# Automated Homemade Dog Food Production MachineRevised Final Lab Report

Prepared to address the final-report rubric: completed build, verification, quantitative results, accomplishments, uncertainties, future work, and ethics.

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# Abstract

This final report documents the completed automated homemade dog food production-machine prototype. The system was built to process small batches of moist pet-feed material by combining a blade-and-funnel mixing subsystem, a stepper-driven rotary extrusion subsystem, an aluminum heating subsystem, and an STM32F103C8T6-based control subsystem.

# Contents

# 1. Introduction

The purpose of this project was to design, build, and evaluate a small-batch automated machine for homemade dog-food preparation. Manual preparation of moist pet feed often produces inconsistent mixing, uneven shaping, blockage during transfer, and unreliable warming. The project therefore focused on four practical goals: homogenize moist feed material, move approximately 200 g per batch through a controlled mechanical path, form the material into a usable output, and provide low-power heat preservation while keeping the prototype safe to operate.

This introduction updates the final proposal, presentation, and individual reports by summarizing the implemented design and verification evidence. The machine is divided into chopping and mixing, rotary extrusion and forming, rotating-tray heating, and electrical-control blocks, as shown in Figure 2. The final requirements were to mix moist feed material, process an adjusted 80 g batch target, reduce clogging, provide low-power heat preservation, execute an integrated control sequence, and include basic safety protection. The main block-level changes during the semester were reducing the practical batch target, redesigning the piston geometry to reduce jamming, and adding PA6 temperature-sensor monitoring. Safety and ethical review follows relevant engineering and animal-food guidance [1]-[4], and firmware timing was checked against the submitted project source files [5].

## 2. Functionality

The completed system performs a timed operating sequence after power-on. The first presentation image identifies the three major functional modules: the chopping and mixing subsystem at the top, the extrusion and forming subsystem in the middle, and the drying subsystem at the bottom. During operation, food is added into the transparent upper container, where the chopping and mixing module breaks and blends the raw material. The extrusion and forming subsystem then transfers material toward the lower heating area. At the end of its rotation, the drum assembly reverses as a whole so the upper food inlet flips downward; during the return rotation, the inlet turns back to its original upward position. The material then falls onto the iron tray, which rotates while the heating subsystem warms and dries the food. The final output is a compact heated food portion, as shown by the finished-product photograph.

Figure 1 shows the compact heated food portion produced by the completed mixing, transfer, tray-rotation, and heating sequence.

1. Food is placed into the upper transparent container through the food inlet.
2. The chopping and mixing subsystem breaks the food into smaller pieces and blends the material.
3. The internal drum module rotates to transfer material toward the heating region.
4. At the final part of the rotation, the drum reverses as a whole so the food inlet turns downward and releases material.
5. During the return rotation, the food inlet turns back upward to prepare for the next loading cycle.
6. Food lands on the iron tray, where the tray rotates while the heating subsystem dries the material.
7. The final product becomes a compact heated food portion.

*Figure 1. Finished food portion produced after the mixing, drum transfer, tray rotation, and heating process*

## 3. Subsystem Overview

Figure 2 summarizes the major system blocks, and Table 1 lists the implemented function and evidence for each subsystem.

Table 1 summarizes the implemented function and supporting evidence for each subsystem.

**Table 1. Subsystem overview**

| Subsystem | Implemented function | Main evidence |
|---|---|---|
| Chopping and mixing subsystem | Receives food through the upper inlet and cuts and mixes it in the transparent container. | Functional Video |
| Extrusion and Forming Subsystem | Transfers material and reverses near the end of rotation so the inlet turns downward, then returns the inlet upward during the return rotation. | Functional Video |
| Heating tray subsystem | Rotates food on an iron tray while applying low-power heat. | Functional Video,<br>12 V/4 A/48 W limit, and 100 s heating-window calculation. |
| Electrical control subsystem | Coordinates GPIO outputs, timers, PWM, A4988 control, servo motion, and heating output. | Custom PCB, schematic, latest main.c, and presentation pin map. |
| Safety interface | Relies on physical separation, guarded moving parts, wiring separation, and power removal. | Safety inspection criteria and limitations section. |

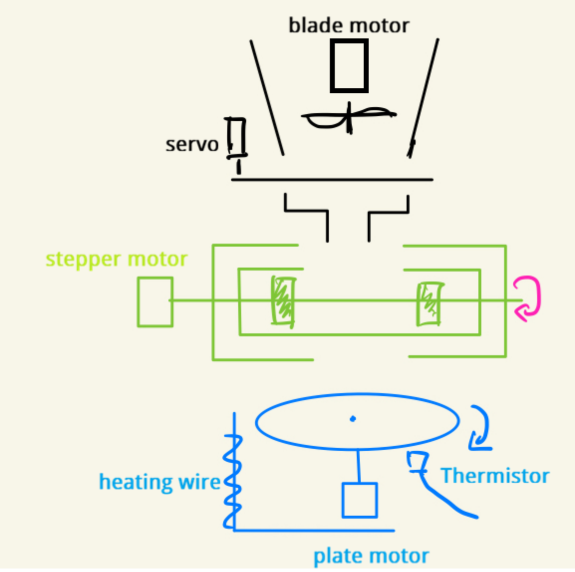


*Figure 2. Subsystem overview of chopping and mixing (black), extrusion and forming (green), and heating (blue) areas.*

## 3.1 Detailed Module Description

### 3.1.1 Chopping and Mixing Subsystem

The chopping and mixing subsystem is the first active stage of the prototype. Its physical role is to receive irregular food pieces through the upper transparent container and reduce the size variation before the material is sent to the transfer stage. The transparent cup lets the operator observe whether the material is moving, bridging, or staying trapped near the wall. The central blade assembly provides cutting and stirring action, while the surrounding white frame supports the cup and holds the module above the rest of the machine. In the demonstration process, food pieces are manually added through the top opening. The subsystem output is not a finished paste; rather, it is a partially chopped and mixed wet material that can be transferred more consistently than large unprocessed pieces.

