

ECE 445

Senior Design Laboratory

Vision-Assisted Pet Feeder

with BLE Proximity and Consumption Monitoring

Project Proposal

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Project scope. This proposal targets one monitored pet and one feeding bowl. BLE is retained as a coarse proximity cue, but the design does not claim to identify multiple pets or prevent another pet from accessing leftover food.

1 Introduction

1.1 Problem and Motivation

Pet owners may be away from home when a scheduled meal is due. Conventional timer-based feeders can dispense food automatically, but they cannot verify whether the correct amount of food actually reaches the bowl, whether the pet approaches the feeder, or whether the pet eats. These situations require different responses: a dispensing failure may indicate a hardware problem, while an untouched meal may indicate that the pet missed or refused the meal. Considering the limitations of conventional approaches, a useful remote feeder should monitor the entire feeding process rather than simply confirm that a dispense command was executed.

The distinction matters because nutritional management includes both a feeding plan and continued monitoring. The American Animal Hospital Association describes nutritional management as an important part of companion-animal health and recommends individualized feeding amounts and frequencies [1]. This project is not intended to diagnose a medical condition. Its purpose is to help an owner follow a predetermined feeding plan and to provide timely, objective observations that may justify checking on the pet.

The prototype deliberately addresses a single-pet, single-bowl use case. It does not use RFID, does not lock food to a particular animal, and does not solve competition between pets. A BLE beacon on the monitored pet's collar is nevertheless useful: its received signal strength gives the feeder a low-computation indication that the pet is near, allowing the camera to move from an armed, low-duty state to active inference. Because indoor RSSI is not a reliable distance measurement, BLE is used only as a coarse proximity trigger and not as evidence that the pet is feeding.

1.2 Proposed Solution

The proposed feeder uses scheduled, closed-loop dispensing as its primary workflow. At each stored feeding time, a real-time clock wakes the main controller. The controller first obtains a stable bowl-weight measurement and computes only the deficit between the measured food mass and the owner-configured target. A stepper-driven auger then dispenses dry food in coarse and fine increments until the target bowl mass is reached. The controller records one dispense transaction per scheduled meal and will not repeatedly top up the bowl during the same observation window.

At the scheduled time, the camera subsystem enters an observation window. A BLE tag on the pet broadcasts a fixed identifier; the feeder filters the tag's RSSI with a moving statistic and hysteresis. A near indication starts full-rate vision processing, while scheduled low-rate checks remain available so that a missing or depleted BLE tag does not make the feeder blind. The Raspberry Pi reports whether a cat or dog is present in a fixed feeding-region mask. The ESP32 combines this information with the bowl-weight history to classify the event as consumption, no approach, or approach without consumption.

The main control and processing architecture is organized as follows:

- The custom main-control PCB contains the ESP32-S3, RTC interface, HX711 load-cell interface, A4988 motor driver, protection circuitry, local indicators, and subsystem connectors.
- The ESP32-S3 is the main state-machine controller. It manages the feeding schedule, BLE scanning, bowl-weight acquisition, motor control, event classification, and Wi-Fi communication.

- The Raspberry Pi operates only as a vision coprocessor. It processes camera frames and reports pet-presence observations to the ESP32, but it cannot directly activate the motor.
- Event metadata is sent over Wi-Fi to the owner’s phone through a TLS-protected messaging service. Images remain local and are not stored or uploaded by default.

The system sequence is therefore

scheduled alarm → weigh bowl → fill to target → monitor BLE/vision/weight → classify event → notify owner.

