ELECTRONIC KEYBOARD LEARNING SUITE

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Abstract

This report records the design process and results of an electronic keyboard learning suite. The system includes a microcontroller, a LED control circuit, a LED array and a power component. The keyboard learning suite mimics synthesis type of game, which uses falling node on a column above a key to guide the learner play the keyboard. The time the node hit the bottom is the time for the play to hit the specific key. The learning suite has two main functions, the first one is learning mode, the student can play the song coded and stored in the microcontroller. The second mode is teaching mode, which records a skilled player’s play and converts it to a playable song.
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1 INTRODUCTION

1.1 Statement of Purpose

Music instruments learning process is usually tedious and annoying for kids and adults. While there exist the Synthesia learning software and others on the market, few of them can actually combine with an actual instrument to become more educational. Our goal is to combine the keyboard keys and an LED array to produce a highly intuitive keyboard learning suite. By using LED array, we can be more intuitive and more efficient than tablet based software.

1.2 Functionality

- Song selection menu on LED array and controlled by keys on keyboard.
- Learning mode: student play pre-stored songs to learn playing keyboard.
- Teaching mode: record skilled player’s play and convert it to a playable song for learner.
2 DESIGN

2.1 Block diagram

2.2 Block description

(1) LED array

The LED array serves as a display of the game system. Every single key on the keyboard has a corresponding column of LED lights. Each column is assigned with 8 LEDs. Each LED comes with a 75 Ω resistor and a MOSFET. The gates of MOSFETs are connected to parallel outputs of shift register. When a certain key need to be pressed, the highest LED light representing a note will turn on, and the note will “fall” from the top to bottom. The time when the note hit the bottom LED will be right time to hit the corresponding key. The “speed” of the falling note will depend on the music.

(2) LED control circuit

The LED control circuit mainly contain a 6 to 64 decoder circuit, 60 flip-flops and 60 shift registers, taking inputs from the microcontroller and generating signals to the LED array to control the LEDs.

(3) Microcontroller
The microcontroller circuit is based on ATmega328, with MAX3421E as USB Host Controller solution and other necessary circuitry.

(4) External Memory
The external Memory will interface with microcontroller using SPI protocol and store the input from the keyboard passed from the microcontroller. The inputs mainly includes the when and what key did the player hit in the recording mode. The memory will also pass the data to the microcontroller, then the data will be implemented on the LED array for the gamer in the learning mode.

(5) Yamaha PSRE433 Keyboard
This is the main input device for the whole game system. It will interface with the microcontroller with USB connection. In the recording mode, the input from the keyboard will be passed to the microcontroller and stored. In the learning mode, the keyboard inputs will be processed by the microcontroller and the result will be calculated based on the processed data.

(6) AC/DC converter
The AC/DC converter will convert the 120V AC to 3.3V DC and 5V DC. In this case, we are using power supply for desktop computer for its high maximum current load.
2.3 Task flow chart

START

RECORD

RECORD MODE OR LEARNING MODE

LEARN

Record key presses & time

Finish recording?

End Button

Select songs

Play songs (play as LED signals)

Finish playing & display statistics

END
2.4 Circuit schematic

(1) LED control circuit

The above is the general 6-to-64 decoder and a sample of temporary JK'-flipflop and shift register.

The 6-to-64 decoder is achieved by cascading a 2-to-4 and four 4-to-16 decoders. The JK'-flipflop acts as transition from decoder to the shift register which output actual control signal to the LEDs.
This is the zoomed in view of JK'-flipflop and shift register. The purpose of this transition JK'-flipflop is to accommodate the two different frequencies of microcontroller(SYSCLK) and shifting LED(SFTCLK). The decoder signal from microcontroller have to follow the SYSCLK which is the operating frequency of the microcontroller. However, the SFTCLK is the typical music note playing speed at around 8Hz. So the JK'-flipflop works at the SYSCLK, temporarily storing the data and waiting for the low frequency shift register to fetch the data in it and reset it.
This is the LED circuit for a single unit. A MOSFET is used for switch on and off of LED. The drain side is connected to voltage source; gate is connected to the parallel output of shift register and source is connected to ground through a 75 $\Omega$ resistor and a LED. With 5V voltage input, the voltage across the LED would be 2.0V and the current through LED is 20mA. The complete LED array will have total of 488 units above and each 8 of them in series.
2.5 Simulation

(1) Decoder simulation

We can see as the 6-bit input goes, the corresponding output goes high.

