Self Playing Harmonica

ECE 445 Design Document - Spring 2026

Group 66

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Table of Contents

ECE 445 Design Document - Spring 2026.......1
Group 66.......1
TA: Wenjing Song.......1
1. Introduction.......3
1.1 Problem:.......3
1.2 Solution:.......3
1.3 Visual Aid:.......3
1.4 High-Level requirements list:.......4
2. Design.......4
2.1 Block Diagram:.......4
2.2 Physical Design:.......5
2.3 Subsystem Overview:.......5
2.3.1 Power Subsystem.......5
2.3.2 Computing Subsystem.......6
2.3.3 Mechanical Subsystem.......7
2.4 Subsystem requirements:.......7
2.4.1 Power Subsystem.......7
2.4.2 Computing Subsystem.......8
2.4.3 Mechanical Subsystem.......8
2.5 Subsystem Verification.......9
2.5.1 Power Subsystem.......9
2.5.2 Computing Subsystem.......10
2.5.3 Mechanical Subsystem.......10
2.6 Tolerance Analysis:.......10
2.6.1 Component failure.......10
2.5.1.1 ESP32.......10

2.6.1.2 MOSFET Back EMF (Pump speed control)........ 11

2.6.2 Motor and solenoid control accuracy........ 11

2.6.2.1 Motor power supply........ 11

2.6.3 Even air distribution for the harmonica........ 12

3. Cost and Schedule........ 12

3.1 Cost Analysis........ 12

3.2 Schedule........ 13

4. Ethics, safety, and societal impact........ 14

4.1 Ethics........ 14

4.2 Safety........ 14

References........ 15

1. Introduction

1.1 Problem:

The harmonica is a versatile, simple, yet technically difficult instrument to play. There is a need for the background music of a live instrument, yet it is difficult to master the harmonica. Some lack the time to practice and learn the harmonica. For others, they may no longer be able to physically play the harmonica, or do not have access to training or musical education. Existing musical devices exist for keyboard and string instruments, but not for wind instruments. There is a need for a self-playing harmonica that can produce melodies without requiring manual lip or breath control.

1.2 Solution:

We propose a device that can play the harmonica. The self-playing harmonica consists of multiple subsystems. The power supply provides power at all required voltages for the MCU, air pumps, and electronic pneumatic valves. The harmonica-computer interface connects to both the harmonica and the MCU, and is responsible for controlling the airflow through the harmonica. It consists of pneumatic tubes, air pumps, and electronic valves. The MCU is responsible for controlling the pumps and valves in the harmonica-computer interface, as well as taking a MIDI file and converting it into a sequence of pump and valve motions. Lastly, songs are uploaded to the MCU through WiFi. We will create a website where the user can upload a MIDI file, and that file will then be available to play on the device.

1.3 Visual Aid:

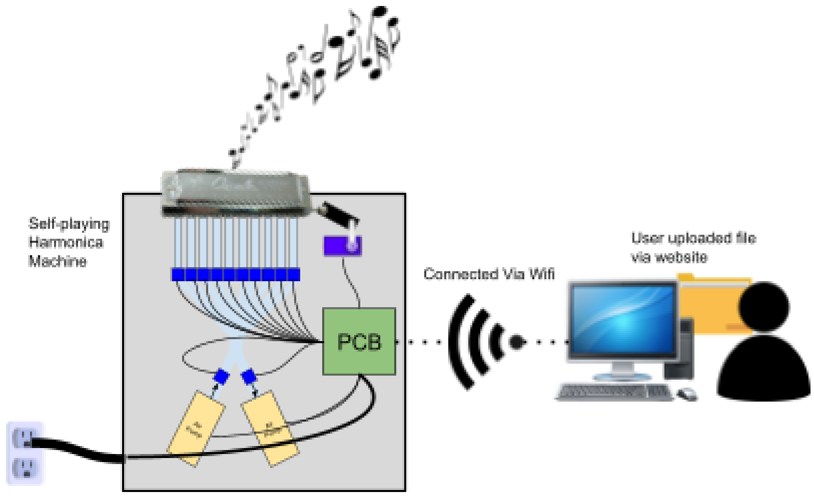

Figure 1. Visual aid for self-playing harmonica. Shows user input, harmonica control, and musical output.