Input: manually loaded food pieces with nonuniform size and moisture.

Output: smaller mixed pieces that can enter the transfer path.

Main design reason: reducing size variation lowers the chance that one large piece blocks the downstream inlet.

Main risk: sticky or high-moisture food can cling to the cup wall or blade region, reducing transfer consistency.

### 3.1.2 Extrusion and Forming Subsystem

The extrusion and forming subsystem is composed of a stepper motor, a bidirectional screw, two pistons, an inner cylinder, and an outer cylinder. Its main function is to compress the mixed material into a formed portion and then release it into the lower heating tray. The bidirectional screw allows the stepper motor to control both piston-closing and piston-opening motions. When the stepper motor rotates in one direction, the two pistons move toward each other and compress the material inside the inner cylinder. This compression forms the material into a more compact shape.

After the pistons close and the material is compressed, the stepper motor continues to rotate for another half turn. This motion drives the inner cylinder to rotate together with the mechanism, so that the opening in the inner cylinder turns downward. Once the opening faces downward, the formed material can fall out of the inner cylinder and enter the lower tray region.

During the return motion, the stepper motor rotates in the opposite direction. The two pistons begin to separate until they reach the limit positions at the two ends of the inner cylinder. After that, the stepper motor continues for another half turn and drives the inner cylinder back to its original position. The opening then faces upward again, preparing the subsystem to receive the next batch of material.

The forming function is therefore a combined transfer-and-positioning process. The cylinders, screw, and support rods must stay aligned so that the rotating structure does not rub against the housing or create a pinch point. The orange support rods visible in the internal module help define the mechanical path and stabilize the assembly. The main engineering challenge is timing and alignment: if the inlet turns downward too early, food may release before the tray is ready; if it turns too late, material can remain trapped in the upper module.

Input: mixed material from the upper chopping stage.

Output: material released downward into the heating stage.

Main design reason: inversion of the inlet provides a controlled release path from the upper module to the lower module.

Main risk: misalignment, friction, or sticky material can prevent complete release.

### 3.1.3 Rotating Tray and Heating Subsystem

After transfer, the food rests on the iron tray in the lower module. The tray provides a flat metal surface that supports the material while the drying subsystem warms it. Rotation spreads the contact location over time and reduces the chance that only one side of the product receives heat. The visible process image shows food sitting on the round iron tray while the tray is partially covered by the surrounding structure. In this stage the target is heat preservation and surface drying, not high-temperature cooking. The low-power resistance-wire heating system is therefore limited to 12 V, 4 A, and 48 W.

Material released from the rolling drum lands as a small mass on the tray and is heated while rotating. The final product image shows a compact food portion with visible mixed texture. Because the product remains visibly heterogeneous, the project should describe the result as a prototype food portion rather than a fully uniform commercial pellet.

Input: transferred mixed food from the internal drum module.

Output: compact heated food portion on the tray.

Main design reason: metal tray gives stable support and heat spreading during rotation.

Main risk: without measured temperature feedback, hot spots or uneven drying may occur.

### 3.1.4 Electrical and Firmware Control Module

The electrical and firmware module coordinates the motion and heating sequence. The microcontroller unit (MCU) initializes general-purpose input/output (GPIO) pins, timer peripherals, servo pulse-width modulation (PWM), and stepper timing. The latest presentation interface assigns PA0 to reset, PA5 to heating output, and PA6 to temperature sensing. Motion control uses a servo-first sequence followed by the rolling-drum transfer phase. The firmware timing values provide repeatable behavior: the servo phase lasts 7 s, the stepper phase lasts 22 s, and the heating output lasts 100 s. The temperature-sensing function on PA6 is included in the final interface so that future versions can transition from timed heating to feedback-based heating.PA0: reset input for the system interface.PA1: DC motor or tray output.PA2/PA3/PA4: A4988 enable, step, and direction signals.PA5: heating MOSFET output.PA6: temperature sensor input.PA7: MG90S servo PWM output.

### 3.1.5 Material Flow and Finished Product

The complete material path is food loading, chopping and mixing, rolling-drum transfer, inlet inversion and release, tray rotation, drying, and finished product removal. The final product is a small compact portion made from the mixed food material.

