

E-PEEL: Electronic Peeling Equipment for Easier Living

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1. Introduction

1.1 Problem

Traditional peelers require both firm grip strength and precise fine motor control to operate safely and effectively. For older adults and individuals living with arthritis, tremors, or other conditions that reduce hand strength or dexterity, these demands make peeling not just difficult but genuinely hazardous. The risk of cuts increases significantly when grip is unreliable or when tremors cause the blade to slip. Though it may seem so, this is not a niche concern: according to the U.S. Census Bureau, over 24 million Americans aged 18 or older require assistance with activities of daily living (ADLs) [1], and the United Nations projects that the global older adult (age 65+) population will almost double from 9.3% in 2020 to 15.9% in 2050 [2]. As this demographic grows, so does the need for developing assistive technologies that preserve functional independence at home.

Meal preparation is widely classified as an instrumental activity of daily living (IADL), a category of tasks essential for independent community living. Including activities such as financial management, shopping, and cooking, an inability to perform IADLs is a key indicator of declining independence [3]. The inability to prepare one's own meals can accelerate dependence on caregivers, contribute to nutritional deficiencies, and diminish overall quality of life. Despite this, the kitchen remains one of the least-addressed environments in assistive technology design. A broad scoping review of over 205 human-robot interaction (HRI) studies spanning 2010-2022 found that meal preparation was one of the least-supported IADL tasks across existing robotics literature [4]. Another scoping review of 100 assistive kitchen technologies further found that peeling and food preparation receive significantly less attention than other kitchen tasks, with device usability and affordability consistently cited as barriers to realistic adoption [5].

Fully autonomous robotic solutions are presented in research literature. A primary example is MORPHeus, a single-arm system that utilizes multimodal active perception to peel a wide variety of vegetables with no user intervention [6]. However, systems of this complexity are expensive, physically large, and otherwise unrealistic for use in residential environments. Additionally, research consistently shows that older adults are consistently less likely to adopt fully autonomous assistive technologies, preferring semi-autonomous designs that maintain meaningful user control [4], [5]. This reflects the need to develop systems that are transparent, interruptible, and operable without training. Any realistic peeling alternative must be sure to balance functionality with simplicity of use.

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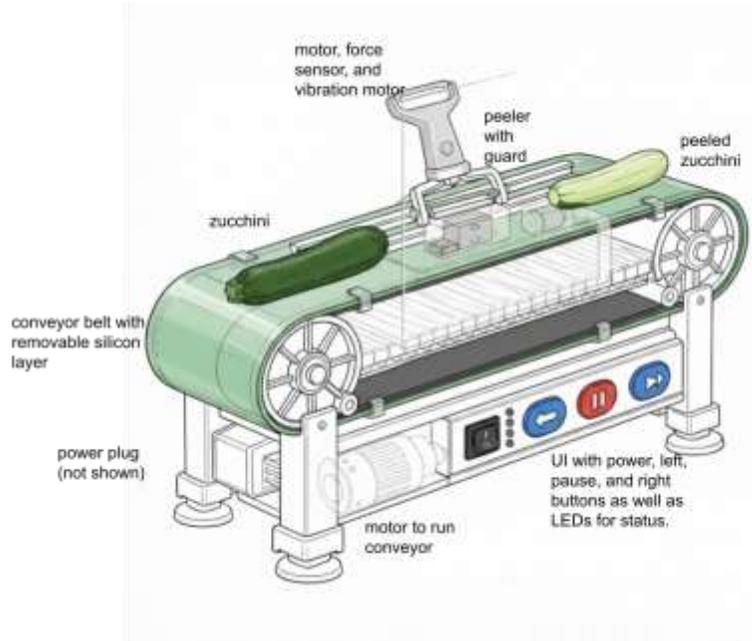
1.2 Solution

E-PEEL is a semi-autonomous peeling assist device designed to eliminate the grip strength and fine motor demands of manual peeling while still preserving the meaningful control of the user. The system consists of two primary mechanisms: a motorized conveyor belt and an actively compliant blade holder. The user places a cylindrical vegetable (e.g. zucchini) lengthwise on the belt, then initiates motion via a single button press. The belt transports the vegetable lengthwise beneath the blade, peeling it along its length without any further user handling. The blade holder uses real-time force feedback from a load cell to maintain consistent blade contact pressure despite varying surfaces and shapes of vegetables. A vibration motor mounted near the blade improves peeling consistency by reducing skin adhesion without increasing applied force. Three push buttons for forward, reverse, and pause allow the user to maintain direct control over the belt's motion, enabling jam recovery and repositioning. The device operates on AC power via an external low-voltage DC adapter, eliminating battery runtime constraints.

