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GCE

Final Report Document

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Executive Summary

Purpose

Great Combination Enterprise Co., Ltd. (GCE) is a leading Taiwanese manufacturer of filtration systems serving the semiconductor industry. The company sought to modernize its production line by addressing a key bottleneck in the manual insertion of separators into pleated air filters. This step, which currently takes 50–70 seconds and requires skilled labor, limits scalability and efficiency, all issues that have become more critical amid ongoing labor shortages in Taiwan.

To support GCE's modernization efforts, Generate collaborated with the client to design and prototype an automated pleat separation and separator insertion system capable of completing a cycle in under 40 seconds. The project involved defining key mechanical subsystems for pleat handling, actuation, and comb insertion; developing a control architecture based on a real-time embedded system; and integrating sensors for safety, feedback, and error detection.

Throughout the semester, the team followed an iterative engineering process, beginning with breadboard prototyping and conceptual CAD models, progressing toward a fully-automated minimum viable solution. Collaboration between mechanical, electrical, and software subteams ensured subsystem compatibility and reliability.

Beyond delivering a functional prototype and system documentation, the project offered valuable learning experiences for the Generate team in industrial automation, sensor integration, and system-level design for manufacturability. The resulting prototype provides GCE with a foundation to pursue full-scale automation, improve throughput, and reduce operator fatigue while maintaining the precision required for high-performance industrial filtration.

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Mechanical Design

Assembly Overview

The mechanical system of this project was designed to allow the user to input GCE's filters and output them accurately separated to 12 mm spacing between each filter pleat. The automated filter pleat separation system consists of four primary subsystems. First, a linear actuator uniformly compresses the filter pleats to ensure consistent spacing. Then, the filter runs underneath a variable-pitch lead screw that separates each pleat evenly. Third, acrylic combs are inserted via rollers into the filter to maintain the established distances between each pleat. Finally, a conveyor system transfers the processed filter for subsequent operations.

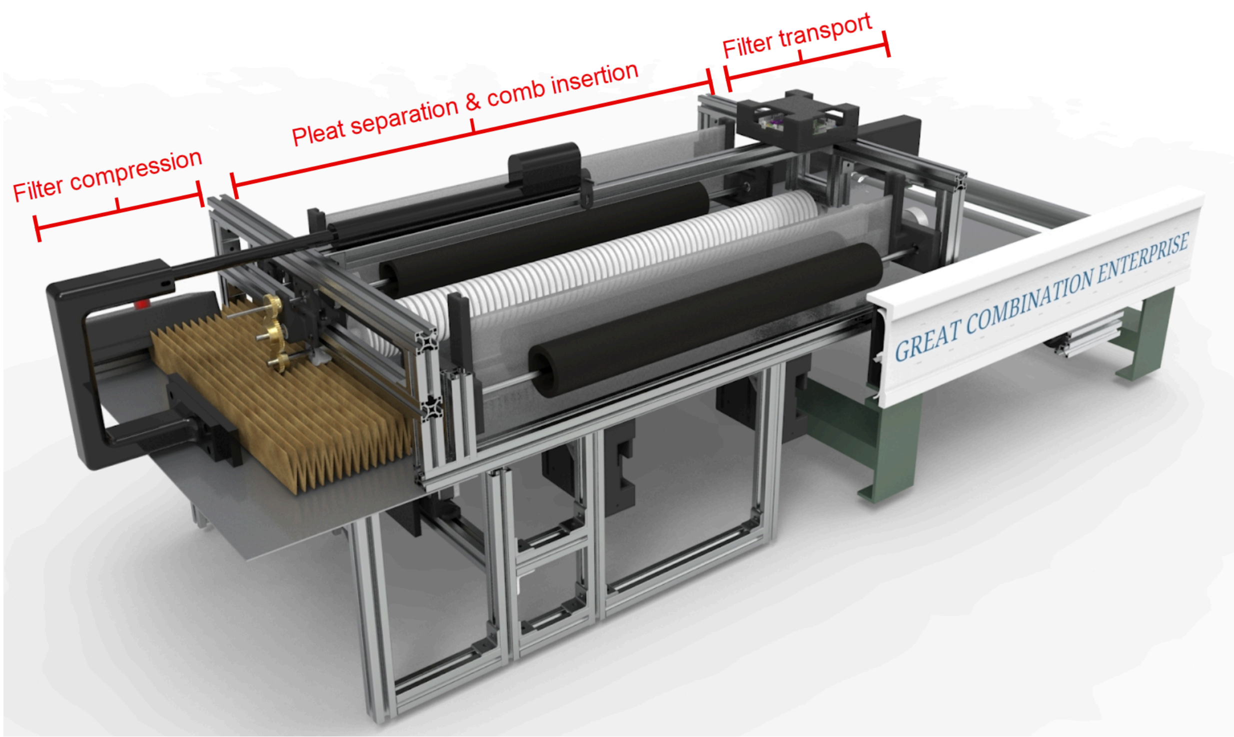
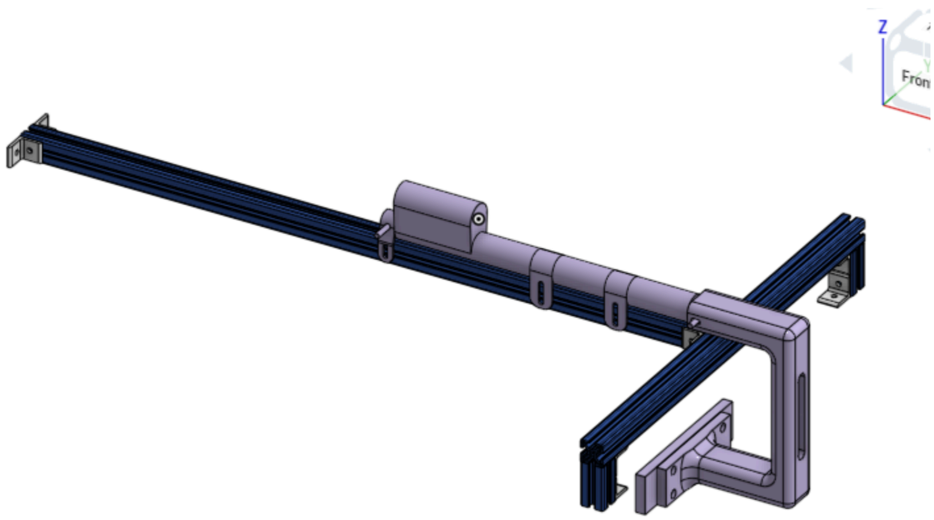
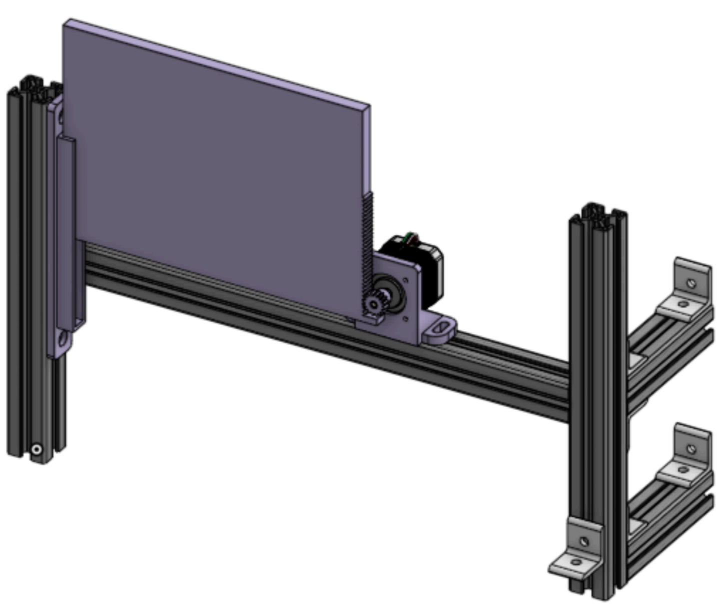