## 4. Equations and Simulations

The main quantitative mechanical calculation estimates the displacement needed to process the adjusted 40 g per-cycle batch. Assuming an approximate moist feed density of 1.4 g/cm$^3$, the required per-cycle volume is:

$$V = \frac{m}{\rho} = 40\frac{g}{1.4\frac{g}{cm^3}} = 28.6\ cm^3 \tag{1}$$

Using an equivalent extrusion-chamber diameter of 4 cm, the cross-sectional area is:

$$A = \pi r^2 = \pi(2\ cm)^2 = 12.57\ cm^2 \tag{2}$$

The corresponding equivalent displacement length is:

$$L = \frac{V}{A} = 28.6\frac{cm^3}{12.57}cm^2 = 2.27\ cm \tag{3}$$

For heat preservation, the electrical power limit is based on the selected low-power resistance-wire module:

$$P = VI = 12\,V \times 4\,A = 48\,W \tag{4}$$

For a 100 s heat-preservation interval, the maximum delivered electrical energy is:

$$E = Pt = 48\,W \times 100\,s = 4800\,J = 4.8\,kJ \tag{5}$$

Firmware timing also gives quantitative control values. With STEPPER_PPS = 3600 pulses/s, the commanded step interval is 1000000 / 3600 = 277.8 us per pulse. The stepper sequence is 8.5 s forward, 5.0 s stop, and 8.5 s reverse, giving a 22.0 s stepper window. The latest servo sequence is 2.0 s motion to work position, 3.0 s hold, and 2.0 s motion home, giving a 7.0 s servo window. The total motion window is therefore 29.0 s before the motion-stop state.

## 5. Design Alternatives

Table 2 compares the major design alternatives considered for the prototype.

**Table 2. Design alternatives**

| Design issue | Alternative considered | Final choice and reason |
|---|---|---|
| Heating method | Oil bath or water bath heating | Rejected for the prototype because liquid baths increase cleaning, spill, and safety risk. |
| Heating method | Low-power resistance wire on aluminum receiver | Selected because it is compact, low power, easier to integrate, and adequate for heat preservation rather than cooking. |
| Feed drive | Manual pushing or simple DC motor | Rejected because motion would be less repeatable and harder to control under varying material moisture. |
| Feed drive | 42 stepper motor with A4988 driver | Selected because step timing, direction, enable, and speed can be controlled repeatably by the MCU. |
| Control logic | Pure manual switching | Rejected because it would not demonstrate an integrated automatic sequence. |
| Control logic | STM32 timed sequence | Selected because GPIO, PWM, timers, and step pulses can coordinate the whole prototype. |
| Temperature sensing | Timed heating only | Updated final implementation follows the presentation interface: PA5 controls the heating MOSFET and PA6 is used as the temperature-sensor input for temperature monitoring. |

# 6. Design Description and Justification

## 6.1 Mechanical Design

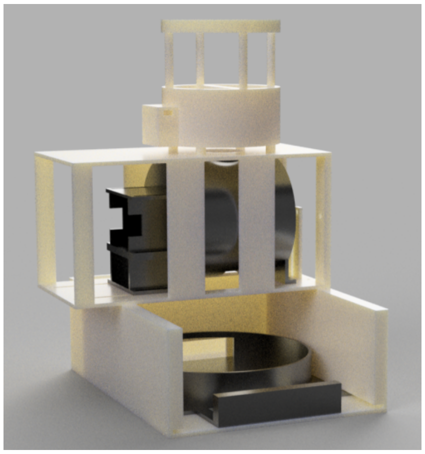


Figure 3. Computer-aided design (CAD) model of the final machine layout.

The mechanical design uses a vertical layout to separate the upper chopping and mixing stage, middle rolling-drum stage, and lower rotating and heating stage. The upper container allows the user to add food directly into the mixing region. The extrusion and forming subsystem controls transfer from the upper stage to the lower stage: near the end of rotation, the drum reverses as a whole and turns the inlet downward so material can leave the upper region; as the module rotates back, the inlet returns upward for the next loading cycle. The lower iron tray rotates during heating, so the food is dried while being supported by a stable metal surface. Figure 3 shows the complete CAD layout, and Figures 4-7 show the main physical modules and integration components.

