ECE 445L
Fall 2023

TA: Aeybel Varghese

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Sarah Mobley
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Capacitive Touch Harp Final Report

Deliverable 1: Final Requirements

Overview

Objectives

The objective of this project is to design, build, and test a microcontroller-based embedded system demonstrating the concepts learned in this class. This project is designed to be a fun assignment for students to use all the skills and knowledge they have gained in this class. As an incentive to engage with the course material, a science-fair style competition will be held on the last class day, where the winners will get extra credit in the class.

We will be building a mini electric harp. Unlike traditional harps, which have 47 strings, the harp will only have 12 strings, using fewer components while still representing multiple octaves.

Roles and Responsibilities

The project will be chosen by a group of at least four students, who are the engineers. The TAs and Professor McDermott are the clients. Our group (Group 11) is made up of 5 students: Malik Bajunaid, Sarah Mobley, Victoria Tyler, Tessa Urwin, and Peiwen Yu. Each member of the group will be assigned to the tasks in one or more of the following subsystems: audio, controls, strings (including lights and sensors), the enclosure, and integration.

Interactions with Existing Systems

Students may use any microcontroller they choose for this project. However, if entering the competition, the system designed must use a TM4C, MSP430, or MSP432. We will be using two TM4Cs. The audio circuitry will be based on the Lab 5 circuitry.

Functional Description

Functionality

All projects must meet the following constraints:

1) Each group shall produce a PCB design (.kicad_sch and .kicad_pcb) for the system.
2) The system should perform something useful.
3) The system shall include at least two inputs, two outputs, and two interrupt service routines.
4) The system must contain four or more identifiable subcomponents, where each team member must be responsible for at least one major subcomponent.
5) This system shall mount an MCU and other chips to the PCB.
6) The final system must fit in an appropriate enclosure.
7) TAs will judge if the project is sufficiently complicated.

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8) Each team can order one two-layer 30in2 PCB from JLCPCB.
9) If you use an ESP8266 from the checkout desk, do NOT solder it to the PCB.
10) Each PCB must conform to JLCPCB's design capabilities,
11) Parts that are not provided must be purchased by the group.
12) You can use two motors and their corresponding wheels from the Lab 10 supplies, but they must be returned.
13) You should NOT use a ground pour (this will introduce difficulties with debugging and fixing your board if there are any errors).

If participating in the competition, the project must meet the following additional requirements:

1) The design shall use only the TM4C, MSP430, or MSP432 as the primary microcontroller.
2) I/O components such as LCD displays, switches, sensors, LEDs, speakers, keypads, and microphones can be off the PCB.
3) All other electronics (resistors, capacitors, ICs, etc) shall be on the PCB.
4) The team shall spend no more than $60 on extra components not provided for other labs.

For our project, the strings will be made of clear plastic tubing, conductive wire, and LEDs. There will also be sensors to record where the strings have been touched. The controls will include switches to change the harp's settings and a screen to display the current settings. This will all be housed in a frame and base that should rest nicely atop a table, which will be 3D printed. The audio will be generated digitally and output to a port that can be used with an external speaker.

Performance

The system will be judged by qualitative measures relating to functionality and ease of use in each of the subsystems. Overall, the software modules must be easy to understand and well-organized. For the strings and audio, the time between touching the string and hearing a note should be indistinguishable, and the strings should reliably play a note when touched. At least two strings must be able to be played at the same time, and the volume should be reasonably audible or adjustable. The audio quality should be good enough to be understood as music. For the controls, the screen interface must be designed intuitively. The enclosure should support and hide all of the electronic hardware while also resembling a harp.

Audio

The audio output will be generated using the microcontroller and then converted to an analog signal using a DAC. For the song feature, the digital signal will be generated corresponding to a lookup table for that song. For the tone feature, the envelope and shape of the signal will be altered according to the type of instrument selected.

Strings

The strings will use two techniques to detect which note the user desires to play: capacitive touch and infrared distance sensors. The system will sense which string has been touched, and thereby which note to play, using a wire and a small-valued capacitor that together act as a capacitive touch sensor. The

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microcontroller will pulse the digital pin connected to the wire and the system will measure the average discharge time of the capacitor. When a human hand gets within a certain distance of the wire, the discharge time of the capacitor will increase relative to its average and the system will detect this change as a touch. We will calibrate this distance so that the user must be touching the string for the system to detect a touch. When a touch is detected, the system will also read a corresponding infrared distance sensor to determine the octave of the note. When the user touches the string closer to the bottom, the note will be a lower octave and when the user touches the string closer to the top, the note will be a higher octave. There will be about 3 octaves per string. The wire will be encased in clear plastic tubing so that the two LEDs on either end light up through the clear tubing.