Figure 2: Overall Mechanical Design

Compression and Alignment

- Component details (make one for each major component)
    - 12” Stroke length Linear actuator
    - Compression Arm
    - Rack
    - 16 teeth Module 1 Gear
    - Rail/Slider



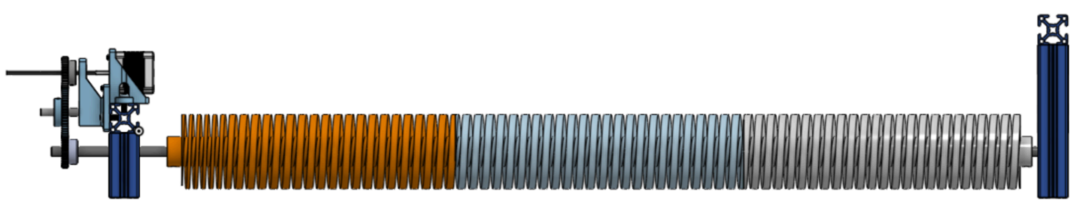


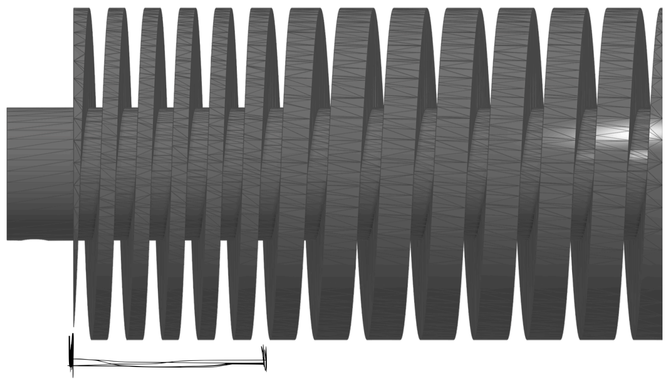
The compression and alignment subsystem is responsible for letting the worker put in the filter already slightly compressed. The linear actuator wall pulls the compression arm and pushes the filter into the lead screw. The rack and pinion lowers the compression wall that is initially there so the filter put in does not put pressure on the lead screw.

The compression mechanism was originally planned to compress the filter slightly before the lead screw but not drive the filter into the screw. After testing and movement of the conveyor belt to be the last step in the process. The lead screw needed a force to push the filter in so the compression subsystem was repurposed and a longer linear actuator with a longer stroke length was chosen and mounted above the lead screw. To secure the linear actuator in place two clips along the length of the wire are screwed in and a clip on the end with a pin prevents rotation of the actuator. To secure the compression arm the arm is designed to wrap around the head of the actuator and a pin is put in place to prevent rotation. The extruded slot in the arm allows for the shafts to come through the wall when the filter has been fully pushed through. Tolerancing in the CAD is given for the wall and the sheet metal plate it works above.

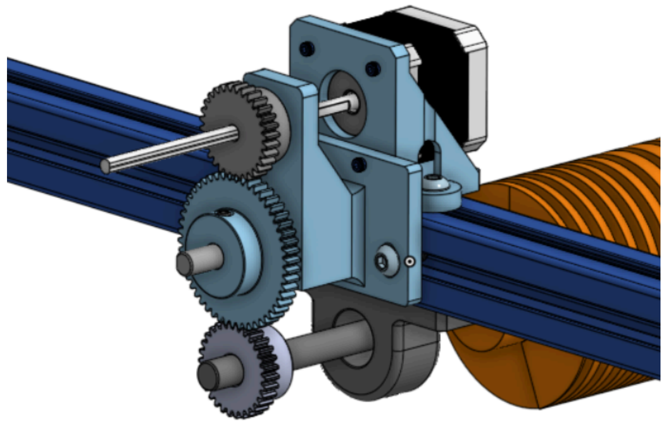
For the rack and pinion, the conveyor system provided was tall and there was space below the full assembly to have a wall that the filter can be pushed up against before it releases and becomes flush with the sheet metal gap. A rack and pinion was chosen to drive the wall for cost, two screws with bearings are mounted next to the wall on the opposite side of the wall so the wall can move up and down mechanically. A slider on the opposite end of the rack side guides the wall's movement. A smaller module was chosen because the motor's torque speed was variably fast and a smaller gear module would bring the speed of the wall down.

Pleat Separation

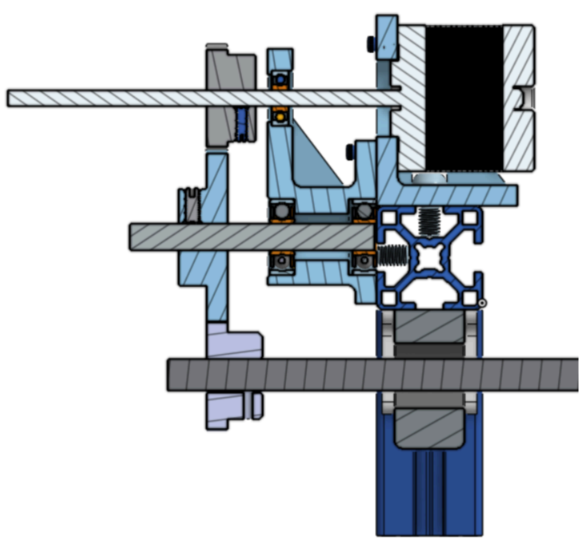
- Screw
    - 
    - Components:
        - 6 interlocking 3D-printed parts
        - Pillow block bearings
        - 1200mm D-shaft
        - 2 set screws
    - The variable pitch lead screw gradually separates the pleats from a compressed state, about 8mm, to the desired 12mm spacing.

