Assistive Digital Piano

Group 45
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Presentation Overview

- Project Overview
- Design
- Successes and Failures
- Future Steps

Project Overview - The Problem

Motivation:

- Piano lessons are expensive ($30-$70/hr)[1] and often boring for children
- Users may teach themselves incorrectly

Goal:

- Force the player to use proper keys and fingering
- Use gamification in order to improve the learning experience for children

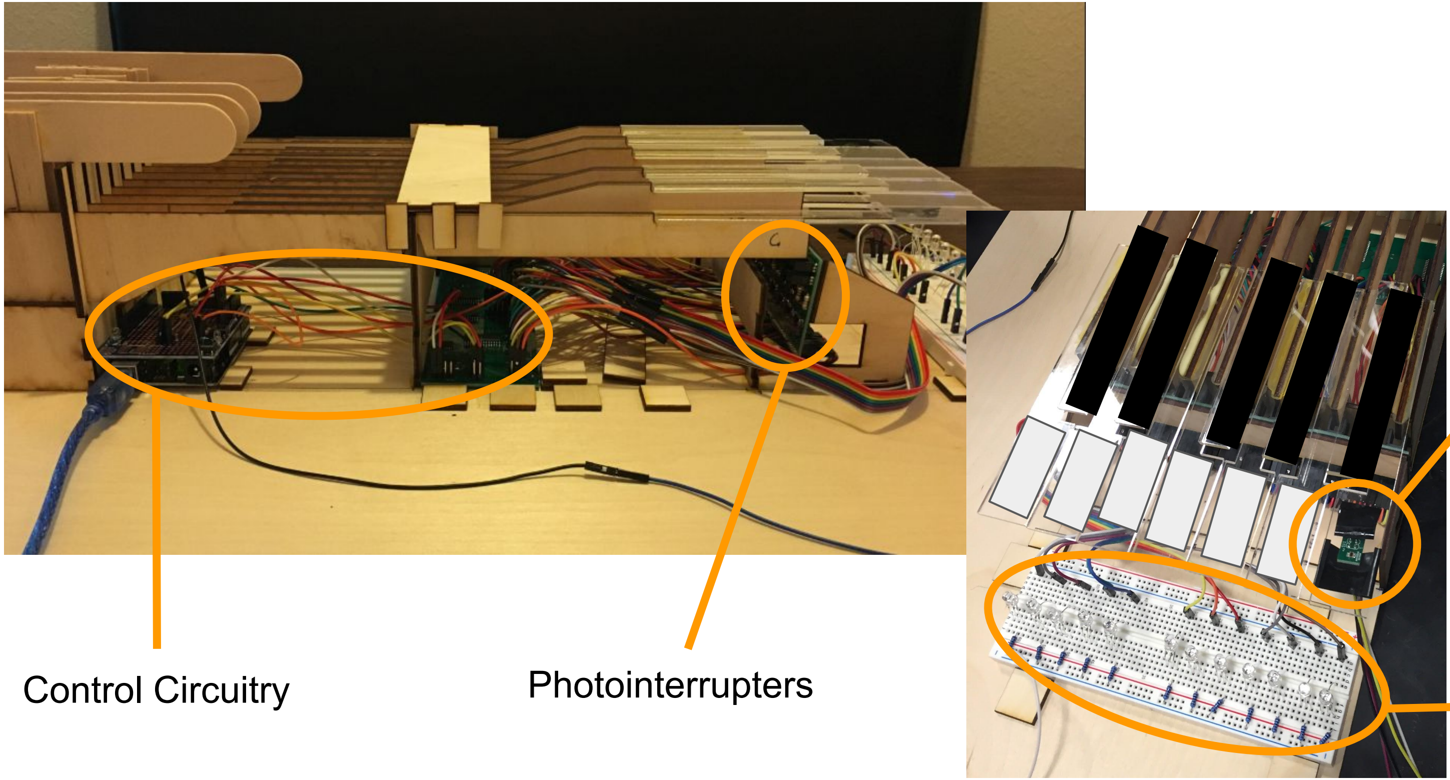
Project Overview - The Solution

A digital piano designed to teach the keys and fingerings to programmed songs.

Achieved through the use of:

- **Photointerrupters** for velocity-sensitive key input
- **Color sensors** and **colored fingertip sleeves** for finger detection
- **RGB LEDs** to indicate fingering for keys
- Software to assess performance and stops wrong notes from making sound