Controls
The controls will consist of two main components: switches and a screen. The switches will be used for the following purposes: turn the system power on and off, select the song to either play or learn, select the tone of the instrument to be played, and adjust the volume. The screen will be used to display the current note being played, the current song, and current instrument tone.

Frame
The frame will be hollow, at least on one side, such that the wires connecting to the distance sensors and LEDs have a path to the PCB. The base will be sufficiently sized to hold the PCB and prevent the harp from tipping over.

Usability
There will be 3 ways to use the harp: manual, autoplay, and learn mode. In manual mode, when the user touches a string, the corresponding note and octave will play and the string's LED will light up. Thus, a user may play a song by touching each string and the strings will light up as they play. While in autoplay mode, the user can choose a song to play from a list displayed on the screen. The harp will automatically play the notes of the song until it is either paused, stopped, or finished. As the song is playing, the strings corresponding to the notes of the song will light up. If the system is in learn mode, it will teach the user how to play a song on the harp. Like in autoplay mode, the user will select a song from a menu on the screen. The system will then light up the string that the user must touch to play the song. When the user touches a string, the system will play the corresponding note. The goal of the user is to play as many of the correct strings as possible.

Deliverables

Reports
In addition to this report, there will be two reports written for the labs corresponding to this project, Labs 8 and 11.

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Outcomes

For each lab, there are three main phases: preparation, demonstration, and the report. For Lab 8, the preparation will be to add all components from the schematic onto the PCB and arrange them suitably. The demonstration will be a completed PCB, ready to order from JLCPCB. The report will include the following:

- Updated requirements document
- Hardware Design
    - KiCAD schematic and PCB (in Github Classroom)
- Software Design
    - System design diagram of the modules created
    - Unit and integration tests written (in Github Classroom under sw/tests folder)
- Measurement Data
    - Total cost of system, parts + PCB

For Lab 11, the preparation will be to revise the project requirements and BOM as well as gather the components and solder your PCB. The demonstration will be to present the system with full functionality (as described in these requirements), the BoM, and project cost. The report will include the following:

- Final requirements document
- Hardware Design
    - KiCAD schematic and PCB (in Github Classroom)
- Software Design
    - System diagram of the modules created
    - Unit and integration tests written (in Github Classroom under sw/tests folder)
- Measurement Data
    - Passive and active power consumption of each subcircuit
- Any other measurements of your system that are needed to demonstrate that it meets performance requirements specified

There is also extra credit, as outlined in the Lab 7, 8, and 11 documents.