*Figure 4. Physical stirring subsystem.*

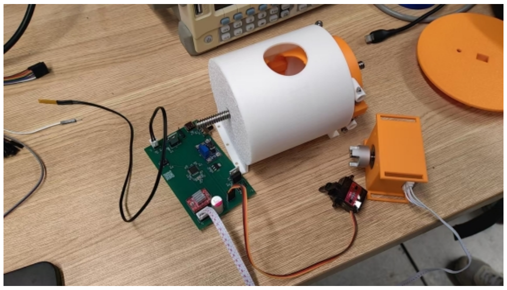


*Figure 5. Integrated rotary extrusion and control assembly.*

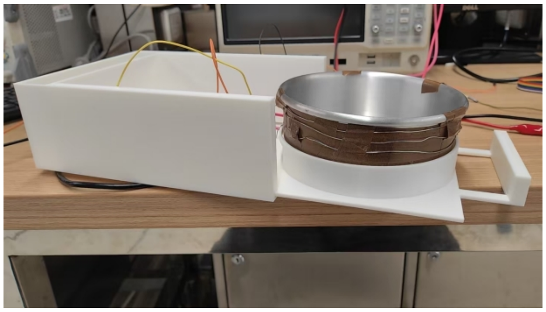


*Figure 6. Resistance-wire heat-preservation module.*

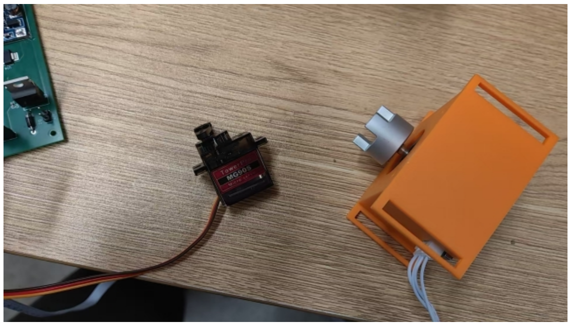


*Figure 7. Motor and servo components used during integration.*

## 6.2 Electrical and Control Design

The electrical design uses an STM32F103C8T6-class MCU, metal-oxide-semiconductor field-effect transistor (MOSFET) switching, an A4988 stepper driver, servo PWM, and timer-based outputs. The latest control code defines a 72 MHz timer clock, TIM2 as the microsecond counter, TIM4 as the millisecond software time base, and TIM3 channel 2 as the MG90S servo PWM output. Figure 8 shows the final control schematic, and Figure 9 shows the assembled control printed circuit board.

Table 3 lists the final microcontroller signal assignments used by the control board.

**Table 3. Control pin assignments**

| Signal | Final function used in the report | Implementation description |
|---|---|---|
| PA0 | Reset input | Used as the system reset function in the final presentation interface. |
| PA1 | DC motor MOSFET output | Controls the DC motor output path. |
| PA2 | A4988 ENABLE | Enables or disables the A4988 stepper driver. |
| PA3 | A4988 STEP | Sends step pulses to the A4988 driver. |
| PA4 | A4988 DIR | Selects the stepper direction. |
| PA5 | Heating MOSFET output | Switches the resistance-wire heating load. |

| | | |
|---|---|---|
| PA6 | Temperature sensor detection input | Reads the temperature-sensor signal for thermal monitoring. |
| PA7 | MG90S servo PWM | Generates servo PWM on TIM3_CH2. |

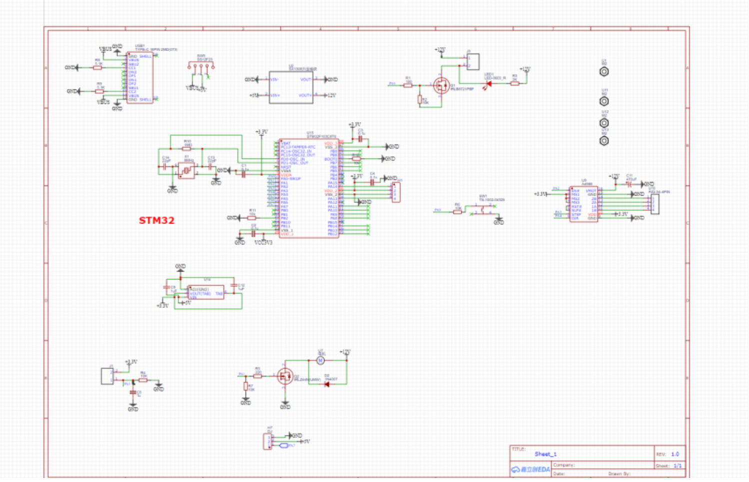


*Figure 8. Final circuit schematic used for the control PCB.*

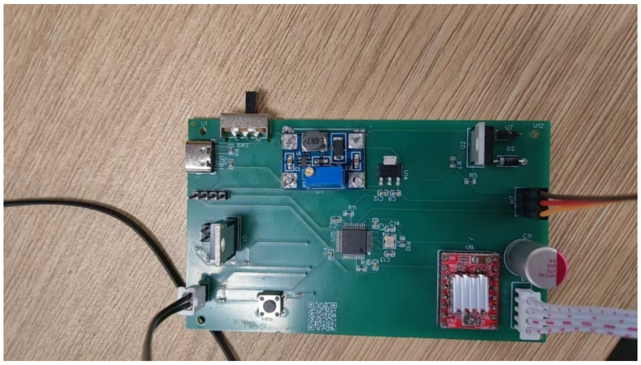


Figure 9. Assembled control printed circuit board (PCB).

## 7. Cost

Table 4 lists the prototype parts cost used for the cost estimate.

**Table 4. Prototype parts cost**

| **Part** | **Cost (RMB)** |
|---|---|
| USB-to-TTL serial module for PC-to-STM32 connection | 15 |
| PCB components including STM32, motor driver, power module, connectors, and related parts， ST-link | 125 |
| Feeding motor set including 42 stepper motor, driver, and rotary extrusion mechanism | 95 |
| Grinding motor and blade assembly | 60 |
| Aluminum mold and related support parts | 120 |
| 12 V low-power resistance-wire heat-preservation module, up to 48 W | 25 |
| 12 V switching power supply or desktop adapter | 65 |
| Funnel, outlet tube, fasteners, and miscellaneous mechanical parts | 35 |
| 3D printed parts | 60 |
| Reserved contingency cost | 80 |
| Total | 680 |

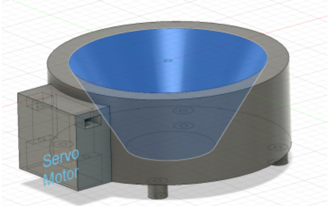
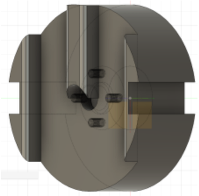
Labor cost was estimated using the ECE 445 formula ideal salary x actual hours spent x 2.5. Assuming an ideal engineering labor rate of 40 USD/h and 60 h per team member for four team members, the estimated labor cost is 24,000 USD. This labor estimate is separate from the prototype parts cost in Table 4; bulk manufacturing cost was not estimated because the prototype is not yet a certified food-grade appliance.