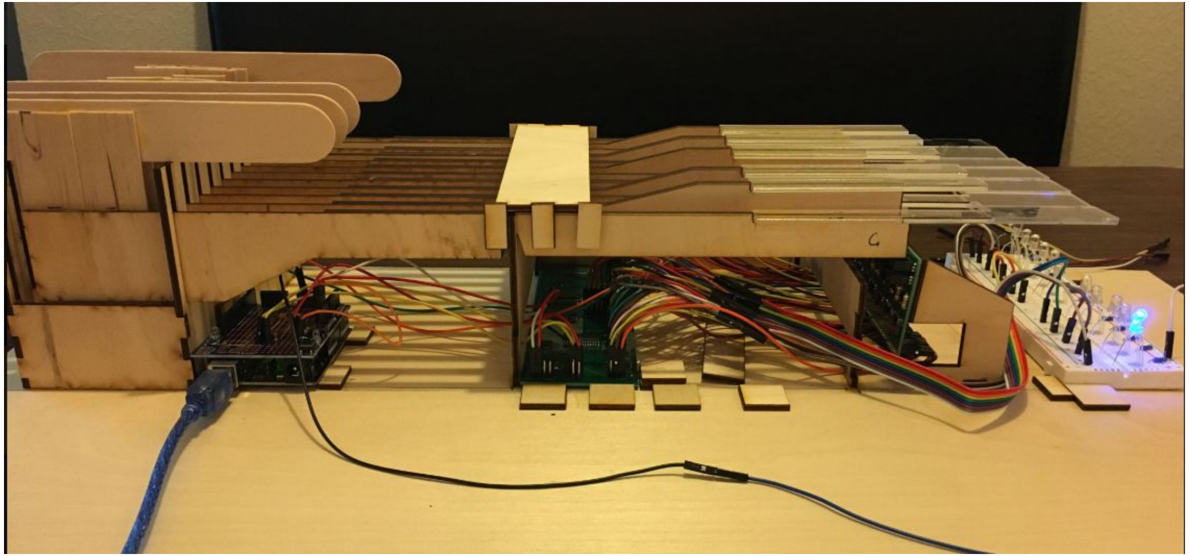
Project Overview - Physical Design



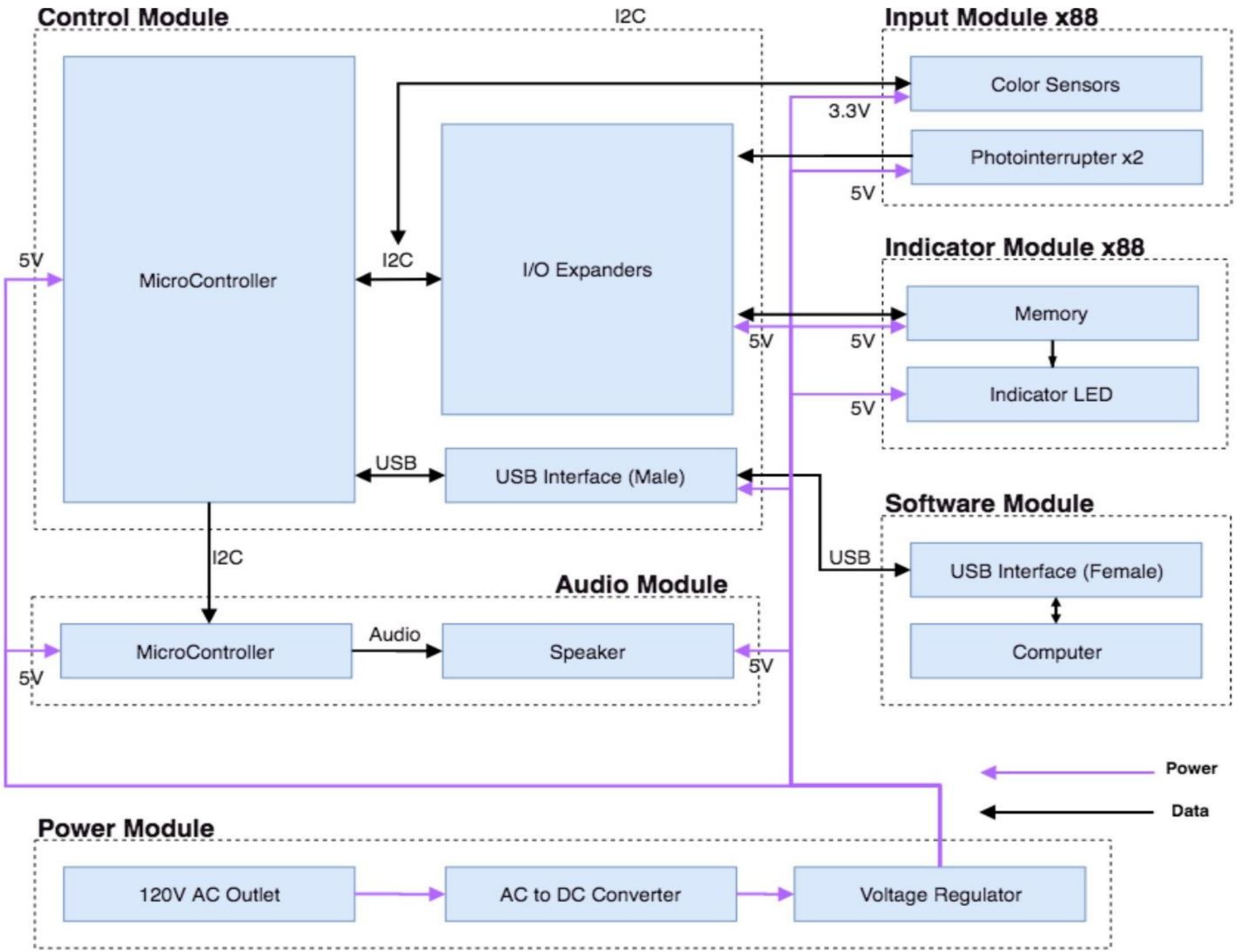
Project Build

A full piano octave

- Physical mechanism to trigger photointerrupters w/ velocity sensitivity
- Note validation w/ simple indicator LEDs