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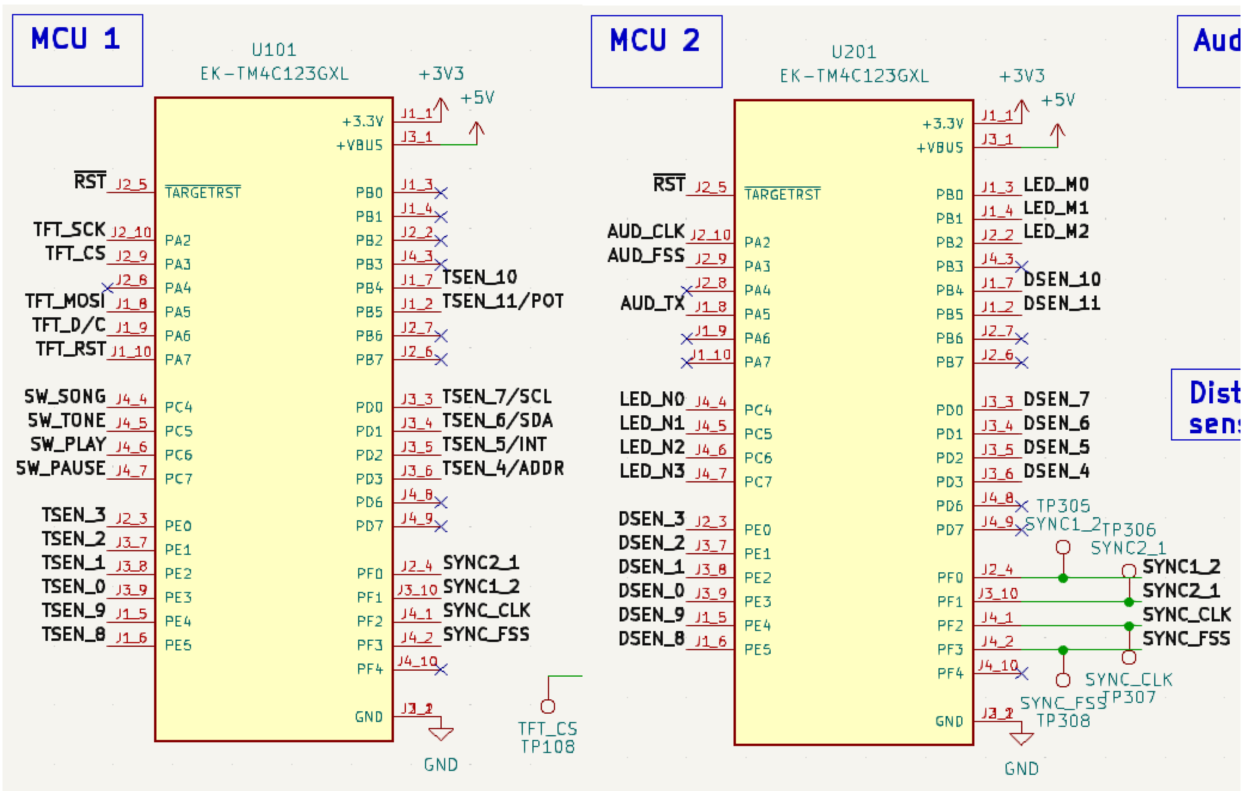
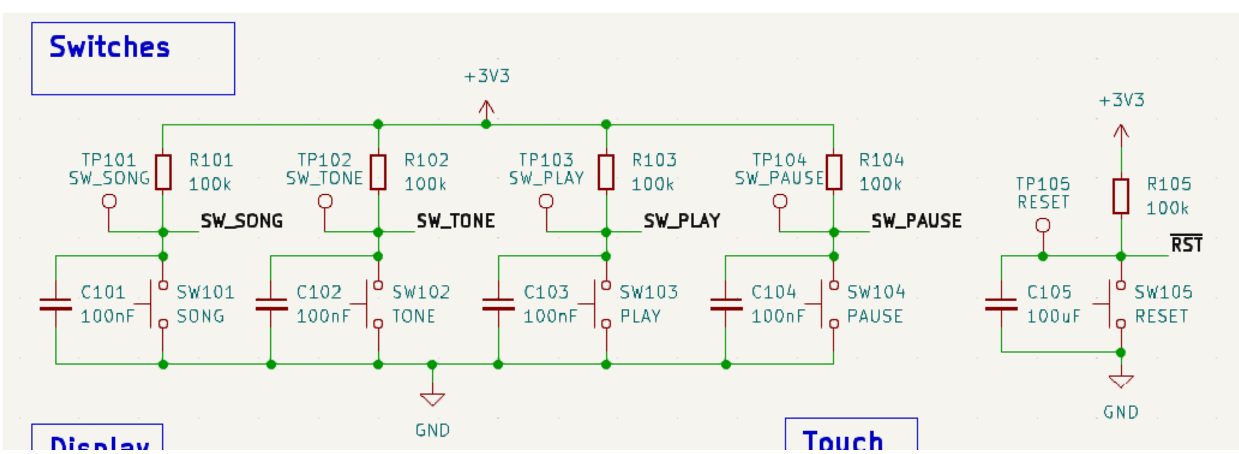
Deliverable 2: Hardware Design

See the GitHub classroom under hw/Final Project.