Safety and ease of cleaning are critical design requirements, as they will determine whether the device is a realistic solution for the target users. All food-contact surfaces are removable without tools: the blade assembly slides off two guide rails secured by a plastic swivel lock, and the conveyor belt's food-safe silicone outer layer clips onto the belt substrate and detaches independently for washing. This separates the stationary mechanical and electrical subsystems from any food-safe components, ensuring straightforward cleaning. To ensure the safety of users, the blade is enclosed by a physical guard that prevents accidental contact from above or from the side during operation. The device also enforces a state machine that restricts blade vibration exclusively to the active peeling state; pressing any button immediately transitions the system to a paused state, halting both belt motion and vibration. Four LEDs provide continuous feedback on power status and belt movement allowing users to instantly and easily confirm device state.

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1.3 Visual Aid



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Figure 1: Preliminary design of E-PEEL (developed with the assistance of Nano Banana Pro)

1.4 High-level Requirements

- The device must successfully peel at least 80% of the surface area of at least two distinct cylindrical vegetables (any combination of zucchini, carrot, potato, or cucumber) within 4 minutes of initiating the first conveyor pass. Peeling coverage must be achievable using only the three control buttons and manual vegetable rotation between passes; the conveyor must transport the vegetable beneath the blade without requiring the user to touch, stabilize, or otherwise manipulate the vegetable while the belt is in motion.
- The device must respond to any user button input (forward, pause, or reverse) within 1 second of actuation, immediately halting blade vibration and belt motion upon a pause or reverse selection, ensuring that the user always retains consistent and meaningful real-time control over the device's behavior.
- The power subsystem must deliver stable voltage of 12 V, 6 V, and 5 V (within $\pm 10\%$) to the stepper driver, servo motor, and microcontroller respectively, under full simultaneous motor load, drawing entirely from a standard 120 VAC wall outlet. All user-accessible surfaces must be isolated from any voltage exceeding 12 VDC. If the current sensor detects a sustained motor stall, the system must automatically halt the conveyor within 1 second to prevent motor burnout.

2. Design

2.1 Block Diagram

Peeler System

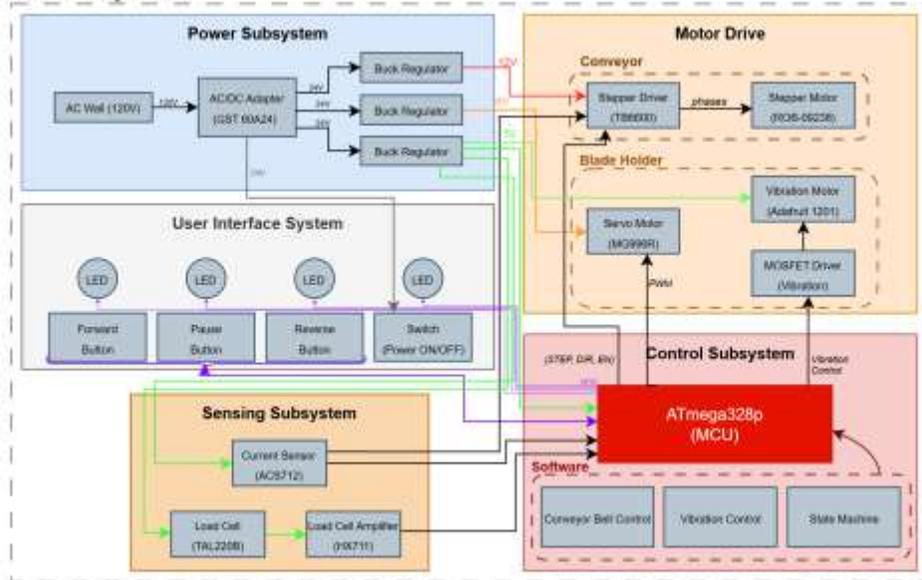


Figure 2: E-PEEL Block Diagram

2.2 Subsystem Overview

2.2.1 Power Subsystem

This subsystem provides all regulated DC power rails for the system from standard wall power. An AC/DC adapter converts 120 VAC to a 24 VDC bus, and buck regulators then step this down to the 12 V, 6 V, and 5 V rails required by the motors, motor drivers, MCU, and sensors. These rails are distributed to the Motor Drive, Control, Sensing, and User Interface subsystems to ensure the full system operates correctly. By using switching regulation and a centralized 24 V supply, the power subsystem maintains stable voltages under changing motor loads, reduces the risk of errors, and minimizes heat dissipation.