Block Diagram



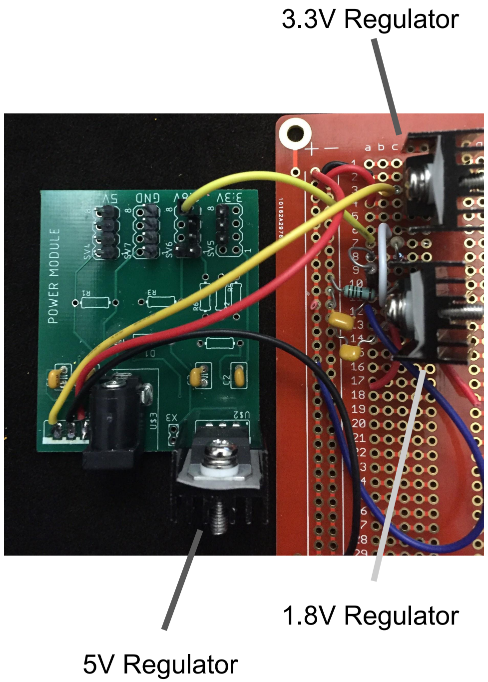
Power Module

Voltage regulator

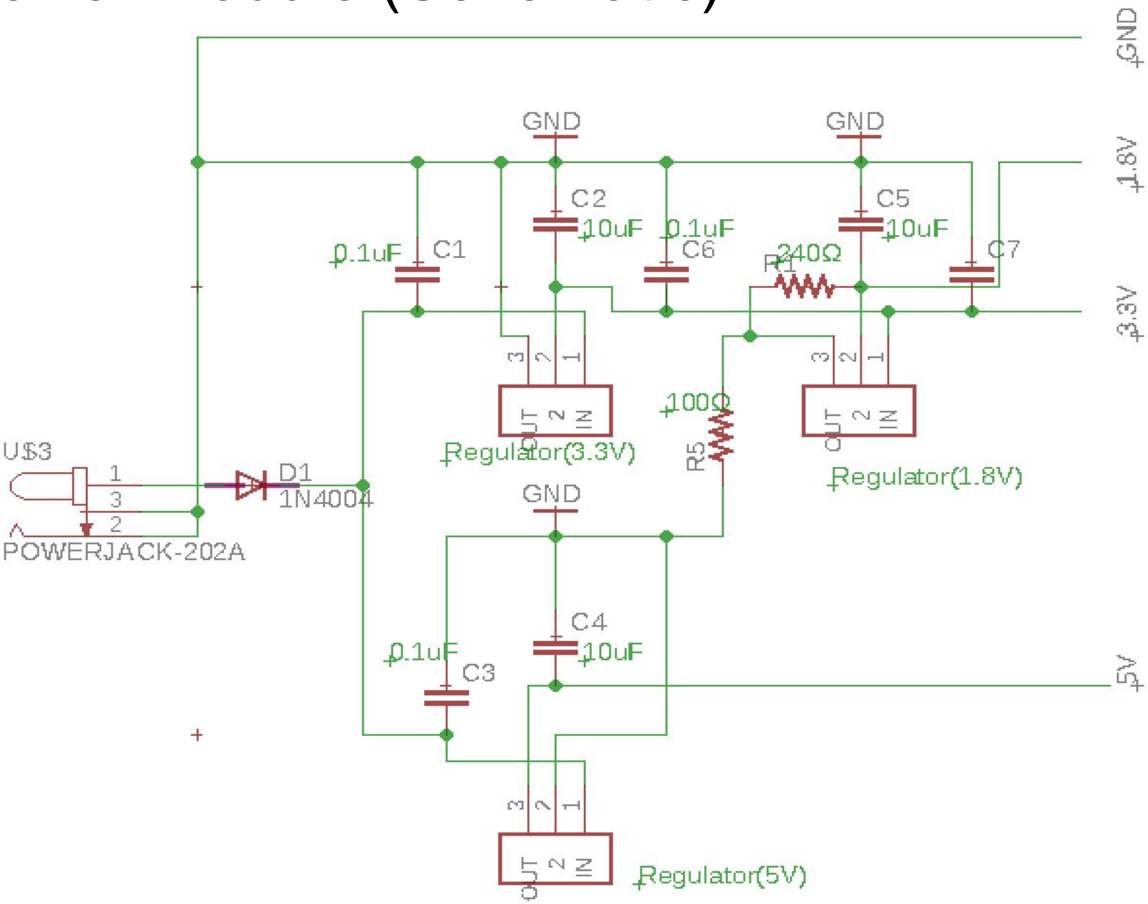
Goal: 9V from AC/DC wall converter → 5V, 3.3V and 1.8V Output

- MAX Current=1.5A

Power Requirement	Module
5V	Input Module (Photointerrupter), Control Module, Indicator Module
3.3.V	Input Module (Color sensor)
1.8V	Input Module (Photointerrupter)



Power Module (Schematic)



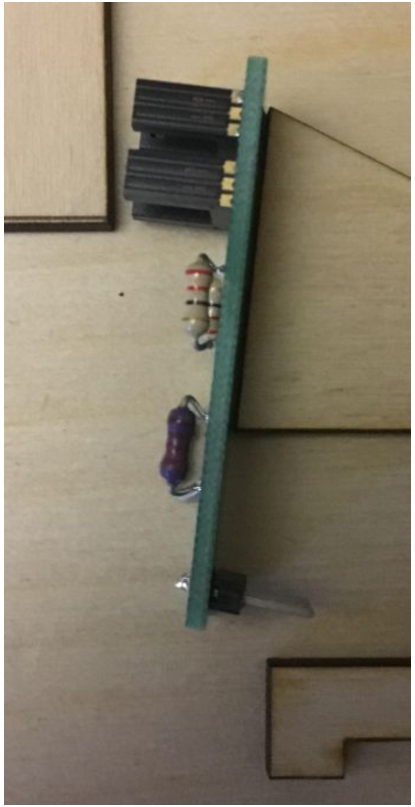
Vout (1.8V) = 1.25 (1+R5/R1)

R5 = 100Ω
R1 = 240Ω

Input Module - Photointerrupters

Goal: Detect keypress and determine velocity of keypress.

- Digital Low Output
- Two for each key, triggered sequentially
- 4 x 9 x 9 mm



Input Module - Color Sensors

Goal: Detect finger sleeve color.

