Brain-controlled Portable Programmable Embedded System

Design Review

Yujie Chen | Shiyang Liu | Xuanyu Zhong

TA: Lydia Majure

February 22, 2013

Table of Contents

Introduction

1.1 Statement of Purpose

The technology of detecting and analyzing electroencephalographic (EEG) signals already exists in labs. For instance, when we stare at a light source which blinks at a specific frequency, our brain will generate a signal at the same frequency along the scalp. The EEG technology is able to detect, amplify and recognize this particular neural signal, which gives us a new way to interact with machines: directly from brain. However, the equipment used for EEG signal detection and analysis is not portable and currently there are no devices integrated with a software system on the EEG technology. Both drawbacks prevent this new technology from prevailing in market. In this project, we aim to create a product which is specially designed for EEG technology in order to provide better user control experience in general. It has the wireless communication component to enable portability and an embedded system which takes EEG signal as input.

1.2 Objectives

1.2.1 Goals

- The device contains LED arrays which blink at different frequencies around the LCD screen so as to visually stimulate the generation of EEG signals along the scalp, which can be captured by the analyzing equipment.
- The device wirelessly obtains analyzed signals.
- The device then classifies and computes the signals and updates the LCD screen based on the software system integrated in the controller.

1.2.2 Functions

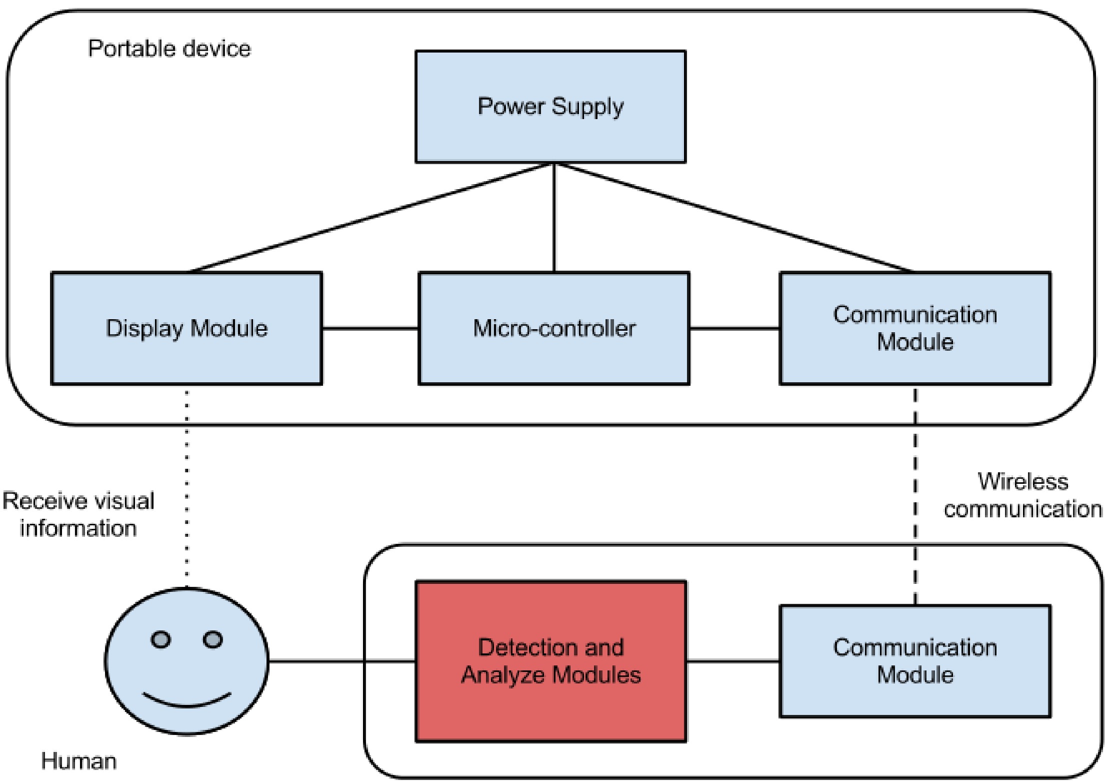
- LCD screen provides interactive displays and the LED arrays stimulate the generation of EEG signals in the user's brain.
- Wireless communication between EEG equipment and the device
- Software system analyzes signals from EEG equipment and updates display accordingly.

