Modular and Affordable Digital Accordion
ECE 445 Design Document - Spring 2025

Project # 13
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Introduction

Problem:

Traditional accordions are expensive, delicate instruments that require regular maintenance. Their sound quality is sensitive to environmental factors such as temperature and humidity, making them less reliable in varying conditions. Additionally, learning to play the accordion presents a steep learning curve, especially for beginners. Currently, digital accordions on the market cost over $7,000, making them inaccessible to most entry-level players and hobbyists. These challenges highlight the need for an affordable, beginner-friendly, and modular digital accordion that can replicate the traditional instrument's features while addressing its limitations.

Solution:

We propose to build a low-cost (less than $150), modular, and beginner-friendly 12-bass digital accordion. Our design will replicate the sound and functionality of a traditional accordion using modern electronics while offering improved durability and ease of maintenance.

Visual Aid

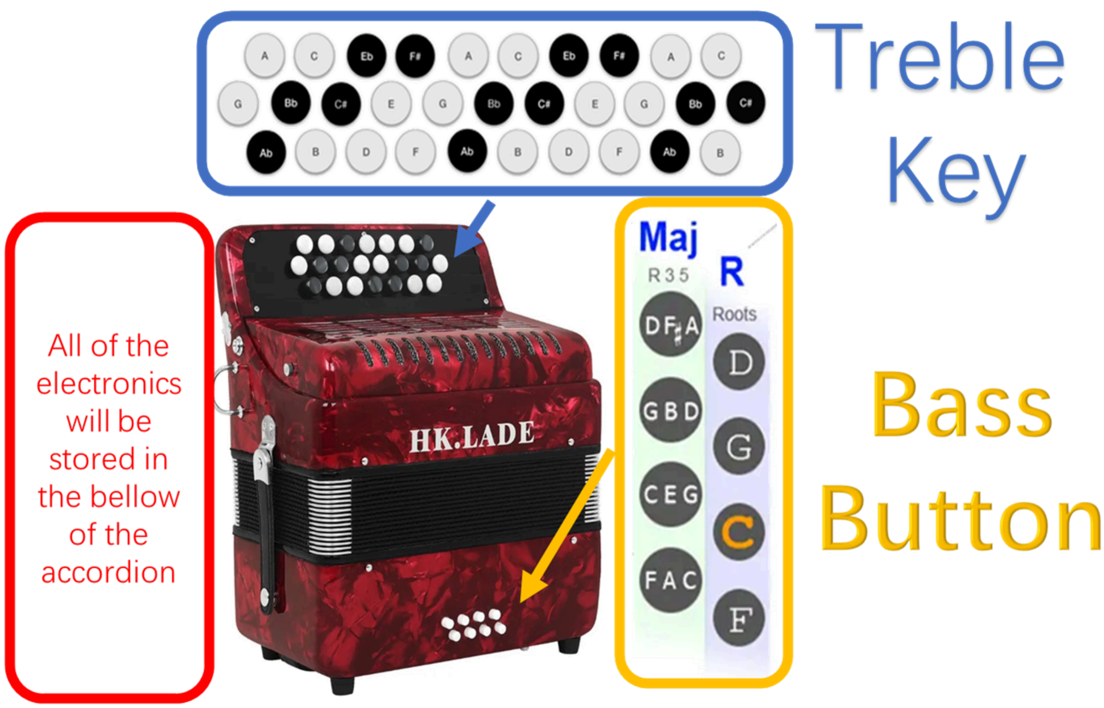


Figure 1. Graphical Illustration of the digital accordion components. The user will be able to press the buttons on treble keys and bass buttons to make 1 or more inputs. The Electronic system will decode the inputs and synthesize monophonic or polyphonic sounds and send it out via the speaker inside the accordion's bellow.

