Simplifying Part Access

By
Matheu Fletcher (matheuf2)
Aidan Yaklin (ayaklin2)
Tejas Aditya (taditya2)

ECE 445 Proposal - Fall 2023
TA: Gregory Jun

September 14th, 2023
Project No. 26

Contents:

1. Introduction

1.1 Problem

Printed circuit board designs, even at the prototype/hobbyist level, can use a significant number of small passive components. Typically, these components are packaged in a reel of paper/plastic “tape” with cutouts for each component and a removable film to hold the components inside the tape. The film can be peeled back to remove a few, but it is very easy to accidentally peel it too far and lose a lot of parts. Thus, the preferred way of working with tape-and-reel packaging is to cut the tape to the required length for the project, leaving the film intact on the rest of the reel.

This in itself poses a problem, though. If a project needs more than a few of the same part, manually counting to find the cut point becomes very tedious.

1.2 Solution

A way to approach this problem would be designing a modular system that the end user can request a specific number of parts from, and it feeds that many out. This can be accomplished by a tileable design where each tile is a box that holds a reel of the desired components on a spindle, which is turned by a motor, and the sections are cut by a motorized blade. To confirm that the correct number of components are dispensed, sensors can be utilized to count the components.

1.3 Visual Aid

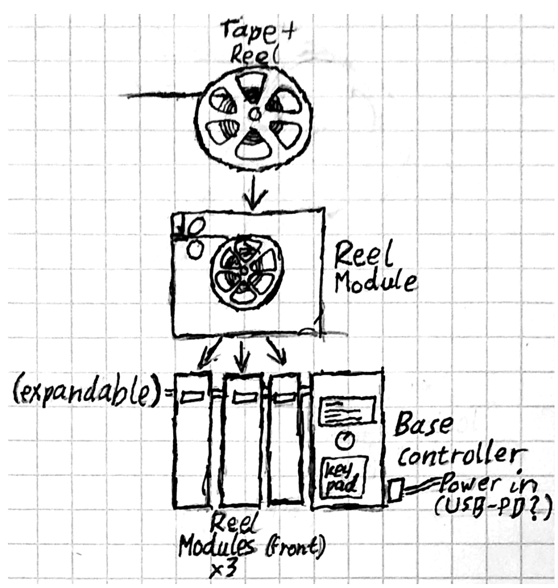

Figure 1: Illustration of proposed overall solution

1.4 High-Level Requirements

- Movement/Sensing - The system should be able to accurately measure out the correct number of components when given the correct component spacing and clocked properly. Movements should be accurate to +/- 1 mm of the requested position.
- The system should accept the most common reel diameters (7 inch/178 mm and 13 inch/330 mm), and it should support tape widths up to at least 25 mm, and tape depths up to at most 4 mm.
- The base controller should be able to support at least 3 reel modules. It should supply enough power to drive 3 reel modules simultaneously, and it should disable additional modules so that power limits are not exceeded. (We are currently planning on building 3 reel modules, so the power-limiting behavior can be tested by reducing the limit to 1 or 2).