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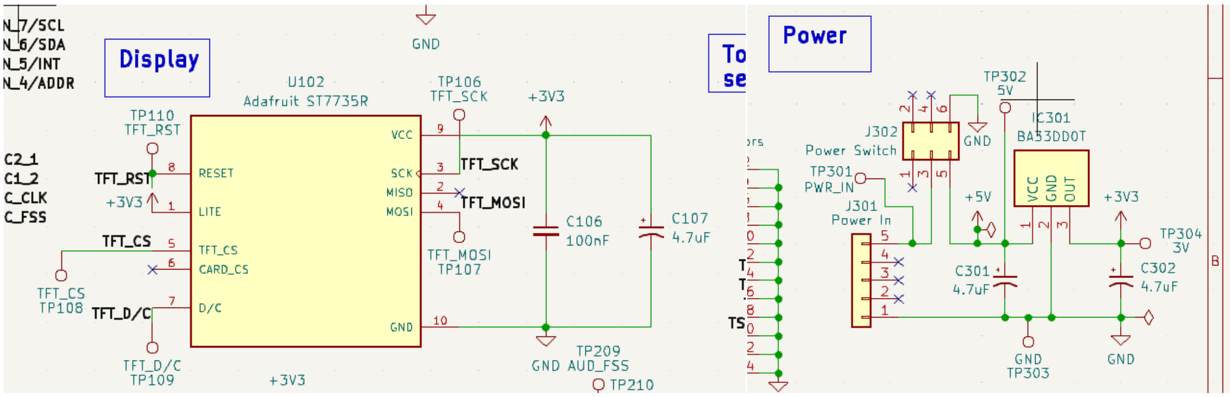