High-level requirements list:

Our project will be considered successful if it meets the following testable criteria:

1. Sound output has a signal to noise ratio more than 40dB.
2. The frequency response of the synthesized output should remain within ±3 dB across the range of 50 Hz – 15 kHz to ensure accurate tonal reproduction.
3. Able to play polyphony sounds (3 or more keys pressed simultaneously)

Design

Block Diagram:

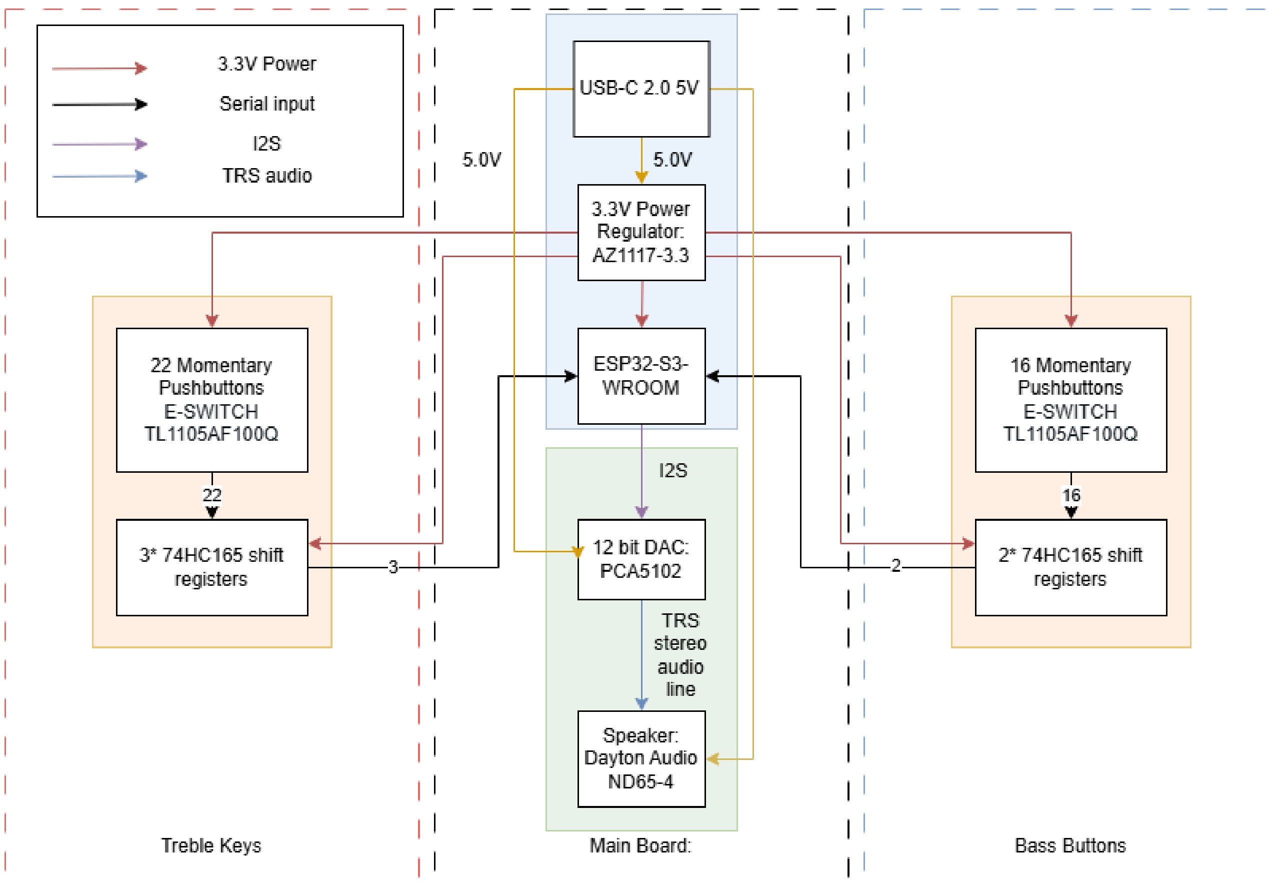


Figure 2. Block Diagram

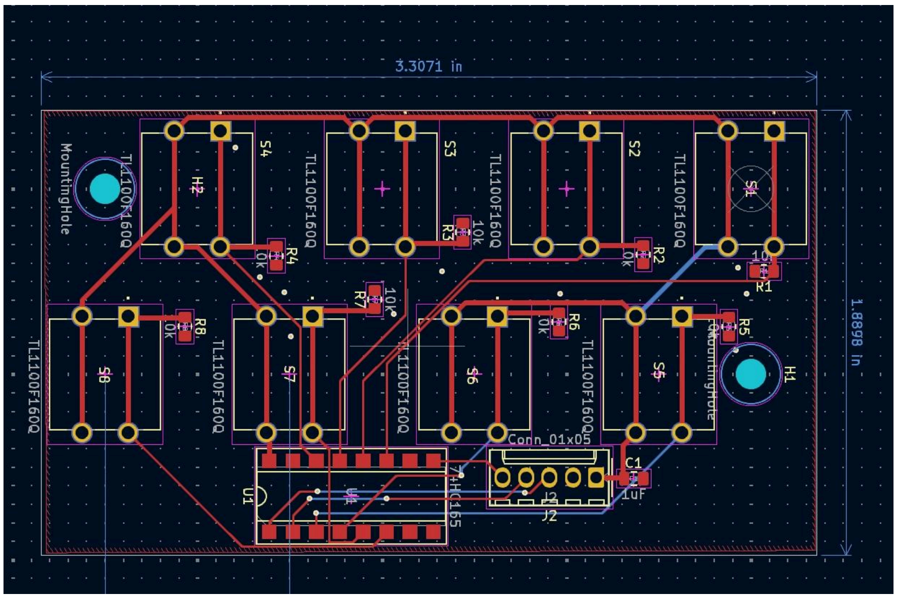
Subsystem: Key Inputs

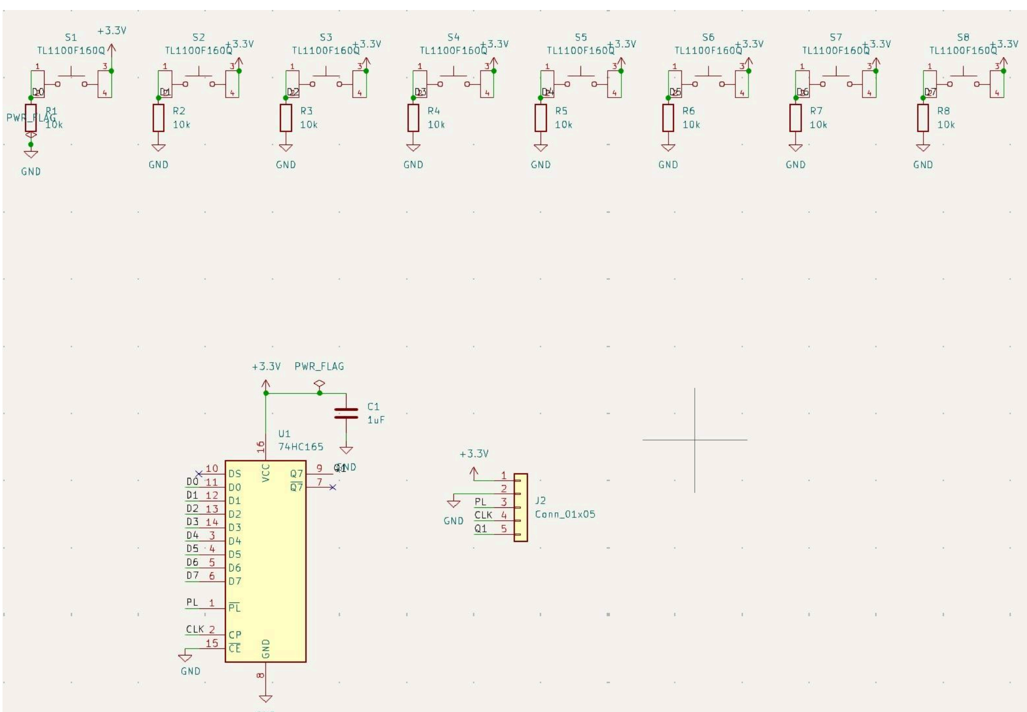
This subsystem is responsible for detecting treble key and bass button presses.