1.4 High-Level requirements list:

1. The device must be able to operate all basic functionality of a chromatic harmonica.
    - Playing all notes (blow in and suck out air for all holes)
    - Engage and disengage the slide.
    - The notes must be audible at 10m from a listener
2. The device must be able to receive song data wirelessly.
    - User interface latency must not exceed 1s
3. The device must be able to operate the harmonica continuously for a minimum of 5 minutes

2. Design

2.1 Block Diagram:

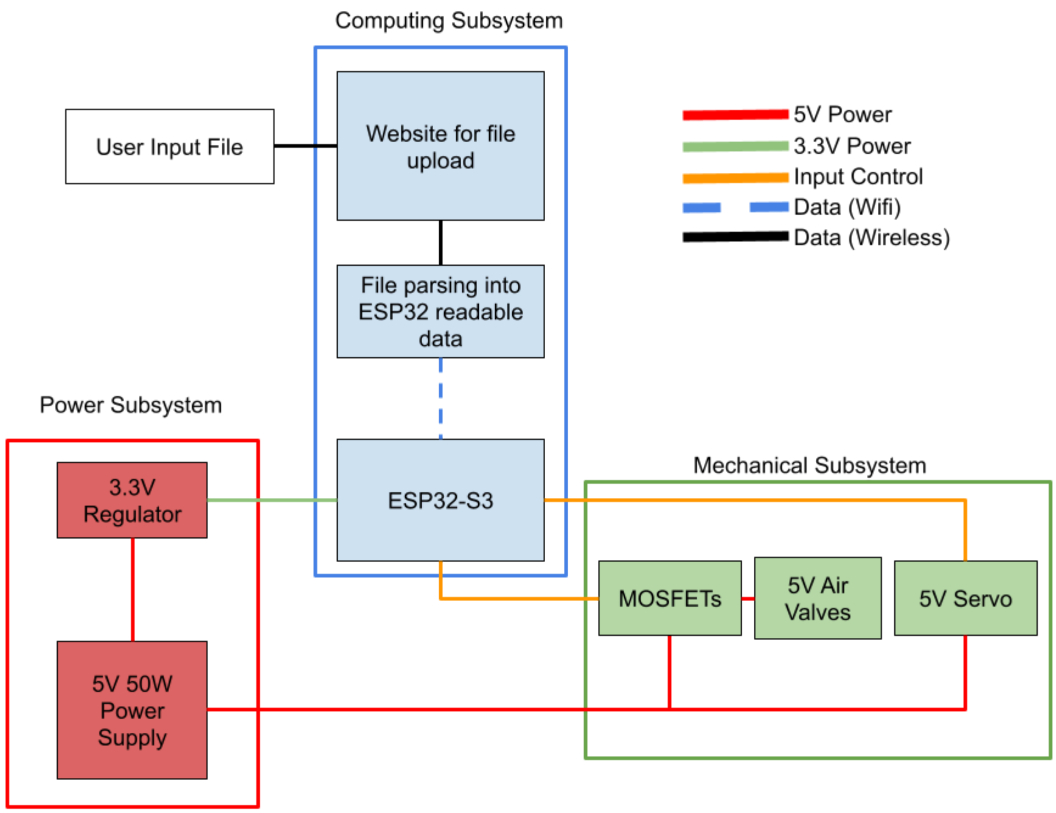

Figure 2. Block diagram of the device, showing all signal paths with color-coded signal type.