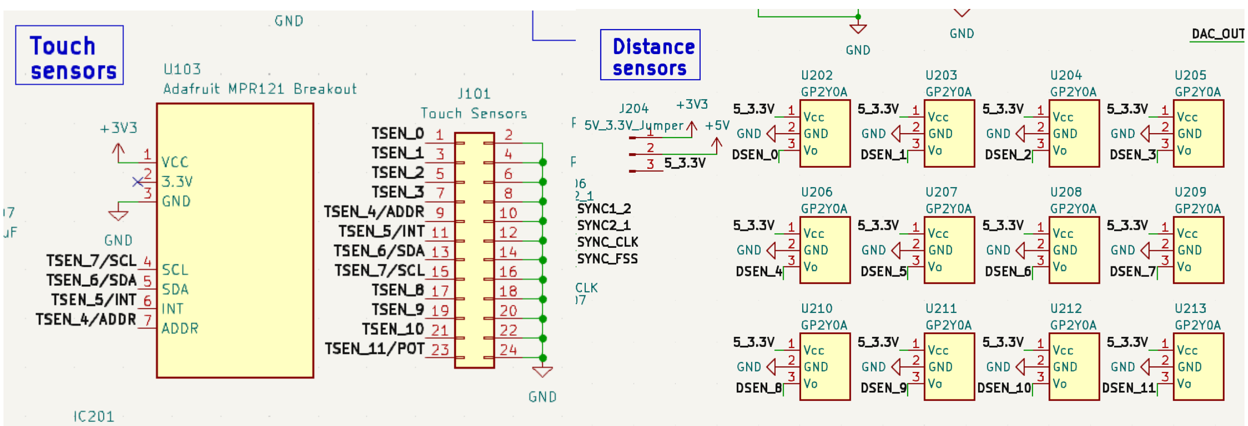

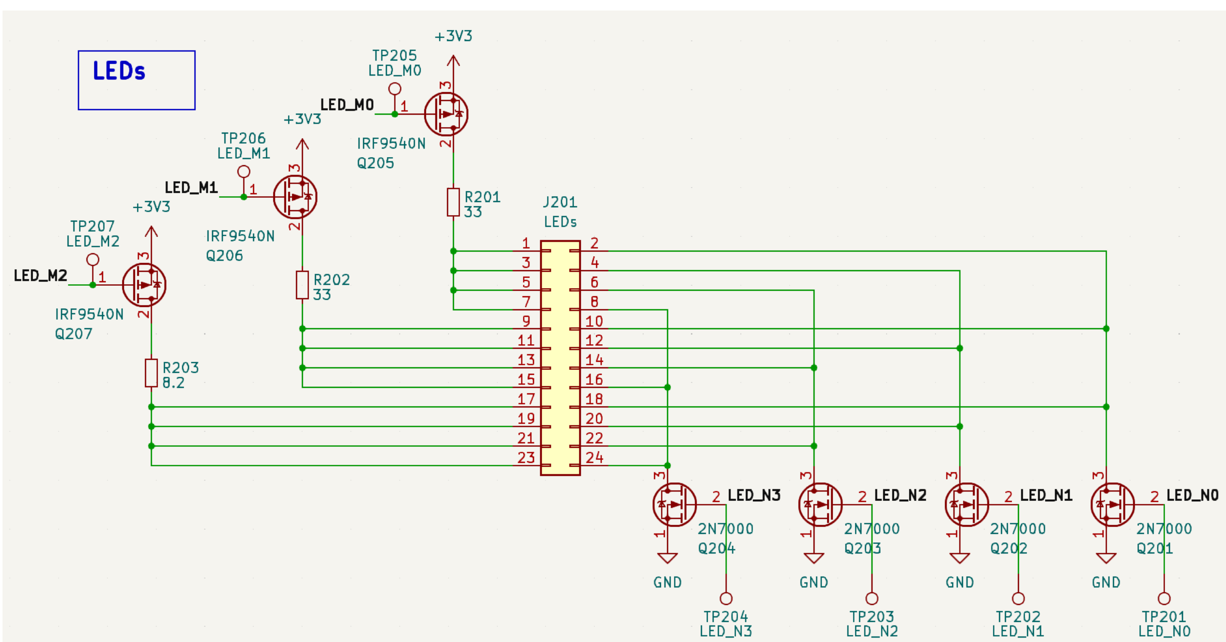

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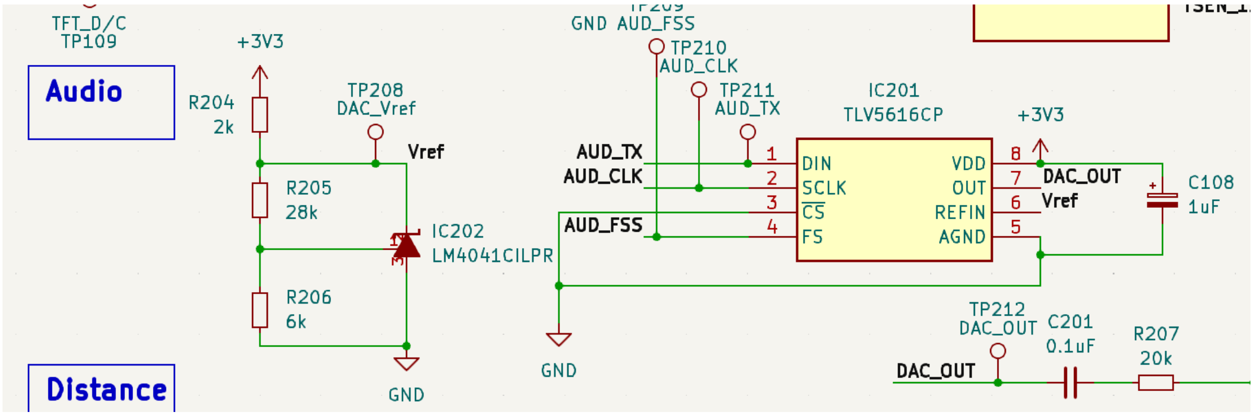