2. Design

2.1 Block Diagram

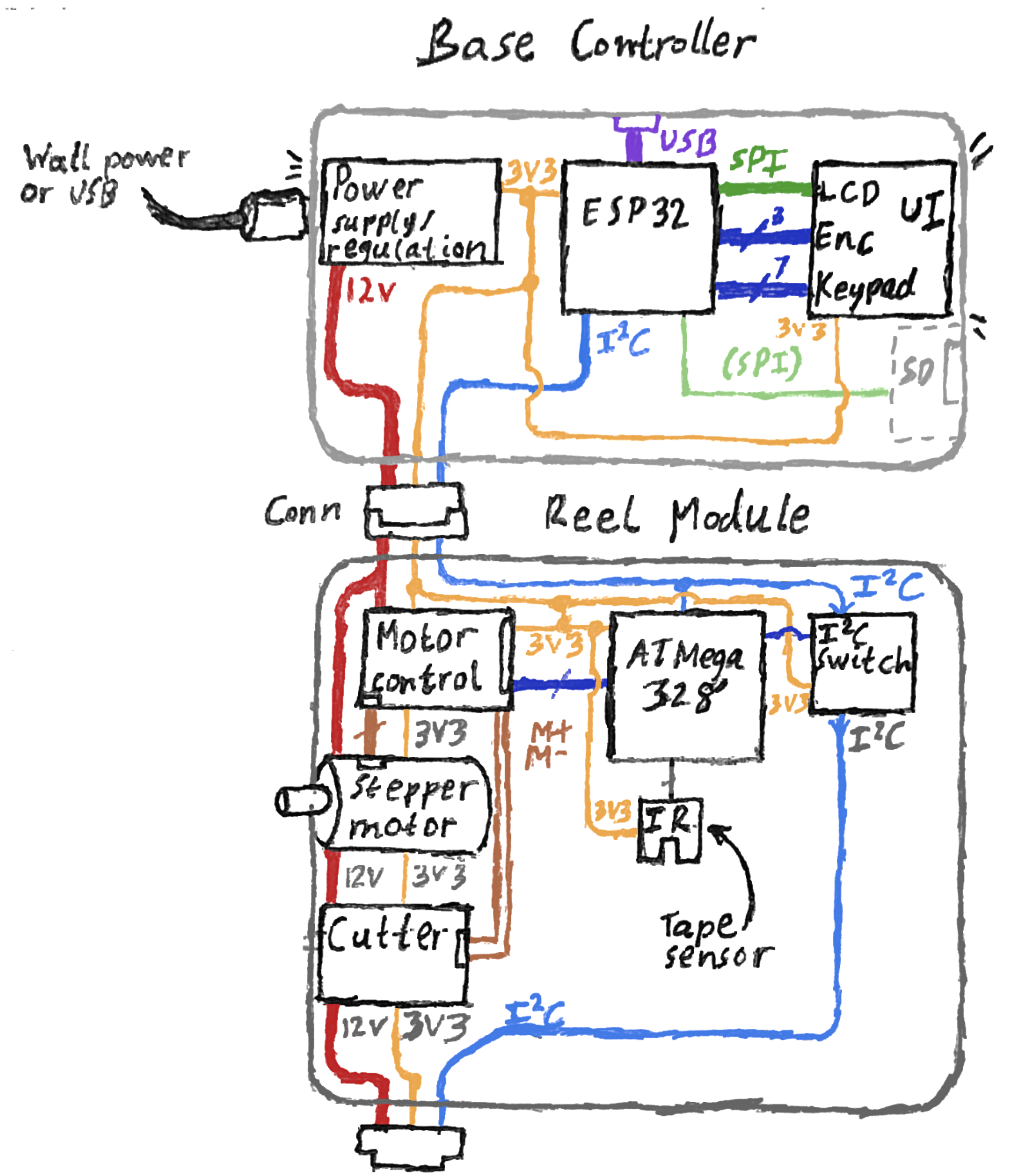

Figure 2: Diagram Showcasing individual circuit components of proposed design

2.2 Subsystems

2.2.1 Base Controller

2.2.1.1 Power Supply

Requirements: Estimated ~30 W power requirement for 3 modules, but may need significantly more depending on the stepper motor choice.
3.3 V (+/- 0.2 V tolerance) required for logic power (can regulate from 5 V or more if needed). Need to estimate power requirements, but they should not exceed 5 W.
12 or 24 V (+/- 10%) required for motor power (depending on which stepper/cutter we choose). Power also depends heavily on which motors we choose.

Options:

- USB Power Delivery
  - Pro: Cheap, readily available devices that can supply at least 65 W
  - Pro: Fully encapsulated; no need to worry about exposed mains voltage
  - Con: May not be specified for highly inductive loads
  - Con: USB-PD uses higher voltages (28, 36, or 48 V) to allow for thinner wires; this would probably need to be regulated for our steppers
- Dedicated power supply module (such as those found in 3D printers)
  - Pro: Reliable, usually designed specifically for motorized devices
  - Pro: Easier integration–modules typically have separate 12V and 5V outputs
  - Con: Usually has exposed screw terminals to connect to mains power
  - Con: Larger and more expensive

2.2.1.2 User Interface

Requirements:

- LCD display capable of alphanumeric text. This will show the state of any active operation and allow the user to input settings and start new operations.
- Rotary encoder + button interface to navigate menus and scroll the display
- Numerical keypad to manually enter spacing dimensions and other calibration data

Nice-to-have:

- SD card and/or USB port with mass storage capability to upload BOM files for component counts

2.2.1.2.1 LCD

Newhaven display with specs of 128x32 graphical pixels, monochrome, and backlit. [1]

2.2.1.2.2 Rotary encoder

Generic clicky knob encoder with integrated switch and D-shaft; we can 3D print a knob for it. [2]

2.2.1.2.3 Numerical keypad

Standard 12-button keypad with 0-9, *, and #. These types of keypads are commonly found in the bottom of generic electronics kits as well. [3]