2.2 Physical Design:

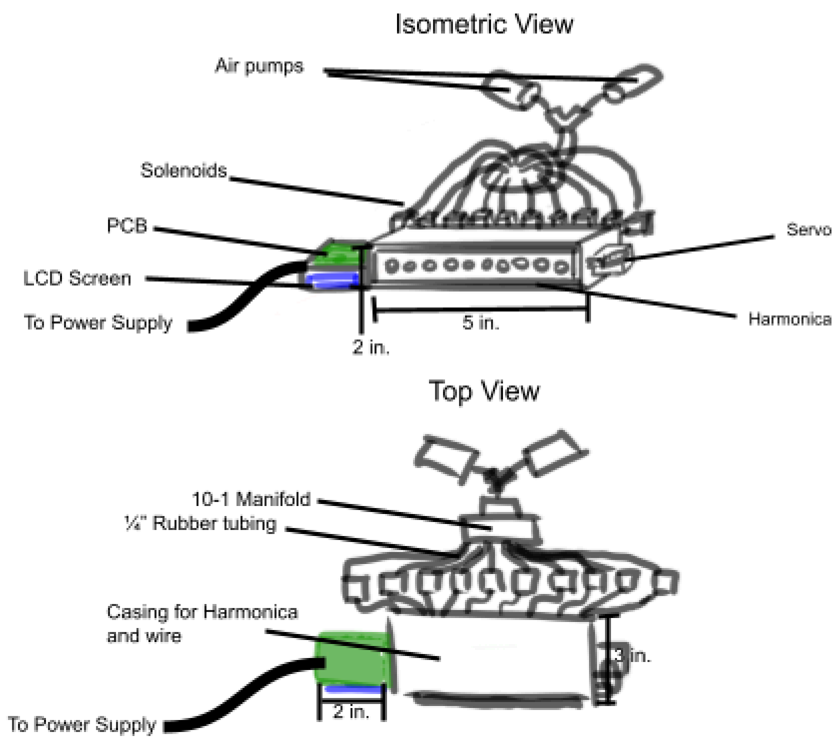

Figure 3. Physical design of Self-Playing Harmonica

The self-playing harmonica, as well as its circuitry and the servo, will be contained within a 3d-printed casing. The LCD screen will also fit onto the 3d-printed case. Outside of the case, the solenoid valves, air manifold, and the pumps will be connected to the harmonica via ¼" rubber tubing, and controlled via the PCB.

2.3 Subsystem Overview:

2.3.1 Power Subsystem

The power subsystem must be capable of supplying 3.3V and 5V power to the device. The 3.3V power supply is for the MCU, and the 5V power supply is used by the pneumatic valves and the servo. We will utilize a 5V 50W power supply that plugs into a wall outlet. We will then convert the 5V power supply into the signal voltage, 3.3V, using a buck converter on the PCB.