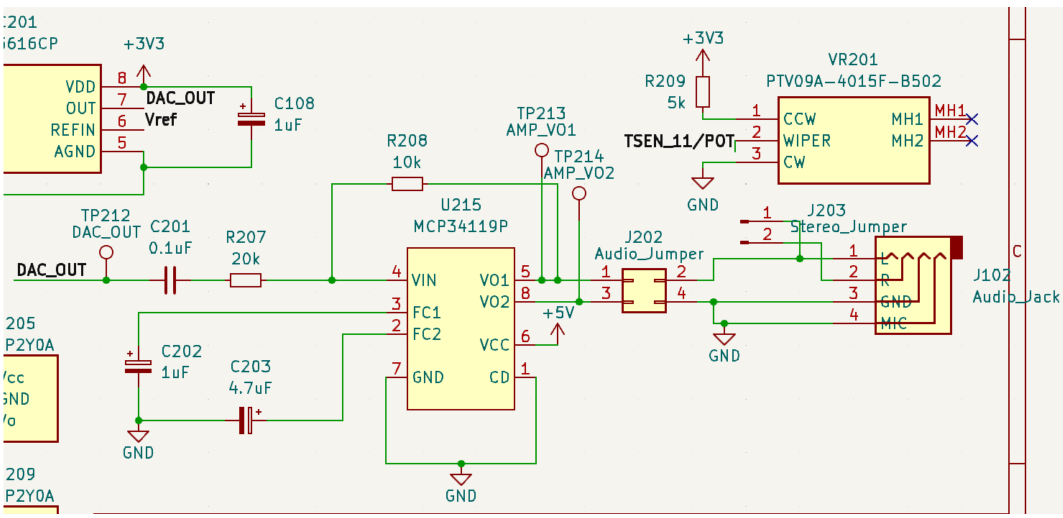

BOM Estimation

2	CPU	TM4C123GH6PM 64-pin LQFP	$11.55	$23.10
1	IC	TLV5616 12-bit DAC	$9.61	$9.61
1	IC	MC34119 audio amp	$1.95	$1.95
1	IC	LM4041CILPR shunt diode reference	$0.77	$0.77
1	LCD	18-bit color 128*160 1.8" TFT LCD display	$19.96	$19.96
4	SW	B3F tactile push button switch	$0.17	$0.68
6	CAP	100nF Capacitor	$0.05	$0.27
1	CAP	100uF Capacitor	$0.38	$0.38
4	CAP	4.7uF Capacitor	$0.22	$0.88
2	CAP	1uF Capacitor	$0.32	$0.63
5	RES	100k Resistor	$0.02	$0.12

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2	RES	33 Resistor	$0.02	$0.05
1	RES	8.2 Resistor	$0.02	$0.02
1	RES	2k Resistor	$0.02	$0.02
1	RES	28k Resistor	$0.02	$0.02
1	RES	6k Resistor	$0.02	$0.02
1	RES	20k Resistor	$0.02	$0.02
1	RES	10k Resistor	$0.02	$0.02
1	RES	5k Resistor	$0.02	$0.02
4	FET	2N7000 MOSFET	$0.49	$1.96
3	FET	IRF9540N MOSFET	$1.39	$4.17
4	SW	B3F tactile push button switch	$0.17	$0.68
1	SW	Red Off board momentary push button	$0.35	$0.35
1	SW	Toggle power switch	$0.85	$0.85
12	SEN	GP2Y0A21YK0F Sharp Distance Sensor	$8.77	$105.24
1	JACK	Headphone jack	$1.30	$1.30
1	JACK	USB Power Breakout Board	$0.59	$0.59
1	POT	B502 5k Potentiometer	$1.02	$1.02
24	LED	LEDs	$0.28	$6.72
1	SEN	12-Key MPR121 Capacitive Touch Sensor	$7.95	$7.95
1	N/A	Plastic tubing	$4.82	$4.82
1	WIRE	Solid core wire	$13.42	$13.42
1	ADPT	Amp adapter	$2.25	$2.25
1	PWR	5V 2A power adapter	$6.99	$6.99
1	N/A	Paint		$5.00
			TOTAL	$232.31

1	PCB	PCB plus shipping	$13.00	$13.00

Competition Budget

1	REG	3.3V Regulator	$3.12	$3.12
24	LED	LEDs	$0.28	$6.72
1	SEN	12-Key MPR121 Capacitive Touch Sensor	$7.95	$7.95
1	N/A	Plastic tubing	$4.82	$4.82
1	WIRE	Solid core wire	$13.42	$13.42
1	ADPT	Amp adapter (3.5mm to ¼”)	$2.25	$2.25

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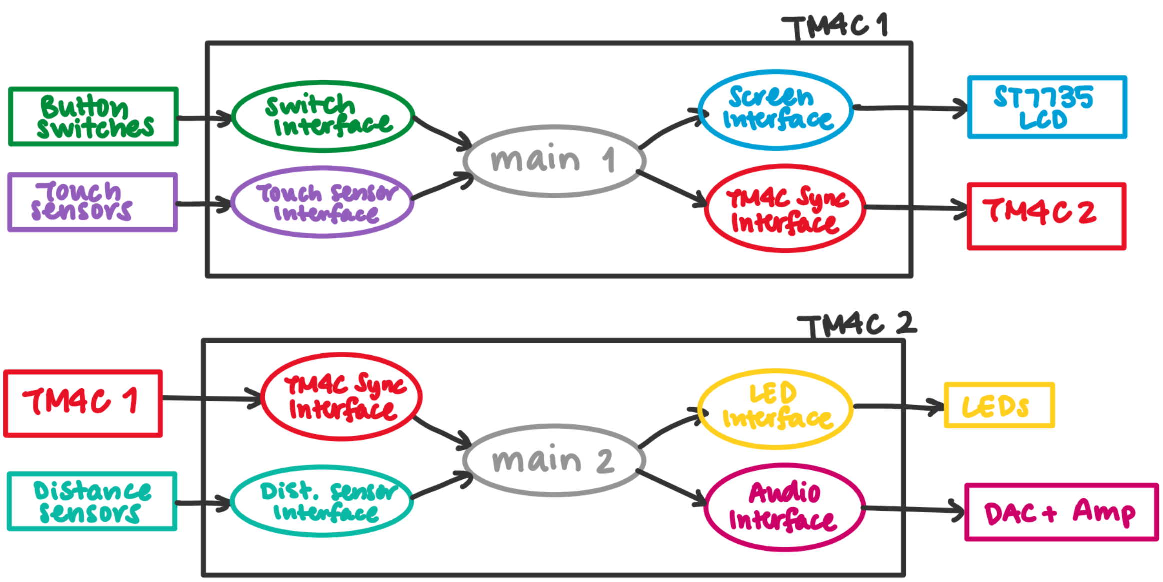
1	PWR	5V 2A power adapter	$6.99	$6.99
1	N/A	Paint		$5.00