1.2.3 Benefits and Features

- Wireless signal transmission provides significant portability
- Interactive displays improve user experience
- Brain-control based inputting method realizes unique and simplified user interactions
- LED arrays provides effective signal stimulation without mutual interference
- Revolutionary control technology

2.0 Design

2.1 Block Diagram



2.2 Block Descriptions

Microcontroller:

We use the Arduino Mega 2560 microcontroller board to analyze wireless signals and drive a LCD display with digital I/O pins. It is programmed to react to different commands (selection of different LED arrays) analyzed from input signals from the user's brain, execute the command accordingly or provide the next list of commands for the user to select from by updating the LCD display. The board is powered by the 9V external power supply.

Display module:

A SainSmart 3.2" TFT LCD touch screen is used. It is surrounded by arrays of LEDs flashing at varying frequencies. By looking at one of these regions, the brain will generate signal that can be distinguished by the detection module through EEG. In this way, the regions act as menus that can be selected by brain. The LCD display has integrated power and a 40 pins interface and SD card reader design. It is relatively convenient to program and provides vivid graphics, which serve as the primary reason for choosing this device.
The system also supports standby state in which the LCD screen goes blank and one array of LED light becomes the media between human-machine interactions.

Communication module:

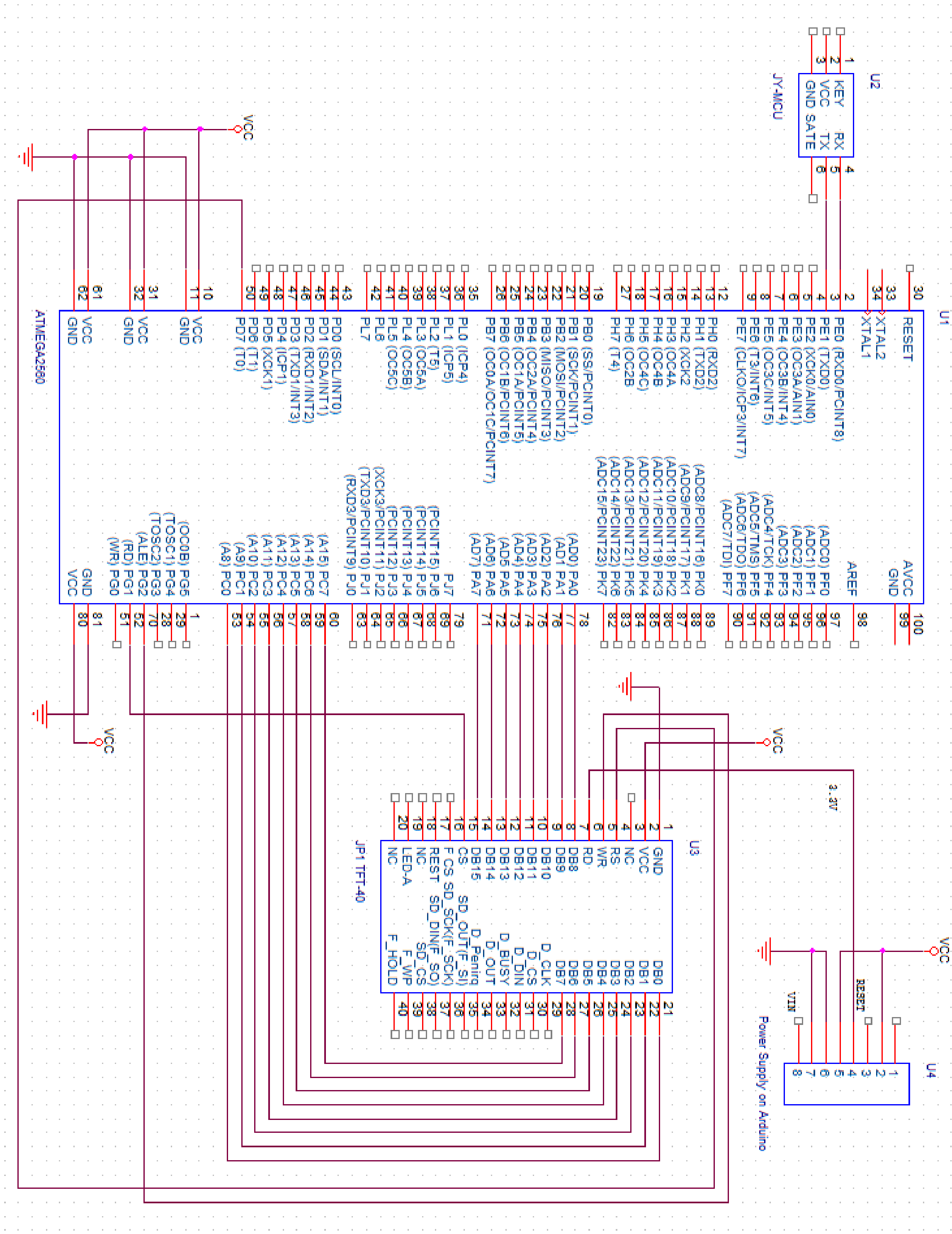
The communication interface implements wireless transmission of signal data from detection module to micro-controller. This allows synchronization between the generation of EEG signals along the scalp and the computation of microcontroller in order to update displays as well as next set of displays based on user's intention. The chip we are using is the HC-05 Bluetooth transceiver module. The Bluetooth module operates at 3.3V and is wired to the Arduino board through RX and TX ports. Analyzed signals are sent wirelessly from the computer in the detection module, picked up by the Bluetooth receiver, inputted to the microcontroller and will finally take action on the current screen.