1.3 Use Context

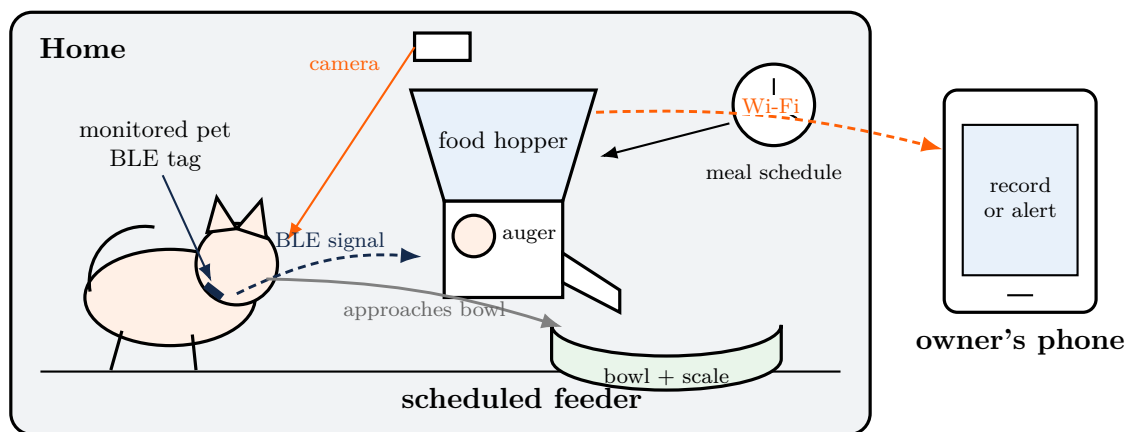


Figure 1: Use context of the proposed feeder. BLE provides a proximity cue, the camera and load cell monitor the feeding event, and the feeder sends an event record or alert to the owner’s phone.

1.4 High-Level Requirements

The following three requirements define successful end-to-end operation.

- HLR 1.** For a configured 20.0 g target and initial residual-food masses between 0 g and 10 g, the system shall finish with $20.0\text{ g} \pm 2.0\text{ g}$ of food in the bowl in at least 9 of 10 trials, without issuing more than one dispense transaction for the scheduled meal.
- HLR 2.** During scheduled observation windows, the combined BLE, vision, and weight pipeline shall correctly classify at least 27 of 30 controlled trials—10 with at least 5 g consumed, 10 with no pet approach, and 10 with a pet approach but less than 5 g consumed—and shall issue the result within 2 s after the relevant threshold is satisfied or the observation window ends.
- HLR 3.** Under normal Wi-Fi and Internet connectivity, the system shall deliver a meal record or abnormal-event alert to the owner’s remote device within 10 s of classification in at least 18 of 20 end-to-end trials; loss of Internet service shall not prevent the scheduled local dispense operation.

2 Design

2.1 System Block Diagram

Figure 2 summarizes the four major subsystems and their interactions. The ESP32-S3 serves as the main controller, while the other subsystems provide scheduling and communication, vision observations, and dispensing and weight measurements. Detailed electrical interfaces and signal requirements are specified in the following sections.