- *assembly drawing will be inserted here*
- Initially the variable pitch at the front of the screw was shorter, arriving at the 12mm separation in only 3 rotations compared to what is now 6 rotations. This pulled the filter apart too quickly, and led to the screw missing pleats. With a longer separation distance, clarified in the picture below, the filter was not dragged apart as quickly.
- 
- Key features of design
    - For cost effectiveness, the screw was FDM 3D-printed in 6 parts. It was printed in 6 parts due to bed size constraints, which led to the keyed feature design. These locating features ensured each print would fit precisely together.
    - A D-shaft ran through the entire screw, to stabilize the numerous 3D prints, locate the center of the screw, and provide a strong part to connect to the motor.
    - A set screw was placed on either end of the screw, ensuring its location on the D-shaft did not move.
- Manufacturing recommendations
    - CNC'ing the screw out of aluminum would produce a more robust, durable screw for high volume use. This would cost roughly $2000 USD.

- Gear chain from motor to screw shaft



- Components
    - 3 gears
    - 3D printed mounting plate
    - 3D printed motor mount
    - Stepper motor
    - Screw Shaft (same as shaft in screw section)
    - Middle shaft
    - 2x 8mm bearings
    - 1x 5mm bearing



Cross-section view: 5mm bearing on top shaft, 2x 8mm bearings on middle shaft (bearings in orange)

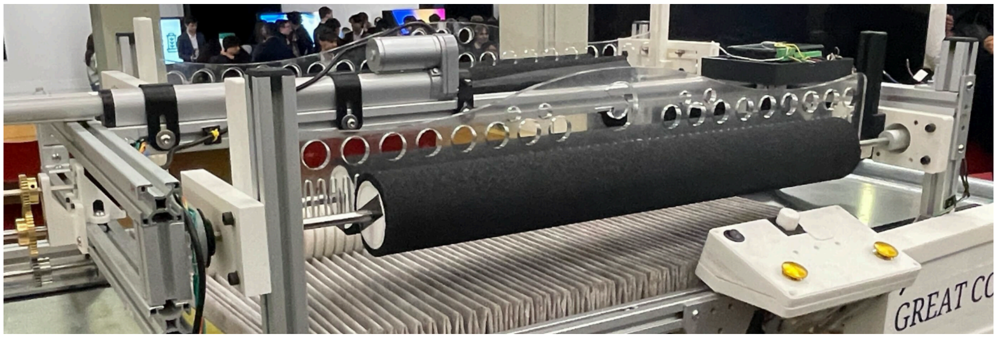
- The gear chain transfers the motor's rotation into the screw's rotational motion.
- The motor needed to be connected to the screw shaft in such a way that the motor did not interfere with the filter. This meant that the motor could not be

connected directly to the screw shaft, because it did not give enough clearance for the filter to fit underneath. To solve this issue, gears were used to translate the motor's rotational motion to the screw shaft. Three gears (gear chain) were used instead of two for similar reasons as the motor, because the filter could not fit below the gear if the gear was too large. A belt was not chosen to translate the motor's rotational motion to the shaft, because it required more custom parts than the gears.

- Key features of design
    - Gears were ordered off the shelf, chosen based on their ability to mesh together and cost. Two were brass gears, which was a cheaper material. One was a carbon-steel gear and customized to fit the 10mm screw shaft.
    - For cost effectiveness, the motor mount and mounting plate for the gears was 3-D printed. The mounting plate featured bearings to support the gear shafts.
- Manufacturing recommendations
    - Gears should be made of the same material to prevent material hardness mismatch. These gears can be bought off the shelf, and are easily customizable through vendors like Misumi. These gears cost roughly $40-45 each.
    - Shaft collars should be used on D-shafts to prevent gears from sliding, in addition to the set screw they already have.
    - D-shafts should be used for mounting each of the gears, which is useful for set screws.

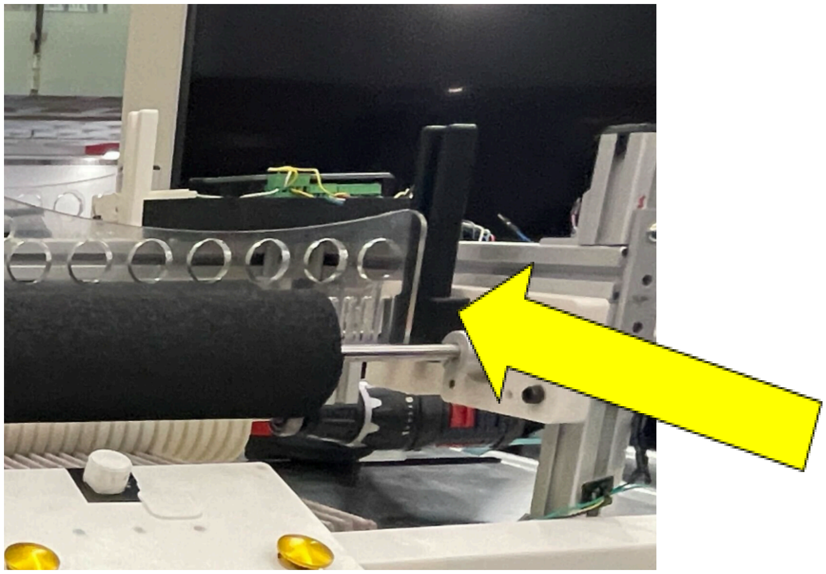
Comb Insertion

- Components:
    - PVC Pipe
    - ¼ inch Thick Nitrile Foam Sheets
    - 10mm Carbon Steel Shaft
    - Conveyor Belt
    - Timing Belt Pulley
    - BLWS 233D 24V Brushless Motor
    - FDM printed brackets and PVC supports



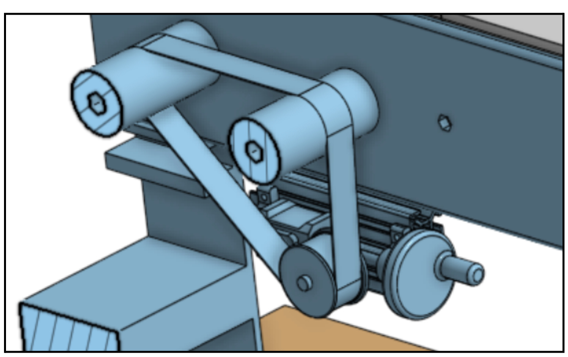
The comb insertion subsystem actuates post-pleat separation, when the media is accurately separated and lying underneath the PVC rollers that push the combs down into the filter. The subsystem consists of two sides: an actuated side with a 24V motor and an idle side that can move laterally to tension a timing belt that connects the two sides. Each side consists of two PVC rollers with ¼ inch nitrile (Buna-N) foam wrapped around. The rollers are connected to the rest of the machine via 10mm diameter steel shafts and 3D printed brackets with bearings that allow the rollers to operate smoothly. Each side lies on either side of the lead screw. The roller attached to the motor is connected to the idle side via a conveyor belt that runs over the lead screw for pleat separation and is tensioned by sliding and clamping the FDM-printed brackets. When the motor actuates, each side pushes the combs down into the filter media, effectively separating the pleats. The combs are supported by PLA rails which ensures they stay upright in between the rollers and during actuation.

