Piano Visualiser Project Proposal

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1. Introduction

We would like to create a product that helps people who have little to no experience in reading music sheets to be able to learn how to play songs on the piano without any difficulties. Therefore, we decided to create our product that displays which key needs to be played for a certain period of time.

1.1 Problem

Learning to play the piano, especially without formal instruction, presents several challenges for beginners. Two of the most significant obstacles are learning how to read sheet music and maintaining accurate timing while playing. Many beginners struggle to translate written musical notation into physical key presses, and they often lack immediate feedback about whether they are playing the correct notes at the correct time. Without real time feedback, it becomes difficult to correct mistakes efficiently. Existing solutions such as mobile applications or smart piano systems often require internet access, external devices, or expensive integrated hardware. There is therefore a need for a standalone hardware system that provides real time visual guidance and feedback while remaining affordable and accessible to users who already own a standard piano or MIDI keyboard.

1.2 Solution

To address these challenges, we designed a real time piano input visualizer that provides guided visual feedback through an RGB LED matrix. The system reads MIDI song files stored on an SD card and displays which keys should be pressed and for how long. As the user plays, the system receives MIDI input from the keyboard and compares the notes played with the expected notes from the selected song. The device provides immediate visual feedback indicating correctness, timing accuracy, and note duration. Additional features include adjustable playback speed, single hand practice mode, and a wait mode that pauses playback until the correct note is pressed. The system can also function in a demonstration mode where it displays notes being played live, making it useful as a teaching aid.

1.3 Visual Aid

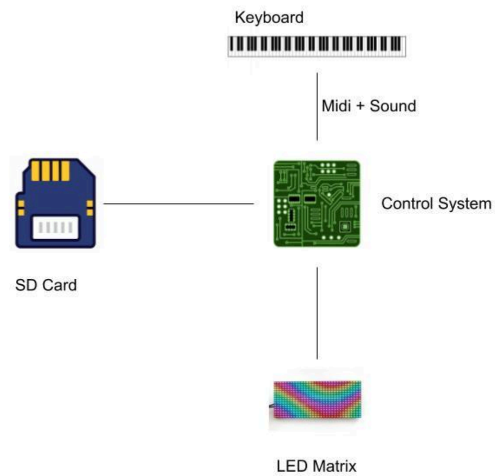

Figure 1 Visual Aid for our project

1.4 Three High Level Requirements

1. The system must be able to read and parse MIDI files from an SD card and visually output the exact piano key to press and how long to press them for on the LED Matrix with a refresh rate of 60 hertz so that the display does not appear to flicker for humans.
2. The system must be able to read user inputs through a Keyboard and visually respond to the keys pressed, indicating whether the keys pressed was the correct or incorrect note through the LED Matrix within 30ms for up to 10 notes at the same time.
3. The system must be able to use its microphone to respond to sound from the keyboard to visually respond to the key pressed, indicating whether the key pressed was correct or not through the LED Matrix within 200ms, for 1 key at a time, with at least 90% accuracy under controlled environments.