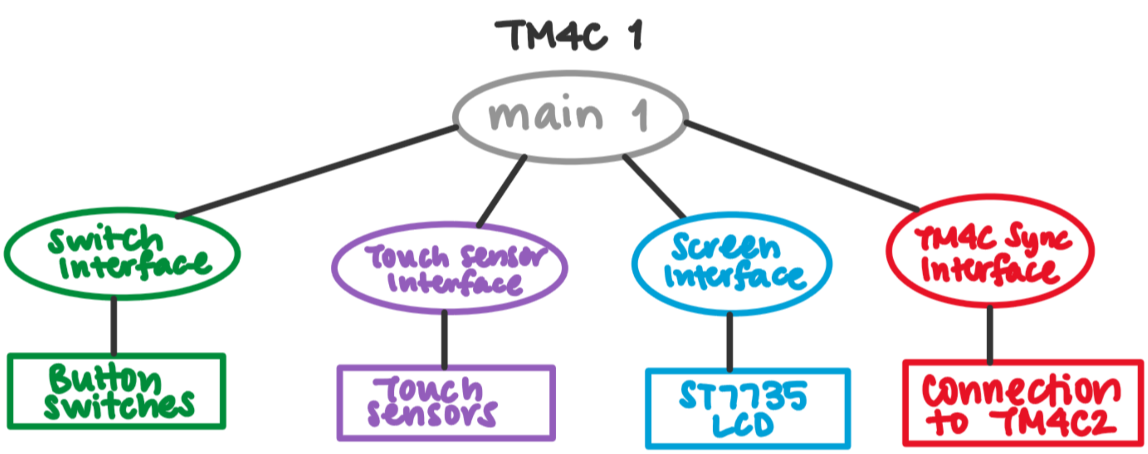
TOTAL	$50.27

Deliverable 3: Software Design

Call Graph



Modules



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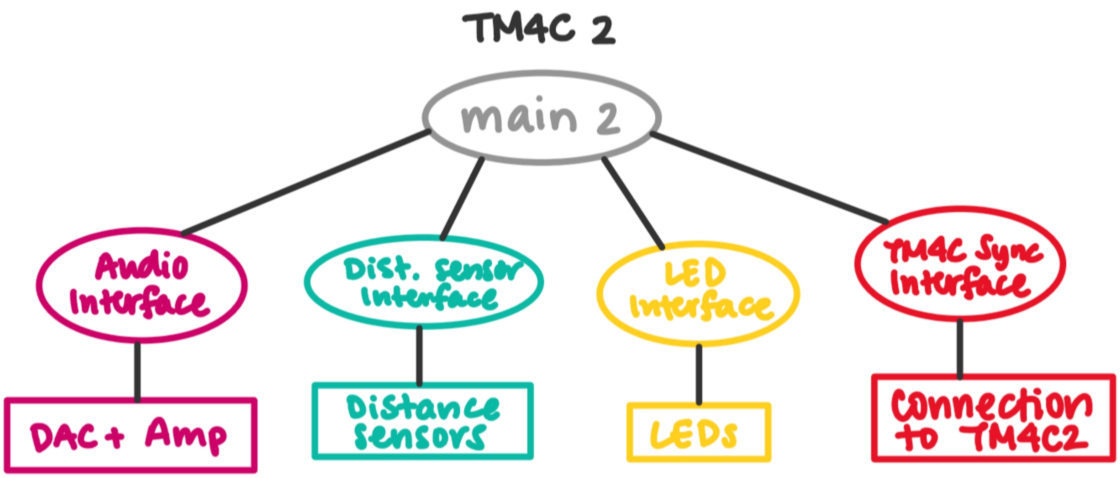

See the GitHub classroom for the following module files under sw.

