# Magic: The Sortening

## Team 24
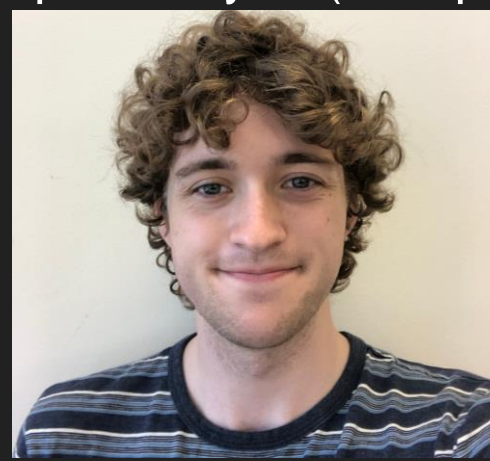
Zalman Lipschitz (MechE)  Prof. Mario Parente  Joseph Maloyan (CompE)

Malcolm Okaya (CompE)  Henry Powell (EE, MechE)  Liam Rees (MechE)

# Background: Secondhand *Magic: The Gathering* cards market

Magic: The Gathering is a trading card game, where players collect cards and combine them into decks to play against each other, or simply collect for rarity (like baseball cards).

The Secondhand market for *Magic* cards is extensive [1].

The value of a given card is determined by its condition and rarity.

How is this condition determined and measured?

# Background: *Magic* card condition rating

There are two major, complementary systems for analyzing card condition. Both are fairly inconsistent & subjective, though there are specific guidelines for each:

## Qualitative [2]

- Mint: Almost no wear whatsoever
- Near Mint: Very little wear
- Lightly Played: Limited wear
- Moderately Played: Worn
- Heavily Played: Very worn
- Damaged: Worthless
- Cards that have been altered (e.g. signed) are generally not given a condition rating

## Quantitative [3]

- 1-10 scale either on the card as a whole or on its individual parts (edges, surface, etc).
- May be mapped to a corresponding qualitative rating.
- Typically used by professional rating services.

# Problem Statement

- Reselling lots of cheap cards has large returns, but is expensive and annoying to sort, especially when grading and checking for forgeries is involved.
- Solutions exist, but they're not good enough, as they only do card ID.
- We'll make a device that does everything needed.

# Goals, Specifications, Testing Plan

# Project Goal

A machine capable of identifying, grading, verifying, and sorting bulk Magic: The Gathering Cards at a comparable level of competency to a human.

# Goals For CDR

- Total integration of every core system:
  - Sorting
  - Grading
  - Fraud Detection

# System Specifications and Verification - Overview

| Item | Description/spec | Test Plan/Verification |
|---|---|---|
| Card Throughput | >2 cards/min, >1000 card capacity | Basic verification of speed and capacity. |
| Card Condition Grading | Catch signs of damage. Provide a valid grading based on that damage. | Demonstrate that solution identifies all damage visible to the human eye. Demonstrate that grading generally agrees with guide used by client. |
| Card ID | Solution must find the name of card as well as the set it comes from. >95% accuracy | Prove with 95% confidence that accuracy is >95% |
| Forgery Detection | Customer asked for 4 benchmarks to detect fakes. Solution must perform all 4 checks. | Demonstrate that all 4 checks are present, and that they pass valid cards, and that 90% of forgeries fail at least one. |
| Card Damaging | No noticeable new damage to cards after processing | Prove with 95% confidence that no cards are damaged. |
| Output Bins | Need at least 15 software-configurable output bins | Demonstrate functionality. |

# Specifications - Card Throughput  (Review)

**Goal:**
>2 cards/min, >1000 card capacity

**Reason:**
Requested by vendor. About what a human person is capable of.

**Verification:**
Basic demonstration of each. Fully process 2 cards in 1 minute.

# Specifications - Condition Grading (Review)

**Goal:**
Find >95% of damage visible to human eye. 90% confidence.
        Sides (new)
        Front
        Back

**Reason:**
Key goal of this project is finding and evaluating damage to cards.

**Verification:**
Manually map all damage on digital image of card. Compare with computer-generated damage map. Do this for front/back/sides. 19/20 pieces of damage visually identified should also be identified by the computer. Do this 10 times.

# Specifications - Card ID (Review)

**Goal:**
Correctly identify cards 95% of the time. 95% certainty.

**Reason:**
Second key goal of this project is sorting cards correctly.

**Verification:**
Run 20 cards through identification. No more than 1 card misidentified. Do this 20 times. Unidentifiable cards that are correctly judged as such don't count.

# Specifications - Forgery Detection (Review)

**Goal:**
Weight check
Glossiness check
Printing verification check 1 (print pattern)
Printing verification check 2 (dots)

**Reason:**
Third key goal of this project is finding forgeries. Vendor mentioned each of these checks.

**Verification:**
90% of legitimate cards pass all 4 tests. 90% of fake cards fail at least one. 90% confidence: Run through 10 of each, 10 times. No more than 1 false positive/negative each run.

# Specifications - Card Damaging (Review)

**Goal:**
Cause minimal damage to cards through processing

**Reason:**
Want to have client trust. Damaging the cards hurts their value.

**Verification:**
Run 1 card through 5 times. Damage detection software should not detect more than 5% additional damage. Visual inspection should also show no damage.

Demonstrate fail-safe by unplugging mid-operation and showing no fires.