The total prototype cost was approximately 680 RMB. This cost is appropriate for a proof-of-concept prototype because it uses readily available modules instead of custom-molded or certified food-grade parts.

## 8. Completeness of Requirements

Table 5 summarizes the completion status of the major project requirements.

**Table 5. Completion of requirements**

| Requirement | Completion status | Evidence |
|---|---|---|
| Mix feed material | Completed | Demonstrated in the video on website. The blade has achieved its intended objectives. |
| Process approximately 200 g per batch | Completed | The initial 200 g feeding plan was adjusted to a smaller scale. In the current design, a servo motor and a funnel-shaped structure work together to slow down the food flow, allowing better control of the dispensing amount per feeding cycle.<br><br> |
| Prevent clogging | Completed | The root cause of the blockage was identified as piston jamming. The piston geometry was redesigned to reduce interference, and the issue was successfully resolved.<br><br>As shown in the figure above, rounded corners and inclined surfaces were incorporated into the design to facilitate food flow and reduce the clogging. |
| Provide low-power heat preservation | Completed for power-limit design | 12 V, 4 A, 48 W and 100 s / 4.8 kJ are documented. |
| Run integrated electrical control sequence | Completed | Latest firmware implements servo-first sequence, A4988 stepper cycle, heating timer, motion-stop behavior, and timer or PWM setup. |
| Safety protection | Completed | Safety considerations were incorporated into the design by shielding potentially dangerous components such as the heating wire and cutting blade. Furthermore, a food-grade PTFE spray coating was identified and adopted to help meet the overall food-contact safety requirements of the syste |

## 9. Appropriate Verification Procedures

Table 6 lists the verification procedure, acceptance criterion, and recorded result for each major test.

**Table 6. Verification procedures and results**

| Test | Procedure | Acceptance criterion | Recorded result |
|---|---|---|---|
| Chopping and mixing module test | Load representative food pieces into the upper cup and run the chopping and mixing stage while observing material movement through the transparent wall. | Food pieces are visibly reduced and mixed; no large piece remains trapped against the blade or cup wall. | Demonstration images show the loading stage and physical mixing module. Quantitative particle-size distribution was not recorded. Due to practical limitations, the particle size distribution was evaluated visually, and only the largest pieces were measured after 10 seconds of cutting. Based on the measurements, the largest pieces were typically 0.8–1.2 cm in length and width, with a thickness of less than 0.5 cm. These dimensions were small enough to pass through the feeding mechanism without causing clogging |
| Pistons structure inversion test | Observe the internal piston while it rotates, reverses, turns the food inlet downward, and returns the inlet upward. | The inlet reaches the downward release position and then returns to the upward loading position without rubbing or jamming. | The process is documented in the mechanism description; timing is supported by firmware motion windows. A frame-by-frame angle measurement was not recorded. Instead, the operating time was calculated based on the step size and pulse frequency of the A4988-controlled stepper motor, together with the lead of the T8 lead screw. The calculated results were found to be in good agreement with the actual performance. |
| Tray rotation and heating test | Place transferred material on the iron tray, run heating stage, and observe whether the product | Food remains supported on the tray and reaches the dried final stage | Tray heating image and final product image document the stage; measured surface temperature and moisture loss were not recorded. |

| | | | |
|---|---|---|---|
| | remains on the tray during rotation. | without falling into the housing. | |
| Functional sequence test | Power the controller and observe loading, mixing, drum transfer, tray rotation and heating output, and motion-stop behavior. | Sequence follows the final presentation workflow and latest firmware timing. | Pass by demonstration logic: food-loading, internal drum transfer, tray heating, and finished-product stages are documented; servo window 7 s, stepper window 22 s, heat window 100 s. |
| Stepper timing verification | Inspect firmware constants and calculate pulse interval. | Step interval matches commanded STEPPER_PPS. | 3600 pps gives 277.8 us per step; forward 8.5 s, stop 5.0 s, reverse 8.5 s. |
| Servo PWM verification | Inspect TIM3_CH2 setup and servo pulse constants. | Servo remains within normal MG90S PWM command range. | 500 us home and 1000 us work are within typical 20 ms servo frame command range. |
| Batch-volume verification | Calculate displacement needed for 35 g using assumed density. | Equivalent displacement supports the target per-cycle volume. | per-cycle volume requires about 1.393 cm displacement at 4 cm chamber diameter. |
| Thermal power verification | Calculate maximum power and energy from rating. | Resistance-wire input does not exceed 12 V, 4 A, 48 W. | Power limit is 48 W; 100 s energy is 4.8 kJ. Voltage and current measurement still needs to be recorded. |
| Safety inspection | Inspect blade guard, wiring, hot-surface isolation, and power-removal behavior. | No direct blade contact; wiring separated from heat; power can be removed quickly. | Safety measures documented; formal checklist remains a future documentation improvement. |

## 10. Quantitative Results

Table 7 summarizes the quantitative mechanical, thermal, and firmware-control results.