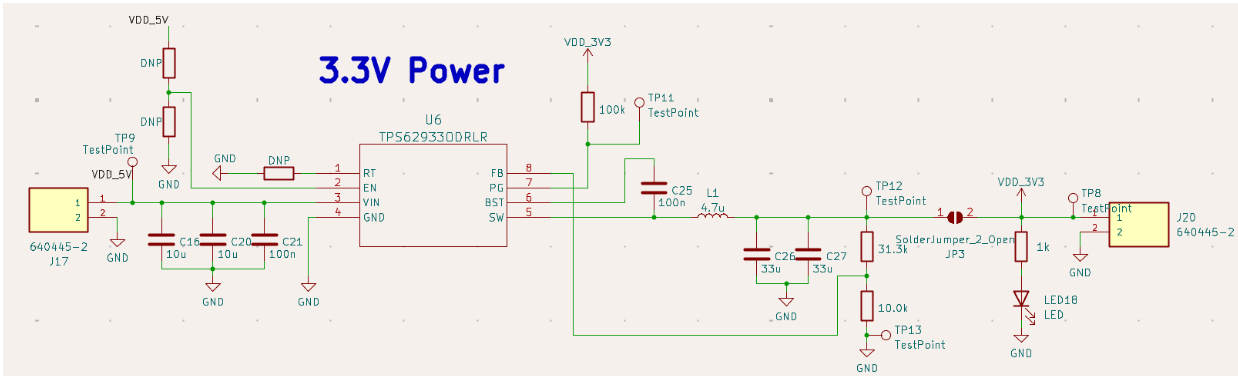

Figure 4: Power Subsystem

2.3.2 Computing Subsystem

The computing subsystem will use an ESP32-S3 WROOM-1 for its WiFi capabilities. The MCU has 2 functions: mechanical control and MIDI upload. The mechanical control will take MIDI inputs and will output the signal to control the motors (solenoids and servos) on the mechanical subsystem. The microcontroller circuit is based off of the example on the ECE 445 website.

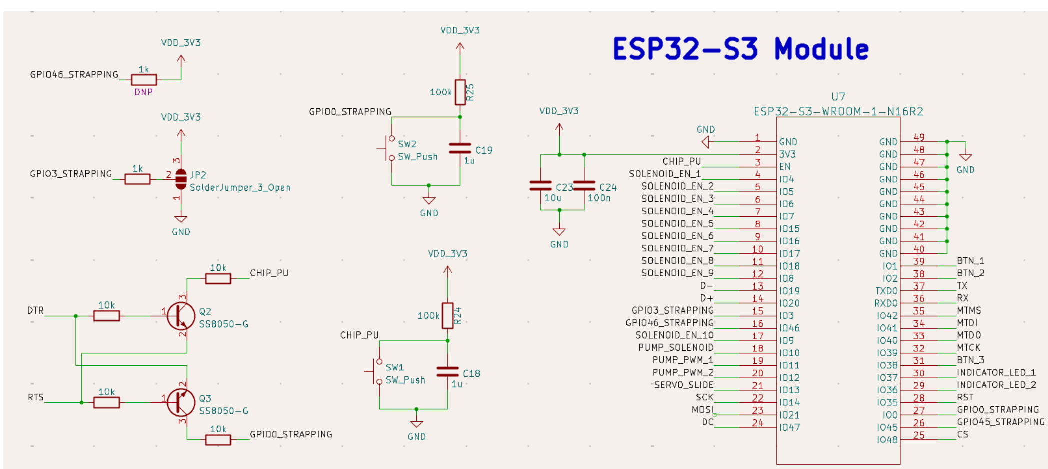

Figure 5: ESP32-S3 Microcontroller Module

On top of using an ESP32-S3 microcontroller, the computing system also contains capability for future manual control. This consists of an LCD screen and buttons. These inputs are managed by the microcontroller, which will control output to the LCD screen. Our computing unit will also include a debug header in which we can connect to via PC to debug our software.

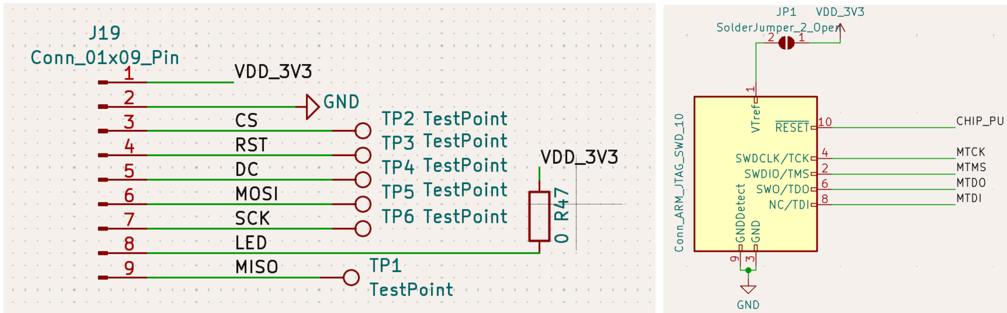

Figure 6: LCD Screen Connection Point and Debug Header

2.3.3 Mechanical Subsystem

The mechanical subsystem consists of all mechanical components of the device. This includes air pumps, solenoids, and each of their respective drivers. The drivers will allow the MCU to control the motors that dictate the airflow and the note being played.