- Each key includes a I2C color sensor

Photointerrupter

Key Address

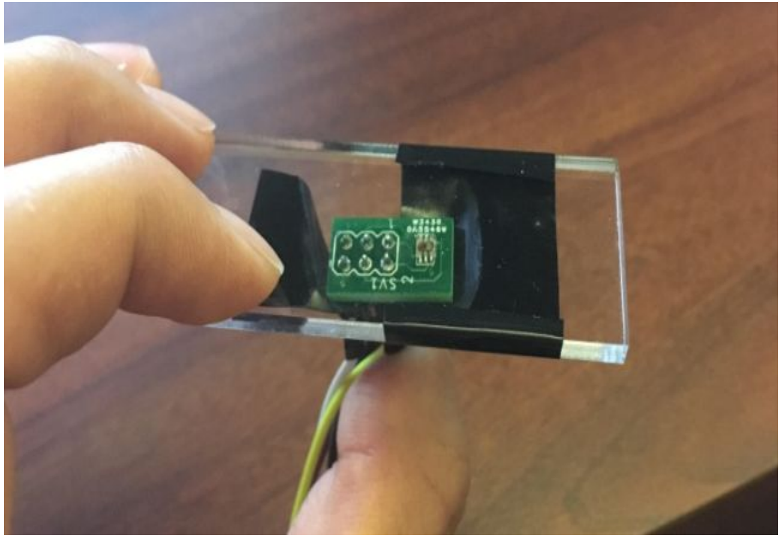
Microcontroller

Select Bits

Color Sensor

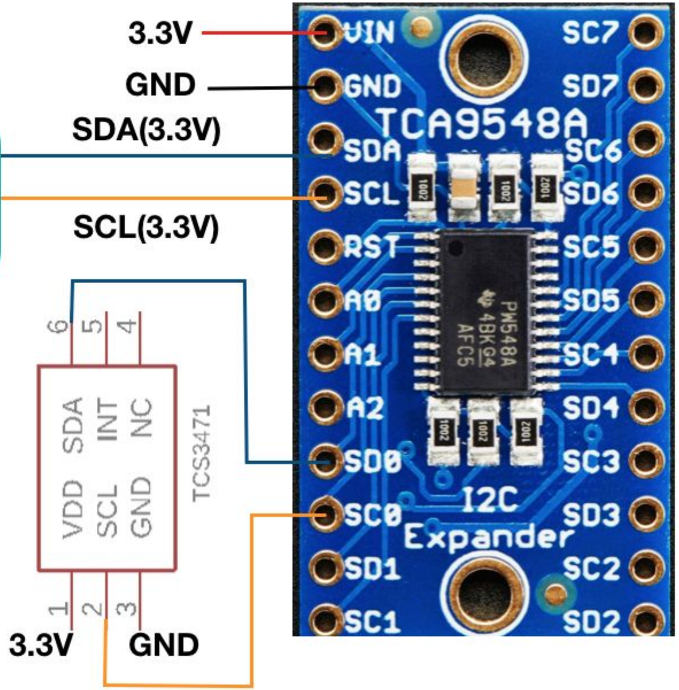
Multiplexer

- Outputs RGB values of the detected color
- Size: 2mm X 2.4mma



Clear key top and placement of the color sensor

Input Module - Color Sensors (Schematic)



CALIBRATION:

AVG=(RED+GREEN+BLUE+CLEAR)/4

RED=RED/AVG

BLUE=BLUE/AVG

GREEN=GREEN/AVG

CLEAR<5000

Input Module - Color Sensors (Results)

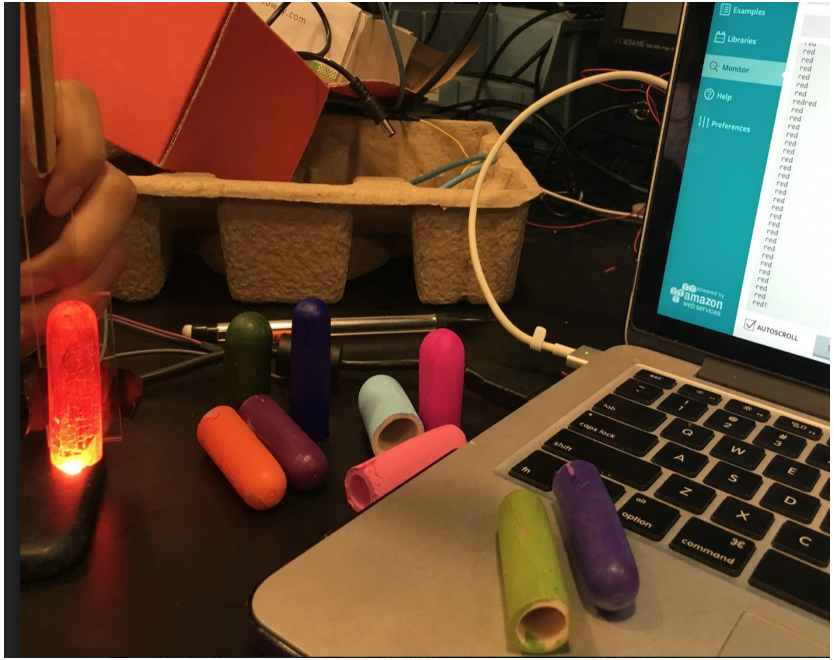
COLOR	RED	GREEN	BLUE	FINGERING
RED	1.60-1.66	0.23-0.25	0.31-0.34	Left Pinky
ORANGE	1.62-1.68	0..25-0.3	0.26-0.28	Left Ring Finger
YELLOW	1.6-1.69	0.55-0.6	0.20-0.22	Left Middle Finger
YELLOW-GREEN	1.2-1.22	0.53-0.6	031-0.35	Left Index Finger
GREEN	0.8--1.10	0.5-0.6	0.22-0.25	Left Thumb
SKYBLUE	1.07-1.10	0.5-0.61	0.43-0.46	Right Thumb
DARK-BLUE	0.86-1.0	0.43-0.56	0.65-1	Right Index Finger
PURPLE	1.2-1.23	0.48-0.53	0.5-0.8	Right Middle Finger
MAGENTA	1.4-1.55	0.33-0.35	0.41-0.44	Right Ring Finger
PINK	1.57-1.62	0.23-0.26	0.33-0.36	Right Pinky
WHITE	1.7-1.9	0.7-0.9	0.7-1	

