-alloy (an isotropic material), can read weights up to 5kg, and has four strain gauges that are hooked up in a Wheatstone bridge formation. The sensor works by using a change in resistance when the strain gauge is subjected to a force to calculate the weight. This is done through equation (1) and (2) below, that calculates the tensile strain (deformation) and change in electrical resistance due to strain, respectively.

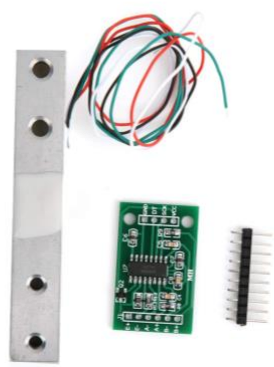

Figure 1: Image of the SENS-5 5 Kg Load Cell Sensor and HX711 Load Cell Amplifier 24-Bit Analog-to-Digital Converter (ADC).

$$e = \frac{\Delta L}{L} \tag{1}$$

$$S_e = \frac{dR}{(R)(e)} \tag{2}$$

The specific strain gauge used in the sensor is a Wire / Metal Foil Strain Gauge. It consists of a fine wire bonded with an elastic carrier. As the material stretches or compresses, the wire's resistance changes proportionally, allowing for strain Measurement shown in Figure 2.

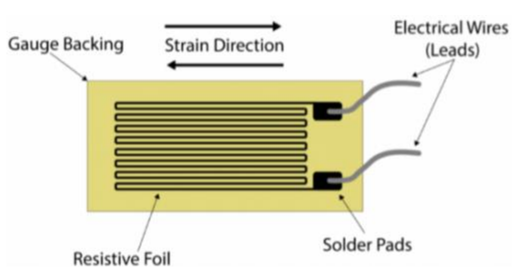

Figure 2: Metal Foil Strain Gauge for the SENS-5 5Kg Load Cell Sensor.

The Strain gauges are arranged in a Wheatstone Bridge Configuration to measure strains in different axes. An excitation voltage is applied across the circuit, and the output voltage is measured across two points in the middle of the bridge shown in Figure 3.

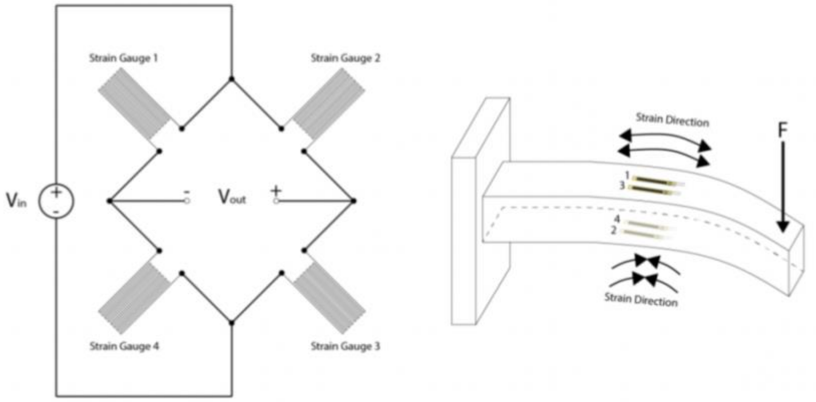

Figure 3: Wheatstone Bridge Configuration for the Metal Foil Strain Gauge for the SENS-5 5Kg Load Cell Sensor.

1.2 Camera

The camera receives an input of light from its lens and directs it into a light-sensitive sensor, stores and displays information as a video on the screen, and feeds said video into the computer vision (CV) model that collects every 60th frame and converts the frame to base64 encoding to identify the specific pet based on an image input by the user.