Each individual solenoid will have its own driver circuit using a MOSfet and diodes in order to isolate the MCU from the 5V power line. The motors will use a similar driver circuit, which does not include an H-bridge as our two motors only need to function in one direction. Finally, the servo only requires connecting pins as it has its own built-in circuit board.

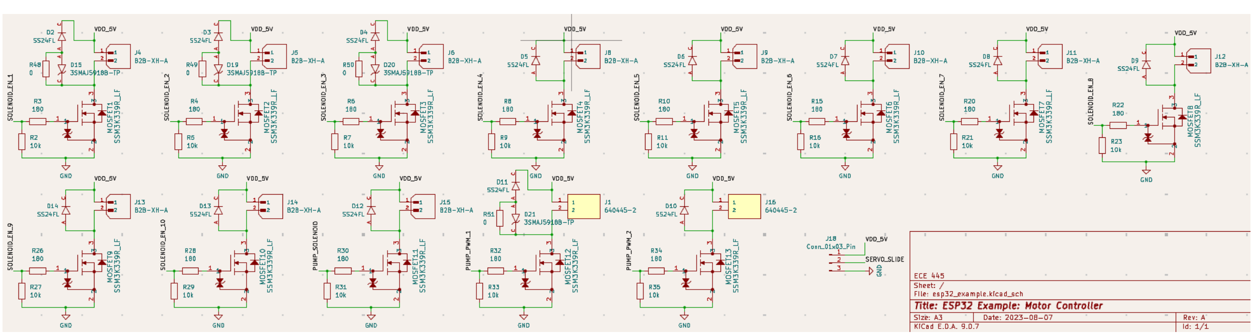

Figure 7: Solenoid, Motor, and Servo Control Circuit

2.4 Subsystem Requirements & Verification

2.4.1 Power Subsystem

Requirements	Verification
Provide 5 +/- 0.5V at a continuous current of 3A	● Plug in calculated load (15W) ● Measure supply line voltage with an oscilloscope ● Supply lines should still be within the specified 5 +/- 0.5V
The power system must also be able to provide 3.3V +/- 0.5V at a continuous current of up to 0.5A.	● Plug in calculated load (1.65W) ● Measure supply line voltage with an oscilloscope ● Supply lines should still be within the specified 3.3 +/- 0.5V
The power system must be capable of handling current spikes in order not to overload the components of the PCB.	● Plug in inductive/capacitive loads (max 15W/1.65W for 5V/3V respectively) ● Measure supply line voltage with an oscilloscope ● Supply lines should be stable enough to power other components on the PCB without damaging them

Methodology:

The power system will be verified by observing power supply rejection ratio (PSRR), power supply ripple, voltage accuracy, and load regulation. PSRR can be tested by observing the input voltage (with noise injected) and the output voltage. This value is measured by $\frac{\Delta V_{in}}{\Delta V_{out}}$ where ΔV represents the amplitude of the noise at the specified stage (noted by the subscript). Power supply ripple, similar to PSRR will be measured by ΔV_{out} or the amplitude of the noise on the output of the power supply. Voltage accuracy will also be measured with an oscilloscope where we take the average value over a period of time. The load regulation verification will require a variable load which will test the limits of how much voltage drops for a certain amount of power output.

In order to meet the requirements the voltage accuracy should be within the range of 5V +/- 0.5V. Under 3A current, the 5V line should still be within the same range of 5V +/- 0.5V. The 3.3V rail should also be tested such that it satisfies 3.3V +/- 0.5V accuracy under no load conditions. The load regulation will be tested under 0.5A and should remain within the same range of 3V +/- 0.5V.

The noise of the output should remain within the tolerances of the power lines specified above (5V +/- 0.5V and 3.3V +/- 0.5V). Given the input voltage does not dip below the minimum input voltage of the power subsystem when accounting for noise, the output voltage should also not exceed the tolerance threshold of +/- 0.5V for either line.