Input Module - Color Sensors (Results)

- Color identification between simultaneous key presses: less than 146 ms

Error Analysis:

- Incident Light
- Distance from color sensor
- Similar Colors, e.g Red, Pink

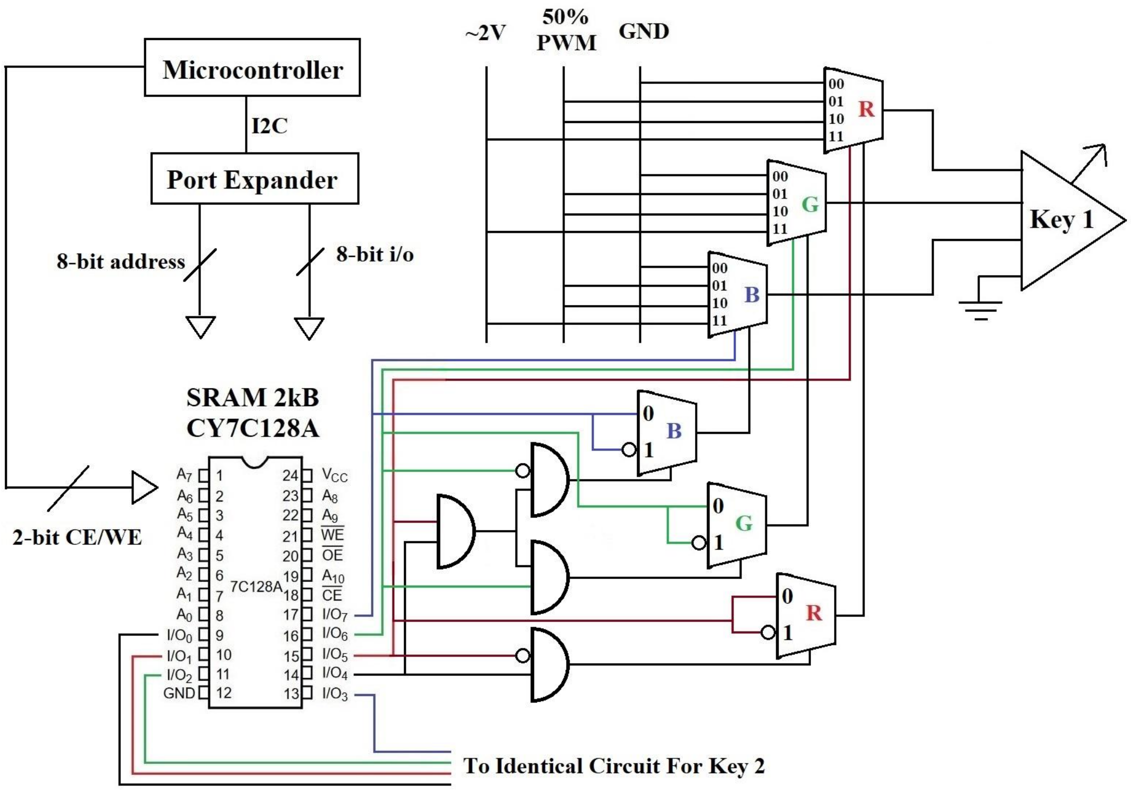


Color sensor reading Red finger sleeve

Indicator Module - Schematic

Goal: Indicate which keys should be pressed with which fingers.

- 4-bit color code to 6-bit color code
- 6 control circuits total (for 1 octave)