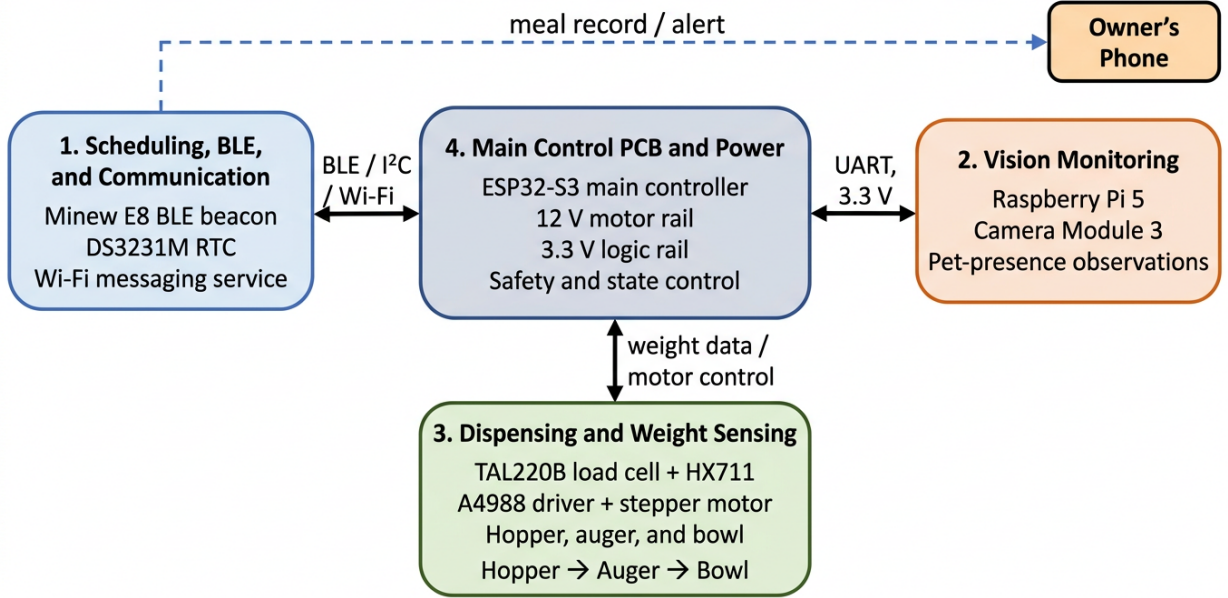


Figure 2: System block diagram of the vision-assisted pet feeder. The ESP32-S3 main-control PCB coordinates scheduling, communication, vision monitoring, food dispensing, and weight sensing.

2.2 Control Sequence and Decision Logic

The ESP32 implements a state machine with the following states: IDLE, PRE-WEIGH, DISPENSE, OBSERVE, CLASSIFY, and REPORT. The RTC alarm causes the only normal transition from IDLE to a meal. In PRE-WEIGH, the motor is disabled and the controller requires a stable filtered mass. If the existing mass is already at or above the configured target, dispensing is skipped but the observation window still occurs. Otherwise, the auger fills only the measured deficit. The meal identifier is marked complete in nonvolatile memory before entering OBSERVE, preventing a reset or repeated pet approach from causing a second fill.

During a nominal 30 min observation window, the BLE RSSI filter labels the tag *near* or *far*. A near transition requests full-rate inference from the Raspberry Pi. The Pi reports only PRESENT, ABSENT, confidence, and a timestamp. The ESP32 independently records bowl mass. A consumption event requires both a valid observation window and a net stable mass decrease of at least 5 g; vision supplies contextual evidence that the decrease occurred while the pet was present.

The following conservative event rules will be used for the prototype:

- **Consumed:** visual presence is confirmed and stable bowl mass decreases by at least 5 g from the post-dispense baseline.
- **No approach:** neither BLE-near nor vision-present occurs within 30 min after the scheduled meal.
- **Approach without consumption:** the pet is visually present for at least 15 s, or enters at least three times in 15 min, while the cumulative stable mass decrease remains below 5 g.
- **Hardware fault:** the motor is commanded but two consecutive fine/coarse bursts produce less than 0.5 g total increase, or the maximum 15 s accumulated motor-on time is reached.

Thresholds are deliberately exposed as configuration parameters so they can be adjusted during verification, but the pass/fail values in the requirements will not be relaxed after testing.

Table 1: Quantitative interface definitions.

Source	Destination	Physical interface	Required behavior
E8 BLE beacon	ESP32-S3	Bluetooth LE advertisement, nominal 250 ms interval	Fixed identifier accepted; five-sample filter and at least 6 dB entry/exit hysteresis after site calibration.
DS3231M RTC	ESP32-S3	3.3 V I ² C, up to 400 kHz; alarm interrupt	Retain schedule through loss of main power and initiate each meal no more than once.
TAL220B/HX711	ESP32-S3	Differential bridge to HX711; DOUT/PD_SCK at 10 samples s ⁻¹	Report calibrated stable mass with no more than 0.5 g RMS error over 0 g–100 g.
ESP32-S3	A4988	3.3 V STEP, DIR, ENABLE	Pulse widths at least 2 μ s; hardware current limit set before connecting the motor.
Raspberry Pi 5	ESP32-S3	3.3 V UART, 115200 baud, 8-N-1	CRC-protected packet acknowledged within 500 ms; malformed or stale packets discarded.
ESP32-S3	Messaging service	2.4-GHz Wi-Fi, MQTT or HTTPS over TLS	Timestamped metadata acknowledged or queued locally for retry; no image transfer by default.