2.4.2 Computing Subsystem

Requirements	**Verification**
The user must be able to provide input to a website hosted by the ESP32	● Find device IP ● Connect to device webserver via IP ● ESP32 webserver should have user interactable buttons
The user inputs must be reflected through GPIO of the ESP32	● Click button on the webserver ● ESP32 GPIO must react (ie turn LED on)
The PCB will have to get its power from the power subsystem, and it will provide all outputs via GPIO pins to the mechanical subsystem.	● ESP32 should visibly power on when supplied power from the power subsystem (LED indicators will turn on) ● GPIO is able to toggle LEDs (visual output for testing and will be replaced with MOSFET drivers)
The ESP32 will control LEDs to display the state of the chip, and buttons for user control.	● LEDs should indicate the state of the chip clearly from the PCB ● Buttons should interact with the board and have a visible or audible reaction that the ESP32 has received the button press

The ESP32 must control a servo via PWM signal	● (For verification only) The ESP32 should be able to visually move a servo back and forth reliably
The ESP32 must control the MOSFET drivers	● Measure the input and output of the MOSFET driver with an oscilloscope ● The ESP32 should be able to PWM the MOSFET driver and have the output of the MOSFET reflect the PWM signal of the ESP32 at a higher voltage level

2.4.3 Mechanical Subsystem

Requirements	**Verification**
The air pumps must receive PWM with varying duty cycles from the MOSFETs	● Measure inputs of the motors with an oscilloscope ● Duty cycle of MOSFET output is reflected in motor speed visually (can test airflow of motors)
The MOSFET drivers must convert the logic level of the ESP32 to the motor driving voltage	● Measure the inputs and outputs of the MOSFET driver with an oscilloscope ● Input voltage should be the logic level of the ESP32 (3V3) and the output voltage should reflect 5V.
The respective air pumps must be able to push/pull air (one push, one pull)	● Turn on the air pump with the MOSFET drivers ● One air pump should push air (test by feel if there is blowing action) ● One air pump should pull air (test by feeling if there is suction action)
The air pumps must be able to push/pull air with resistance (through the rubber tubing and 10-port air manifold)	● Turn on air pump with MOSFET drivers ● Pumps should audibly push air with manifold and rubber tubing attached
The valve must be able to control which air pump is accessing the rubber tubing	● Turn on respective air pump with MOSFET drivers ● When the valve is off, the output

	should push air (test by feeling if there is blowing action) ● When the valve is on, the output should pull air (test by feeling if there is suction action
The servo must be able to actuate the harmonica lever	● Turn on servo with PWM ● Harmonica lever is visibly pushed ● Harmonica notes are audibly changed from whole notes to accidentals

2.6 Tolerance Analysis:

2.6.1 Component failure

2.5.1.1 ESP32

Our system makes use of 2 voltage lines, one at 5V and another at 3.3V. The logic found on the ESP32 is 3.3V, and the power input V_{cc} is only 3.3V-tolerant due to the FLASH chip it utilizes. When considering the fabrication of the device, the voltage input of the ESP32 must not coincide with the 5V lines through any means to avoid damaging the ESP32.

2.6.1.2 MOSFET Back EMF (Pump speed control)

Another concern of our system comes from how we will control airflow. More specifically, we will PWM 1 (or 2) pumps to control the amount of airflow through the pneumatic system. The problem arises when the motor is turned off and generates voltage across its terminals. This voltage can damage the MOSFETs, which control the motor, and must be dealt with via a flyback/free-wheeling diode. The flyback/free-wheeling diode will be placed across the motor in order to clamp any stray voltage generated by the motor when being pulsed.

2.6.2 Motor and solenoid control accuracy

Accurately playing a song on a harmonica requires precise timings of pushing and pulling air through the harmonica. Therefore, it is highly important for the accuracy of the music that our device controls when to play notes and stop playing notes with high precision. This is a challenge because the compressibility of air makes it so that there will be some delay between the pump starting to push air and the note starting to play. This limits the speed at which we can switch from playing to not playing, and vice versa. Given that the pump has a maximum output of 2.5 LPM and the tubing is ¼ inch, we can calculate that the air speed through this tubing is 4.3 feet per second. Then, estimating that we will have about 3 feet of tubing from the pump to the harmonica, that means that the pump to harmonica delay will be approximately 0.7 seconds. This is useful to know because we can factor this into our controls and change our input timings to adjust for this delay.