1.3 Ultrasonic Distance Sensor

The HC-SR04 Ultrasonic Sensor shown in Figure 4 reads 1 measurement per second resulting from delays in our code. The sensor has an input trigger signal (Trig) with a $10\mu s$ voltage pulse that is applied to the piezoelectric membrane causing the material to deform/vibrate at a frequency in the ultrasonic range (40 kHz ultrasonic pulses) to start the measurement cycle. In Addition the time between the transmission of the pulse detection of the echo is recorded. When these ultrasonic pulses are blocked by an object, some of the sound waves reflect back to the sensor and apply mechanical pressure on the piezoelectric membrane, causing the material to generate a small electrical voltage pulse with a width of the time of flight (the time it takes for the transmission of the ultrasonic pulse to receive the echo) that can be calculated using equation (3) to determine the distance from the object.

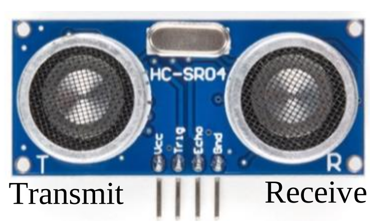

Figure 4: Image of the HC-SRF04 Ultrasonic Distance Sensor.

$$TOF = \frac{2D_m}{V_s} \tag{3}$$

Between the SHARP GP2Y0A02YK0F Distance Measuring Sensor and the Ultrasonic Sensor, we decided to use the ultrasonic sensor over the infrared for various reasons described below.

Depending on the coat and fur of the pet that needs to be fed, the infrared sensor could have varying efficiency. Some light and dark fur coats could reflect or absorb infrared radiation respectively in different ways. Therefore, the Ultrasonic Sensor would be more effective in finding different materials that it comes across with better accuracy.

The environment can greatly affect the efficiency of either sensor. The Ultrasonic Sensor has a wider field of view and detection range, allowing flexibility for the positioning of the dog feeder in the home. Varying light conditions in the house can affect the accuracy of the SHARP IR sensor as well as other IR blasters that are present (i.e. motion detectors). However, the IR sensor is less affected by acoustic interference than the ultrasonic since there are rarely high-frequency noises in a home.

Overall, in our testing, the ultrasonic output was able to achieve a much higher precision as well as accuracy. The output from the SHARP sensor was often very noisy and could not measure distances effectively.

2.0 Analysis And Identification Of Appropriate Actuators

2.1 Servo Motor

The HS-422 Servo Motor shown in Figure 5 operates at 4.8 to 6.0 volts and draws around 150-200 mA of current during no-load operation, and reaches up to 600-800 mA when a load is attached. Unlike the QSH4218 Stepper Motor the servo motor only draws current when it is changing position, not when it is still. The team's specific dog feeder operates at 5V and draws just under 300 mA while running. The Servo Motor is a Permanent-Magnetic DC Motor (PMDM) meaning its poles are made of permanent magnets mounted with the N-pole's and S-pole's of each magnet alternatively faced towards armature and it does not require an external field circuit.

Figure 5: Image of the HS-422 Servo Motor

The Servo Motor is brushed, operates in a closed-loop control system with feedback control (unlike the Stepper Motor that uses open loop control) and uses a relative pulse-width modulation (PWM) signal to generate a digital control signal and if an error occurs during the execution of the project, the feedback system will correct it in real-time. It anticipates an update every 20 ms with Pulses between 0.9 and 0.21 ms, resulting in a duty cycle (indicates what percentage of the time a signal is on) range of 4.5% to 10.5%.

Unlike the Stepper motor, the torque that the servo motor provides is proportional to the weight of the load, lowering the overall power consumption of the motor. The speed regulation of the Servo motor cannot be precisely calculated since the angular speed with a full load is not provided in the motor's specifications but would be calculated using equation (4).

$$SR = \frac{\omega_{nl} - \omega_{fl}}{\omega_{fl}} \times 100\% \tag{4}$$

3.0 Core Objectives

In Figure 6, a flow chart dictating system operation is provided to give the reader a better understanding of the feeder's logic.

