E-PEEL: Electronic Peeling Equipment for Easier Living

By:

Saathveek Gowrishankar

Hyun Jun Paik

Varun Ramprakash

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TA: Manvi Jha

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Contents

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. An inability to perform IADLs, including activities such as financial management, shopping, and cooking, 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.

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 three primary mechanisms: vegetable rotation, blade movement, and blade pressure. The user sticks a cucumber onto the prongs to hold it in place, then initiates motion via a single button press. The blade then drops down to the cucumber, stopping when it makes contact. Next, the prongs start to rotate the cucumber as the screw system moves the blade mechanism laterally across the cucumber. The blade holder uses real-time force feedback from a load cell to maintain consistent blade contact pressure. Three push buttons for forward, reverse, and pause allow the user to maintain direct control over the system'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. The food-contact surfaces are removable without tools: the blade system can be removed for easy 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; pressing any other button while in the forward state immediately transitions the system to a paused state, halting both screw motion and rotation. Four LEDs provide continuous feedback on power status and screw movement allowing users to instantly and easily confirm device state.

1.3 Visual Aid

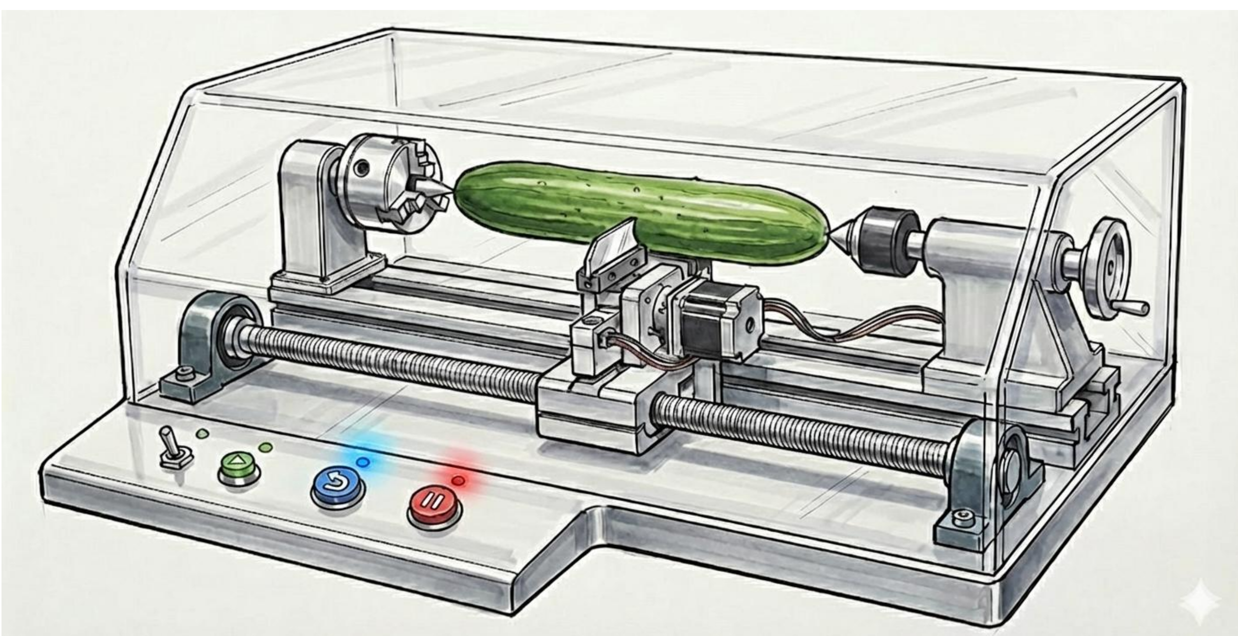

Figure 1: Redesign of E-PEEL (developed with the assistance of Nano Banana Pro)

1.4 High-level Requirements

- The device must successfully peel at least 85% of the surface area of a cucumber (additional vegetables will be considered after success with a cucumber) within 2 minutes of initiating the peeler. Peeling coverage must be achievable using only the three control buttons; users should not have to remove the acrylic shell between the initiation and completion of peeling.
- The device must respond to any user button input (forward, pause, or reverse) within 1 second of actuation, immediately halting blade movement upon a pause 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 5 V, 6-8.4 V, 12 V, 24 V (within ±10%) to the stepper motor driver, servo motor, gearmotor, microcontroller, and stepper motor 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 screw within 1 second to prevent motor burnout.