2 Design

2.1 Block Diagram

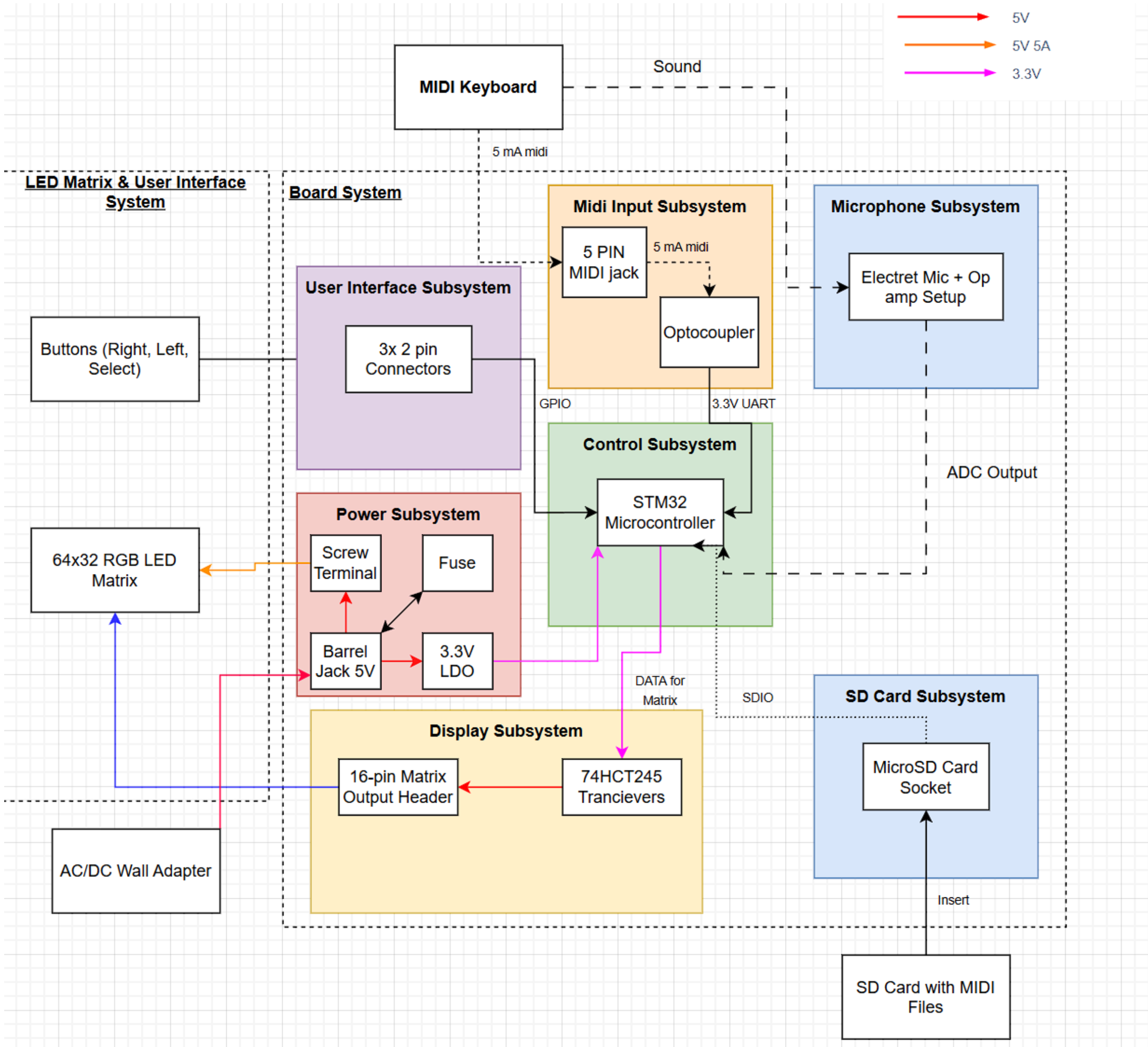

Figure 2 Block Diagram of the entire system.

2.2 Subsystem Overview

2.1.1 RGB LED Matrix Subsystem

The RGB LED matrix serves as the primary output device and provides visual guidance to the user. It displays which piano keys should be pressed and highlights their duration. The selected matrix operates at 5 volts and can draw up to 4 to 5 amps under maximum brightness conditions. The STM32F446RET6 microcontroller drives the matrix using direct memory access to maintain a stable refresh rate and minimize flicker. Because the microcontroller operates at 3.3 volts and the LED matrix requires 5 volt logic levels, a 74HCT245 transceiver is used to shift voltage levels appropriately. The matrix is large enough to display four octaves of keys, which covers most beginner and intermediate level songs, while remaining expandable for future versions.

2.1.2 SD Card Storage Subsystem

The SD card subsystem allows the system to store and retrieve MIDI song files. A microSD socket is soldered directly onto the PCB and interfaced with the microcontroller. When a user selects a song, the microcontroller reads and parses the MIDI file to extract note number, velocity, and timing information. This data is then used to control the LED matrix display and serve as the reference for evaluating user input. Using an SD card allows users to easily add new songs without modifying firmware.

2.1.3 MIDI Input Subsystem

The MIDI input subsystem enables real time interaction between the keyboard and the visualizer. A standard 5 pin MIDI jack is used to receive input from a digital piano. MIDI communication operates using a 5 mA current loop at a baud rate of 31250. To ensure electrical isolation and prevent ground loops, a 6N138 optocoupler is included in the design. The optocoupler converts the incoming MIDI signal into a logic level compatible with the 3.3 volt microcontroller. The microcontroller processes Note On and Note Off messages, extracts velocity values, and determines note duration. This information is compared with the expected notes from the loaded song to determine correctness and timing accuracy.

2.1.4 User Interface Subsystem

The user interface subsystem allows the user to control system operation. Push buttons are used to navigate through songs, select playback modes, adjust speed, and start or stop playback. The LED matrix also displays simple text or indicators related to menu navigation and system status. This approach keeps the interface simple while maintaining full functionality.

2.1.5 Power Management Subsystem

The system is powered using an external 5 volt DC adapter. The LED matrix operates directly at 5 volts and will use up to 4A if every LED is on and turned to white, to account for this possibility we plan to use a 5V 5A supply for the matrix. The microcontroller and other low voltage components require 3.3 volts, which is provided by an AMS1117-3.3 low dropout regulator. A fuse is included in the power path to protect against excessive current draw, particularly due to the LED matrix. Screw terminal blocks are used to ensure secure power connections.