# Specifications - Output Bins (Review)

**Goal:**
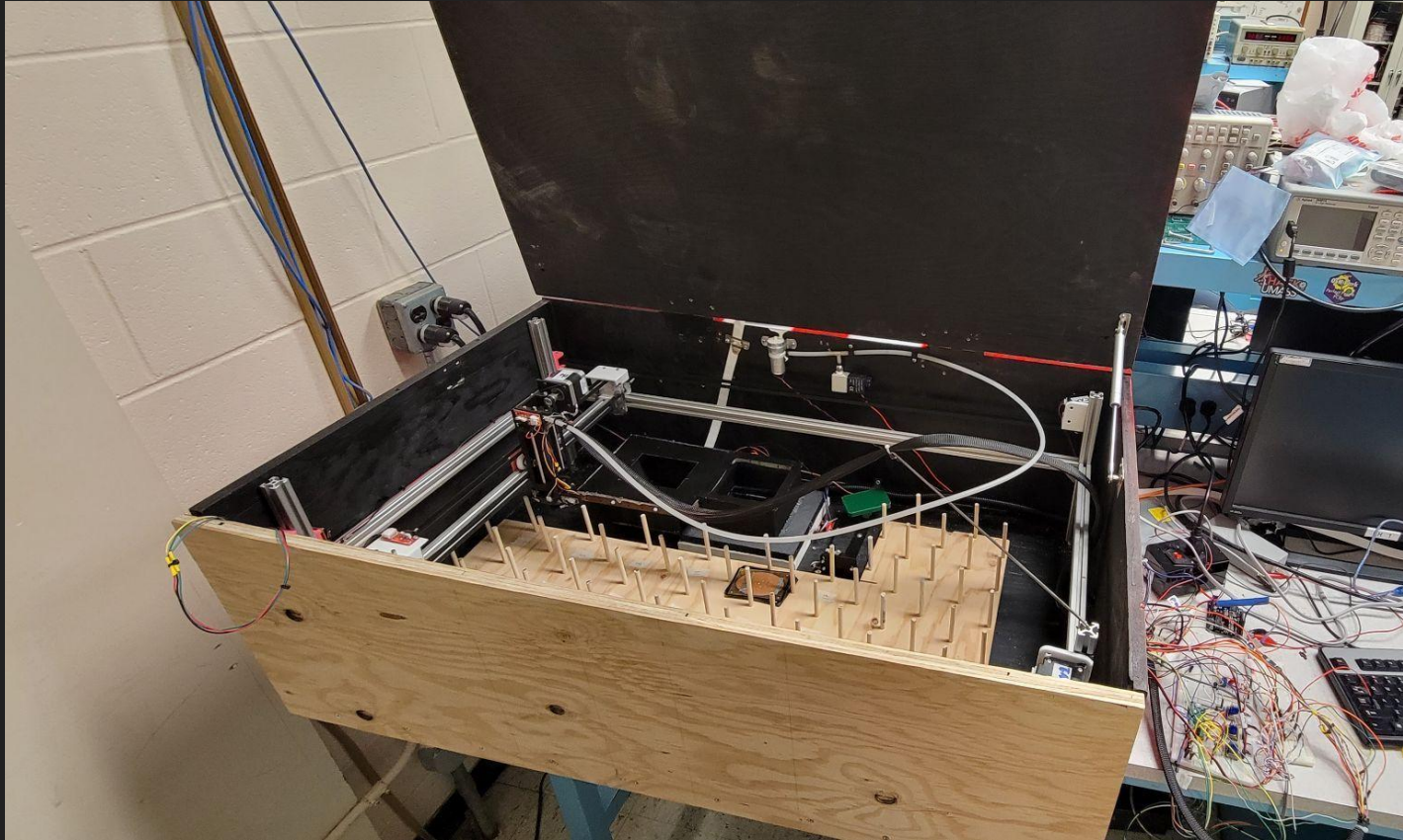At least 15 configurable input/output bins.

**Reason:**
Distributor identified maximizing number of possible outputs as very desirable.

**Verification:**
Demonstrate system is capable of accessing each bin. Demonstrate that they may be configured.

# System Design

# Current Design — General

# Hardware Diagram + Path of a Card
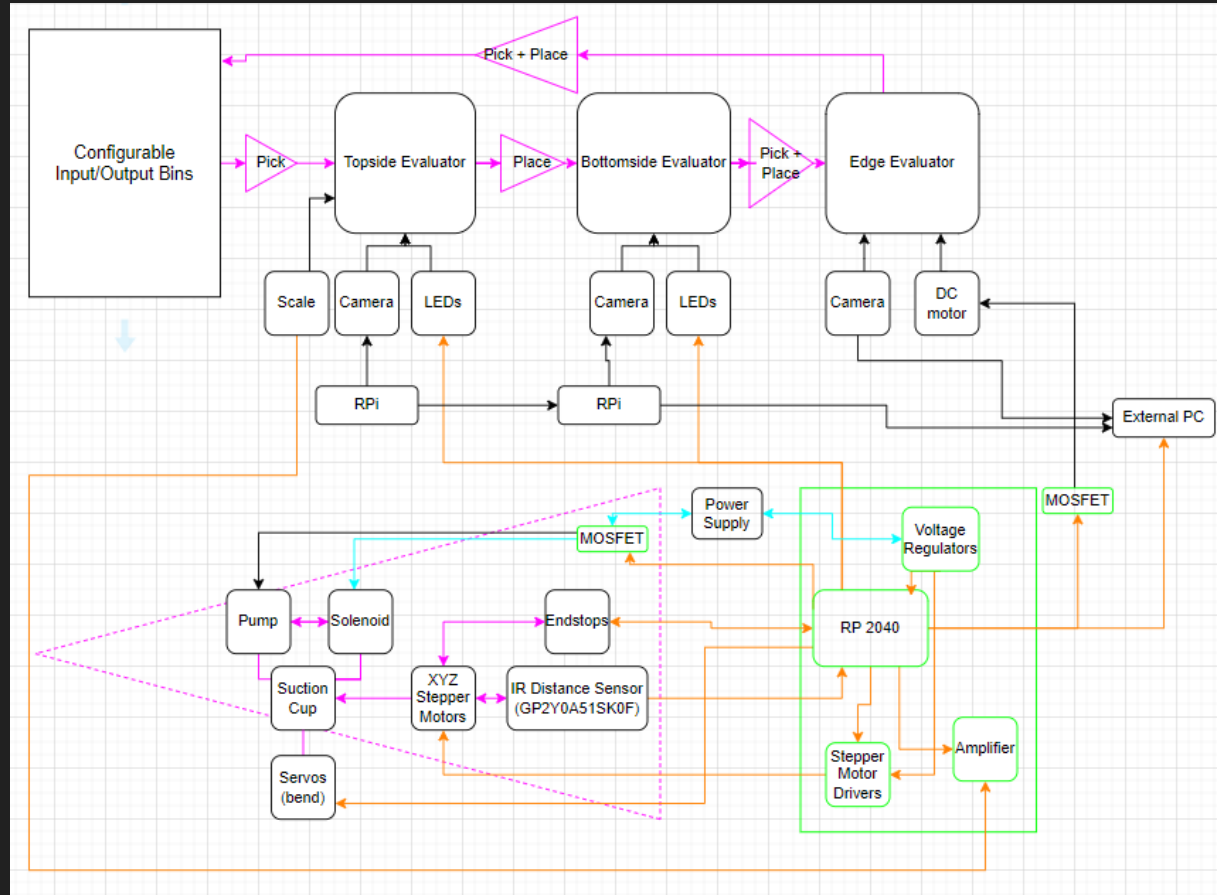
# Hardware Diagram

# Software Diagram



Power on all systems, establish connection with PC program, and load configuration file

Wait for sorting to begin

Sorting started →

Move head to input bin and retrieve card

Take images of both sides of the card

Place on scale to check weight, while taking pictures of the side of the card

Transfer images to PC via serial

Compare against database of known cards via hashing and feature matching to identify card

Process images of card to map damage and determine quality

Evaluate card authenticity based on images and weight

Sorting finished

Current card sorted, unsorted cards remaining

All cards sorted

Save results to database on PC

Place card in output bin according to sorting criteria

# Prototype Performance

# Card Throughput, Capacity, & Configurability

**Throughput Goal:**
>2 cards/min, >1000 card capacity

**Current Ability:**
Card processing rate is not yet determined but could potentially be up to 5 cards/min. Capacity surpasses 1000 cards

**Configurability Goal:**
At least 15 configurable input/output bins.

**Current Ability:**
There are 27 bins - we anticipate using 13 as input, and 14 as configurable outputs.



Each bin has ~250 card capacity, giving the system a total capacity of ~3,250 cards and an estimated runtime of ~28 hours if the minimum throughput goal is met.

# Condition Grading

**Goal:**
Find >95% of damage visible to human eye. 90% confidence.