Motor Drive

This subsystem converts electrical power and MCU commands into the mechanical motion required to peel and transport the vegetables. It includes the blade-holder actuation and the conveyor drive: the MCU commands the MG996R servo using a PWM control signal to adjust blade position by determining the pressure put to the vegetable in real time based on force feedback from the sensing subsystem, while a MOSFET switching stage enables the vibration motor near the blade to improve peeling consistency. For vegetable transport, the MCU provides control signals to the TB6600 stepper driver, which generates the phase currents needed to drive the conveyor stepper motor and move the vegetable forward or reverse as required by the system state and user inputs. The Motor Drive subsystem receives regulated power rails from the Power Subsystem and interfaces with the Control Subsystem MCU for critical motor control.

User Interface System

This subsystem provides manual control inputs and visual status feedback for operating the peeler. A power switch enables or disables the system, while the Forward, Pause, and Reverse push buttons send user commands to the MCU through dedicated GPIO inputs. The MCU interprets these button commands within the state machine to control conveyor motion and overall operation. Four LEDs driven by MCU GPIO outputs provide clear indication of the current operating state (forward, paused, reverse, and power/ready), allowing the user to confirm the machine's status at a glance. This subsystem interfaces directly with the Control Subsystem for logic level signaling for the buttons and LEDs.

Sensing Subsystem

This subsystem measures physical quantities needed for safe and consistent peeling and provides these measurements to the Control Subsystem for feedback and protection. A load cell (TAL220B) mounted in the blade holder measures the normal force applied by the blade to the vegetable. Its low-level signal is amplified by the HX711 load cell interface, which sends force readings to the MCU over a digital clocked interface (SCK). In addition, a current sensor (ACS712) is connected to the conveyor stepper driver so it can measure the current. These measurements allow the MCU to regulate blade contact force and to detect stall or jam conditions so the system can pause or limit actuation to prevent motor burnout and improve overall safety. The sensing subsystem is powered by the Power Subsystem and interfaces directly with the Control Subsystem through digital and analog signal connections.

Control Subsystem

This subsystem serves as the central controller that coordinates user commands, sensor feedback, and motor actuation to operate the peeler safely and consistently. The ATmega328p reads the Forward/Pause/Reverse buttons and power/status inputs through GPIO, and it acquires measurement data from the sensing subsystem, including blade force readings from the HX711 and motor drive current from the ACS712. Based on these inputs, the MCU executes the system state machine and generates the required control outputs: signals to the TB6600 for conveyor motion, a PWM control signal to the MG996R servo to adjust force applied on blade, and a control signal to the MOSFET driver to enable the vibration motor when appropriate. The MCU also drives the LEDs to indicate the current operating state to the user. This subsystem is powered from the regulated power rail provided by the Power Subsystem and interfaces directly with the User Interface, Sensing, and Motor Drive subsystems.

2.3 Subsystem Requirements

2.3.1 Power Subsystem

This subsystem converts 120VAC wall power into regulated DC rails to meet all other subsystem component requirements for reliability and safety. A Mean Well GST60A24-P1J component would generate a 24V DC bus (2.5A, 60W max) which would feed into three different buck regulators for 12V, 6V, 5V power rails. Pololu D36V50F12 component converts 24V to 12V which powers the conveyor stepper driver. Pololu D36V50F6 component converts 24V to 6V which powers the servo motor mounted on the blade holder. Pololu D36V50F5 component converts 24V to 5V which powers the MCU for 16 MHz, vibration motor, current sensor, and the load cell. The subsystem must maintain each rail within its specified tolerance under the worst-case scenarios to prevent unintended behaviors.

- AC/DC Adapter: Mean Well GST60A24-P1J (24V DC $\pm 3\%$, 2.5A rated current, 60W max)
 - Datasheet: <https://www.meanwell.com/Upload/PDF/GST60A/GST60A-SPEC.PDF>
- 12V rail option: Pololu D36V50F12 (Input: 13.3–50V, Output: 12V with 4% accuracy, 4.5A)
 - Datasheet: <https://www.pololu.com/product/4095>
- 6V rail option: Pololu D36V50F6 (Input: 6.5–50V, Output: 6V with 4% accuracy, 5.5A)
 - Datasheet: <https://www.pololu.com/product/4092>
- 5V rail option: Pololu D36V50F5 (Input: 5.5–50V, Output: 5V with 4% accuracy, 5.5A)
 - Datasheet: <https://www.pololu.com/product/4091>