2.2.1.2 Main Processor

Requirements:

- Control the user interface
- Enumerate the reel modules on startup
- Send commands to the reel modules via I2C
- Read the status of the modules
- Cut power to the reel modules in case of a communication failure or other error
- USB port available for programming and (possibly) mass storage

Nice to have:

- Provide a local web interface to send settings and files to the base controller

We are going to use the ESP32-S3 module because of its high speed, low cost, I/O pin count, and Wi-Fi option (although this is not a requirement for the project). Microcontrollers with similar performance and pin count typically cost significantly more or require external flash. [4]

To test, we can connect the atmega238 systems to the esp32 and see that they show up, along with looking at the screen and confirming that it, the rotary encoder, and the keypad all work. This is the basis of proving without having the extra modules completed.

2.2.2 Reel Module

This module plugs into the power supply and I2C bus connections of the base controller or another reel module. Beyond these connections, these modules are practically autonomous, as they control the motors and sensors.

2.2.2.1 Feed Motor

Requirements:

- Maximum feed rate of at least 5 mm/s
- Tape feed positional accuracy of at most +/- 1 mm
- Sufficient torque to pull tape from the reel, especially at low speeds (need to experimentally determine this value)

Nice to have:

- Tape feed positional accuracy of +/- 0.25mm to support very closely packed components

We are currently tentatively looking at the Mercury Motors small stepper motor[5]. A low-profile motor is ideal so that we can minimize the width of each reel module.
We can test that this works by connecting the system and attempting to feed a specific number of components, and that it is repeatable.

2.2.2.2 Cutter

Requirements:

- Maximum 2 second cut time for full-width tape (need to determine our actual test parameters because full-width tape reels will probably be expensive)
- Maximum of 1 cut failure in 10 consecutive tests
- Can reliably cut paper and plastic tape without jamming (under the above test parameters)

Nice to have:

- Much lower rate of cut failures (ideal but potentially difficult/expensive to test)

This could either be a solenoid or motor-based solution. We have not determined a part for this.
To test, we can similarly run test runs that

2.2.2.3 Tape Sensor

Requirements:

- Detects the sprocket holes in the tape
- Can locate the edges of the sprocket holes to within +/- 1 mm when feeding at a slow (1 mm/s) rate
- Can reliably (max 1 failure out of 100) detect sprocket holes in black plastic and paper tapes

Nice to have:

- Can detect sprocket holes in clear plastic tape

Tentatively choosing an optical sensor from DigiKey [6] but may need to change to one with different dimensions.

Choosing to use the IR sensor in this case, our goal is to be able to precisely detect the spacing between sprocket holes. We can test this in combination with the feed system to make sure we can accurately count the number of components dispensed.

2.2.2.4 Motor Controllers

Requirements:

- Can drive the module's motors/actuators without overheating

Stepper control will vary if we choose a different stepper, but we are looking at a Motor driver from Allegro MicroSystems [7] that seems to support a wide range of stepper motors.

We still need to decide what kind of motor will be used for the cutter, but a simple MOSFET switch or H-bridge driver should be sufficient.

2.2.2.5 Microcontroller

Requirements:

- Can communicate with the base module over I2C at 400 kHz
- Can send pulses to the stepper driver at a consistent rate (not sure what is needed; can probably use PWM)
- Can poll the reel sensor data rapidly (not sure how fast is required, but 10 Hz seems like a reasonable minimum)
- Can save reel configuration and calibration to the chip when powered off

Communication specifics:

- Boots in “enumeration” mode, waiting for an ID from the base controller. There should be a mechanism (analog switch or I2C buffer) to disable communication passthrough to the next connected module until this device has been enumerated.
- The base controller sends an ID to the first connected module, and then the module re-enables I2C passthrough so that the next module (if any) can be enumerated. Already-enumerated modules ignore the ID assignment command.
- The base controller can then send commands (update settings, dispense components, etc.) to the reel modules.
- The reel modules respond to requests for status.

Microcontroller: ATMega328PB - we have a lot of these already on hand, and they have reasonable performance/pin count/reliability. They can be run at 3.3V if the clock frequency is reduced from 20 MHz to 16 MHz.

Idea for enumerating the modules - we can put a switch IC on the I2C passthrough so that when the system powers up, the base can only talk to the module connected directly to it. Then the base can assign an ID to that module, and it can connect the next module to the bus so it can be enumerated.