2.6.2.1 Motor power supply

Another concern of the system is that the motors we are using are rated for 6V. However, we have constrained our system for 5V for the convenience and availability of 5V supplies and regulators. While the motors are rated for 6V, the specification sheet further elaborates a range of 5.2V to 6.5V at <420mA. Our design uses 5V regulators which have a continuous current rated for 500mA. Under a single air pump this rated max current is below the max continuous current from the driver. However, given we are driving 2 air pumps, we have a cumulative max of 840mA which is above our rated 500mA driver. We solved this issue by separating the drivers for each pump which can supply 5V at up to 500mA to each pump individually.

2.6.3 Even air distribution for the harmonica

Even air distribution is vital for chords on the harmonica. However, because the airflow through the harmonica only affects the volume of the note being played, the chord being recognizable will be considered acceptable. This is because it is difficult to design a 10-port air manifold that has both even distribution and low delay, given our low air pressure of ~1 psi. In order to prevent uneven air distribution, a 10-to-1 air manifold can be used in order to mostly reduce the unevenness of the air.

3. Cost and Schedule

3.1 Cost Analysis

Part	Part Number	Per-unit Cost ($)	Quantity	Procurement	Sum ($)
Harmonica	N/A	30.99	1	Amazon	30.99
DC Motor Pump	1528-4699-ND	7.95	2	Digikey	15.9
Solenoid Valve	**DFR0866**	4	10	Digikey	40
Servo	1528-1501-ND	2	1	Machine Shop	2
PCB			1	JLCPCB	0
ESP32-S3 WROOM-1	ESP32-S3-WROOM-1-N16 R2	6.13	1	Digikey	6.13
10 Port Air Manifold		4.13	1	Aquarest Spas	4.13
3D printer filament		10	1	Machine Shop	10
Buck Converter	TPS62933ODRLR	1.08	1	Machine Shop	1.08
Capacitor - 10µF / 50V (0805)		0.1	3	E-shop	0.3
5ft ⅛" Rubber Tubing		6	1	Amazon	6
Capacitor - 1 µF / 50V (0805)		0.1	2	E-shop	0.2
Capacitor - 33µF / 10V (0805)		0.1	2	E-shop	0.2
Diode - SP0503BAHTG (SOT143-4)		0.1	14	E-shop	1.4
LED - GREEN LTST-C171GKT (0805)		0.1	3	E-shop	0.3
LED -RED	587-2939-1-ND	0.25	3	Digikey	0.75
Connector - Micro USB-B		0.1	1	E-shop	0.1
Resistor - 10KΩ 1%(1/8W) (0805)		0.1	20	E-shop	2
Resistor - 1kΩ 5%(1/8W) (0805)		0.1	5	E-shop	0.5
Resistor - 100kΩ 5%(1/8W) (0805)		0.1	3	E-shop	0.3
Resistor - 180 Ohm	P180DACT-ND	0.0572	13	Digikey	0.7436
Resistor - 31.6 kOhm	P31.6KDACT-ND	0.061	1	Digikey	0.061
Resistor - 0Ω (1/8W) (0805)		0.1	5	E-shop	0.5
Switch - Tactile		0.1	5	E-shop	0.5

MOSFET	SSM3K339RLFCT-ND	0.228	13	Digikey	2.964
2-pin male connector	455-B2B-XH-A-ND	0.073	3	Digikey	0.219
2-pin male lock connector	A1971-ND	0.131	10	Digikey	1.31
2-pin female lock connector	A24111-ND	0.159	10	Digikey	1.59
5.1V Zener Diode	353-3SMAJ5918B-TPCT-ND	0.259	5		1.295

Total cost of parts: $131.426

In addition to parts, there will also be a labor cost as well. At $35/hr for 8 hours a week per employee for 3 employees over 12 weeks, that amounts to a total of 35*8*3*12 = **$10,080.**

In total, the project will cost approximately **$10,211.43** to fund the development and manufacture of the self-playing harmonica.