**Current Ability:**
Very strong performance to isolate the card art from any damage/dust(artifacts). In future, we plan use blown air to move dust in order to distinguish between damage and dust.

# Card ID

**Goal:**
Correctly identify cards 95% of the time.
95% certainty.

**Current Ability:**
We have been able to identify the
majority of cards tested so far.



Top is original image. Bottom is
identified photo in database!

# Forgery Detection

**Goal:**
Weight check
Glossiness check
Printing verification check (pattern)
Printing verification check 2 (dots) — stretch

**Current Ability:**
Scale integration is incomplete - physically installed, software incomplete.

Glossiness check is incomplete

The pattern check is incomplete

Known dot pattern check is incomplete

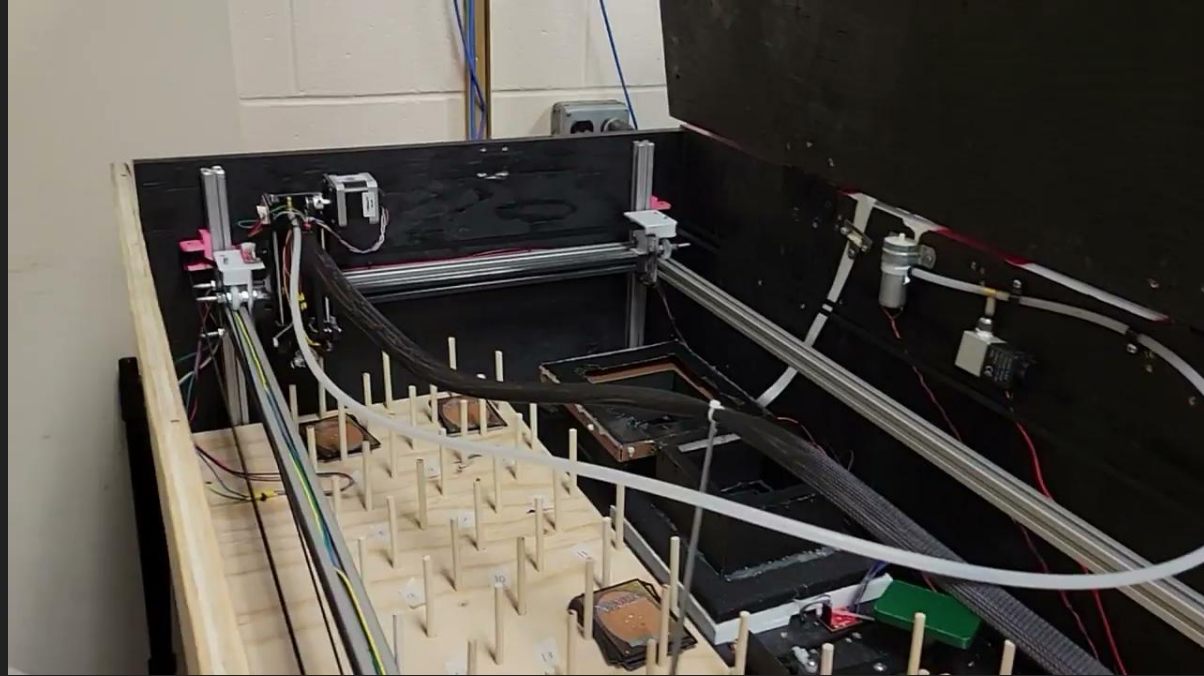While incomplete, they are all still goals

Fake

Real

# Card Damaging

**Goal:**
Cause minimal damage to cards through processing

**Current Ability:**
With careful calibration, we are able to process a card with no discernable damage.

# CDR Performance Summary

| Item | Specification | Capability |
|---|---|---|
| Card Throughput, Capacity | >2 cards/min, >1000 card capacity | Full. Need to perform formal verification for throughput, but shouldn't be a problem. Capacity is met. |
| Card Condition Grading | Catch signs of damage. Provide a valid grading based on that damage. | Full. Need to perform formal verification. May be some improvements required in the looking-up case |
| Card ID | Solution must find the name of card as well as the set it comes from. >95% accuracy | Full. Need to perform formal verification. |
| Forgery Detection | Weight check<br>Glossiness check<br>Printing verification checks (pattern & dots) | Partial. |
| Card Damaging | No noticeable damage to cards. | Partial. Further changes are needed to improve the reliability. |
| Output Bins | Need at least 15 software-configurable output bins | Partial. Need to finish programming coordinates. |