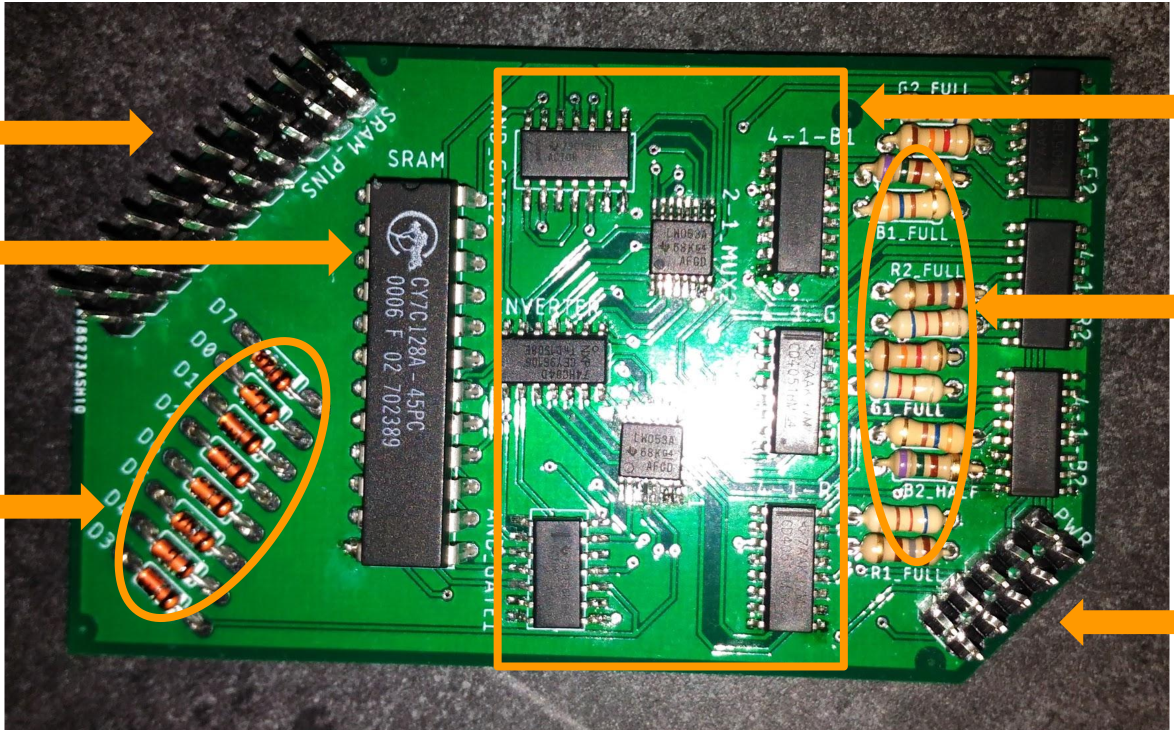


Indicator Module - Original Design

SRAM Input

SRAM

** Diodes



4-bit to 6-bit

** Resistors, not PWM

Power Input, LED Output

Indicator Module - Final Design

R/V

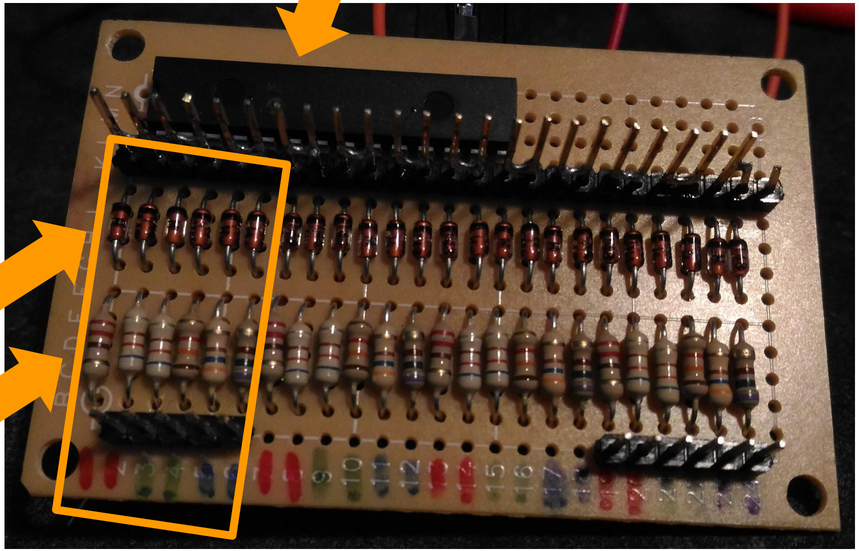
- 10 distinct colors
- Unnoticeable latency