2.3 Subsystem 1: Scheduling, BLE Proximity, and Remote Communication

This subsystem determines when a meal begins, supplies a coarse indication that the monitored pet is near, and reports the final result. It directly supports the scheduling and duplicate-prevention portion of HLR 1, as well as HLR 2 and HLR 3. The ESP32-S3-WROOM-1-N8R8 is suitable because the module combines Bluetooth LE and 2.4-GHz Wi-Fi with the UART, I²C, timers, and GPIO

needed by the other blocks [2]. A DS3231M temperature-compensated RTC provides timekeeping and alarm outputs even when main power is interrupted [3]. A Minew E8 Bluetooth 5.0 beacon is used as the collar tag; it is a compact, battery-powered transmitter with a configurable beacon identifier [4].

BLE is intentionally treated as a classifier between two calibrated zones, not as a ranging instrument. Twenty calibration observations will be taken at the installation site. The entry threshold will be selected to separate a 0.5 m near-zone test position from a 3.0 m far-zone test position, and the exit threshold will be at least 6 dB lower than the entry threshold. If the BLE observation disagrees with the camera, the vision and load-cell observations will take precedence in the feeding-event classification.

Subsystem 1 requirements

- 1.1:** The RTC and controller shall begin a stored meal within 2 s of its alarm, retain time across at least a 60 s main-power interruption, and prevent more than one dispense transaction for the same meal identifier.
- 1.2:** With the beacon advertising nominally every 250 ms, the BLE algorithm shall assert near within 2 s in at least 18 of 20 trials at 0.5 m line of sight and shall remain far in at least 18 of 20 trials at 3.0 m in the same room.
- 1.3:** The RSSI decision shall use at least five recent valid advertisements and separate entry and exit thresholds by at least 6 dB to prevent rapid state changes.
- 1.4:** For each classified meal, the controller shall form a record containing the scheduled time, pre- and post-dispense mass, estimated consumption, proximity and presence results, and alert code.
- 1.5:** Under normal connectivity, the event record or alert shall be displayed on the owner's remote device within 10 s in at least 18 of 20 trials. When offline, the controller shall preserve at least 50 records in nonvolatile storage and retry transmission without delaying future meals.

2.4 Subsystem 2: Computer Vision and Feeding-Zone Monitoring

This subsystem supplies primary confirmation that a pet is physically inside the defined feeding region. A Raspberry Pi 5 receives images from a Raspberry Pi Camera Module 3 through CSI-2. The camera uses the Sony IMX708 sensor and supports autofocus and 1080p video [5]. The Pi will run OpenCV with a lightweight, quantized object detector. A cat or dog detection is counted as pet presence only when its bounding box overlaps a user-defined polygon around the bowl. A MobileNetV2-based SSD detector is one candidate because the inverted-residual architecture of MobileNetV2 was designed for efficient mobile inference [6]. The final model choice will be based on measured accuracy and latency, not on model name alone.

At a meal time, the camera enters an armed observation mode. A BLE-near message causes the Pi to process frames continuously. Periodic low-rate frames are still processed while BLE is far, so that the system can detect a pet even if the tag is dead or missing. Presence is asserted only after at least three positive frames in a five-frame window. The Pi does not decide whether food was consumed and cannot command the motor. It transmits a framed presence observation to the ESP32, which combines the observation with the bowl-mass record.

Subsystem 2 requirements

- 2.1:** The camera shall cover the entire bowl and a surrounding feeding-region mask at a minimum processed resolution of 640×480 pixels under normal indoor illumination.
- 2.2:** While active, the Pi shall process at least 5 frames per second and deliver a valid UART presence update no later than 500 ms after the fifth frame used in a decision.
- 2.3:** On a labeled set of at least 200 frames, including at least 100 positive and 100 negative examples, collected under at least two indoor lighting conditions and including partial occlusion, the inside/outside feeding-zone classification accuracy shall be at least 90%.
- 2.4:** A presence transition shall require at least three agreeing detections among five consecutive processed frames. Each UART message shall include state, confidence, timestamp, sequence number, and a CRC-8 or stronger error-detection code.
- 2.5:** Raw frames shall remain on the Raspberry Pi and shall not be transmitted or retained by default. A development recording mode may be enabled only with the pet owner's knowledge. Frames recorded in this mode shall be deleted after the labeled evaluation set has been produced.