# Custom PCB

# The PCB



- RP2040 microcontroller
- Voltage regulation from 24V to 5V and 12V
- Interface with sensors for system
    - IR distance sensor for z-axis of gantry
    - endstops for all 3 axes of gantry
    - load cell
    - current sensor on pump to check if card is dropped accidentally (spike)
- Motor drivers
- Current status is not fully functional so breadboard is used.
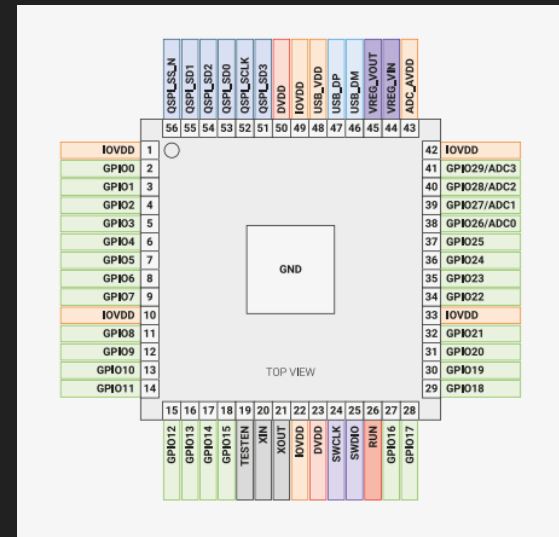
# Main PCB Full Image
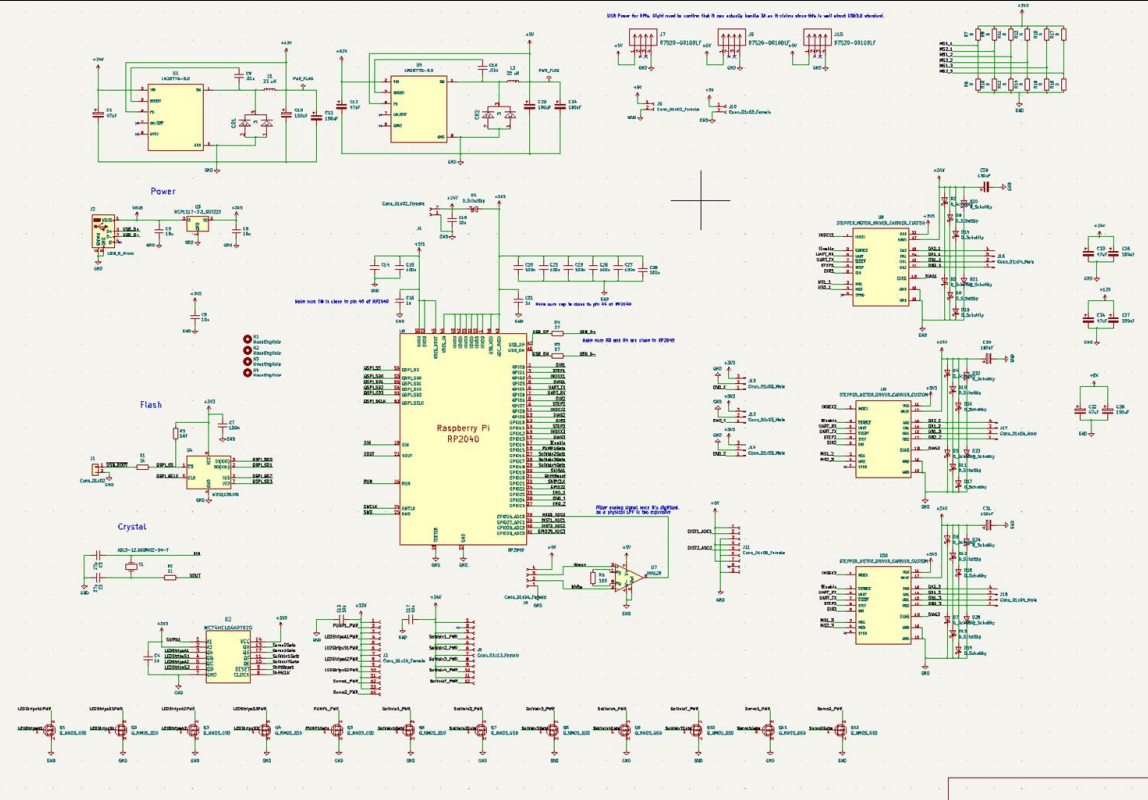


The main PCB had around 120 components.

We will go over some of the subsections in future slides.