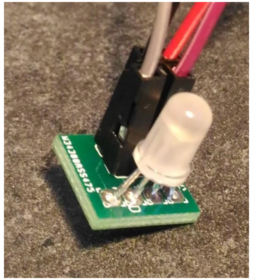
** Never fully integrated

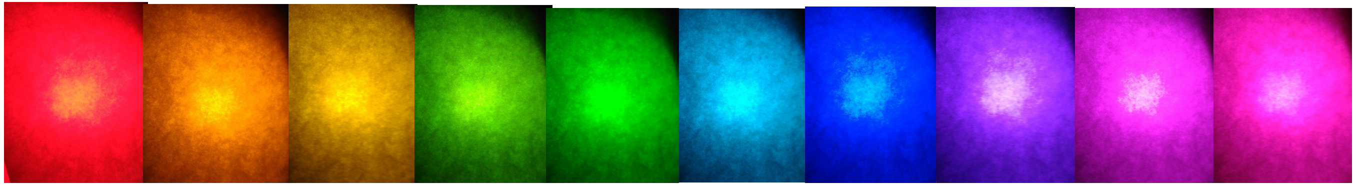
I/O Expander

Diodes

Resistors







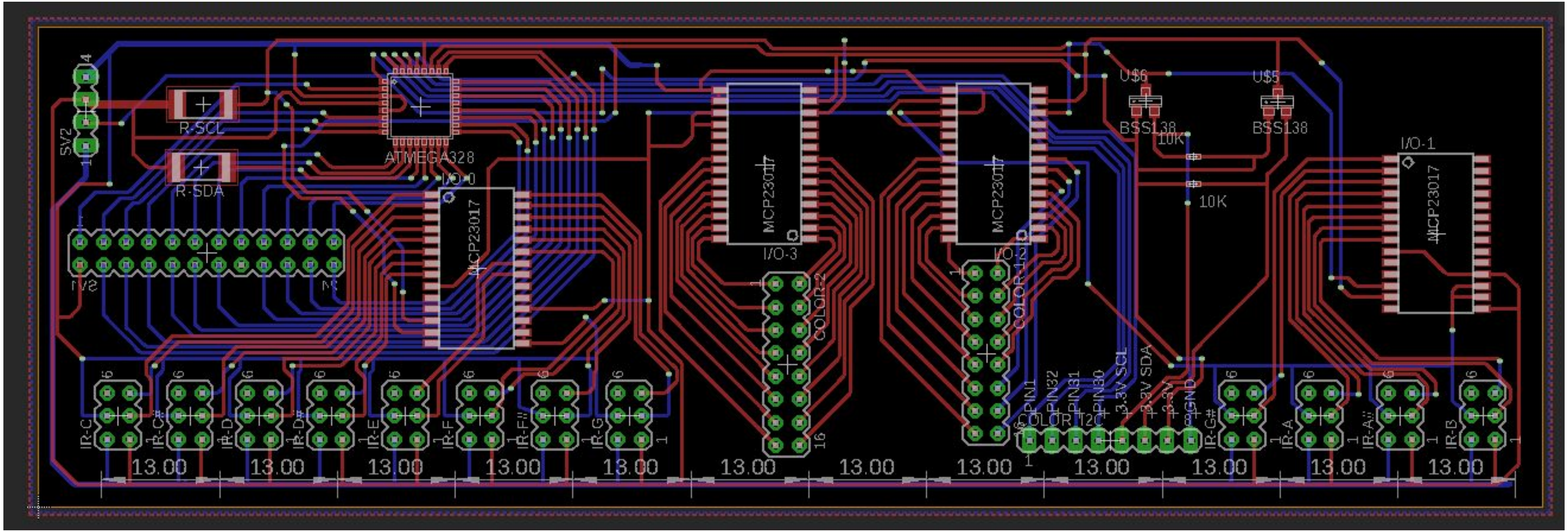
Control Module - Overview

Goal: Handle I/O between modules, key verification, and key processing.

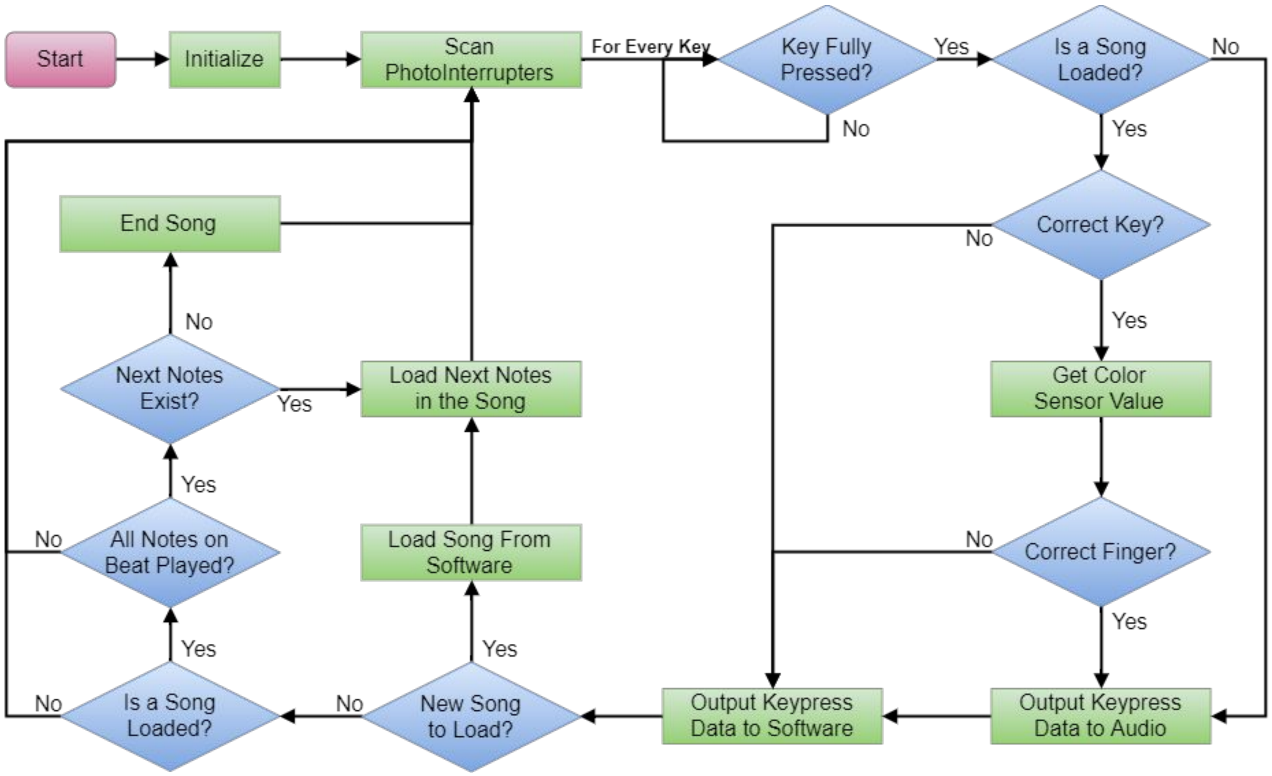
Three modes of operation:

1. Normal Piano
2. Piano with programmed note verification
3. Piano with programmed note and finger verification

Control Module PCB Design



Control Module - Original Microcontroller Program



Control Module - Requirements

- Process I^2C to I/O Expanders at 1.7MHz
- Output color codes to the correct LEDs
- Process 10 simultaneous key presses within 1 ms

Control Module - ???

Designed to be scalable (up to full 88 keys)