2.3 Tolerance Analysis

This device needs to align the cut position within +/- 1 mm of the expected position. In order to do this, we need the resolution of the stepper motor to be small enough to achieve this accuracy. Our current choice of stepper motor has a specified 7.5 degree stride[5], and the stepper driver has support for 8 levels of microstepping[7]. We can calculate the angular resolution θ_M with N levels of microstepping and stride θ_S as:

$$\theta_M = \frac{\theta_S}{N} = \frac{7.5°}{8} = 0.9375°$$

From this, we can determine the maximum wheel radius that will allow our angular resolution:

$$s = r(\pi \times \theta_M)/180 = 0.5\,mm$$

$$r(0.016) = 0.5\,mm$$

$$r = 30.55\,mm$$

Having a larger wheel radius gives us additional pulling force from our stepper torque. We can use the upper bound from this result to determine the trade-off between torque and resolution when choosing exact parts and dimensions.

After doing these calculations, we realized our initial stepper motor choice was of convenience without enough research behind it, so we did more work and found a different stepper [9] that has a specified 0.9 degree full step, which would allow us to reach our desired level of precision without microstepping; further research has suggested that microstepping can cause missed steps, which reduces the accuracy of the step count as a position measurement. That said, we can always apply small amounts of microstepping if we need to refine it further, but while these calculations told us that the precision was originally possible, they also helped us find a better option for even better expected results.

Additionally, to further confirm that these tolerances are met, we can make use of feedback from the IR sensor to tell us if the movement was accurate based on the sprocket holes, and make further micro adjustments as needed. This will increase the long-term accuracy significantly by keeping track of how far the tape slips over time.

3. Ethics and Safety:

Primary possible safety concerns associated with this project would be if the cutter is exposed and poses risk of injury, or if the cutter fails and poses risk of injury while fixing. The easiest fix to the former would be to enclose the cutter so that it is not exposed for an individual to get cut by. Since a slot is needed to feed components out of the machine, this should be made small enough that fingers cannot fit into it. Similarly the latter can be approached by making sure we have a power shutoff switch such that the motor for the cutter cannot engage while attempting to fix any issues with it.

That said, on the matter of Ethics, there are no clear ethical risks or violations we are worried about, as we are not dealing with any sort of private information, or conflicts of interests, while we also agree to seek honest criticism as specified by IEEE 7.8 I.5 [8]. Similarly, we also will make sure we work together as a group both for our group, along with the TA and other students and individuals we work with to treat others fairly as specified by IEEE 7.8 II [8].

4. Citations:

[1] "Newhaven Display Intl NHD-C12832A1Z-NSW-BBW-3V3," Digi-Key Electronics. https://www.digikey.com/en/products/detail/newhaven-display-intl/NHD-C12832A1Z-NSW-BBW-3V3/2059235 (accessed Sep. 14, 2023).

[2] "Bourns Inc. PEC16-4220F-S0024," Digi-Key Electronics. https://www.digikey.com/en/products/detail/bourns-inc/PEC16-4220F-S0024/3534239 (accessed Sep. 14, 2023).

[3] "SparkFun Electronics COM-14662," Digi-Key Electronics. https://www.digikey.com/en/products/detail/sparkfun-electronics/COM-14662/8702491 (accessed Sep. 14, 2023).

[4] "Espressif Systems ESP32-S3-WROOM-1-N16," Digi-Key Electronics. https://www.digikey.com/en/products/detail/espressif-systems/ESP32-S3-WROOM-1-N16/16162647 (accessed Sep. 14, 2023).

[5] "Small Stepper Motor - ROB-10551," SparkFun Electronics. https://www.sparkfun.com/products/10551 (accessed Sep. 14, 2023).

[6] "SHARP/Socle Technology GP1S093HCZ0F," Digi-Key Electronics. https://www.digikey.com/en/products/detail/sharp-socle-technology/GP1S093HCZ0F/720401 (accessed Sep. 14, 2023).

[7] "Allegro MicroSystems A3967SLBTR-T," Digi-Key Electronics. https://www.digikey.com/en/products/detail/allegro-microsystems/A3967SLBTR-T/1006301 (accessed Sep. 14, 2023).

[8] "IEEE Code of Ethics," *IEEE Code of Ethics*. https://www.ieee.org/about/corporate/governance/p7-8.html (accessed Sep. 14, 2023).

[9] "Nema 17 Bipolar 0.9" StepperOnline. https://www.omc-stepperonline.com/nema-17-bipolar-0-9deg-11ncm-15-6oz-in-1-2a-3-6v-42x42x21mm-4-wires-17hm08-1204s (accessed Sep. 28, 2023)