# Voltage regulation for power
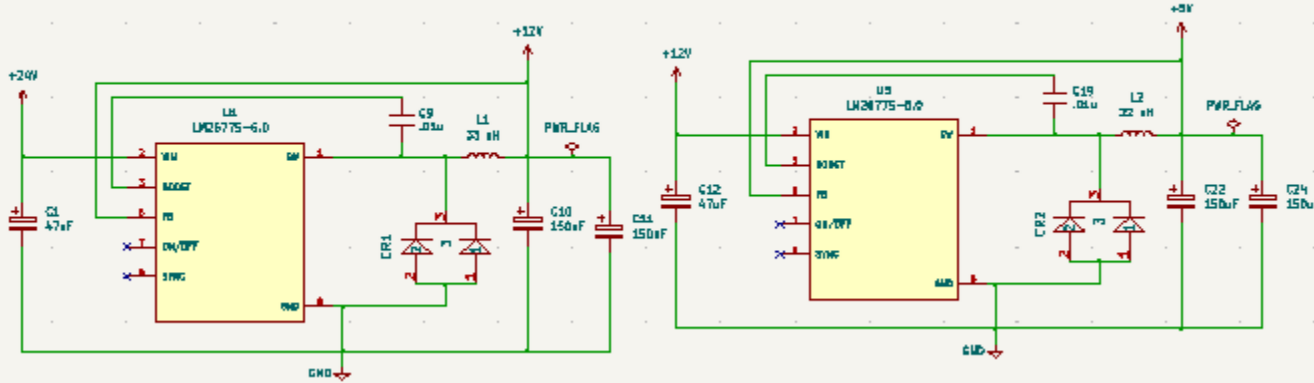


Large capacitors and inductors are required to manage the high power throughput.
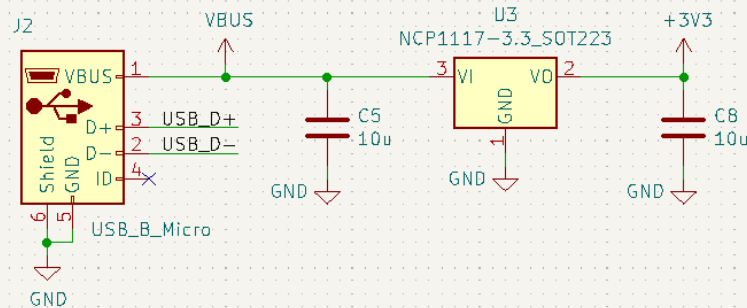
Power for RP2040 is provided by connection to RPi over usb.

Overall the system is fully populated, but not fully functional.

# Power Output Control
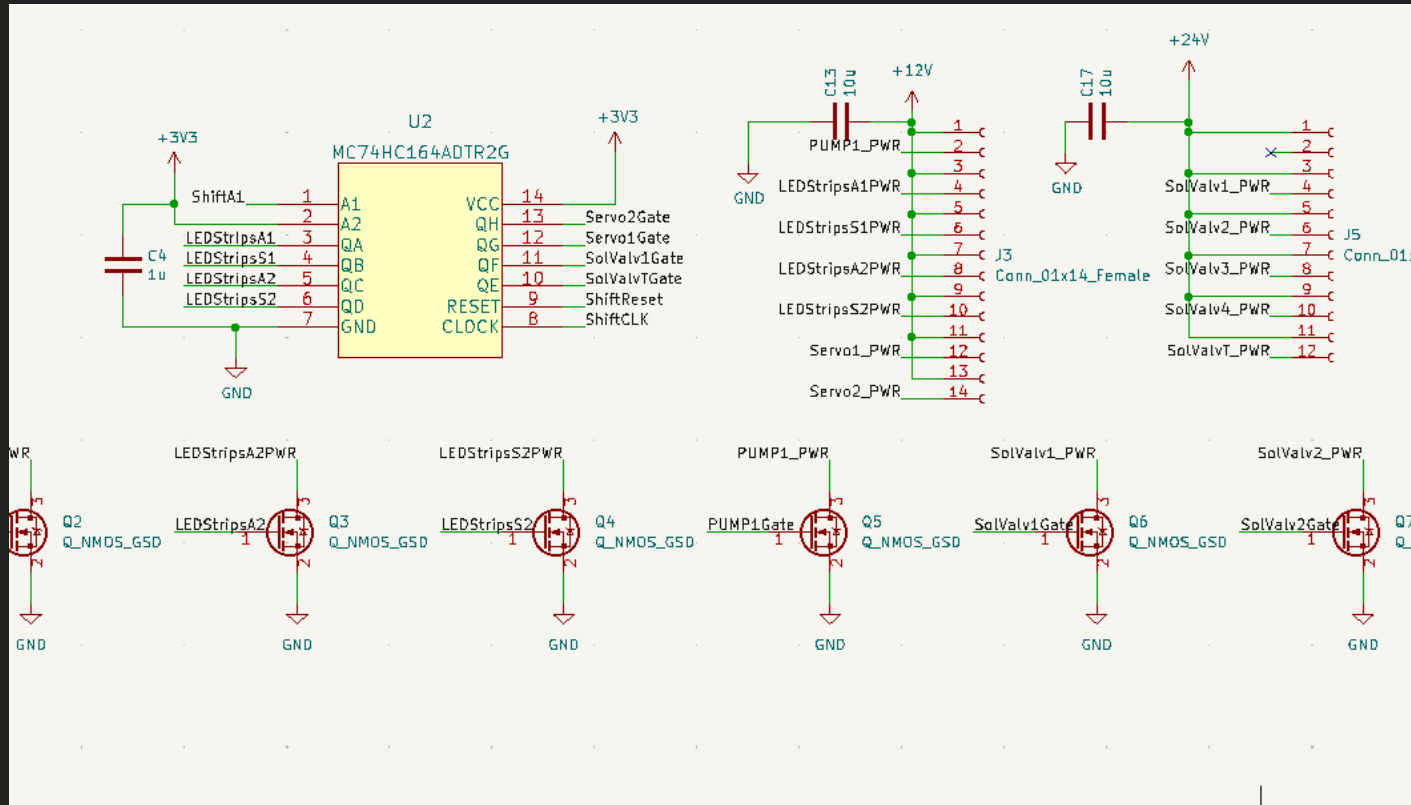


Shift register is used to extend I/O. NMOS are used to power the pumps, motors, and LEDs (in breadboard we use TIP31C NPN)