Design:

Configuration: Shift registers will be used to detect inputs from 26 treble keys and 12 bass buttons. The outputs from the shift registers will be transferred to the IO pins of ESP32 of the Sound Synthesis Subsystem. To minimize the cost, the input subsystem is divided into several parts. Each part contains a shift register, eight buttons, and the corresponding debouncing resistors and capacitors.

CAD Drawings and Schematic:





Components:

- Tactile push buttons (low-cost option): TL1100F160Q x 40 since we need 26 buttons for the treble keys, 12 buttons for the bass sound, and some other buttons for further additional functionalities.
- Shift register: 74HC165 x 5 since each shift register could take 8 inputs from the buttons. To meet our demand, we need the register to be parallel-in and serial-out.
- Resistors and Capacitors: Used for debouncing to control the debouncing time ≤ 6ms. By calculation, the resistance we need for each resistor is 10k Ohm, and the capacitance of the capacitor is 1uF.
- Debounce time

Key Features:

- Accurate key press detection with minimal input lag.
- Scalable design for modularity.

Requirements:

- Must detect all key presses within 10ms latency.
- Key detection must have a debounce time ≤ 7ms.
- If any row or column is disconnected, keys in that section must not interfere with others.

Tolerance:

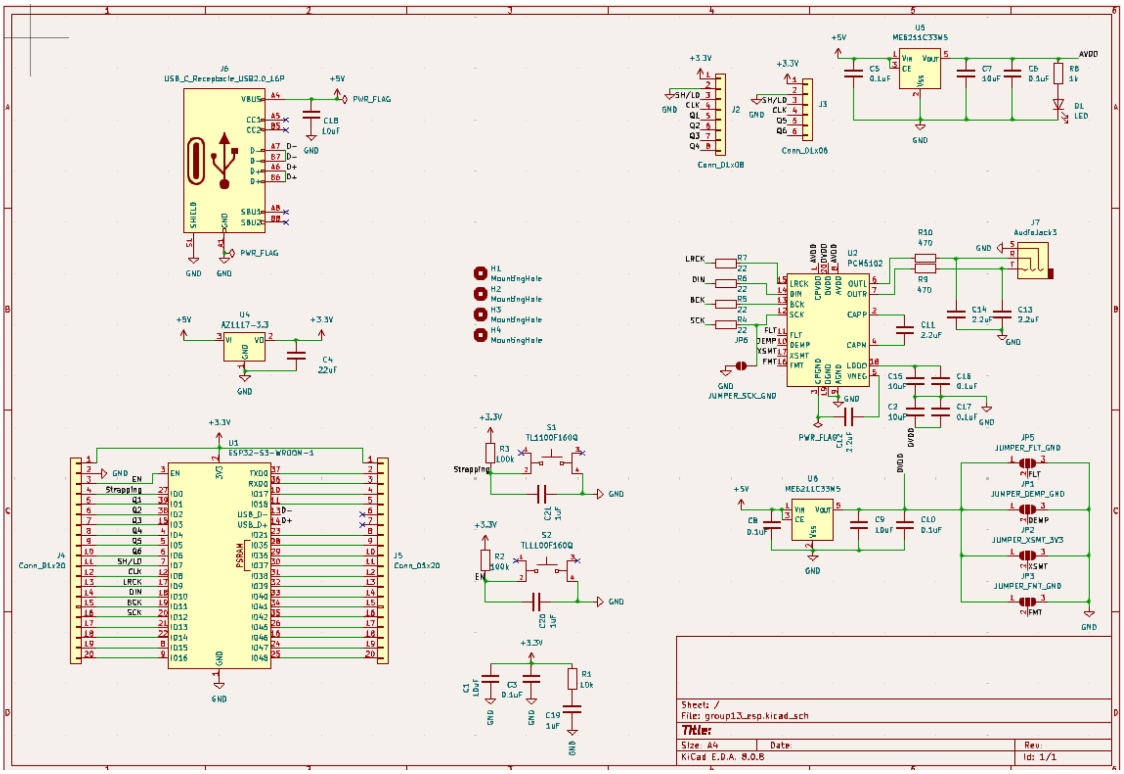
- Button Debouncing and latencies

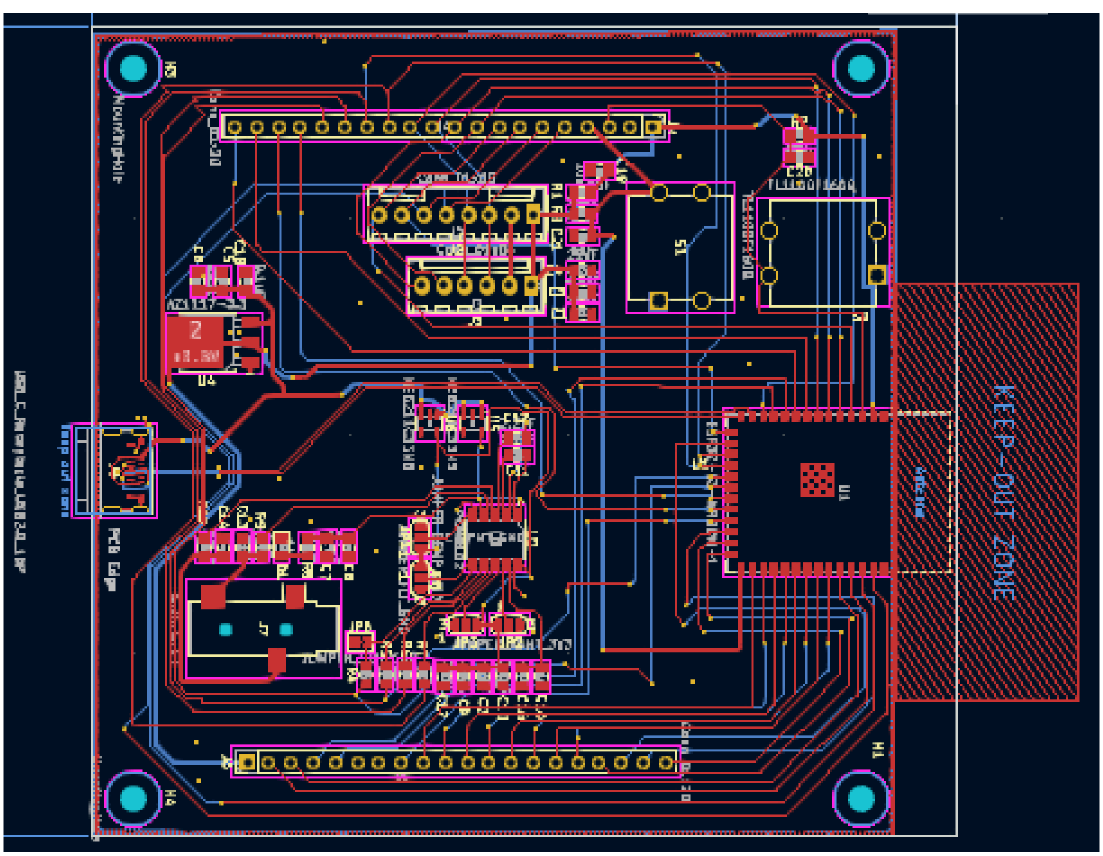
  Latency of the buttons should be less than 1 ± 0.5ms. We want to make sure that the sound of the instrument comes out as soon as possible. In addition, the debouncing time of the button should be limited to ≤ 7ms.
- Clock of Shift register

  In order to achieve the latencies stated above, the frequency of the clock applied to the shift register should be ≥ 100Hz ± 1%.

Subsystem: Sound Synthesis

KICAD PCB Layout and Schematic for ESP32:





This subsystem synthesizes high-quality accordion sounds in real time based on user inputs.
Design:

- Waveform Generation: The ESP32-S3 processes register inputs with the AMY (A high-performance fixed-point Music synthesizer librarY for microcontrollers) library to create polyphonic waveforms corresponding to multiple notes.
- DAC Processing: The PCM5102A DAC ensures high-resolution conversion for better audio fidelity.
- Memory Storage: MIDI data and sound samples are stored in the ESP32-S3's memory, removing the need for an external SD card.
- Signal Smoothing: A low-pass filter minimizes aliasing and noise in the final output.