2. Design

2.1 Block Diagram

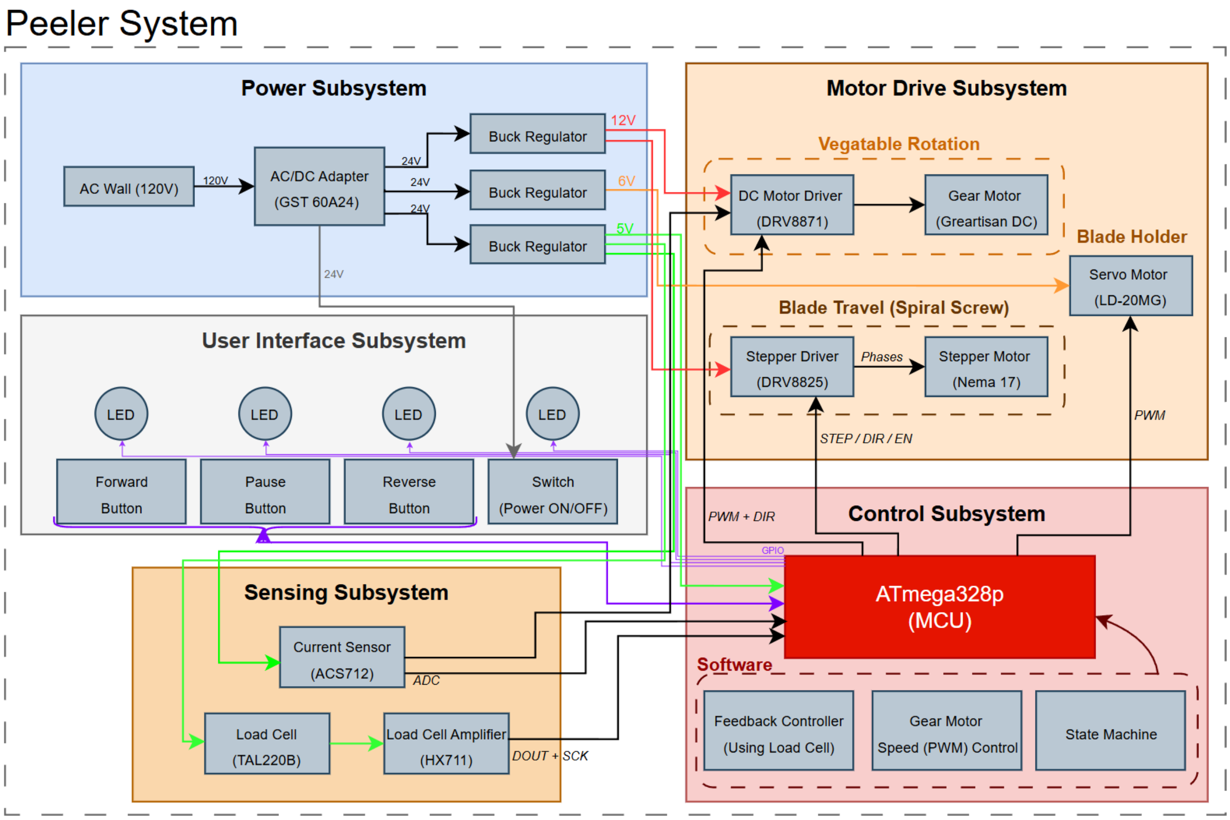

Figure 2: E-PEEL Block Diagram

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.

2.2.2 Motor Drive Subsystem

This subsystem converts electrical power and MCU commands into the mechanical motion required for vegetable rotation, blade positioning, and controlled peeling. It includes three motor controls: vegetable rotation, blade travel, and blade pressure adjustment. The vegetable rotation uses the gearmotor, which operates in one rotational direction to ensure continuous and uniform peeling. The blade pressure is connected to a servo motor so that the blade holder position can adjust to maintain consistent contact with the vegetable surface during peeling. The blade travel uses a stepper motor (NEMA 17) which actuates the spiral screw to move the blade linearly along the vegetable. Each of the motors interfaces with the MCU for precise motion control and receives regulated power from the power subsystem.

2.2.3 User Interface Subsystem

This subsystem provides manual control inputs and visual status feedback for operating the peeler. A power switch enables and 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 the blade positioning 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.

2.2.4 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 DC motor drive so it can measure the current. These measurements allow the MCU 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.