# Stepper Motor Driver Carrier on Main PCB
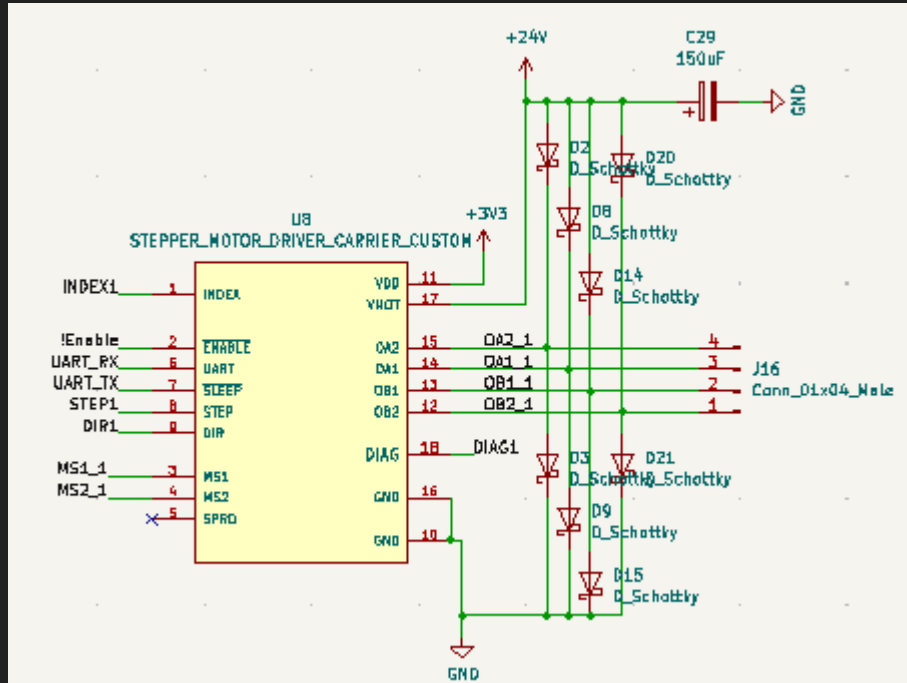


The diodes insure that back EMF doesn't harm the motor driver or other components.

# Stepper Motor Driver Carrier PCB
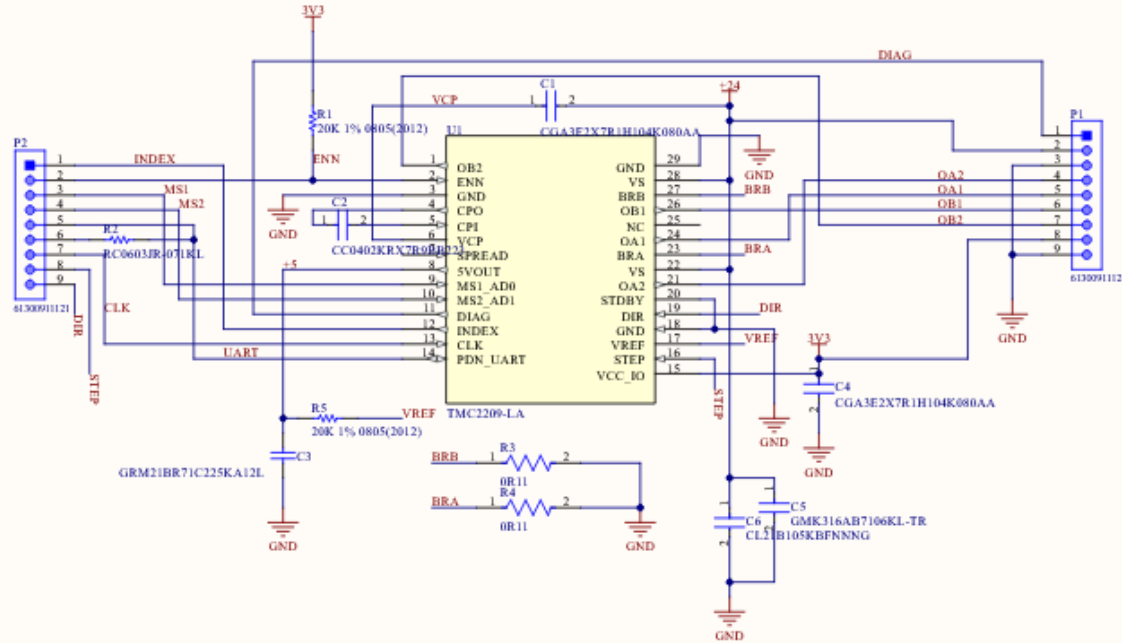


Errors were found in the pin layout, and some resistors and connections were missing, but UART demonstrated functionality. New version was ordered and has shipped but not arrived.