(2) JK′-flipflop & shift register simulation

We set the two clock to be at a different yet not practical frequency to ensure a clear view. First of all, an output from decoder is high and at the first positive edge of SYSCLK, q, the output of JK′-flipflop goes high. But as soon as the SFTCLK is high, the data is loaded into the first bit of shift register, and the JK′-flipflop is reset. Then the shift register shifts normally as the SFTCLK goes.
2.6 Calculation

(1) LED current & power

This our first thought, which is not necessary.
From the datasheet [1] of a desired LED light bought from ECE store, the continuous forward running current would be 30mA. 488 LED lights would require approximately 15A to run.

\[ I = 488 \times 0.03A = 14.64A \]  
(1.1)

A single LED light power dissipation is 69mW from the datasheet. Therefore 488 LED lights would require approximately 34 Watts power.

\[ P = 488 \times 0.069 = 33.672W \]  
(1.2)

From these calculation, we can see that the maximum current and power rating is really high, when working at full load, safety is a big concern.

However, we realized it would not be necessary to make the worst case scenario as every single LEDs are turned on. Since Human has 10 fingers, there are ten inputs at most per unit time. Since there are 8 LED per column per key,

\[ 8 \times 10 = 80 \text{ keys} \]

80 LEDs at most would be active at the same time. Therefore the maximum overall current would be

\[ I = 80 \times 0.03A = 2.4A \]

The maximum power would be

\[ P = 80 \times 0.069 = 5.52W \]

These current and power rating are more reasonable and doable.

(2) File storage

The file format inputted by the keyboard will be in .mid format. From the sample file TurkishMarch.mid I have, it takes 14.3KB with a duration of 2 minutes and 7 seconds. We set a number to be 100 songs lasting 2 minutes each to be an appropriate amount for our storage requirement.

\[ 100 \times 14.3 \text{ KB} = 1430 \text{ KB} = 1.3965 \text{ MB} = 11.17 \text{ Mb} \]

So based on the calculation, we choose the external memory to be Microchip SST26VF016B, which has a 16Mb [2] size to suffice our implementation.
<table>
<thead>
<tr>
<th>Part</th>
<th>Requirement</th>
<th>Verification</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED array</td>
<td>1. Shift the node downward by the “falling” LED light implementation.</td>
<td>1. Single LED parameters (5 pts)</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>2. When a single LED is turned on, the voltage across should not exceed 2.3V</td>
<td>• Connect 5V to the drain of the MOSFET and negative pin of LED to the ground. Use a wire with one end connect to 5V voltage source and the other end connect to the gate of MOSFET, the LED should be turned on.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. The LED should be on when gate is high, which should be 3.8V to 5V.</td>
<td>• Place a voltmeter across each LED light and check its voltage, which should fall in to range 1.85V to 2.20V.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. The current go through a single LED when gate of MOSFET is high should not exceed 0.03A</td>
<td>• Connect an ammeter in series with a LED, read it’s current, which should be 20mA to 30mA.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5. When every LEDs in column are turned on, the current go through should not exceed 0.03A * 8 = 0.24A.</td>
<td>• Use 8 wires with one end connected to 5V and the other end touch all the 8 gates of the MOSFETS. The</td>
<td></td>
</tr>
</tbody>
</table>
| Microcontroller with a USB host shield | 1. Receive the data of which is hit at what time from the keyboard through USB connection.  
2. Output signal to the decoder of the LED control circuit according to the song.  
3. Compare the user’s inputs with stored music information to output a rating of the performance.  
4. During the record mode, the microcontroller will store the inputs from the keyboard into EEPROM. | 1. Data reception (10 pts)  
- Connect the microcontroller to the keyboard  
- Open the terminal on the PC  
- Play the piano and check the key information (time and midi data in 3 bytes) on the terminal.  
2. Performance rating (5 pts)  
- Write a sample song with only 1 key.  
- Hit the key at different timing to check if the performance rating is right.  
3. Record the song played  
- Turn on record mode  
- Play a sample song  
- The stored song | 20 |
<table>
<thead>
<tr>
<th>Circuit</th>
<th>Description</th>
<th>Score</th>
</tr>
</thead>
</table>
| LED control      | 1. A 6 to 64 decoder, constructed by one 1 to 2 decoder and four 4 to 16 decoders. It will take a 6 bit strings input and give the corresponding port in total of 64 ports 5V.  
2. 60 Flip-flops that used to store the input from the decoder and fetch the data to the shift register.  
3. 60 shift registers used to control the LED column and shift the node down.                                                                 |       |