2.5 Subsystem 3: Food Dispensing and Weight Measurement

This subsystem places the requested quantity of dry food in the bowl and measures subsequent removal. A TAL220B parallel-beam load cell supports a 5 kg maximum load and uses four strain gauges arranged as a Wheatstone bridge [7]. An HX711 supplies bridge excitation, amplification, and 24-bit analog-to-digital conversion for weighing applications [8]. The bowl platform will be mechanically isolated from the feeder frame so that the bowl load is transferred through the load cell. Measurements affected by auger vibration or pet contact will be rejected until the reading becomes stable.

A 17HS4401 NEMA-17 bipolar stepper turns the auger. The reference motor has a 1.8° full-step angle, 1.7 A-per-phase rating, and approximately 0.40 N m holding torque [9]. The custom PCB uses the A4988SETTTR-T driver, whose STEP/DIR interface, microstepping modes, overcurrent protection, and up-to-35 V motor supply are documented by Allegro [10]. The prototype will limit phase current to approximately 1.2 A; required auger torque will be verified with the chosen pellet geometry before this value is increased.

Weight is sampled only while the motor is disabled. The controller waits for five consecutive samples whose range is no greater than 0.8 g, then accepts their median as a stable mass. Coarse continuous rotation is used while the deficit exceeds 5 g; the final portion uses short step bursts separated by settling intervals. After dispensing, the controller records a stable post-dispense baseline. Measurements affected by pet contact are rejected, and the next stable measurement is used to estimate food removal from the bowl. The design estimates mass change, not calories, chewing, or a medical diagnosis.

Subsystem 3 requirements

- 3.1:** After a two-point calibration, the load-cell assembly shall measure certified test masses from 0 g to 100 g with no more than 0.5 g RMS error and no more than 1.0 g peak error across ten measurements at each of five mass values.
- 3.2:** For a 20.0 g target and initial residual masses of 0 g, 5 g, and 10 g, the closed loop shall finish within $20.0 \text{ g} \pm 2.0 \text{ g}$ in at least 9 of 10 randomized trials.

- 3.3:** The motor driver shall sustain the selected phase-current limit for a complete 15 s worst-case dispense without entering thermal shutdown. Motor operation shall stop on a timeout or jam indication.
- 3.4:** While the remaining deficit exceeds 5 g, if two consecutive motor bursts produce less than 0.5 g total measured increase, the controller shall disable the A4988 within 2 s and record a jam or empty-hopper fault instead of continuing indefinitely.
- 3.5:** In 20 controlled post-dispense trials, the subsystem shall distinguish manual removal of at least 5 g of pellets from no removal in at least 18 trials after the load settles.

2.6 Subsystem 4: Main Control PCB and Power

The custom PCB is the main embedded controller, not a passive breakout board. It mounts the ESP32-S3-WROOM-1-N8R8, DS3231M, HX711, A4988SETTR-T with exposed-pad copper area, input protection, bulk and local decoupling capacitors, status LEDs, buzzer, programming header, and locking connectors for the motor, load cell, UART, and DC input. The ESP32 controls the schedule, state transitions, safety timeouts, weight acquisition, motor pulses, BLE scan, Wi-Fi messaging, and event log.

A listed external adapter supplies the low-voltage DC input. The motor uses a protected 12 V rail; a buck converter and 3.3 V regulator supply the logic rail. Motor return current is routed directly to the power-entry ground and kept away from the load-cell analog return until a single controlled connection point. At least 100 μ F of bulk capacitance is placed close to the A4988 motor supply in addition to the data-sheet decoupling, because stepper wiring can produce destructive supply transients [11]. The Raspberry Pi is powered independently by the recommended 27 W USB-C supply [12]. The two subsystems share a common ground at the UART interface, and the motor rail never powers the Pi.