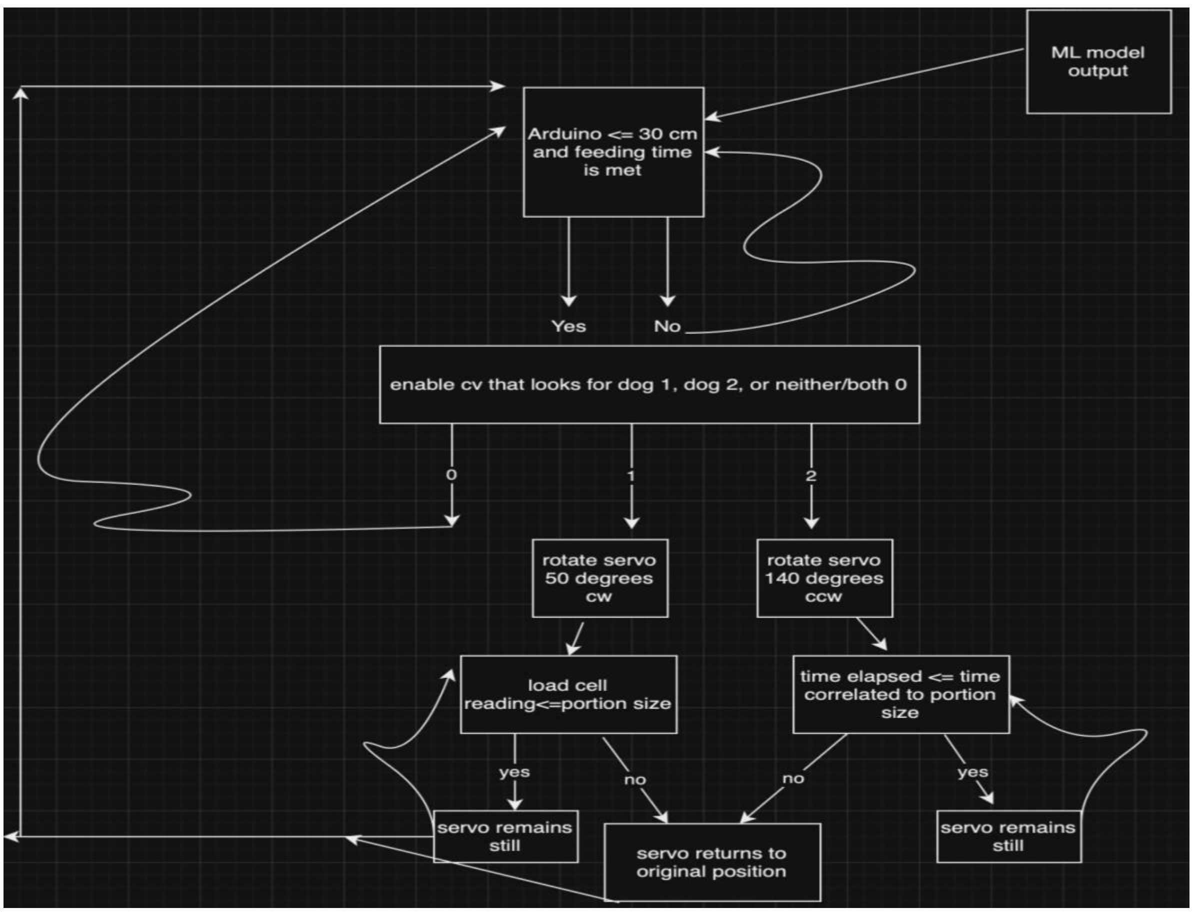

Figure 6: Flow chart of pet feeder system operation design.

3.1 User Control of Portion Size, Feeding Intervals, and Scheduling

The pet feeder can take user input for portions, feeding intervals, and scheduling. The Arduino code allowed directives for two different pets regarding how many times they eat a day, how much they eat per interval, and when they eat every day.

3.2 Accurate Portion Control

The pet feeder takes input from the user in grams to determine how much to feed the designated pet. As a limitation, the design could only utilize a single load cell sensor since a second one was not provided. But ideally, both bowls would have been equipped with one. When the output of the load cell reaches the desired portion amount from the user, it tells the servo to return to the resting position and stops the flow of food. However, in the design, one of the bowls utilized a timer, as the amount of time that the servo was dispensing directly correlated with how much food was output.