2.3.2 Motor Drive

The Motor Drive subsystem receives the regulated power and MCU control signals which allows to transport the vegetable and maintain effective peeling contact. For the conveyor, a TB6600 stepper driver is powered from 12V supply rail and receives MCU control inputs (STEP/CLK, DIR/CW-CCW, and EN) to generate the two-phase coil currents required by the SparkFun ROB-09238 stepper motor (1.8° step angle, 12V, 0.33A). The conveyor includes an ACS712 current sensor placed in series with the TB6600 supply so the current can be monitored. For the blade holder, the MCU outputs a PWM control signal approximately 50 Hz to the MG996R servo which is powered from the 6V power rail to adjust blade position/force based on load cell feedback. It is connected to a MOSFET switching stage to power the Adafruit 1201 vibration motor with a controlled duty cycle to improve peel consistency.

Requirements:

- MCU STEP/CLK pulses must meet minimum pulse width $\geq 2.2 \mu\text{s}$ for reliable stepping.
- Target Force Value: Initial target normal force is $\sim 1\text{--}2 \text{ N}$, which is sufficient to peel typical vegetables like zucchini, carrot, and potato. We will experiment with these values to find the best-performing force.
- Force Range Variation: Peeling force varies with vegetable type and skin toughness. Some papers indicate forces between 0.8 N and 2.5 N are generally effective for common cylindrical vegetables, we'll have to test this.

Components:

- Stepper Driver: Toshiba TB6600
 - Motor supply voltage: 9V – 42V
 - Output current: up to 4.5A peak
 - STEP/DIR interface
 - Datasheet: https://toshiba.semicon-storage.com/info/TB6600HG_datasheet_en_20160610.pdf?did=14683&prodName=TB6600HG
- Stepper Motor: SparkFun ROB-09238
 - Rated Voltage: 12V
 - Step Angle: 1.8° (200 steps/rev)
 - Phase Current: $\sim 0.4\text{--}1.2\text{A}$ per phase (verify exact listing revision)
 - 4-wire configuration (A+, A-, B+, B-)
 - Datasheet: <https://www.sparkfun.com/stepper-motor-32-oz-in-200-steps-rev-1200mm-wire.html>
- Servo Motor: TowerPro (MG996R)
 - Operating Voltage: 4.8V – 7.2V
 - Stall Torque: $\sim 9\text{--}11 \text{ kg}\cdot\text{cm}$
 - Stall Current: up to 2.5A peak

- Control: PWM (50 Hz, 1–2 ms pulse width)
- Datasheet: <https://towerpro.com.tw/product/mg996r/>
- Vibration Motor: Adafruit 1201
 - Operating Voltage: 2–3.7V
 - Typical current: ~80–100 mA
 - Datasheet: <https://www.adafruit.com/product/1201>

2.3.3 User Interface System

- (4x) Green LED: Mouser Electronics 606-4302H5-5V

- Operating Voltage: 5-7.5V
- Rated current: 12 mA

Datasheet: <https://www.mouser.com/ProductDetail/VCC/4302H5-5V?qs=qp111mKzDjjxM5ex4WzyIw%3D%3D>

- (3x) Button: E-Switch TL1105BF160Q

- 12V supply
- Rated current: 50 mA

Datasheet: <https://www.e-switch.com/product/tl1105-series-through-hole-tactile-switch/>

- Switch: Gardner Bender SPST Appliance Rocker Switch GSW-42

- Current: 16A at 125 VAC, 8A at 250 VAC

Datasheet: https://www.gardnerbender.com/-/media/inriver/GSW-42_SPEC.pdf?modified=20200714164659

2.3.4 Sensing Subsystem

The ACS712 current sensor is connected in series with the TB6600 stepper driver to measure the current of the driver and the output is connected to the MCU. The current sensor's analog output is read by the MCU ADC to detect jam or stall conditions and trigger protective actions (pause/disable/reverse) to avoid overheating. The blade force is measured using a TAL220B load cell (output 1.0 ± 0.1 mV/V, excitation 3–10 V, ~1000 Ω input resistance), whose differential bridge output is digitized by an HX711 24-bit load-cell ADC. The HX711 communicates force measurements to the MCU using the DOUT/SCK serial interface.