Subsystem 4 requirements

- 4.1:** The PCB shall accept 12 V $\pm$ 5% and provide a 3.3 V rail within $\pm$ 5% while BLE scanning, Wi-Fi transmitting, HX711 sampling, and motor control are active.
- 4.2:** The motor path shall include reverse-polarity protection, a replaceable or resettable input fuse, at least 100 μ F local bulk capacitance, and an A4988 current limit set to no more than 1.2 A per phase for initial tests.
- 4.3:** The controller shall drive the active-low A4988 ENABLE pin high within 100 ms after a jam is detected or the motor-on timeout is reached. The controller shall enforce a maximum accumulated motor-on time of 15 s for one meal transaction.
- 4.4:** UART logic levels shall remain between 0 V and 3.3 V. Malformed or stale packets shall be discarded. After 2 s without a valid Pi packet, the controller shall mark vision monitoring as unavailable without interrupting scheduled local dispensing.
- 4.5:** After any brownout or watchdog reset, the controller shall restore the most recent meal identifier from nonvolatile memory and shall not re-dispense a meal already marked complete.

2.7 Tolerance and Risk Analysis

The highest implementation risk is the closed-loop auger/load-cell interface. Dry pellets do not flow as a continuous fluid: an auger burst releases a variable discrete mass, some pieces remain in the chute after motor stop, and vibration corrupts the scale while the motor runs. This risk directly threatens the ± 2 g tolerance in HLR 1. BLE and vision errors can be measured and filtered, but no later software stage can remove food after an overshoot.

Let T be the target food mass, $\hat{m}_k$ the accepted stable mass after fine burst k , e_L the absolute load-cell measurement error, q_f the largest mass released by one fine burst, and m_f the maximum food still in flight when a stable reading is accepted. If fine dispensing stops when $\hat{m}_k \geq T$, the worst positive error is bounded by

$$m_{\text{final}} - T \leq e_L + q_f + m_f. \quad (1)$$

The design budget is

$$e_L \leq 0.5 \text{ g}, \quad q_f \leq 0.8 \text{ g}, \quad m_f \leq 0.6 \text{ g}, \quad (2)$$

which yields a calculated worst-case overshoot of 1.9 g. This is inside the 2.0 g HLR 1 tolerance with 0.1 g of budget. The bound is conservative because it sums worst-case values with the same sign; it must nevertheless be demonstrated before the full dispenser is accepted.

The underfill bound is smaller under normal operation. Because dispensing stops only after $\hat{m}_k \geq T$, the final stable mass satisfies

$$T - m_{\text{final}} \leq e_L, \quad (3)$$

so the maximum calculated underfill is 0.5 g.

The three budget terms will be measured separately. Certified masses determine e_L with the motor disabled. Thirty single-burst tests at the selected microstep count determine the largest observed value of q_f . A clear catch tray placed below the chute after motor stop measures m_f . Coarse feed will stop at least 5 g below target. Subsequent fine bursts will be separated by at least 300 ms and will not begin until the stable-mass criterion has been satisfied. If either $q_f > 0.8$ g or $m_f > 0.6$ g, the team will reduce the burst step count, reduce auger speed, or narrow the outlet before end-to-end tests. If the budget still cannot be met, the mechanical auger is the element to redesign; the acceptance tolerance will not be widened after observing results.

3 Ethics, Safety, and Societal Impact

3.1 Ethical Responsibilities

The IEEE Code of Ethics emphasizes decisions consistent with public safety and honest, realistic statements based on available data [13]. The ACM Code likewise emphasizes avoiding harm, honesty, privacy, and robust security [14]. These duties lead to the following project-specific commitments.

First, this device will not be described as a medical monitor. An alert means only that the chosen camera and weight thresholds were met; it is not evidence of a disease and is not a substitute for veterinary advice or in-person care. The final report will disclose false-positive and false-negative rates, lighting conditions, tested food geometry, and the single-pet limitation. The team will not imply that BLE identifies the animal with certainty or measures an exact distance.