3.3 Pet Safety

The pet feeder was constructed with 3D-printed PLA plastic, which is considered food-safe. Other materials used include two generic soda bottles, also constructed with food-safe materials. In Addition the sharp edges from construction were sanded to maintain no harmful surfaces for the pet.

3.4 Secure Food Storage

The pet food is stored in rigid plastic bottles with pet-safe lids, preventing overeating or food theft directly from the source. This allows for secure food storage and easy refilling of the food reserves.

3.5 Cost-Effectiveness

The overall cost of the device remains affordable, and a BOM can be seen in Table 1. It uses cheap 3D prints in PLA plastic. These prints could use a lower infill as the overall structure remains strong even with a 10-20% infill percentage. This reduces the print time as well as wasted filament. The rest of the construction is done with generic 591mL soda bottles, which are common as household “waste”. It utilizes a couple of different sensors, a servo motor, and an Arduino. The computer vision model is extremely affordable, with each API call only costing $0.002, so it is considered negligible in the BOM. Figure 7 shows the monthly cost of the API during testing, which is much more expensive in comparison to commercial use since the vision model is only ran once each time the feeding time of a dog approaches and the Ultrasonic Sensor reads a distance less than 30 cm.

Table 1: Complete BOM of Pet Feeder.

Item	Quantity	Cost $CAD 1 (Dec 2023)
HS-422 Servo Motor	1	21
Breadboard	1	8
SENS-5 5Kg Load Cell Sensor	1	10
HC-SRF04 Ultrasonic Distance Sensor	1	10
Arduino Uno R3	1	35
USB Cable (Type B)	1	5
HX711 Load Cell Amplifier	1	15
3D Printer Filament	~1kg	21
Screws	4	4
Jumper Wires	1 bundle	15
Hot Glue	10 sticks	3
Bowl	2	3
TOTAL		$130

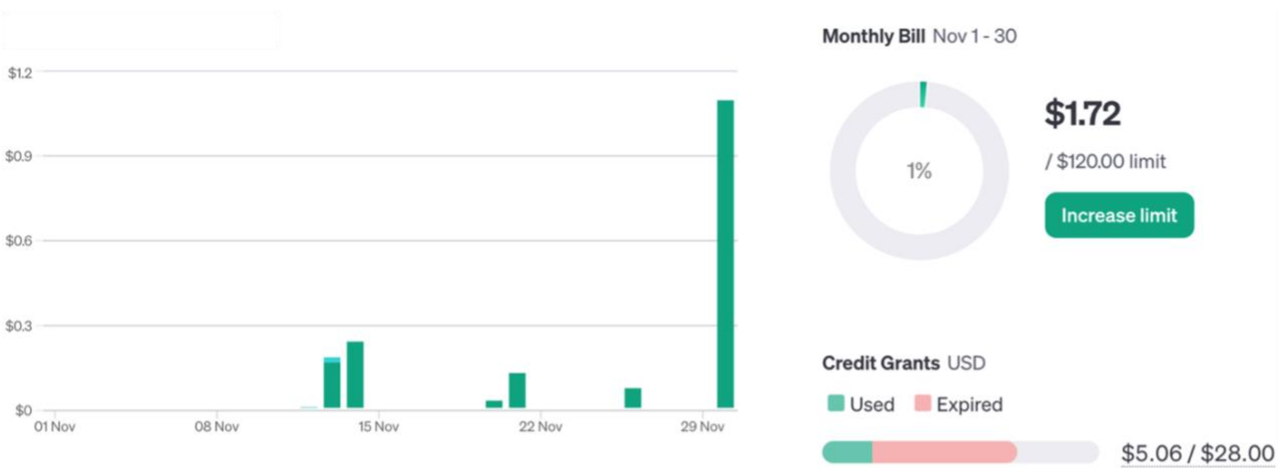

Figure 7: Monthly cost of the vision model API during peak testing.