- Key features of design
    - Nitrile foam sheets: Flame retardant sheets that compress well and provide good friction between rollers and acrylic comb for insertion
    - Rail System: Provides comb with a pathway to lodge in between rollers while simultaneously holding them upright for proper integration with filter media



Conveyor System

This conveyor system prototype leveraged a conveyor module (equipped with rollers and a fixed conveyor actuator, and fixed brackets & footing) acquired externally free of cost, but the mechanical system of the system remains in compliance with any modules of similar sizing capable of fitting the air filter on the platform and permitting at least 2 ft total of vertical clearance (1.25 ft above the conveyor for mechanical actuators), 0.75 ft below the conveyor for electronics, linear tensioners, and conveyor actuator housing). The roller-style conveyor module in this prototype was modified to remove all but 2 rollers for air filter exit motion, serving primarily as a table housing for the automation mechanisms above.



The linear tensioning mechanisms are a lightweight assembly fixed underneath each conveyor belt with the purpose of allowing an operator to manually modify the tension in the endpoint belts. A majority of components were 3D printed in-house (PLA material) with $30 in COTS hardware for 2 assemblies. In addition, the belt selection (approximately 45" circumference per belt) totaled $30 per belt and were sourced on McMaster (ID: 6082K12).

The operator rotates the handle accordingly, which translates to proportional linear motion via leadscrew mechanic. This assembly is fixed onto the conveyor belt with 80-20 components interfacing between the linear tensioner assembly and large conveyor bracket. The ideal material for use in a final product iteration for the linear tensioners are a durable plastic form (PETG or ABS), as PLA proves consistently a poor option for operation floor environments.

Framing

The cosmetic enclosure- custom tailored to this particular conveyor bracket but easily reconfigurable to fit any other bracket- was designed consisting of multiple 3D printed components (panels, plaques and press fit joints) that can be joined together with no external equipment (no adhesion or fastening). The enclosure holds onto the conveyor bracket. Therefore, this cosmetic enclosure is also easily removable.

Name of Component

-
- Component details (make one for each major component)
    - Image
    - Part Drawings may/may not be included
    - What is this design's function? Relate to the overall assembly
    - How did you get here in the design process?
    - Key features of design

        Ex. Material Selection--why is this the best choice? Cost, performance, etc.

        Ex. Tolerances
    - Manufacturing recommendations

        Include cost estimates if you can. Cite online resources or quotes from manufacturer

Electrical Design

Design Overview

- Electrical Subsystems

Supporting Subsystems:

1. Power: Supplies voltage rails to control PCBAs, and Consisting of an off the shelf AC-DC power supply and custom DC-DC converter PCBA.
2. Control:

FIlter Manipulation Subsystem Flow:

1. UI:
2. Filter Alignment:
3. Pleat Separation
4. Comb Insertion: BLDC-controlled insertion of 2 large "combs," used as spacers, into the filter media. Limit switches used to track location of combs (loaded/not loaded).
5. Filter Transport

- Design Considerations

1. Safety: Considerations included an emergency stop, two hand start, fail state detection, over current sensing, and camera validation.
2. Reliability: Consistent machine operation is ensured by checkpoint sensing using beam brakes for filter separation, limits switches for comb loading, and CAN-FD communication across control boards.
3. Modularity: Uniform and configurable control PCBAs were designed to be deployed in three subsections of the machine {input, UI, and output}. This design choice benefits ease of repair as replacement control boards can be purchased in bulk from PCB vendors such as JLCPCB, programmed uniformly, and rapidly deployed to any subsection of the machine.

- I/O of the electrical systems in relation to mechanical, software, etc.

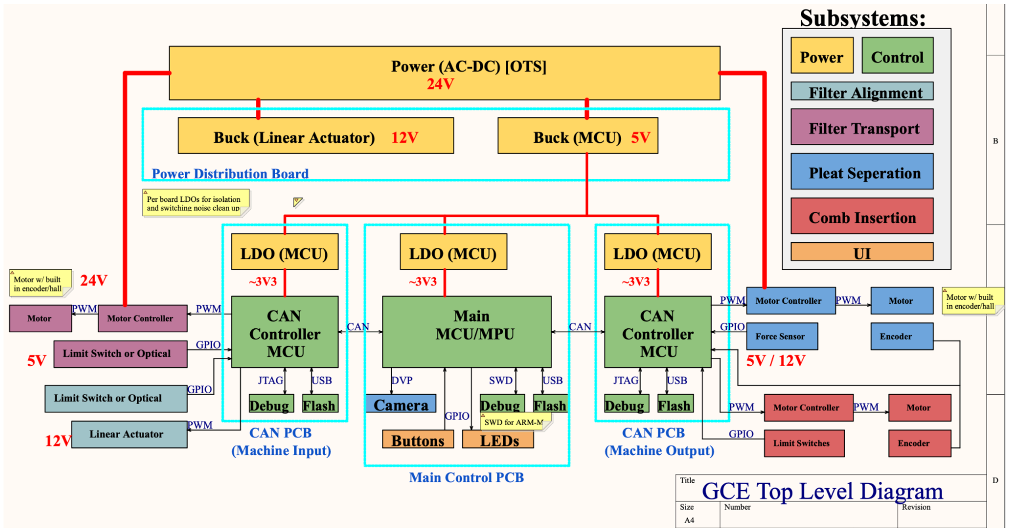


Figure $10: Electrical Block Diagram

Two custom PCBs have been designed for this project: the power board and control board. The system requires an external 24VDC power supply.

The power board, seen in Figure $11, is a small PCB which accepts 24VDC input from the left-hand connector (JST VH series) and outputs 12VDC through connector J1 and 5VDC through connector J3. The power board features 2x TPS56A37RPAR buck regulators to drop from 24V to 12V and from 24V to 5V. The 12V rail is rated to a maximum of 7.4A, and the 5V rail is rated to a maximum of 3A. The power board should first be mechanically plugged in, then powered on to avoid dangerous overcurrent conditions on startup.