Second, a camera in a home can capture people as well as pets. All inference will be local, and the default remote record will contain timestamps, state labels, and masses only. Raw images will not be uploaded. Any temporary development images will be collected with the household owner's knowledge, stored on team-controlled media, and deleted when the labeled test set is no longer needed. Network credentials will not be printed in logs, and remote records will use TLS.

Third, animal welfare takes priority over demonstration convenience. The team will not withhold food, force an animal into the camera region, or expose it to moving parts. Calibration and most verification will use certified masses, dry test pellets, prerecorded or labeled imagery, and a mock pet target. Before any live-pet test, the team will obtain owner consent and confirm with course staff whether institutional animal-care approval is required. Live-pet use, if approved, will occur only during the animal's ordinary feeding routine under owner supervision.

3.2 Safety Plan

Mechanical hazards. The rotating auger creates pinch, hair, and entanglement hazards. It will be surrounded by a rigid housing with no pet-accessible opening large enough to reach the moving element. The motor driver enforces phase-current limiting, while firmware enforces no-flow detection and a 15 s run-time limit. Power will be disconnected before clearing a jam; hands or tools will never enter the auger while energized.

Food-contact and animal hazards. Food-contact parts will be removable, washable, and made from commercially documented food-contact stainless steel or polymer. For example, FDA regulations identify conditions for olefin polymers used in food-contact articles [15]. Unsealed hobby 3-D prints will not be used for long-term contact with food. Early tests will use non-food pellets or food that is discarded. The BLE tag will be secured to a breakaway collar, have no exposed battery, and be removed if its enclosure is cracked or can be chewed. The feeder will not dispense if a stable bowl-mass measurement cannot be obtained or if the measured food mass is already at or above the configured target.

Electrical and thermal hazards. Only listed, isolated, low-voltage external supplies will connect to the prototype. The custom PCB will include input protection, a fuse, current limiting, bulk capacitance, connector strain relief, and an enclosure that prevents contact with conductors. The A4988 exposed pad and copper area will follow the manufacturer layout guidance, and thermal testing will verify that the driver does not enter shutdown during the worst-case dispense. Wiring changes will be made with supplies disconnected. The Raspberry Pi and motor will use the power arrangements described in Subsystem 4 rather than sharing an undersized rail.

Failure behavior and cybersecurity. A lost Wi-Fi connection must never cancel the local meal schedule; it only delays remote reporting. Similarly, loss of Raspberry Pi communication will disable vision monitoring but will not prevent scheduled local dispensing. Remote messages will not directly energize the motor. The prototype will accept schedule and portion configuration only after authorization, cap the target portion and number of daily meals, reject stale packets, and retain an audit record. During an active dispense operation, a controller reset, invalid mass measurement, jam indication, or motor timeout shall place the motor in the disabled state.

3.3 Societal, Economic, Environmental, and Global Context

The design may help owners who work irregular hours, have mobility limitations, or must verify a feeding event from another location. Separating local feeding from Internet reporting also makes the essential function less dependent on broadband availability. However, the device still assumes electricity, Wi-Fi for remote features, dry food compatible with the auger, and an owner able to clean and inspect the machine; it must not be presented as a replacement for daily animal care.

Closed-loop fill-to-target operation reduces repeated top-ups and may reduce wasted food. The separable electronics, motor, hopper, and washable bowl support repair rather than disposal of the entire product. A commercial reusable beacon avoids a second custom radio PCB during the prototype phase, while replaceable batteries and electronic waste will be handled through appropriate recycling streams. If developed beyond a course prototype, regional radio, electrical, food-contact, privacy, and animal-welfare regulations would require a new compliance review rather than assuming that a U.S. laboratory prototype is universally deployable.

4 Conclusion

This proposal combines a reliable scheduled-feeding core with evidence about what happened after the meal. Closed-loop bowl weight controls the delivered quantity; BLE supplies a useful coarse proximity cue; computer vision confirms presence in the feeding zone; and subsequent weight loss provides direct evidence that food left the bowl. The custom ESP32 PCB remains the main controller and enforces safe operation even when the Raspberry Pi or Internet connection is unavailable. The requirements and tolerance budget make each claim testable within one semester while preserving the explicit single-pet scope established during project approval.

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