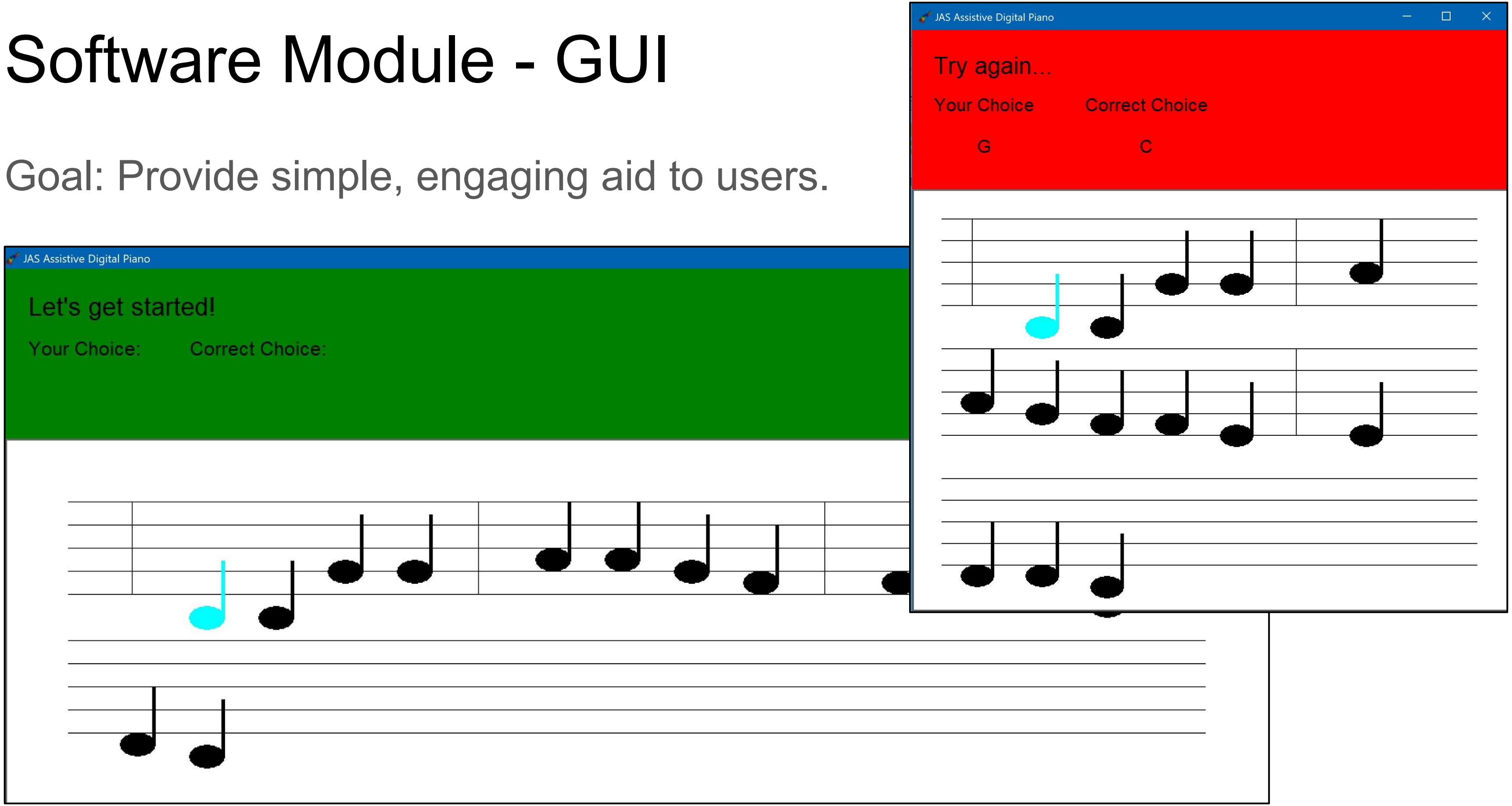
- 174 Photointerrupters
- 88 Color Sensors
- 88 Indicator LEDs

Soft Requirement: Ensure time resolution of velocity sensing

- Will return to this topic later

Software Module - GUI

Goal: Provide simple, engaging aid to users.



Verification Failures

- Power Module
  - 1.67 V supplied (1.8 V required)
  - 250 mA supplied (350 mA required)
- Control Module
  - Serial communication from computer to microcontroller did not work

Integration and Reliability Failures

These components worked alone, but could not be integrated into the final build.

- Color Sensor (all 12)
- Indicator Module
- GUI

These components worked most of the time.

- Input Module - Color Sensors
  - I^2C Communication sometimes shut down (Interrupts failed to trigger)
  - Values were inconsistent without a bright white light source

Velocity Sensing Time Resolution (1)

Velocity Sensing Time Resolution Mistake

Original Target: minimum 0.5 ms per scan

1.7MHz I^2C

- ~.259 ms to scan 174 Photointerrupters
- ~.140 ms to output 10 colors to indicator LEDs

TCS3471 Color Sensor is only capable of 400kHz I^2C!

- ~1.8 ms to scan 10 color sensors

Velocity Sensing Time Resolution (2)

Assuming ~ .1ms for all other program logic

.10 + .259 + .14 + 1.80 = 2.30 ms

The next keyscan in 1.80 ms late!

- Not significant latency, but is significant for dynamic control.
- Fast keypresses were measured in under 2ms.

Improving the Time Resolution (1)

Color Sensor Scanning - Hardware Solution

- Use an intermediate data buffer
- Poll color sensors at a fixed interval
- Faster communication between microcontroller and buffer

Disadvantages:

- Results in a much more complicated and costly circuit
- Increases power consumption significantly

Improving the Time Resolution (2)

Color Sensor Scanning - Software Solution

- Keep a queue color sensors to scan
- Ensure photointerrupter scans are not delayed

- Trades inaccurate velocity sensing for a negligible amount of latency

Improving the Time Resolution (3)

Increasing Photointerrupter Scanning Speed

Use layers of multiplexers or a large key matrix:

- Much faster than I^2C to I/O port expanders
- Uses a large number of pins

Physical Considerations

Piano

- Keys need good alignment and solid structure
- Indicator LED placement

Colored Finger Sleeves

- Bother experienced players
- Color sensing is difficult
  - Placement
  - Lighting

Future Steps

- Finish integrating all modules
- Graphical display of notes compared to metronome beats
- Detailed analysis of key press data
- Pedal and speaker integration
- On-board memory
- Full 88 keys
- Key action improvements
- And more...

Questions