Requirement:

- Current Sensor: Allegro Microsystems ACS712

- 5V supply
- Analog voltage output

Datasheet: <https://www.allegromicro.com/-/media/files/datasheets/acs712-datasheet.ashx>

- Load Cell (5kg Straight Bar): SparkFun TAL220B

- Rated Load: 5 kg (≈ 49 N)
- Rated Output: ~ 1.0 mV/V
- Excitation Voltage: 3–10 V (Recommended: 5V)
- Maximum Excitation Voltage: 10V
- Bridge Resistance: ~ 1 k Ω (typical)
- Output Type: Differential analog (Wheatstone bridge)

- Load Cell Amplifier: Avia Semiconductor HX711

- 24-bit ADC
- 2.6V–5.5V supply
- 2-wire interface (DOUT/SCK)

Datasheet: https://cdn.sparkfun.com/datasheets/Sensors/ForceFlex/hx711_english.pdf

2.3.5 Control Subsystem

The MCU we chose is ATmega328p. The device operates in 5V logic which is compatible with the TB6600 stepper driver, HX711 load cell amplifier, Adafruit 1201 vibration motor, ACS712 current sensor, servo PWM control, push buttons, and LED indicators, eliminating the need for level shifting circuitry. It also provides GPIO pins which support the LED indicators, PWM output for servo motor. Including the PWM signals, step pulses, and integrated ADC is a sufficient match to our device.

Requirements:

- Control Algorithm: We will use a threshold-based incremental adjustment: if the measured force is above the target range, the servo retracts slightly; if below, it advances. This approach is simpler than PID and sufficient for the semi-autonomous design.
- State Machine: Controls the overall system behavior and will have 4 states: Idle, Forward, Pause, Reverse. When fault conditions occurs during the forward state (peeling state), it will force stop for safety

- Vibration Control: Only enabled during the Forward state and disabled during pause or Reverse.

2.4 Tolerance Analysis

A critical risk of the proposed design is the ability of the blade to apply a consistent peeling force across different vegetables and different shapes. If the force applied is too low, the vegetable will not be peeled; if the force applied is too high, the peeler may cut into the vegetable, wasting produce and potentially stalling the conveyor. Successful completion of the project depends on whether the sensing system can reliably maintain the desired force range. Through testing, a successful range across different shapes and vegetables can effectively be determined.

3. Ethics, Safety, and Societal Impact

3.1 Ethical Considerations in Design

Engineering design requires careful consideration of the safety and trust of those who will interact with the product. Principles from both the IEEE Code of Ethics and the ACM Code of Ethics provide several general guidelines to abide by in this aspect, emphasizing avoiding harm, being transparent about limitations, and keeping potential societal effects in mind. These principles heavily influence the development of the E-PEEL device.

Because this product involves a motorized blade and moving mechanical parts in addition to being driven by electrical power, the major ethical consideration is user safety. The design intentionally minimizes user interaction during the peeling process by communicating system state and including safeguards that prevent hazardous behavior. The goal of this device is to assist individuals with reduced grip strength, arthritis, tremors, or other motor limitations. Thus, the project properly aligns with the ethical goals of using engineering to enhance accessibility and quality of life.

3.2 Safety Hazards

3.2.1 Mechanical Safety

The primary safety hazard in the system is accidental contact with the peeling blade as well as the conveyor when it is moving. Several design choices have been made to mitigate this risk. A fixed blade guard prevents access to the blade. Load-cell force sensing limits blade pressure to a safe range. Control logic ensures that the system can easily and safely be stopped and reversed, and the device stops if abnormal force or current is detected.

3.2.2 Electrical Safety

The system receives power from a standard 120V AC wall outlet and converts it to lower DC voltages required for operation. Dealing with high voltages present shock, so electrical isolation and proper power handling are critical design considerations. To reduce the risks, the device uses a certified AC/DC adapter to perform the conversion externally. All internal wiring will be insulated and will not be exposed to the user, especially from the food contact and blade regions to prevent accidental exposure to moisture. Users will be instructed to operate the device with dry hands to avoid introducing water during cleaning. The circuit will include overcurrent protection to prevent overheating and short circuits.

3.2.3 Motor Safety

If the conveyor becomes jammed, the motors may overheat. The current sensor allows the microcontroller to monitor the current being sent through the motor, and if abnormal current is detected, the system automatically stops to avoid motor damage and overheating.

3.2.4 Food Safety

Because the system is in direct contact with food, hygiene is critically important. The conveyor belt is covered with a removable food-grade silicone layer that can be detached and cleaned.

3.3 Transparency About Limitations

Transparency about system limitations is also critical. The device is semi-autonomous, and it is designed for specific types of vegetables. Documentation will be provided that clearly communicates operating procedures to prevent unsafe or unrealistic conditions or expectations.

3.4 Societal Impact

The E-PEEL device is designed to improve independence in daily living for individuals with limited motor control. By enabling safer meal preparation, the system has potential societal benefits including increased accessibility and reduced reliance on caregivers. Compared to complex robotic solutions, this device offers a simpler and more accessible solution.

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