4.0 Desired Objectives

4.1 Pet Identification and Food Theft Prevention

The pet feeder uses a computer vision model that prompts the user to input an image of both of their pets (if the user only has one pet, they also just upload one image). The model can then identify the two pets that walk into the frame of the camera with a 95% accuracy per frame processed. Since the Python code takes every 60th frame and the live video input is running at 60 fps, this means that even if the pet is not identified within the first second, it will almost always be identified in the second. When it detects the first pet in the frame, it sends a 1 to the serial port of the Arduino, initiating the feeding process for the first pet (same thing for pet 2 with a 2 to the serial port). The pet feeder logic outputs a 0 (does not feed either pet) if neither pet is in the frame or if both pets are in the frame to implement theft prevention.

4.2 Accommodation of Multiple Pets

The design can feed two different pets with the use of two different containers containing two different foods by having one stationary plate with two holes connected to both the dog bowls and a rotating plate above that with two holes. The feeder is designed in a way such that rotating the disk 50 degrees clockwise feeds dog 1 and rotating the disk 140 degrees counter clockwise feeds dog 2. The design can feed two different pets with differing schedules in time fed and number of times fed in a day. The logic in the code is also able to facilitate different portion sizes to the different pets with the use of the load cell or time variables.

4.3 Pet Activity Monitoring and Feeding schedule / Portion Size Adjustment

The accelerometer data is considered in the code and can therefore adjust the portion sizes based on the oets activity levels for the day and how many daily calories the pet needs if the user desires. It is run off a machine learning model that considers the pet’s age, weight, gender, neutered status, breed, and activity (based off accelerometer data that can be attached to a pet's collar). It is a random forest model with an extremely low error rate.

Figure 8: Flow chart outlining how the group integrated accelerometer data and dog specifications to make predictions on caloric requirements.

Below is a discription of each of the nodes in the flow chart shown in Figure 8 above.

Start Node: Simply indicates the start of the process.
Data Collection: Different data sets were collected with details on accelerometer data and pet specifications.
Data Processing: Cleaning the data (dealing with any missing values and outliers in the data set).

Creating Dataset: All the information in different data sets were combined to carry on with model training/validation.
Developing Random Forest Model: A Random Forest Model is a series of decision trees that each output a prediction, a vote is then casted, and the majority vote is taken. The model input features set for prediction as the accelerometer data and specifications of the dog. The target is the recommended caloric intake of the dog.
Validating Model: To validate the model, the mean squared error is calculated to be about 0.003
User Interaction: User inputs their pets activity level, weight (in kg), age, and gender (0 for male and 1 for female). An example is shown in the flow chart in figure 8.
View Predictions: Model outputs a recommended caloric intake based on the user inputs.
Feeder Synchronization: Feeds model output to the dog feeders Arduino code in order to alter portion sizes to maintain a healthy weight.
End Node: Simply indicates the End of the process.

4.4 Energy-Efficient

The only thing that is constantly running is the ultrasonic sensor, and therefore reduces the wattage of the apparatus while it is running to consume around 0.0075 Watts in standby mode in comparison to 5.575 Watts in active mode when all the sensors and actuators are being ran. These values were obtained from using the sensors and actuators specifications of voltage and current in equation (5) below. Only after the ultrasonic sensor sees something less than 30 cm away from it, the computer vision model will turn on, only if the computer vision model sees one of the two pets that it was trained to detect, it will activate the servo motor and load cell sensor. This three-step process is meant to reduce the overall power consumption.

$$P = VI \tag{5}$$

Additionally, the team chose to use a servo motor instead of a conventional stepper motor as it is more efficient in high-precision applications and will therefore be more efficient for longer term applications.

4.5 Ease of Cleaning and Maintenance

The upper half of the apparatus could be unscrewed and easily cleaned with household items such as soap and water. This user-friendly design also allows for easy maintenance as the two bottles acting as containers can be easily untwisted and replaced with new ones.

4.6 Video Interaction / Remote Monitoring

The computer vision model relies on a webcam. With the webcam running, it is easy to remote into the instance therefore having a live video feed of the pets and monitor how much of the food dispensed the pets have eaten as they fed throughout the day since the camera has the food bowls in frame.

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