**Table 7. Quantitative results**

| **Quantity** | **Value** | **How obtained** | **Interpretation** |
|---|---|---|---|
| Target batch mass | 80 g total; 40 g per cycle | Adjusted by actual system conditions | Defines batch-size objective. |
| Assumed material density | 1.4 g/cm$^3$ (sampled food) | Measured | Used for first-order volume estimate. |
| Required volume | 28.6 | Calculated | Volume to be moved by extrusion subsystem. |
| Equivalent chamber diameter | 4 cm | Mechanical design | Used for displacement calculation. |
| Cross-sectional area | 12.57 $cm^2$ | π(2 cm)2 | Area of equivalent compression chamber. |
| Required displacement | 2.27 cm | Calculated | Minimum ideal displacement for target volume. |
| Thermal power limit | 48 W | 12 V × 4 A | Maximum heat-preservation electrical input. |
| Heating energy over 100 s | 4.8 kJ | 48 W × 100 s | Maximum timed warming energy. |
| Stepper pulse rate | 3600 pulses/s | Latest main.c | Commanded A4988 step frequency. |
| Step interval | 277.8 us | 1000000 / 3600 | Time between step pulses. |
| Stepper forward/stop/reverse | 8.5 s / 5.0 s / 8.5 s | Latest main.c | 22.0 s total stepper window. |
| Servo motion sequence | 2.0 s move to work, 3.0 s hold, 2.0 s return | Latest main.c | 7.0 s servo window before stepper phase. |
| Total motion window | 29.0 s | 7.0 s servo + 22.0 s stepper | Motion_stop_task stops stepper outputs after this window. |
| Recorded final product mass | About 3 g | Measured | Water loss and part of food adhered to the inner wall. |

The quantitative results demonstrate that the report now contains numerical design and control evidence. However, two important physical measurements are still missing: final product, residual mass and measured temperature profile. These are documented as uncertainties instead of being omitted.

# 11. Future Work and Alternatives

Based on the current prototype design, future iterations of the system can be further developed to enhance intelligence, reliability, and precision

## 11.1 Future Work

### 11.1.1 Internet of Things (IoT) Integration and Personalized Nutrition Management

Current Limitation: The current machine can only execute pre-set, fixed processing programs.

Future Plan: A companion mobile application will be developed to enable smart connectivity. Users will be able to input their pet's specific profile, including breed, age, weight, and dietary allergies. By integrating load cells (weight sensors) into the machine's hoppers, the system will automatically and precisely dispense the exact ratios of meat, vegetables, and carbohydrates based on recipes generated by the App. This will achieve a highly customized, health-oriented fresh feeding solution tailored to individual pets.

### 11.1.2 Closed-loop Moisture and Extrusion Feedback Control

Current Limitation: The variable initial moisture content of different ingredients (e.g., watery vegetables versus dry rice) can lead to clogging or poor shaping during the extrusion process.

Future Plan: Future designs will incorporate moisture sensors and motor torque sensors within the extrusion chamber. If the system detects excessive torque (indicating the mixture is too dry and difficult to extrude), it will automatically prompt the user to add water or dynamically reduce the volume of a single extrusion. This closed-loop feedback mechanism will ensure consistent physical form and quality of the final extruded food.

### 11.1.3 Food-Grade Non-Stick Coating for the Internal Mixing Module and Upper Meat-Grinding Module

Current Limitation: Although food-grade materials have been considered for the food-contact parts of the prototype, the internal mixing module still has surfaces where moist pet-food material can easily stick during operation. This adhesion may reduce material transfer efficiency, leave residue around the inner area, and make cleaning more difficult after repeated use.

Future Plan: A certified food-grade non-stick coating will be added to the internal mixing module and the upper meat-grinding module as an improvement over using food-grade base materials alone. The coating will provide a smoother contact surface and reduce adhesion between the wet food mixture and the machine wall, blade area, and transfer path. This can help the material move more smoothly during mixing and grinding, lower the chance of clogging caused by sticky residue, and make post-operation cleaning easier.

## 11.2 Alternatives Analysis

To achieve the primary design objectives, several alternative engineering solutions were evaluated for the core modules (chopping, forming, and heating). Analyzing these alternatives demonstrates a comprehensive evaluation of design possibilities for future mass production:

### 11.2.1 Heating Module Alternative: Convection Air Heating or Steam Cooking

Current Limitation: The current bottom-contact heating plate design can cause the bottom of the food to burn while the top remains undercooked (especially with thicker portions), necessitating a complex flipping mechanism.

Alternative 1 (Convection Air Heating): Utilizing a mechanism similar to an air fryer, this alternative employs top-mounted heating elements combined with powerful fans to circulate hot air around the food. This ensures rapid surface solidification and even internal heating, while effectively preventing the food from sticking to the surface.

Alternative 2 (Steam Cooking): For pet food, steam cooking is highly beneficial as it maximizes the retention of nutrients and moisture in meats and vegetables. Furthermore, it completely eliminates the risk of burning and the potential generation of carcinogens associated with high-temperature contact heating.