/TM4C1

- Screen Interface (Display.c)
- Switch Interface (Switches.c)
- Autoplay Feature (Songs.c)
- Touch Sensor Interface (TouchSensors.c)
- TM4C UART Interface (Transmitter.c)

/TM4C2

- TM4C UART Interface (Receiver.c)
- Distance Sensor Interface (DistanceSensors.c)
- LED Interface (LEDs.c)
- Audio Interface (Sound.c)

See the GitHub classroom for unit and integration tests under sw/tests.

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Deliverable 4: Measurement Data

Power Consumption by Subcircuit

Component	Quantity	Idle current (mA)	Active current (mA)	Power (mW)
TM4C	1	45.1*	45.1	297.48
LCD	1	50	50	
Buttons	4	0	0.033	0.424
LEDs	24	0	20	
Touch sensors	12	0	0.393	2.012
Distance sensors	12	0	40	2457.6
Reference diode	1	25	25	
DAC	1	0	1.35	4.452
Amplifier	1	0	3	6.459
Potentiometer	1	0	0.66	
	TOTAL (A)	**0.1151**	**1.09**	**2933.327**

**We will not be using sleep mode.*

Maximum current rating of power source: 2A

Maximum power rating of power source: 10W

System Measurements

We used an Arduino to test the capacitance module and verify that it was working properly before putting it in our system.

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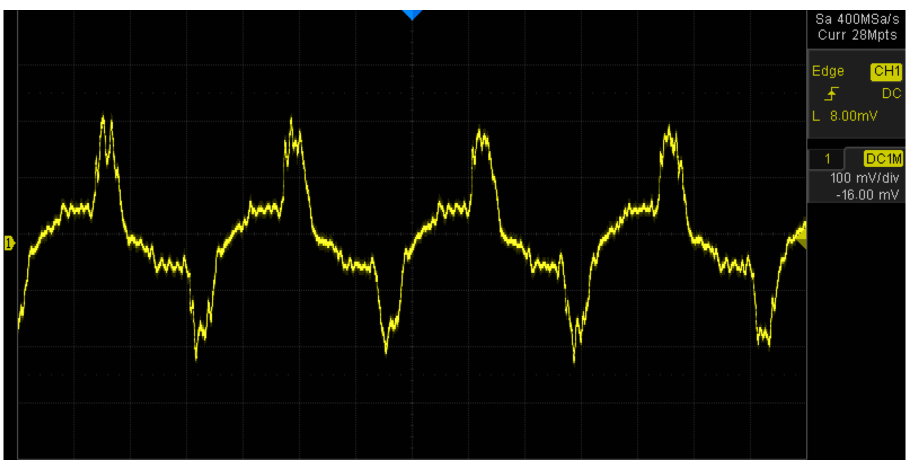
Analysis and Discussion Questions

1. **How did you debug your system? How intrusive was it?**
   We have not fully breadboarded and tested our system yet. We plan to debug our system with the Keil debugger by storing test values in an array (minimally intrusive) and use breakpoints (very intrusive) only if we have to, since our system is very time dependent. We will also use an oscilloscope and logic analyzer to test hardware.

2. **What's the difference between unit testing, integration testing, and functional testing?**
   Unit testing is a process in which a program is divided into the smallest testable components (units) and then each unit is verified for correct operation. Integration testing builds upon unit testing by combining (integrating) the units into larger blocks of code, then testing them and verifying their correctness as a group. Finally, functional testing occurs when the program is integrated to the point where each feature (the program's functionality) is tested against the software requirements.

Extra Credit

Signal to noise ratio (SNR) of audio output



We used an oscilloscope to measure the amplitudes of the signal and noise and then calculated the SNR. 60 dB is considered a good SNR for audio, but our SNR was only 49.16 dB. As a result, listeners could potentially tell there was a noise in the audio signal. However, this SNR is within the specifications of the project, since the user could definitively tell what note was being played, and the noise, if noticeable at all, did not impact usage of the device. Better components could improve the SNR, but there could also be errors with the oscilloscope measurements or with the connections to the circuit.