1. **Decoder check** (5pts)  
   - Connect 6 wires to the input of the decoder, with the first, third and fourth wire connected to Voltage source, and the other connect to the ground. This give an input of 001101 to the decoder.  
   - Connect the positive side of the voltmeter to the output side of the flip flop. Connect the input to 5V.  
   - Repeat above steps with input 110010 and 100110, check if port 50 and port 38 are 5V respectively.  
2. **Flip flop check** (5 pts)  
3. Connect the positive side of the voltmeter to the output side of flip flop. Connect the input to 5V. | 15    |
| **AC/DC converter** | 1. An AC/DC converter will bring 120V AC voltage to 5V DC voltage supply. | • Use the voltmeter with positive port connect to Voltage output and the other port to the ground, the reading should be 5V±0.5. | 0 |
4 SAFETY & ETHICS

4.1 Safety

(1) The LED array require a very high operating current (More than 6A from our calculation), which could be extremely dangerous. When making changes to the circuits, make sure that the circuit is powered off.
(2) After finishing building the LED array, make sure the circuit and the wires is properly encased to avoid direct contact with users or developers while using.
(3) Use a wire specially designed for high current, instead of the thin wire used in the other labs, to connect the power input and LED array.
(4) Do not work at lab alone.

4.2 Ethics

The main ethic concern for our project is that music products are copyrighted work. So for our pre-loaded LED signal songs, we will focus on classic music which their copyrights are already expired.

5 COST ANALYSIS

5.1 Parts

<table>
<thead>
<tr>
<th>Item</th>
<th>Part No.</th>
<th>Supplier</th>
<th>Quantity</th>
<th>Cost($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microcontroller</td>
<td>ATmega328</td>
<td>DigiKey</td>
<td>1</td>
<td>3.38</td>
</tr>
<tr>
<td>USB Host controller</td>
<td>MAX3421E</td>
<td>Mouser</td>
<td>1</td>
<td>8.41</td>
</tr>
<tr>
<td>Serial flash memory</td>
<td>SST26VF016B</td>
<td>Microchip</td>
<td>1</td>
<td>1.38</td>
</tr>
<tr>
<td>LED-green</td>
<td>LT1821-81-HE</td>
<td>Jameco</td>
<td>250</td>
<td>37.5</td>
</tr>
<tr>
<td>LED-yellow</td>
<td>UT1834-81</td>
<td>Jameco</td>
<td>300</td>
<td>20.7</td>
</tr>
<tr>
<td>4-to-16 decoder</td>
<td>74154N</td>
<td>Jameco</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>2-to-4 decoder</td>
<td>74139N</td>
<td>Jameco</td>
<td>1</td>
<td>0.69</td>
</tr>
<tr>
<td>JK'-flipflop</td>
<td>74LS109N</td>
<td>Jameco</td>
<td>64</td>
<td>44.16</td>
</tr>
<tr>
<td>8-bit shift register</td>
<td>74LS164N</td>
<td>Jameco</td>
<td>64</td>
<td>35.2</td>
</tr>
<tr>
<td>Hex inverter</td>
<td>74LS04N</td>
<td>Jameco</td>
<td>12</td>
<td>5.88</td>
</tr>
<tr>
<td>Voltage regulator</td>
<td>MCP16311</td>
<td>Microchip</td>
<td>20</td>
<td>26.4</td>
</tr>
<tr>
<td>AC/DC converter</td>
<td>CX430M</td>
<td>Corsair</td>
<td>1</td>
<td>48.99</td>
</tr>
<tr>
<td>PCB of LED control circuit</td>
<td>N/A</td>
<td>PCB minions</td>
<td>5</td>
<td>122.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td>365.69</td>
</tr>
</tbody>
</table>
5.2 Labor

<table>
<thead>
<tr>
<th>Name</th>
<th>Hourly rate</th>
<th>Hours</th>
<th>Total = Hourly rate * 2.5 * Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yuhao</td>
<td>40</td>
<td>175</td>
<td>17500</td>
</tr>
<tr>
<td>Yiyang</td>
<td>40</td>
<td>175</td>
<td>17500</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>350</td>
<td>35000</td>
</tr>
</tbody>
</table>

5.3 Total cost

<table>
<thead>
<tr>
<th>Section</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>35000</td>
</tr>
<tr>
<td>Parts</td>
<td>365.69</td>
</tr>
<tr>
<td>Grand Total</td>
<td>35365.69</td>
</tr>
</tbody>
</table>

6 CITATION