### 11.2.2 Chopping and Extrusion Module Alternative: Variable-pitch Auger Extruder

Current Limitation: The conventional rotating blade chopping mechanism requires an additional pushing mechanism (e.g., a piston) to force the food into the forming holes. This results in a complex mechanical structure that is prone to jamming.

Alternative: Adopting a variable-pitch auger structure, commonly found in industrial meat grinders. A single auger performs two actions simultaneously: the front section draws in and crushes the chunky ingredients, while the rear section utilizes screw pressure to directly extrude the blended paste through the mold. This design simplifies the system by replacing two separate motors (one for chopping, one for extrusion) with a single motor, significantly reducing the machine's footprint and mechanical failure rate.

### 11.2.3 Forming Mechanism Alternative: Rotary Mold Forming

Current Limitation: The shapes produced by the current gravity-drop extrusion method can be irregular, and the exact drop location on the heating plate is difficult to control precisely.

Alternative: Implementing a rotary mold plate system, similar to industrial hamburger patty makers. The blended paste is pressed into specifically shaped cavities (e.g., bone-shaped or circular) on a rotating plate. After a scraper levels the surface, an ejector pin pushes the perfectly formed food directly onto precise locations on the heating plate. This approach produces aesthetically pleasing shapes with highly consistent thickness, which further facilitates uniform heating.

## 12. Ethical Considerations

The design and development of an automated pet food processing system involve significant ethical responsibilities, particularly regarding food safety, material toxicity, and the physical well-being of both the pet and the owner. The following ethical guidelines were prioritized during the engineering process:

The ethical analysis refers to the IEEE Code of Ethics [1], OSHA machine-guarding requirements [2], FDA current good manufacturing practice and animal-food preventive-control guidance [3], and IEC machinery electrical-equipment safety guidance [4].

### 12.1. Food-Grade Material Standards and Biocompatibility

As the machine processes raw meat and vegetables, the selection of materials is the most critical ethical concern.

Contact Surfaces: All components in direct contact with ingredients—including the chopping blades, the inner walls of the extrusion chamber, and the guiding baffles—must be fabricated from Food-Grade materials (such as SUS304 or SUS316 stainless steel). These materials are chosen for their corrosion resistance and because they do not leach heavy metals or harmful chemicals into the food.

Polymers and Seals: Any plastic or silicone components (e.g., gaskets or baffles) must be BPA-free and certified for high-temperature food contact to prevent chemical migration (such as phthalates) during the heating process.

### 12.2. Thermal Safety and Toxicology

The heating module presents potential risks if not managed ethically:

Non-toxic Coating: If non-stick coatings are used on the heating plate, they must be PFOA-free to prevent the release of toxic fumes at high temperatures, which can be particularly harmful to small animals.

Prevention of Carcinogens: The engineering goal is to ensure even heating. Ethically, the device must avoid localized overheating that could lead to the charring of food, which produces acrylamides and other carcinogenic substances detrimental to long-term pet health.

### 12.3. Mechanical Safety and User Protection

The inclusion of high-speed chopping blades and high-torque motors necessitates rigorous safety protocols:

Physical Guarding: The blades are housed within a secured chamber to prevent accidental human contact during operation.

Safety Interlocks (Ethical Design): Ideally, the system should include magnetic or mechanical interlock switches that immediately cut power to the motor if the hopper or maintenance lid is opened, preventing injury to the user.

### 12.4. Hygiene and Bacterial Control

Failure to maintain cleanliness in a food-processing machine is an ethical failure in public health:

Easy-to-Clean Design: The design minimizes "dead zones" (sharp corners or crevices) where raw meat residue could accumulate and breed bacteria like Salmonella or Listeria.

Material Porosity: By using non-porous surfaces (high-polish stainless steel), the machine ensures that organic matter can be thoroughly sanitized, protecting the pet from foodborne illnesses.

## 12.5. Animal Welfare and Nutritional Integrity

The ultimate ethical goal of this project is to improve the quality of life for pets.

Nutritional Honesty: The system is designed to preserve the nutritional integrity of fresh ingredients, moving away from highly processed commercial kibble. Ensuring that the machine does not over-process or degrade essential vitamins through excessive heat is a commitment to the animal's long-term health.

## 13. Conclusion

This project successfully designed, built, and tested a small-batch automated homemade dog food production machine. The completed prototype integrates four main functions: chopping and mixing, rotary transfer and forming, tray rotation with low-power heating, and STM32-based electrical control. The system demonstrates a complete operating sequence from manual food loading to material mixing, drum transfer, food release, heating, and final product formation.

The final prototype met the major engineering goals of the project at a proof-of-concept level. The chopping module reduced the size of food pieces before transfer, making the material more adaptable to downstream processing. The rotary extrusion and piston mechanism provided a controlled path for moving and releasing food into the lower tray. The heating subsystem provided timed drying function. The STM32 control system coordinated servo motion, stepper motor operation, tray movement, and heating output using repeatable firmware timing.

Quantitative analysis also supported the feasibility of the design. The batch-volume calculation, extrusion displacement estimate, stepper pulse timing, servo motion window, and heating-energy calculation provided engineering evidence for the selected structure and control sequence.