Components:

- ESP32-S3 (signal processing and waveform generation)
- Texas Instruments PCM5102A DAC (16/24/32-bit digital-to-analog conversion)
- Capacitors and Resistors (to stabilize power and signal output)
- Low-pass filter (to refine the audio output)

Requirements:

- DAC resolution must be ≥16-bit for high-fidelity sound.
- I2S communication speed must be ≥1 MHz to prevent data loss.

Tolerances:

- Signal Timing Accuracy
  The I2S bus operates at ≥1 MHz, ensuring proper synchronization between the ESP32-S3 and DAC. Clock drift is limited to ±50 ppm, keeping timing errors minimal.
- Power Stability
  The PCM5102A requires separate digital and analog voltage inputs, which operate at 3.3V (digital) and 3.3V-5V (analog) ±5%. Hence, we decided to use two additional low noise voltage regulators to supply the power of the DAC.

Subsystem: Output

This subsystem delivers audio to external devices through both wired and wireless methods.
Design:

- Wired Output: A 3.5mm audio jack to support headphones or external speakers.
- Bluetooth Output: Integrate Bluetooth streaming for wireless audio playback.

Components:

- 3.5mm audio jack and connectors.
- Bluetooth module included in ESP module.

Requirements:

- Speaker output must be ≥ 85dB SPL at 1m
- Amplifier must handle at least 3W power per channel

Tolerance:

- ESP32-S3 to DAC Timing and Accuracy
  The ESP32-S3 sends digital audio to the DAC at 44.1 kHz or 48 kHz with a clock drift of ±50 ppm, leading to a max frequency deviation of ~2.2 Hz, which is negligible. The system ensures a latency ≤10 ms for real-time audio.

- DAC to Speaker Analog Output Tolerance
  The DAC output voltage stays within ±1%, ensuring clean signal conversion. Harmonic distortion (THD+N) is ≤0.5%, keeping audio quality high.

Cost

Description	Manufacturer	Part Number	Quantity	Unit Cost ($)	Total Cost ($)
Switch Tactile SPST-NO 0.05A 12V	E-Switch	EG1821-ND	40	0.4388	17.55
IC 8-Bit Shift Register 16-DIP	Texas Instruments	296-8251-5-ND	5	1.1800	5.90
Capacitor Ceramic 10uF 25V X5R 0805	Samsung Electro-Mechanics	1276-2891-1-ND	11	0.0840	0.92
Resistor SMD 10 Ohm 1% 1/8W 0805	Vishay Dale	541-3976-1-ND	39	0.0410	1.60
USB 2.0 Type C 24P SMD RA	Amphenol CS	664-124019772112ACT-ND	1	1.9000	1.90

Capacitor Ceramic 0.1uF 10V X7R 0805	YAGEO	311-3556-1-ND	7	0.2000	1.40
Capacitor Ceramic 1uF 16V X7R 0805	KEMET	399-C0805C105K4RACTU-ND	3	0.1200	0.36
Capacitor Ceramic 2.2uF 10V X7R 0805	KEMET	399-C0805C225K8RACTUCT-ND	4	0.2000	0.80
Capacitor Ceramic 22uF 6.3V X5R 0805	KEMET	399-C0805C226M9PACTU-ND	1	0.1700	0.17
LED Orange Clear 25mcd	Kingbright	754-1860-1-ND	1	0.3300	0.33
Connector Header 20POS 2.54MM	Sullins Connector Solutions	S1011EC-20-ND	2	0.6000	1.20
Connector Header 6POS 2.54MM	Molex	WM2748-ND	1	1.1300	1.13
Connector Header 8POS 2.54MM	Molex	WM50016-08-ND	6	0.3000	1.80
Connector Jack Stereo 3.5MM SMD	Same Sky	CP1-3523N-ND	1	0.9800	0.98
Resistor SMD 100K Ohm 1% 1/8W 0805	Vishay Dale	541-3978-1-ND	2	0.1000	0.20
Resistor SMD 22 Ohm 1% 1/8W	Vishay Dale	541-4151-1-ND	4	0.1000	0.40