3.2 Schedule

Time	Goals	Description	Roles
3/1-3/7	● Test Delivered Components ● Complete Design Review ● Breadboard construction	Verify that the components delivered are functional and working as intended for the project (ie motors, solenoids, servos, MOSFETs, etc). Revise design document after review. With all delivered components, create a preliminary breadboard demo with ESP32 motor control.	Robert: Component testing, breadboard construction Sean: Component testing and design document revision, breadboard construction David: Design document revision, breadboard construction
3/8-3/14	1. Solder and test PCB 2. Breadboard completion 3. Preliminary physical device construction	1. Build first revision of PCB (First time) 2. Verify design with simulations if possible 3. Complete breadboard and demo	Robert: PCB soldering Sean: ESP32 and wifi software David: Physical construction and CAD design

3/15-3/21	Spring Break		Robert: Sean: David:
3/22-3/28	1. Cost reduction (If first revision is functional) 2. Complete physical device construction	1. See if it is possible to cut down on overall cost of design 2. Test the individual subsystems to see what works 3. Complete 3d printed casing	Robert: PCB and software revisions Sean: Software revisions David: Complete casing and tubing
3/29-4/4	Revise design & Order, individual progress reports	Create or revise the old design in accordance to what is needed. Order the new revision.	Robert: Complete report and revise PCB and software Sean: Complete report and revisions David: Complete report and revisions
4/5-4/11	Build new revision & Verification/Debugging, Progress Demo, Team contract assessment	Begin soldering of the second PCB if needed. Work on team contract assessment.	Robert: PCB soldering and testing, team contract Sean: Software revisions and team contract David: PCB soldering and testing, team contract
4/12-4/18	1. Cost reduction (If second revision is functional) 2. Begin final report	Finish second PCB and testing and verification, begin final report (both technical and english)	Everyone: PCB soldering and testing, as well as final report
4/19-4/25	Mock demo with TA, continue final report	Make sure device is fully functioning, robust, and is ready for demo	Everyone: Hardware and performance testing, final report
4/26-5/2	Final demo, complete final report	Perform the demo!	Everyone: Demo performance and final

			report submission

4. Ethics, safety, and societal impact

4.1 Ethics

Creating a self-playing harmonica brings up questions about the ethical considerations surrounding accessibility as well as the role of automation in the arts. On one hand, this device could significantly expand access to music for individuals with physical impairments. On the other hand, there could possibly be concerns raised by the possibility of replacing humans with automation. As a team, we think that the ethical concerns are addressed by the intention of the design as well as its capabilities. The device we are proposing to create is not meant to replace human musicians, nor will it have the same capabilities as a musician. Rather, the self-playing harmonica is meant to increase the spread and awareness of harmonica music. The IEEE code of ethics section I.2. states that members should strive to improve the understanding of the public of intelligent systems and emerging technologies. By introducing this device, we aim to increase the awareness of smart systems. Therefore, we believe that we are operating in accordance with this code of ethics.

4.2 Safety

According to our analysis, our device can draw upwards of 5 amps. In order to have substantial overhead, we choose to utilize a 5V 10A power supply. This could be dangerous, as 10A is a very high current. We will follow proper electrical safety procedures in the lab safety training to ensure the safety of our team members as we proceed with this project.

References

IEEE. "IEEE Code of Ethics | IEEE." *Ieee.org*, 2020, www.ieee.org/about/corporate/governance/p7-8.

Datasheets:

DFR0866 2-Position 3-Way Air Valvet

ESP32-S3 Technical Reference

Sunfounder 1080SF Servo

ZR370-02P Pump