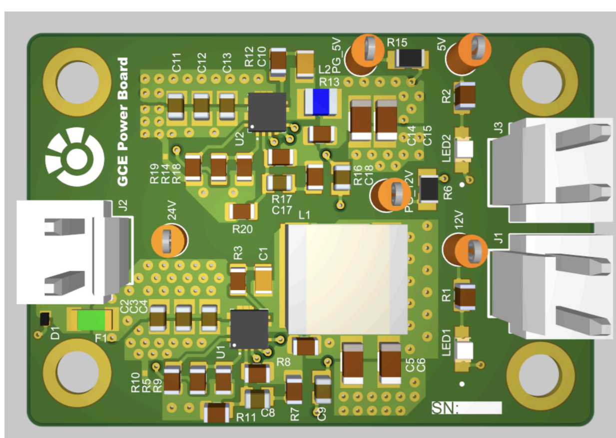


Figure $11: Power Board

The Control Board, seen in Figure $12, is designed around NXP's MCXN947VNLT, a 150MHz microcontroller with … . Each control board is assembled uniformly, but should be used in

3 separate configurations, determined by the DIP switch, U11. There are 3 control boards used throughout the system, representing input, output, and the main control board. The input board controlled the stepper motor that drives the pleat separator while the output board maintained the BLDC that inserted the comb. The main control board controlled each state of the system, sending the appropriate commands through CAN. Each control board has a wire coming from the back side that must be powered by an external 1V power supply in order to ensure that the chip is powered.

The headers around the perimeter of the board are organized depending on the subsystem. The top left corner contains the UI buttons that start the entire system and the status LEDs. The center at the top of the board connects to the camera via SPI through male headers. The top right corner is the headers for the insertion system including the headers for the BLDC motor and the limit switches. For alignment, there are two headers to connect to the linear actuator that controls the compression of the filter. The bottom right of the board consists of another set of headers for the BLDC and limit switches. At the bottom of the board, is the USB-C that powers and flashes code onto the board. In the bottom left of the corner, there are two headers for the beam breaker. For the filter separation, the stepper motor connects to the lower blue header on the left side of the board. The header for the ultrasonic distance sensor sits right above the previous header. Finally, the CAN interface is on the middle of the left side of the board that allows each board to talk to each other.

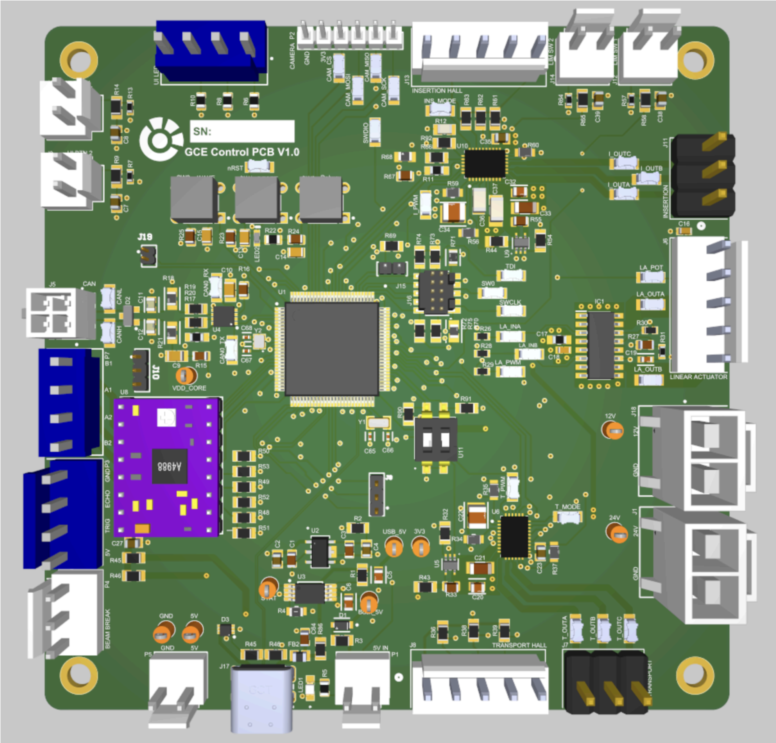


Figure $12: Control Board

Power

Board Power

The control board should be powered via connector P1 with 5VDC, though it may also be safely powered over USB. 12VDC and 24VDC should also be supplied to the board through connectors J18 and J1, respectively.

24VDC should be supplied directly to each Control Board in order to drive BLDC motors directly. 24V can also be supplied to U8, the Pololu module used to drive stepper motors. 24V is supplied through a 0 ohm resistor; only R45 is populated by default, but the population status of these resistors may be swapped to supply the module with 12V instead of 24V. If both R45 and R46 are not populated, the module will not receive power to drive stepper motors with, and if both are populated, 12V will be shorted to 24V, damaging the board.

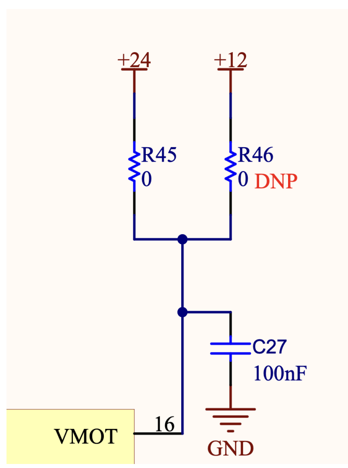


Figure $16: Power selection for U8

A power selector IC TPS2115APWR is used to select a 5V power input between direct power and power over USB. The IC selects the higher of the two voltages. Since the direct 5V input is fed through a forward-biased diode, its voltage is near 4.7V at the IC's input, so 5V from USB will be selected if present.

5V is then fed into an LDO with 700mA peak current output to generate the 3.3V rail which is used across the board for all logic functions. An LED "LED1" is present near the USB-C connector. This lights up as soon as 3.3V is present on the board and can be used as a visual "power good" check.