0805					
Resistor SMD 470 Ohm 1% 1/8W 0805	Vishay Dale	541-4147-1-ND	2	0.1000	0.20
IC DAC 16/24/32BIT 384K 20TSSOP	Texas Instruments	296-36707-1-ND	1	4.4300	4.43
RF TXRX MOD Bluetooth U.FL SMD	Espressif Systems	1965-ESP32-S3-WROOM-1U-N4CT-ND	1	5.0600	5.06
IC REG Linear 3.3V 800MA SOFT223	STMicroelectronics	497-3504-1-ND	1	0.3400	0.34
IC REG Linear 3.3V 150MA SOT23-5	STMicroelectronics	497-3504-1-ND	2	0.7500	1.50

TOTAL COST FOR PARTS: 48.17$
LABOR: 40$/h * 2* 1hrs = 80$
Total: 128.17$+10.04$(delivery+tax) +20$(PCB)= 158.21$

Schedule

Week of 2/10: Project approval
Week of 2/17: Project Proposal and order parts
Week of 2/24: Drawing schematics and CADs and order parts
Week of 3/3: Building breadboard and working on design document
Week of 3/10: Soldering PCBs
Week of 3/17: Spring Break
Week of 3/24: Continuing soldering PCBs
Week of 3/31: Debugging and checking requirements
Week of 4/7: Working on mechanical parts
Week of 4/14: Final debugging and get prepared for the mock demo
Week of 4/21: Mock demo and modifications for final demo
Week of 4/28: Final demo and prepare for final presentation
Weed of 5/5: Final presentation

Ethics and Safety:

Issue 1: Intellectual Property Compliance
One of the primary concerns in the development of a digital accordion is ensuring compliance with intellectual property laws, particularly regarding the use of MIDI sound banks and pre-recorded accordion samples. Many commercially available sound banks and sample libraries are protected by copyright, meaning unauthorized use could lead to legal repercussions. To mitigate this risk, we use open-source MIDI and sound synthesis libraries that are explicitly licensed for free use and distribution. By taking this precaution, the project remains legally compliant while allowing for greater flexibility in sound customization.

Issue 2: Hearing Protection & Volume Limits
Extended exposure to high sound levels can lead to hearing damage, making it essential to implement safeguards in the digital accordion's audio system. The primary concern is that prolonged use at high speaker output levels could exceed safe listening thresholds, potentially reaching hazardous decibel levels. To address this, an automatic gain control (AGC) system can be integrated into the design, ensuring that the volume does not surpass 85dB SPL (Sound Pressure Level). AGC dynamically adjusts the output to maintain consistent audio levels, preventing sudden spikes in volume that could harm the user's hearing. This approach not only protects users but also enhances the instrument's usability in various settings without compromising sound quality.

Issue 3: Overheating Prevention
Electronic components such as the voltage regulator and PCM5102 DAC generate heat during operation, and excessive heat buildup can lead to component failure or, in extreme cases, fire hazards. Since the digital accordion is expected to be a compact, portable device, heat dissipation is a critical design consideration. One effective solution is to incorporate heat sinks or small cooling fans to regulate the temperature of heat-sensitive components. Heat sinks can passively dissipate excess heat, while fans can actively improve airflow around the circuitry. Proper thermal management ensures the longevity of the components and prevents performance degradation due to overheating.

Issue 4: Overheating Prevention 2
Beyond component-level heating, poor ventilation within the enclosure can exacerbate thermal issues by trapping heat inside the device. Without proper airflow, internal temperatures could rise, potentially damaging sensitive electronics and increasing fire risks. To counter this, the enclosure design should include ventilation slots or perforations to allow heat to escape. Strategic placement of these openings, such as near heat-generating components, can significantly improve air circulation while maintaining the instrument's structural integrity. Additionally, using thermally conductive materials for the enclosure can further aid in heat dissipation. By optimizing ventilation, the risk of overheating is minimized, ensuring safe and reliable operation over extended periods.

Citations

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Lucifero, G. (2022, December 30). 12 bass accordion chart - diagram, bass notes, list of chords. AccordionChords.com. https://accordionchords.com/stradella-bass-layouts/12-bass-accordion-chart/

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