# PCB Layout for rev 2
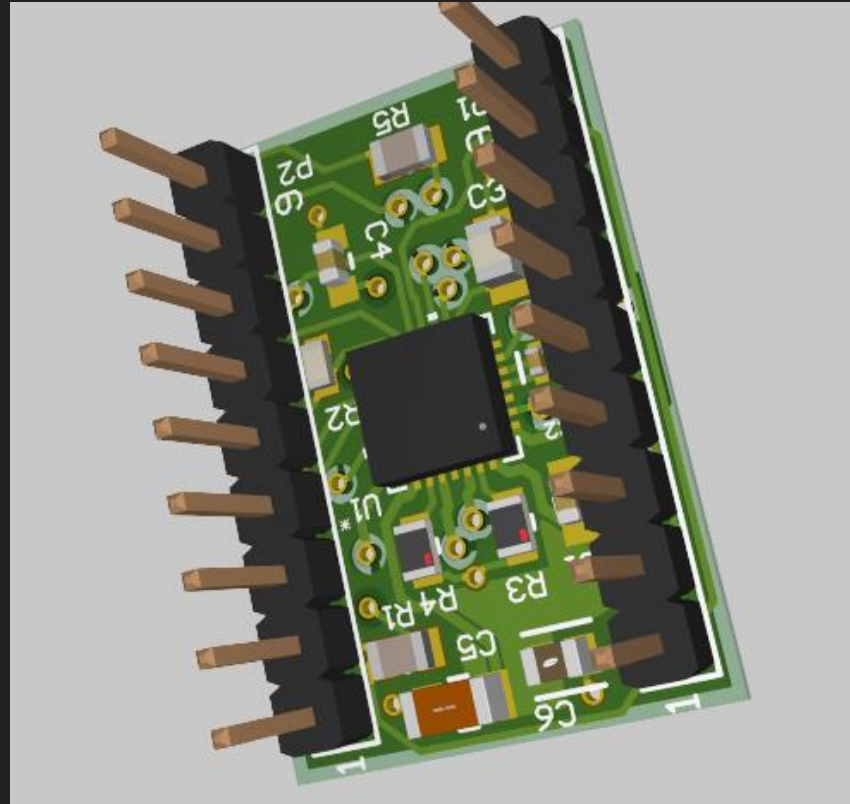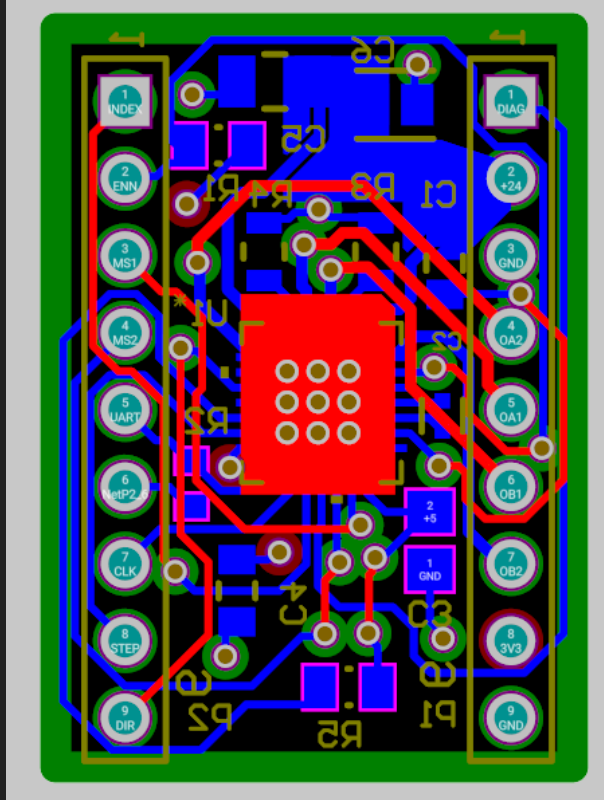
# FPR Plan

# FPR Revisions

- Improve integration, reliability, and repeatability
  - Enclosure
  - Wire management
  - Card Stack Location
  - PCB and PSU
- Improve capability of prototype for core performance
  - Damage Detection
  - Forgery Detection: Glossiness
  - Side of Card

# Gantt chart through FPR

| Task Name | Start Date | End Date | Team Member(s) | 3/20/2022 | | | | | 3/27/2022 | | | | | 4/3/2022 | | | | | 4/10/2022 | | | | | 4/17/2022 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | M | T | W | Th | F | M | T | W | Th | F | M | T | W | Th | F | M | T | W | Th | F | M | T | W | Th | F |
| **Hardware** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Finalize Controls and Integration | 3/20/2022 | 4/10/2022 | MO, HP, ZL | | | | | | | | | | | | | | | | | | | | | | | | | |
| Final Revision Head | 3/20/2022 | 4/3/2022 | LR | | | | | | | | | | | | | | | | | | | | | | | | | |
| Evaluator Performance Improvement | 4/3/2022 | 4/17/2022 | HP, JM | | | | | | | | | | | | | | | | | | | | | | | | | |
| Forgery Detection Finalization | 3/20/2022 | 4/10/2022 | MO, JM, HP | | | | | | | | | | | | | | | | | | | | | | | | | |
| Finishing touches | 3/27/2022 | 4/17/2022 | HP, MO, LR, ZL, JM | | | | | | | | | | | | | | | | | | | | | | | | | |

# FPR Demonstration Plan

- Put together a small deck of cards representative to our system capabilities (of different damage levels, of different values, and some forgeries)
- Process the small deck in front of whoever is watching

# Expenditures & Management

# Expenditures: Hardware

| Item | Description | Link | Price (to us) | # | Justification | | |
|---|---|---|---|---|---|---|---|
| LDO-42STH38-1004A | Stepper Motors for each gantry axis | https://ldomotors.en | $0.000 | 3 | Free to us | | |
| Makerbot Mechanical Endstop V1.2 | Endstops for each gantry axis & head | https://www.amazon | $0.000 | 3 | Free to us | | |
| A4988 Stepper Motor Driver Carrier | Breakout boards for A4988 Stepper Motor Drivers | https://www.pololu.c | $0.000 | 3 | Free to us | | |
| Ramps 1.4 Board + Arduino Mega | Board to control stepper motors | | $0.000 | 1 | Free, used for prototyping (will be replaced by PCB) | | |
| 20mm Tslot frame rail | Frame Rail | https://www.mcmast | $11.000 | 6 | compatible with other frame components. Of smallest viable size. | | |
| 2020 Series Aluminum Extrusion Conne | Frame Connectors | https://www.amazon | $17.000 | 1 | compatible with other frame components. Of smallest viable size. | | |
| 48 PCS 3D Printer POM Pulley Wheel S | Wheels for carriages | https://www.amazon | $19.000 | 1 | compatible with other frame components. Of smallest viable size. | | |
| 5M GT2 Timing Belt 6mm Width + 4pcs | Belt and belt accecories for carriages | https://www.amazon | $16.000 | 1 | compatible with other frame components. Of smallest viable size. | | |
| Electric Solenoid Air Valve | Solenoid to engage and disengage vacuum | https://www.amazon | $0.000 | 1 | free to us | | |
| NW Air Pump 5V-6VDC Miniature Vacui | pump to generate vacuum | https://www.amazon | $0.000 | 1 | free to us | | |
| Servo - Generic (Sub-Micro Size) | Micro servo to bend cards | https://www.sparkfu | $9.000 | 2 | very small. may be used to bend cards to stop them sticking. | | |
| RPi NoIR Camera V2.1 | camera to generate images of each side of cards. | https://www.cytron.i | $29.000 | 2 | Good Quality, relatively low price camera | | |
| IR Distance Sensor | Distance Sensor to determine clearances on head | https://www.robotsh | $12.000 | 1 | Very low range IR Distance sensor at low price | | |
| Suction Cup 5427A786 | Used to pick up cards and to place them | https://www.mcmast | $10.000 | 1 | Good dimensions and capabilities | | |
| Mini Load Cell - 100g, Straight Bar (TAL | load cell to be used to determine card weights | https://www.sparkfu | $9.000 | 1 | appropriate size and fidelity for use on playing cards | | |
| Alise 100N/22.5lb Up Opening Pneuma | Hold box open | https://us.amazon.c | $12.990 | 1 | good spec & cheap | | |
| Design House 181438 6-Hole x 3 1/2", 5 | Hinge for box door | https://www.amazon | $6.100 | 1 | good spec & cheap | | |
| 40PCS L Bracket Corner | Hold box & gantry together | https://www.amazon | $8.990 | 1 | good spec & cheap | | |
| HATCHBOX PLA 3D Printer Filament | Printer filament | https://www.amazon | $22.990 | $1 | good spec & cheap | | |
| 20 Sets Jst 2.0 Ph 4 Pin Connector Plug | connector pins | https://www.amazon | $7.690 | 1 | correct spec | | |
| Jetson | Image processor | https://store.nvidia.c | $60 | 1 | Good at image processing and OK price | | |
| DC Converter | 24V - 5V 5A | https://www.digikey. | $25.48 | 1 | Necessary to have sufficient current to power all parts that need it | | |
| DC Converter | 24V - 3.3V 2.5A | https://www.digikey. | $27.57 | 1 | power pump and low-power devices | | |