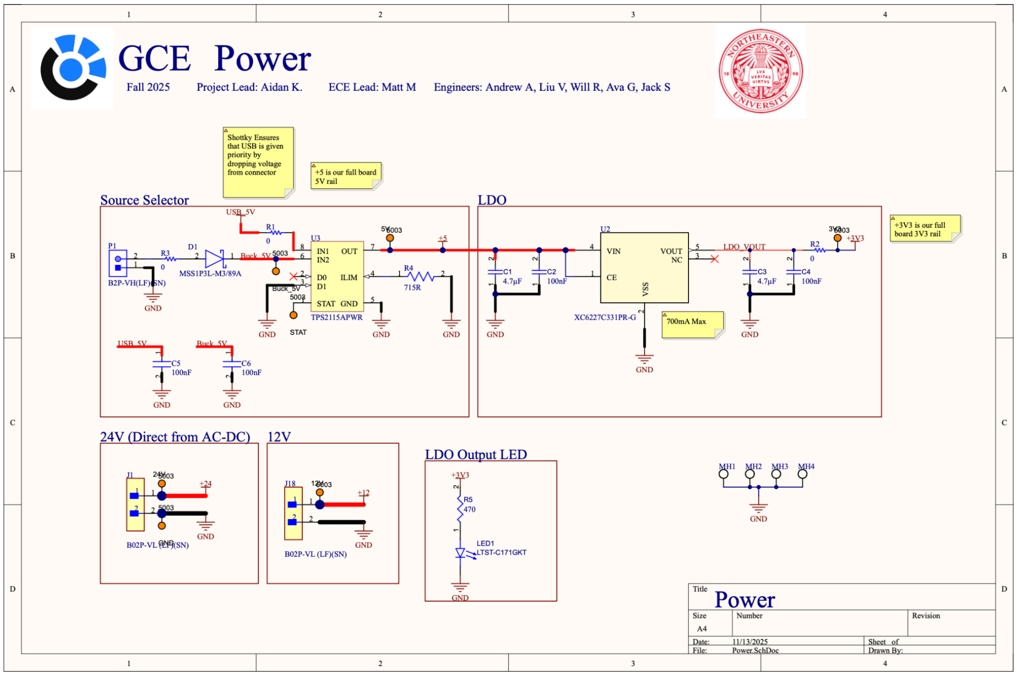


Figure $17: 5V to 3.3V power supply schematic

MCU Power

All I/O banks on the MCU are supplied with 3.3V; all logic on the PCB runs on 3.3V. 0 ohm resistors have been added to isolate nets for troubleshooting, as seen in Figure $18. The DCDC power regulator did not function as expected, so it was disabled by removing the inductor L1, as well as unnecessary capacitors C60, 61, and 62. VDD_CORE's output should be between 1.0V and 1.2V for proper operation of the MCU; it has been measured to be 1.08V.

R77 should be depopulated to disconnect VDD_SYS from 3.3V, as 3.3V is above the electrical maximum for the VDD_SYS pin. VDD_SYS should output 1.8V from the internal LDO, however adequate current draw from the MCU was not observed in this configuration, and the MCU could not be detected by any computer. The internal power regulator was then bypassed by connecting VDD_DCDC to VDD_SYS and injecting that node with external 1.8V. This enabled the MCU as expected and allowed the MCU to be flashed.

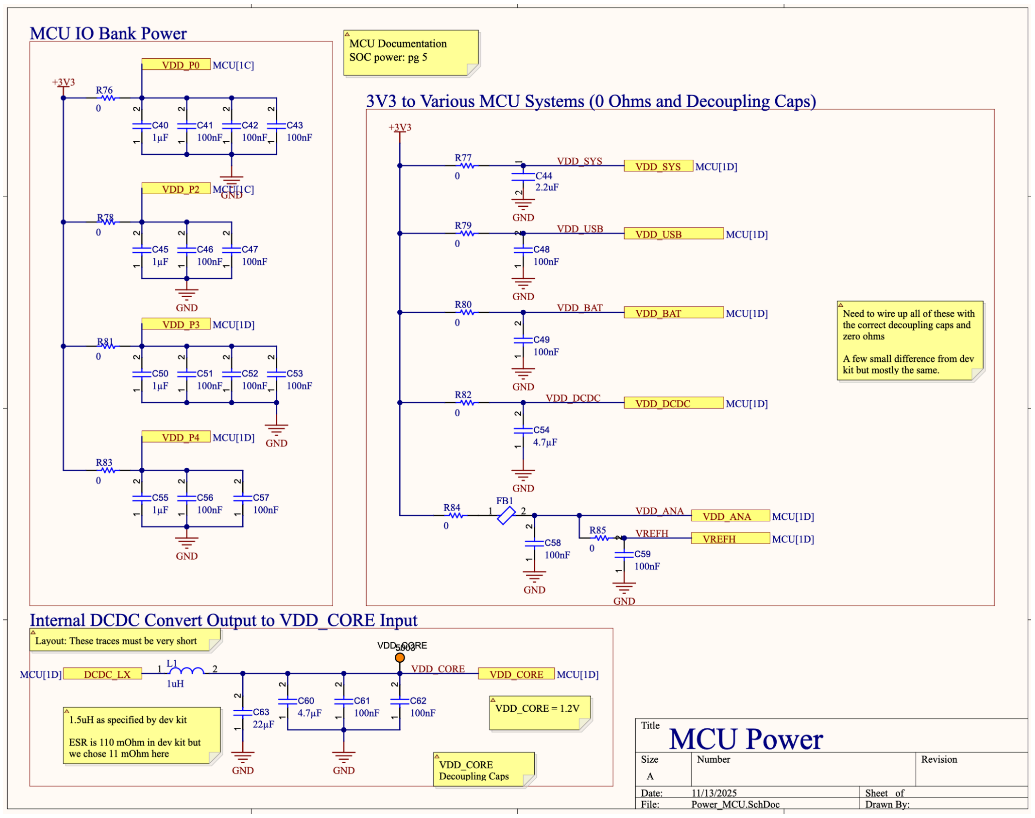


Figure $18: MCU power schematic

Motors

Stepper Motor Control

The stepper motors NEMA 17 are controlled by the Stepper Motor Driver Carrier DRV8434, which runs on 3.3V. The stepper motors are used in the subsystems “Alignment” and "Separation" in schematics. The stepper motors are used in alignment for the vertical moving wall as for the spinning movement of the lead screw.

BLDC Motor Control

BLDC motors BLWS233D-24V-4000-12AE are controlled by the half-bridge BLDC motor driver MCT8315Z0HRRYR, which runs on 3.3V logic. BLDC motors are used in the systems labelled “Insertion” and “Transport” in schematics. The BLDC motors, however, are only used for the comb insertion system, as the transport system utilizes a linear actuator, which is controlled in the same manner as a stepper motor.

The comb insertion subsystem’s BLDC motor control layout and schematic can be seen in Figures $13 and $14, which includes all I/O used for the comb insertion system. J13 connects to the BLDC’s internal hall effect sensors, providing position feedback to the control IC used. J11 is the

3-phase power output used to drive the BLDC motor. J12 and J14 each connect to a limit switch, discussed further in the "Sensors" section of this report.