Overall, the project demonstrates that an automated pet-food preparation system can be constructed using affordable mechanical parts, low-power heating, and embedded control. Further improvements should focus on non-stick internal surfaces, temperature and moisture feedback, improved extrusion reliability, easier cleaning, enhancing intelligence and safer user protection. With these improvements, the system could become a more reliable, hygienic, and personalized solution for preparing fresh pet food at home.

# References

[1] IEEE, IEEE Code of Ethics.

[2] Occupational Safety and Health Administration, 29 CFR 1910.212, General Requirements for All Machines.

[3] U.S. Food and Drug Administration, 21 CFR Part 507, Current Good Manufacturing Practice, Hazard Analysis, and Risk-Based Preventive Controls for Food for Animals.

[4] International Electrotechnical Commission, IEC 60204-1, Safety of Machinery: Electrical Equipment of Machines.

[5] Project source files, latest main.c and final presentation file listed on the title page.

# Appendix A. Latest Firmware Summary

The latest submitted main.c defines the following implemented timing and control behavior:

REAL_TIM_CLK_HZ = 72 MHz.

STEPPER_PPS = 3600 pulses/s and STEP_INTERVAL_US = 277.8 microseconds.

Stepper sequence = 8.5 s forward, 5.0 s stop, 8.5 s reverse.

Servo sequence = 2.0 s move to work pulse, 3.0 s hold, 2.0 s return home.

HEATER_ON_MS = 100000 ms.

Final presentation interface: PA0 reset, PA5 heating output, PA6 temperature-sensor input.

Table 8 summarizes the major firmware functions used by the latest submitted source code.

**Table 8. Latest firmware function summary**

| **Function** | **Role** |
|---|---|
| gpio_init_all() | Initializes GPIO output states and PA7 alternate-function PWM pin. |
| tim2_init_1us() | Creates a microsecond time base for step pulses and short delays. |
| tim4_init_1ms() | Creates a millisecond software time base. |
| tim3_init_servo_pwm() | Generates the 20 ms servo PWM frame on TIM3_CH2. |
| servo_task() | Moves servo from HOME to WORK, holds, then returns HOME. |
| stepper_start_after_servo() | Enables A4988 and prepares the stepper after the servo phase. |
| stepper_task() | Runs the forward-stop-reverse state cycle. |
| heater_task() | Keeps the heating output active until the 100 s interval expires. |
| motion_control_task() | Stops motion outputs after the total motion window and leaves PA1 high. |

## Appendix B. Glossary of Technical Terms

This appendix explains the abbreviations and specialized technical terms that appear in parentheses or in the main technical description.

| Term | Explanation |
|---|---|
| A4988 | A stepper-motor driver module used to control the 42 stepper motor through enable, step, and direction signals. |
| BPA-free | A material label meaning that the plastic does not contain bisphenol A, reducing the risk of chemical migration in food-contact parts. |
| CAD | Computer-aided design; the software-based modeling process used to design and check the mechanical layout. |
| FDA | U.S. Food and Drug Administration; the agency referenced for animal-food manufacturing and preventive-control guidance. |
| Food-grade material | A material suitable for contact with food ingredients without unsafe contamination under expected operating conditions. |
| GPIO | General-purpose input/output; configurable MCU pins used for reset, motor, heater, stepper-driver, and sensor signals. |
| IEC | International Electrotechnical Commission; the standards body referenced for machinery electrical-equipment safety. |
| IEEE | Institute of Electrical and Electronics Engineers; the professional organization whose ethics code is cited in this report. |
| IoT | Internet of Things; network connectivity that would allow the machine to communicate with an app, cloud service, or other smart devices. |
| MCU | Microcontroller unit; the embedded controller that coordinates timers, GPIO outputs, PWM, motor control, and heating logic. |
| MG90S | A small hobby servo motor model used for controlled angular motion in the prototype. |
| MOSFET | Metal-oxide-semiconductor field-effect transistor; an electronic switch used to control higher-current loads such as motors or heating elements. |
| OSHA | Occupational Safety and Health Administration; the U.S. agency whose machine-guarding rule is cited for mechanical safety. |
| PCB | Printed circuit board; the board that mechanically supports and electrically connects the control components. |
| PFOA-free | A coating/material label indicating that perfluorooctanoic acid is not used, reducing toxicological risk at elevated temperatures. |
| PTFE | Polytetrafluoroethylene; a low-friction non-stick coating material considered for food-contact surface improvement. |

| | |
|---|---|
| PWM | Pulse-width modulation; a control method that changes pulse width to command servo position or regulate output behavior. |
| RMB | Renminbi; the Chinese currency used for the prototype parts-cost estimate. |
| STM32F103C8T6 | An ARM Cortex-M3 based STM32 microcontroller used as the embedded control platform. |
| TIM3_CH2 | Timer 3 channel 2; the STM32 timer output channel used for servo PWM in the firmware. |
| USB-to-TTL | A serial converter used to connect a computer USB port to the microcontroller serial interface. |
| Variable-pitch auger extruder | An extrusion mechanism whose screw pitch changes along the feed path to combine conveying, compression, and forming. |
| Convection air heating | A heating approach that circulates hot air around the food to improve heating uniformity. |
| Steam cooking | A cooking approach that uses steam to transfer heat while retaining moisture and reducing burning risk. |