Approximately $20 left in budget

# Expenditures: Board Components

| | | | | | |
|---|---|---|---|---|---|
| W25Q128JVSIQ-ND | IC FLASH 128MBIT SPI/QUAD 8SOIC | https://www.digikey. | $1.880 | 2 | PCB component |
| NCP1117DT33GOS-ND | IC REG LINEAR 3.3V 1A DPAK | | $0.760 | 2 | PCB component |
| X983-ND | CRYSTAL 12.0000MHZ 32PF TH | | $0.700 | 2 | PCB component |
| SN74HC164PW-ND | IC SHIFT REGISTER 8BIT 14-TSSOP | | $1.160 | 2 | PCB component |
| A19473-ND | CONN HEADER VERT 9POS 2.54MM | | $0.700 | 2 | PCB component |
| 609-1045-ND | CONN RCPT USB2.0 TYPEA 4POS R/A | | $0.930 | 6 | PCB component |
| RMCF0805FT100RCT-ND | RES 100 OHM 1% 1/8W 0805 | | $0.100 | 2 | PCB component |
| A98333-ND | TERM BLK 2P SIDE ENT 2.54MM PCB | | $1.450 | 2 | PCB component |
| 296-48568-1-ND | IC REG BUCK 5V 5A TO263-3 | | $6.950 | 2 | PCB component |
| ED10568-ND | TERM BLK 12P SIDE ENT 2.54MM PCB | | $3.320 | 4 | PCB component |
| NVTR4503NT1GOSCT-ND | MOSFET N-CH 30V 1.5A SOT23-3 | | $0.306 | 24 | PCB component |
| 541-1343-1-ND | FIXED IND 22UH 7.2A 46.97MOHM SM | | $3.960 | 2 | PCB component |
| SRP1265A-330MCT-ND | FIXED IND 33UH 8A 58 MOHM SMD | | $2.140 | 2 | PCB component |
| LM2677SX-12/NOPBCT-ND | IC REG BUCK 12V 5A TO263-7 | | $6.950 | 2 | PCB component |
| 1276-1015-1-ND | CAP CER 10000PF 50V X7R 0805 | | $0.100 | 4 | PCB component |
| 478-7804-1-ND | DIODE SCHOTTKY 40V 500MA 1206 | | $0.315 | 50 | PCB component |
| 455-2932-1-ND | CONN RCP MICRO USB B 5POS SMD RA | | $2.650 | 2 | PCB component |
| 1276-1043-1-ND | CAP CER 0.1UF 25V X5R 0402 | | $0.011 | 18 | PCB component |
| SS5P4-M3/86AGICT-ND | DIODE SCHOTTKY 40V 5A TO277A | | $0.670 | 4 | PCB component |
| 493-4685-1-ND | CAP ALUM POLY 47UF 20% 50V T/H | | $4.279 | 10 | PCB component |
| 1189-2325-ND | CAP ALUM 47UF 20% 50V RADIAL | | $0.192 | 12 | PCB component |
| 1276-1122-1-ND | CAP CER 10UF 6.3V X5R 0805 | | $0.086 | 14 | PCB component |
| 311-1019-1-ND | CAP CER 27PF 50V C0G/NPO 0402 | | $0.026 | 10 | PCB component |
| 1276-1275-1-ND | CAP CER 1UF 10V X7R 0805 | | $0.059 | 10 | PCB component |
| 493-3717-ND | CAP ALUM POLY 150UF 20% 16V T/H | | $0.782 | 10 | PCB component |
| RMCF0402FT1K00CT-ND | RES 1K OHM 1% 1/16W 0402 | | $0.015 | 10 | PCB component |
| 311-27JRCT-ND | RES 27 OHM 5% 1/16W 0402 | | $0.013 | 10 | PCB component |
| 311-27JRCT-ND | RES 27 OHM 5% 1/16W 0402 | | $0.013 | 10 | PCB component |
| S7042-ND | CONN HDR 9POS 0.1 GOLD PCB | https://www.digikey. | $0.670 | 6 | PCB component |
| 311-.11SCT-ND | RES 0.11 OHM 1% 1/8W 0805 | | $0.360 | 10 | PCB component |

Total So Far: $503.84 (note that some of this is out-of pocket).

# Project Management

- Mechanical Lead - Gantry: Zalman Lipschitz
  - Insuring there is a proper mechanical system for moving the head to where it needs to go.
- Mechanical Lead - Evaluator: Liam Rees
  - Designing and managing the head of the gantry, responsible for picking up cards as well as taking pictures of them
- Software Lead: Malcolm Okaya
  - Card ID tweaks as needed, controlling motors, code for sensors, code for fraud detection.
- Damage Detect Lead: Joseph Maloyan
  - Using CV to find damage on the card and grade it.
- PCB Lead and Team Coordinator: Henry Powell
  - Need to manage all sensor systems, as well as power and motor drivers.