2.2.5 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 commands according to the finite state machine that manages states such as idle, forward, reverse, and pause for the blade travel. The MCU generates necessary control outputs for all motors. 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 DC motor Driver (DRV8871) for the vegetable rotation and stepper driver (DRV8825) for the blade travel on the spiral screw. Pololu D36V50F6 component converts 24V to 6V which powers the servo motor (LD-20MG) mounted to the blade holder . Pololu D36V50F5 component converts 24V to 5V which powers the MCU for 16 MHz, current sensor (ACS712), and the load cell (TAL220B). 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 ±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 Subsystem

The Motor Drive subsystem receives the regulated power and MCU control signals which enables driving the three motors responsible for vegetable rotation, blade travel, and blade pressure control. The DC motor driver (DRV8871) is powered by the 12V rail and connected with the gearmotor for vegetable rotation. The MCU provides PWM and DIR signals to control the gearmotor RPM speed. Also, the current sensor (ACS712) detects any jam or stall during the motor operation. When detected, the MCU disables the driver to stop the rotation for safety purposes. The stepper Driver (DRV8825) is also powered by the 12V rail and connected to the stepper motor (Nema 17) for blade travel. The MCU sends STEP / DIR / EN signals to the driver which generates the speed of the spiral rotation and direction of the rotation. Based on the signals received, it sends phases to the stepper motor so it would generate the appropriate control. The servo motor (LD-20MG) is powered by the 6V rail and receives PWM signals from the MCU. The feedback signals from the load cell provide exact signals to adjust the blade to have consistent contact and pressure onto the vegetable during peeling.

Requirements:

- MCU STEP/CLK pulses must meet minimum pulse width ≥ 2.2 µs for reliable stepping.
- Target Force Value: Initial target normal force is ~1–2 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: DRV8825
    - Operating voltage: 5V
    - Max Drive Current: 2.5A
    - STEP/DIR Interface
    - Datasheet: https://www.ti.com/lit/ds/symlink/drv8825.pdf

- Stepper Motor: Nema 17 Stepper Motor Bipolar 2A 59Ncm(84oz.in) 48mm Body 4-Lead
    - Rated Voltage: 12-24V (recommended 24V)
    - Speed: 200 rpm
    - Step Angle. 1.8°

- Servo Motor: LD-20MG (20kg Digital Servo)
    - Operating Voltage: 6V – 8.4V
    - Stall Torque: 20 kg·cm @ 7.4V
    - Stall Current: 2.4 – 3A
    - Control: PWM (50 Hz, 500–2500μs pulse width)
    - Wire Layout:
        - Red → +V
        - Black → GND
        - White → Signal

- Gearmotor: Greartisan DC
    - Rated Voltage: DC 12V
    - Reduction Ratio: 1: 31.6
    - No-Load Speed: 100 RPM
    - Rated Torque: 4.5Kg.cm
    - Rated Current: 1.1Amp
    - D Shaped Output Shaft Size: 6*14mm (0.24" x 0.55") (D*L)
    - Gearbox Size: 37 x 24.5mm (1.46" x 0.96") (D*L)
    - Motor Size: 36.2 x 33.3mm (1.43" x 1.31") (D*L)
    - Mounting Hole Size: M3 (not included)

- DC Motor Driver (DRV8871)
    - Rated Voltage: 6.5 V – 45 V (abs max 50 V)
    - Peak Drive Current: 3.6 A peak
    - PWM Frequency (recommended operating conditions): 0 – 200 kHz
    - Current Limit / Regulation: ILIM pin + resistor to GND sets trip current
    - Datasheet: https://www.ti.com/lit/ds/symlink/drv8871.pdf

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: Momentary Button - Panel Mount
  - Datasheet: https://www.sparkfun.com/momentary-button-panel-mount-black.html

- 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 DC motor driver (DRV8871) 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 kΩ (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 HX711 load cell amplifier, 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. Including the PWM signals, step pulses, and integrated ADC is a sufficient match to our device. The MCU would have software implementation for feedback control from the load cell, gearmotor speed control, and finite state machine for the correct operation of the blade travel. It is connected to all motor drivers and motors, and it sends accurate signals for proper operation: DC motor driver receives PWM + DIR signals, stepper driver receives STEP / DIR / EN signals, and servo motor receives PWM signals.

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.

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 enough or at all; if the force applied is too high, the peeler may cut into the vegetable, wasting produce. 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. Several design choices have been made to mitigate this risk. An acrylic cover 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 presents 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 gearmotor is 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.

3.3 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. Although food-safe materials would ideally be used in production of this product, the goal is primarily to create a prototype that demonstrates peeling functionality.

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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