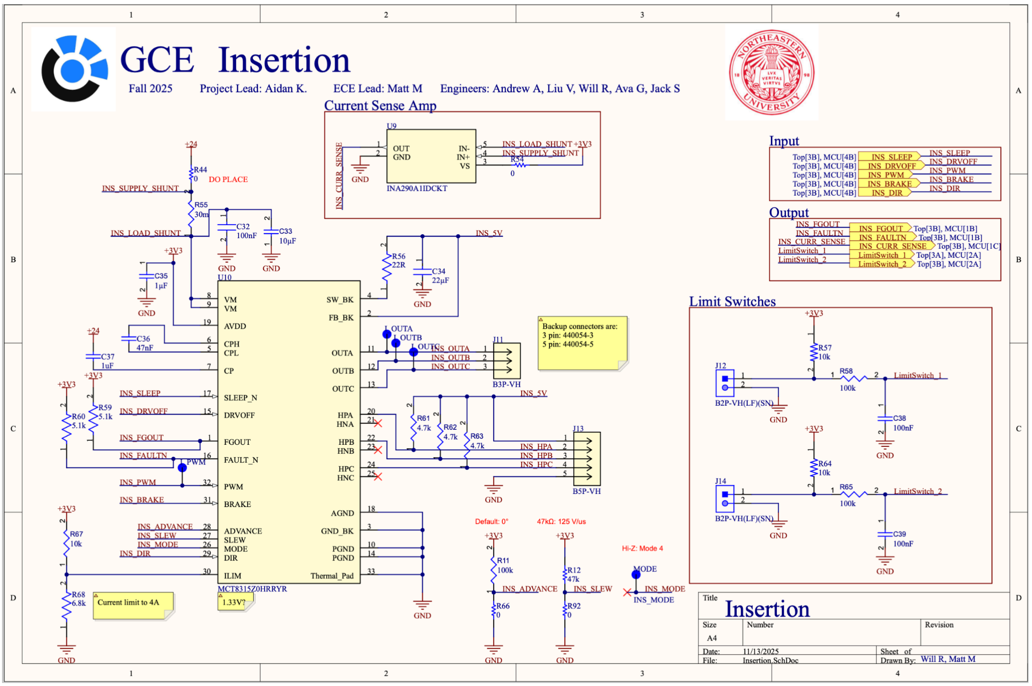


Figure $13: BLDC Motor Control (Comb Insertion) Schematic

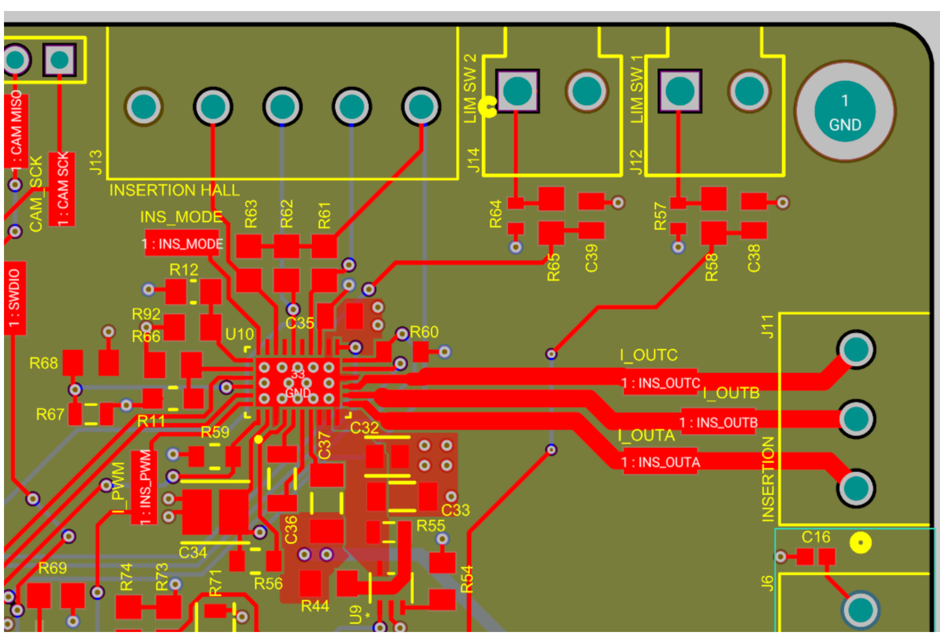


Figure $14: BLDC Motor Control (Comb Insertion)

The controller MCT8315Z0HRRYR uses PWM to control motor speed and a HI (3.3V) or LO (0V) signal to control direction of the motors. The MCU can also toggle pins to control sleep mode (SLEEP), turn the driver off, (DRVOFF), and apply a brake (BRAKE). The IC's mode is set to mode 4, indicating digital hall input and synchronous modulation. The slew pin is tied to VDD through a 47k ohm resistor to set the slew rate to 125V/s (R92 should not be populated). The advance pin is tied to VDD through a 100k ohm resistor to set the advance angle to 0° (R66 should not be populated).

The BLDC motor controller requires 24VDC input to power the motor through the IC's three-phase output. A shunt resistor is used on the 24V input to measure current draw of the motor; a current sense IC INA290A1IDCKT is used to perform this task and return the output to the MCU.

The IC has an internal buck regulator, which is not used.

Sensors

Beam Break

To see where the filter was while it was being transported through the project, IR break beam sensors were used to start and stop the pleat separation. With the transmitter on one side of the machine, and the receiver on the other side lined up, the beam would be broken by the filter when it is traveling through. The break beams used had a sensing distance of 508mm, a little over the width of the filter. The transmitter was connected to the PCB with ground and 5V and then the receiver was connected to ground, 5V, and logic. Within the correct installation of these sensors, the system will know when the filter is completely separated and additionally when the filter is fully transported out.

Limit Switch

Two normally open SPDT limit switches SS-5GL were chosen for this design to indicate comb position for the comb insertion subsystem. Limit switch tabs are smooth so combs may move past the switch with minimal resistance. When a comb is in place, the switch is depressed, shorting its terminals to GND. When a comb is not in place, a pullup resistor sets the limit switch's MCU pin to 3.3V. By this, the MCU reads in HI when a comb is not present and ready to be inserted, and LO when a comb is in place, ready to be inserted.

The limit switch is SPDT, meaning three poles are present. The COM and NO pins should be connected to the PCB to pins 1 and 2 of the JST connector (directionality is trivial); the NC pin should be left floating. The limit switch model is rated to 30 million cycles.

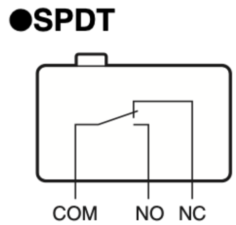


Figure $15: Limit Switch connection diagram

Circuit Board

- Schematics
- Any input / output and where it connects to sensors, mechanical devices, etc.
- Images to show relative size and placement within the overall system

Software Design

General Software Design

Development Environment

Host System:

- macOS with Zephyr RTOS 4.3.0
- VSCode
- West build system for compilation and flashing

Target Hardware:

- FRDM-MCXN947 development boards
- Custom PCBs for production

Required Libraries and Tools

Core Dependencies:

- Zephyr RTOS kernel (multithreading, scheduling)
- GPIO and CAN-FD drivers
- Device tree for hardware abstraction

Custom Software Modules:

- CAN protocol layer (message routing/parsing)
- System state machine (assembly sequence coordination)
- Board role handlers (MAIN/INPUT/OUTPUT logic)
- Motor drivers (stepper and BLDC)
- UI management (buttons/LED)