2.2 Subsystem Requirements

2.2.1 RGB LED Matrix Subsystem

- The LED matrix shall operate at 5 V and support up to 5 A current draw.
- The display shall refresh at a sufficient rate to prevent visible flicker.
- The system shall represent at least four octaves of piano keys.
- The brightness of LEDs shall be adjustable based on MIDI velocity data.
- The MCU shall use level shifting to safely interface 3.3 V logic with 5 V display inputs.

2.2.2 SD Card Storage Subsystem

- The system shall read standard MIDI files from a microSD card.
- The microcontroller shall correctly parse note number, velocity, and timing data.
- The system shall allow users to select among multiple stored songs.
- The SD interface shall operate reliably without data corruption.

2.2.3 MIDI Input Subsystem

- The subsystem shall accept standard 5 pin DIN MIDI input at 31250 baud.
- The circuit shall include electrical isolation using an optocoupler.
- The system shall detect Note On and Note Off events in real time.
- The subsystem shall detect simultaneous notes.
- Total input processing latency shall remain under 30 ms.

2.2.4 User Interface Subsystem

- The system shall include physical buttons for navigation and control.
- The interface shall allow song selection, playback speed adjustment, and mode selection.
- The LED matrix shall display menu or status information when required.

2.2.5 Power Management Subsystem

- The system shall operate from a regulated 5 V external supply.
- The design shall include a 3.3 V regulator for logic components.
- The system shall include overcurrent protection using a fuse.
- All power traces and components shall be rated for expected current levels.

2.3 Tolerance Analysis

The primary design aspect that poses risk to a successful completion of our project and meeting all of our high level goals is the microphone subsystem. The main challenge here is going to be to find a balance between accuracy and speed, as matching audio input from a piano to predefined notes would require digital signal processing techniques such as FFT analysis. We will have to select an appropriate point size for the FFT and ensure that the LED display stays flicker-free and the response time for the input is still reasonable.

The MCU we plan to use (STM32F446RE) has a maximum internal clock speed of 180MHz. Performing an FFT using the CMSIS-DSP library takes varying amounts of time depending on the number of points in the FFT, 512 points is under 0.1 millisecond, 1024 points is under 0.2 milliseconds, 2048 points is up to 0.3 milliseconds and 4096 points is around 3 milliseconds. From this, the 2048 appears to be the highest possible accuracy without an unreasonable waiting time for the user.

To maintain 60hz on a 64x32 matrix (HUB75) with a 1/16 scan rate, we essentially need the MCU to give 16 orders, 60 times a second which leads to 960hz to maintain the display. 960 hertz means we need to send new data to the display every 1.04 milliseconds, since the 2048-point FFT takes 0.3ms, we have around 0.7ms to match the FFT to the note and tell the MCU which LEDs to turn on which gives us enough time to do so, meaning it is possible.

3. Ethics Safety and Societal Impact

This project follows the professional responsibilities outlined in the IEEE Code of Ethics. We ensure that all reported performance metrics, including timing accuracy and response latency, are based on measured data rather than ideal estimates. All design decisions, testing procedures, and failures are documented to support transparency and reproducibility.

From a safety perspective, the system operates at low voltage using a 5 volt external supply. A fuse protects against excessive current draw from the LED matrix, and a voltage regulator provides stable 3.3 volt power to logic components. The MIDI interface includes an optocoupler to electrically isolate the keyboard from the microcontroller, preventing ground loops and protecting connected equipment. The environmental damage is minimized as it uses a max of 5 volts of external supply.

Societally, the device promotes accessible music education by providing a standalone learning tool that does not require internet access or expensive proprietary hardware. It supports independent learning while remaining affordable and safe, aligning engineering practice with positive community impact.

According to the I. of IEEE Code of Ethics[3], we need to make a design that holds safety of the public, and our product is created to fit the ethical design that is purposed for creating something that is beneficial for the public, and it has complies with safety standards as we operate under 5 volts. We disclosed all the possible factors of the product that might pose a threat in the second paragraph.

Additionally, we take criticism of our product from peers, faculties, professors, and users, which is part of I. in IEEE code of ethics[3]. Our members have gone through basic safety training and technological experiences for creating the product and will give each member credit for the contribution to the product.

Our product meets Illinois Information Technology Accessibility Act Standards 1.0 as our product utilizes “input method that complies with Telecommunication Products”[2]. In addition, our product does not cause “screen flicker greater than 2Hz and lower than 55Hz.”

While in the process of making the product, we will follow the safety rule of ECEB, and we will assemble and solder the product in the lab areas, using safe practices.

References

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