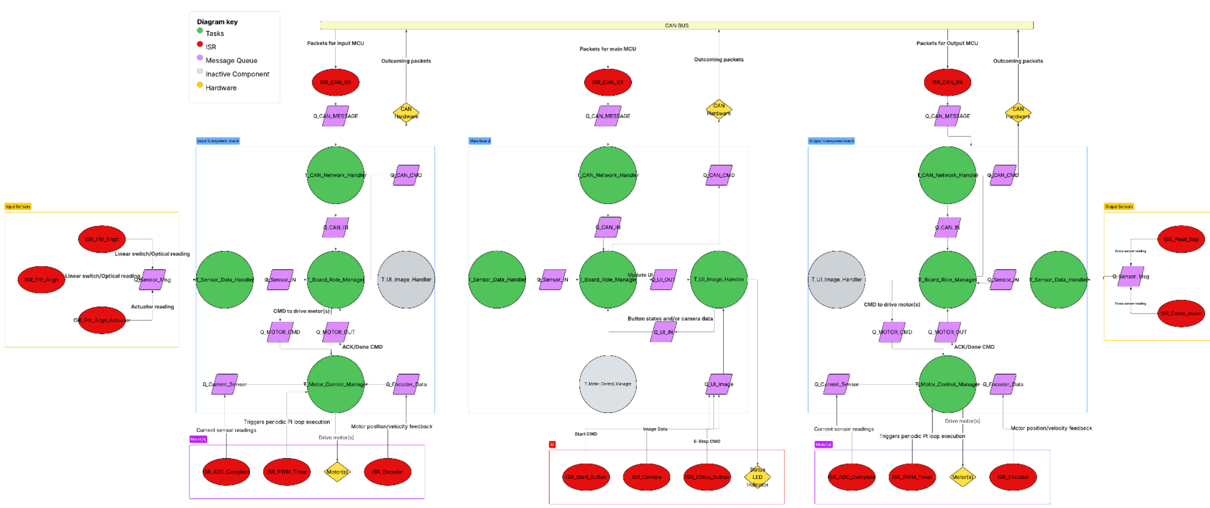
Flowchart of Software Flow

Referencing the provided diagram:

The three-board system begins with each board determining its role during initialization, then setting up CAN communication, motor drivers, and I/O peripherals before spawning concurrent threads. The MAIN board waits for the operator to press both safety buttons simultaneously. Once activated, MAIN broadcasts a state change message via CAN to all boards.

Each board receives the state broadcast and executes its role-specific actions for that state. When a board completes its assigned task, it broadcasts the next state transition, advancing the entire system through the assembly sequence. This process loops continuously, progressing through the states until the cycle completes and returns to IDLE.

Multiple threads run concurrently on each board. The CAN Handler thread operates at high priority to receive and route messages without delay. The State Machine thread runs at medium priority, executing board-specific control logic based on the current state. Motor Control threads run at high priority to generate precise timing signals for stepper and BLDC motors. The UI Monitor thread runs at low priority on the MAIN board, handling operator feedback through buttons and LEDs.



Explanation of Overall Software Decisions

The system implements a distributed peer-to-peer architecture where three identical boards run the same firmware with runtime role determination. CAN-FD was selected for inter-board communication due to its robust error handling, deterministic message delivery, and widespread adoption in industrial automation—critical for coordinating mechanical operations in a noisy factory environment. Each board determines its role (MAIN/INPUT/OUTPUT) at startup through a configuration parameter, eliminating the need for three separate codebases and enabling field-interchangeable hardware. State transitions are broadcast over CAN, triggering role-specific actions on each board: the MAIN board handles UI and coordination, INPUT controls filter compression and pleat separation mechanisms, and OUTPUT manages comb insertion and conveyor ejection. This event-driven state machine advances based on actual task completion rather than fixed timers, adapting to mechanical variations while the thread-based concurrency model ensures time-critical motor control timing is never compromised by communication or decision-making logic.

Communication

The CAN protocol uses seven message types:

- **MSG_STATE_CHANGE** coordinates the assembly sequence,
- **MSG_EMERGENCY_STOP** provides immediate safety halts,
- **MSG_MOTOR_CMD** controls individual motors,
- **MSG_MOTOR_STATUS** reports motor feedback,
- **MSG_HEARTBEAT** monitors board health,
- **MSG_ERROR** signals fault conditions, and
- **MSG_SYSTEM_STATUS** exchanges general information.

Commands Available

- **State Change Command** drives the assembly through seven states: IDLE (awaiting operator input), HOMING (actuators return to zero), COMPRESSION (INPUT compresses filter), SEPARATION (INPUT separates pleats), COMB_INSERTION (OUTPUT inserts retention comb), OUTPUT (conveyor ejects filter), then returns to IDLE. Each board executes role-specific actions upon receiving state broadcasts, with the completing board triggering the next transition.
- **Motor Control Commands** directly specify speed, direction, and enable/disable for individual actuators when needed beyond state-driven coordination.
- **Emergency Stop** immediately halts all motors, disables drivers, and requires operator intervention to resume.

How to Interpret

CAN packets contain a message type, sub-identifier, and 6-byte payload. The extended identifier embeds priority, source node, and destination node for hardware-level filtering. Four node addresses exist: NODE_MAIN (0x00), NODE_INPUT (0x01), NODE_OUTPUT (0x02), and NODE_BROADCAST (0x0F). Boards automatically filter messages by destination, receiving only those addressed to them or broadcast to all. The CAN handler thread routes incoming messages to appropriate handlers based on type.

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Next Steps

Current System Status

As the prototype stands, the system demonstrates successful operation of all major mechanical subsystems. The linear actuator compresses and positions the filter against the alignment wall, the variable pitch lead screw fully separates the pleats, and the comb insertion rollers are capable of placing the separators into the media. These results confirm that the subsystem designs are mechanically sound and validate the feasibility of full automation.

Limitations

Despite these successful individual operations, the system cannot yet perform these tasks in a continuous or coordinated sequence. The alignment wall can raise and lower, but its motion is not synchronized with the actuator-driven compression steps. The linear actuator and lead screw can operate simultaneously, but the screw lacks automated stop conditions and requires manual oversight to prevent overtravel. Similarly, the comb insertion motors can place separators but currently require manual activation, as the insertion logic has not been integrated into the state machine.

Root Causes

These limitations stem not from mechanical constraints, but from incomplete firmware integration and partial electrical system functionality. Specifically, motor controllers, limit-switch feedback, and subsystem state transitions are not yet unified under a continuous control architecture. As a result, no single-board or multi-board sequence can automatically coordinate compression, alignment, pleat separation, and comb insertion.

Summary

Although the system requires a comprehensive firmware and electronics overhaul to support continuous manufacturing, testing confirms that the mechanical design and subsystem behaviors are viable. This establishes a strong foundation for future development toward a fully integrated automated solution.

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For next steps and recommendations:

Mechanical Specific:

- Get a higher fidelity lead screw, possibly aluminum machined via cnc
- Get a functional wall that will allow for continuous manufacturing
- Build a comb feeding system so the combs can be held in batches above the comb insertion mechanism
- Consider conveyor interfacing on either side

Electrical Specific:

- Create a continuous system that links the motors and actuators into the push off a button