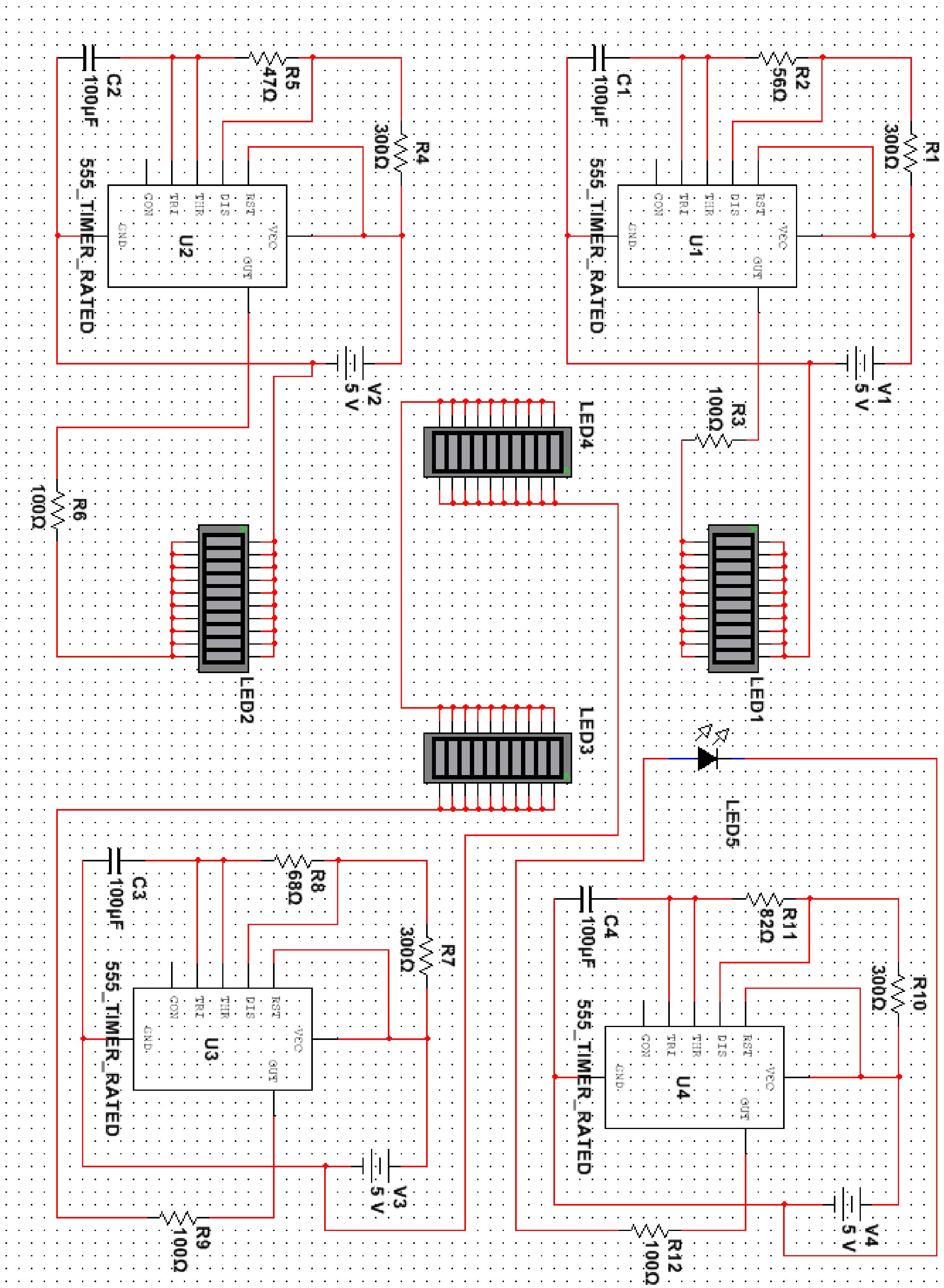
Detection module:

The detecting and analyzing modules capture the EEG signals from user by recording brain's spontaneous electrical activity over a short period of time with EEG sensors attached along the scalp. The signals detected are then amplified so that they can be applied to the algorithms of classification and wirelessly transmitted to the transceiver and microcontroller. This module is provided by James Norton and his group.

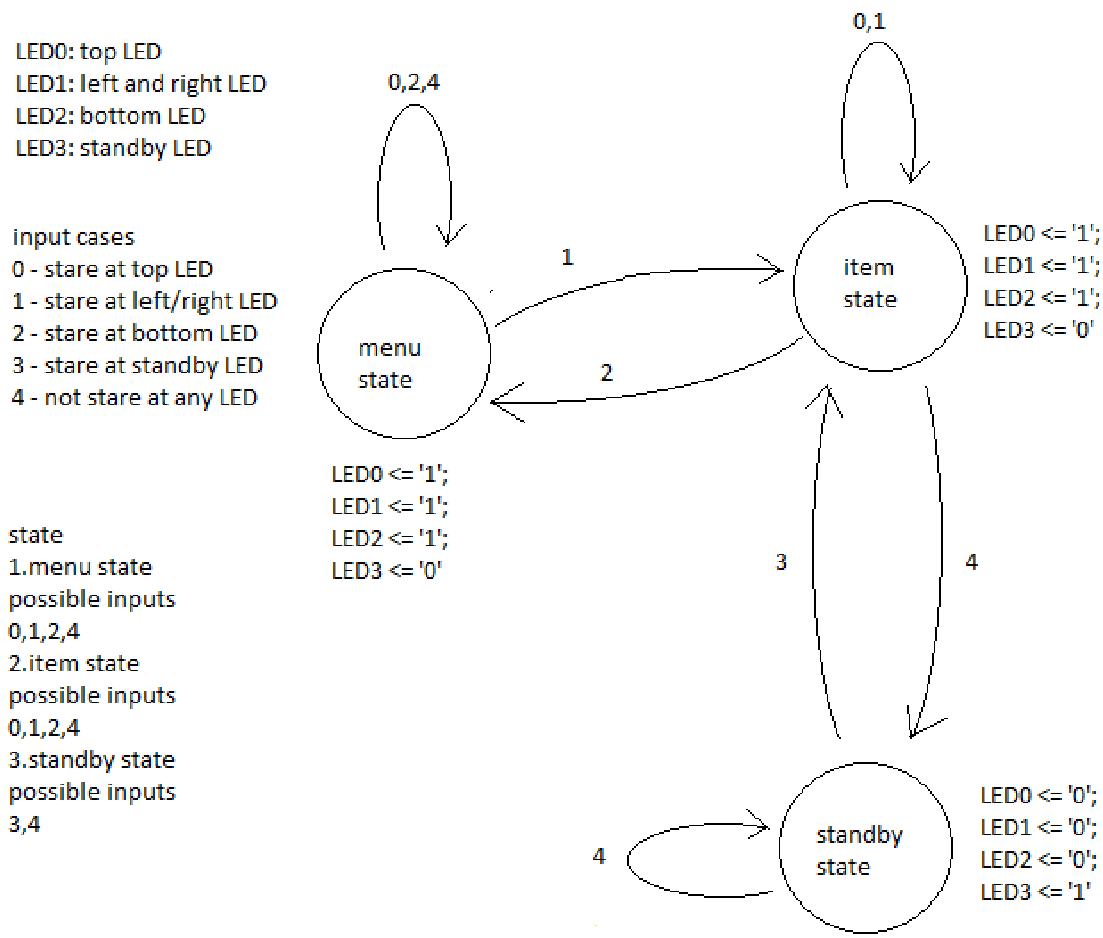
2.3 Schematics

Overall Schematics:



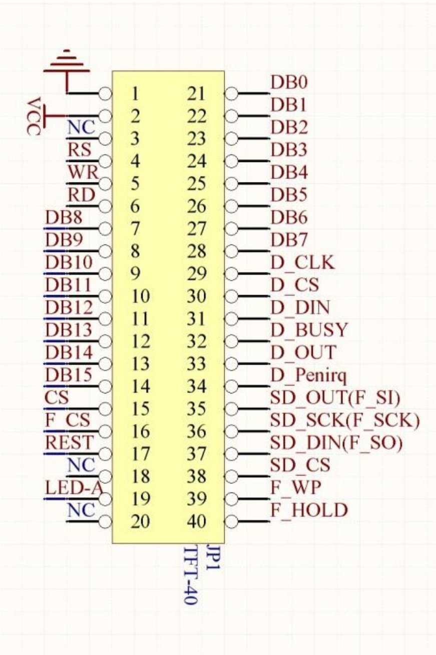

R1 300Ω
R2 56Ω
C1 100µF
U1
555_TIMER_RATED
VCC RST DIS THR TRI CON GND OUT
V1 5 V
R3 100Ω
LED1
R4 300Ω
R5 47Ω
C2 100µF
U2
555_TIMER_RATED
V2 5 V
R6 100Ω
LED2
LED3
LED4
LED5
R7 300Ω
R8 68Ω
C3 100µF
U3
555_TIMER_RATED
V3 5 V
R9 100Ω
R10 300Ω
R11 82Ω
C4 100µF
U4
555_TIMER_RATED
V4 5 V
R12 100Ω

State Diagram:

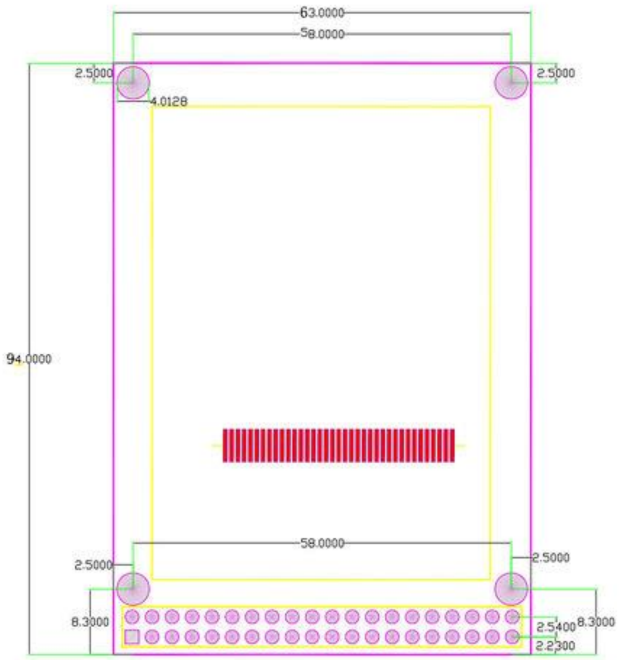


Display Module: SainSmart 3.2'' TFT LCD display and touch panel

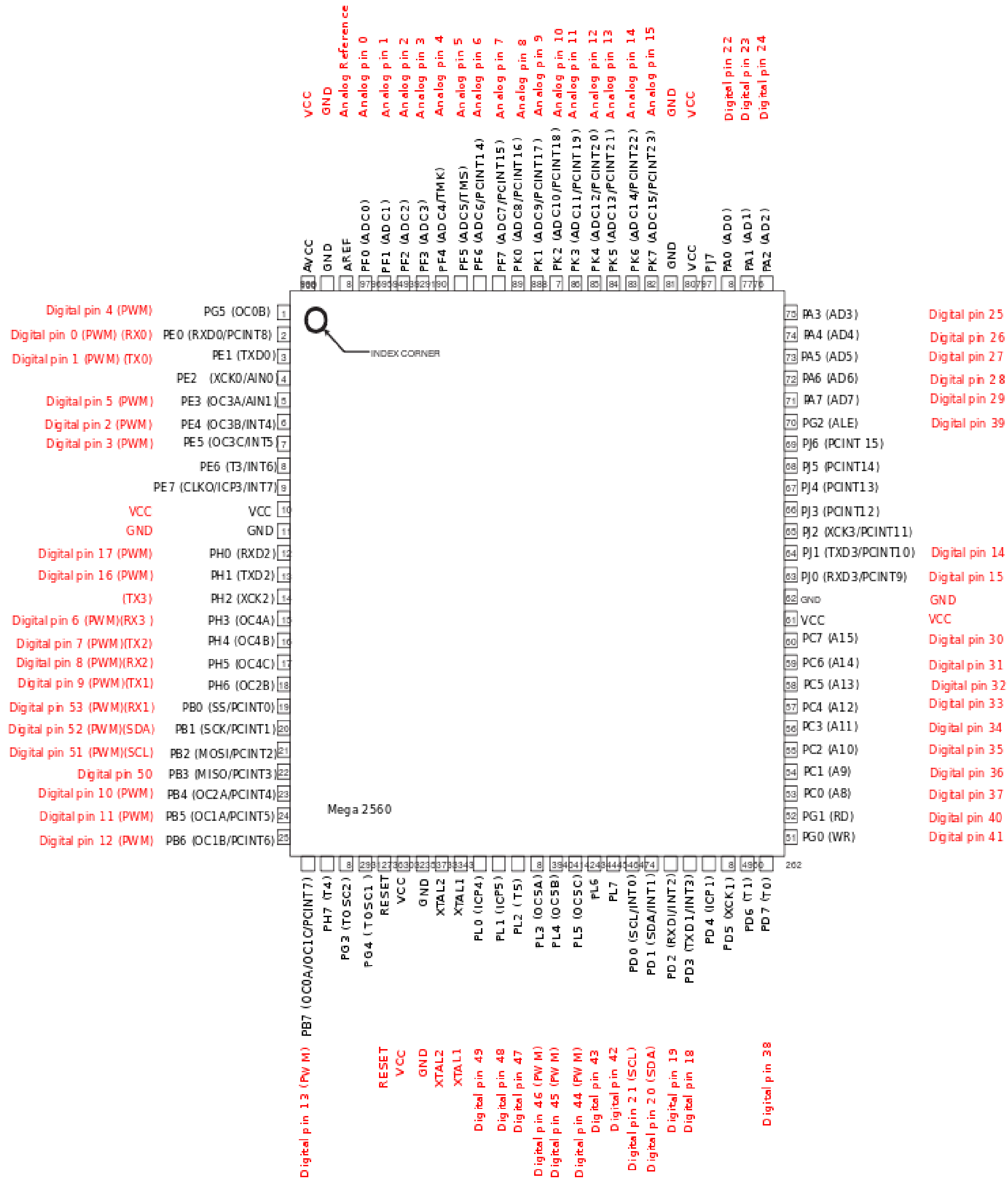
Layout:



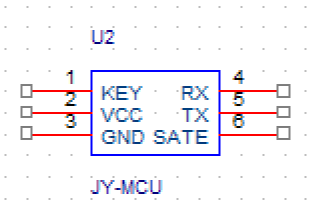
Size:

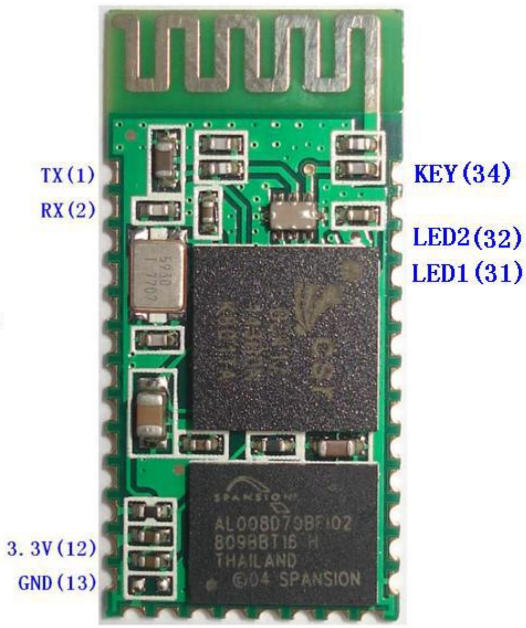


Control Module: Arduino Mega 2560



Communication Module: HC-05 Bluetooth transceivers

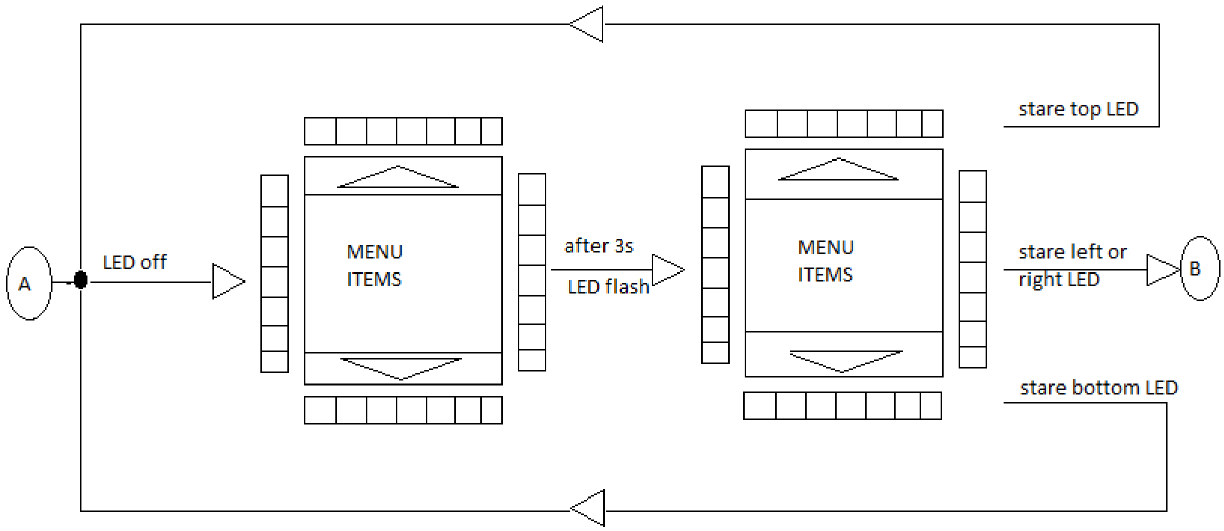


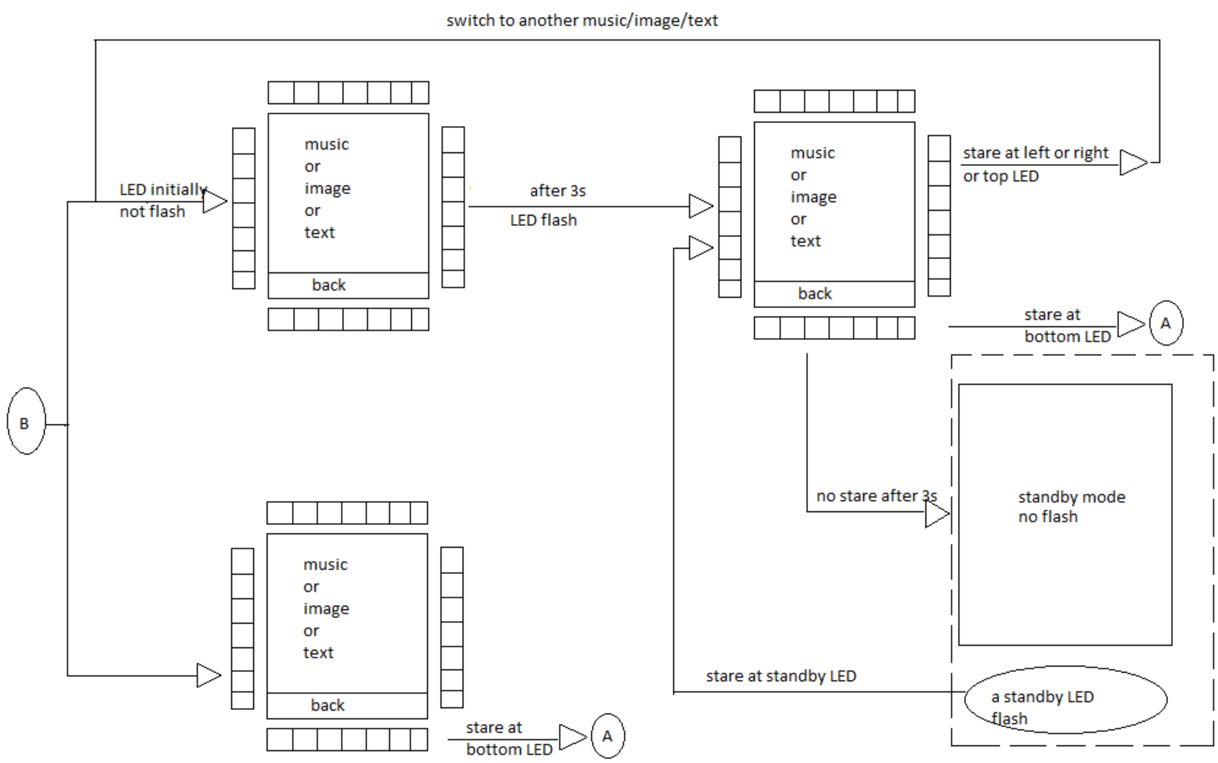


Graphic Design Implementation:

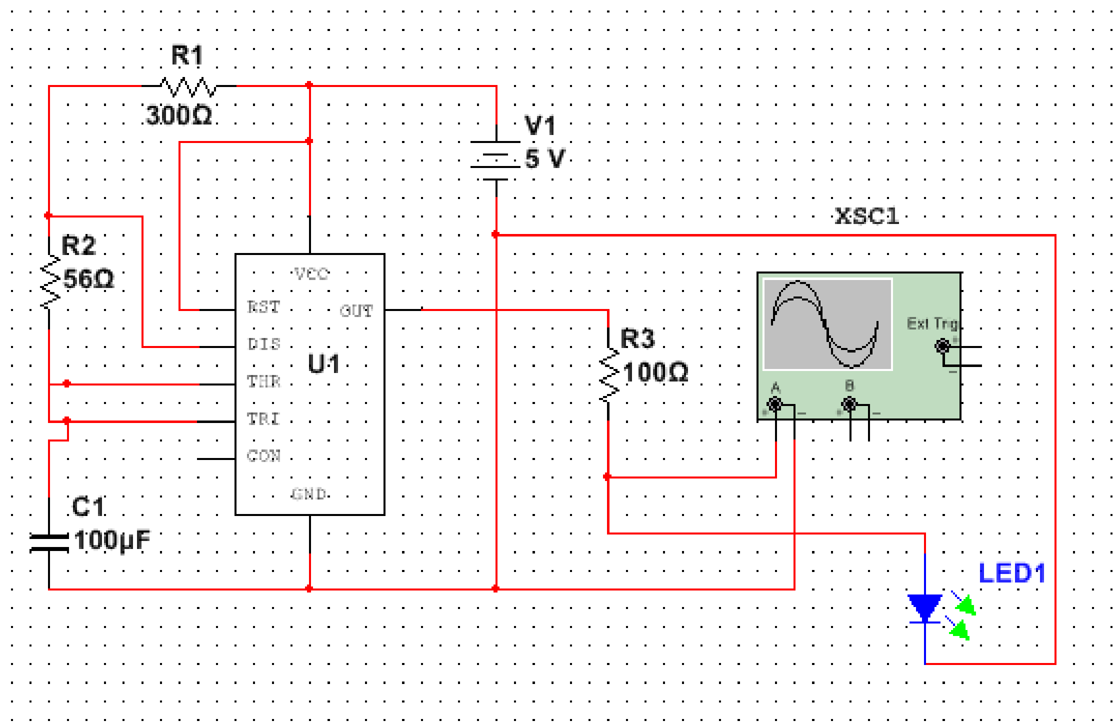
Graphic design and display programming are to be implemented with Arduino mega 2560 microcontroller chip. Arduino library support for our LCD board, ITDB02_graph16 (has been replaced by UTFT), can be found here:
http://www.henningkarlsen.com/electronics/library.php?id=51

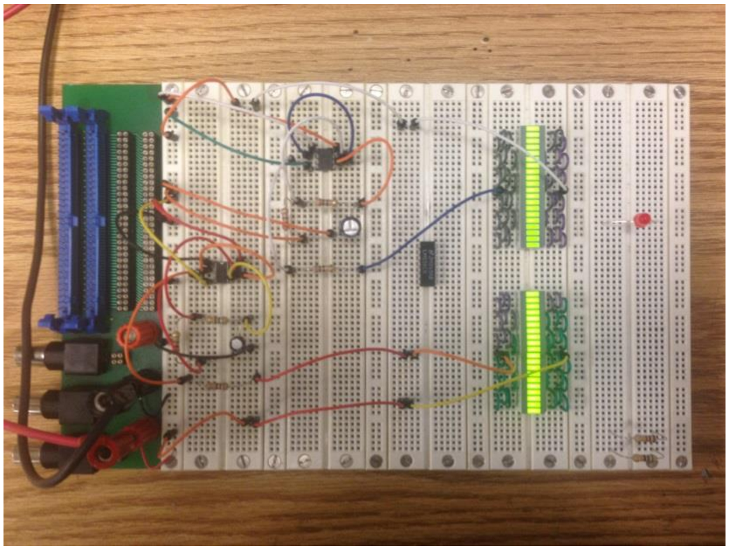
Software Logistic Flow Chart:





2.4 Simulation and Calculation





Calculation:

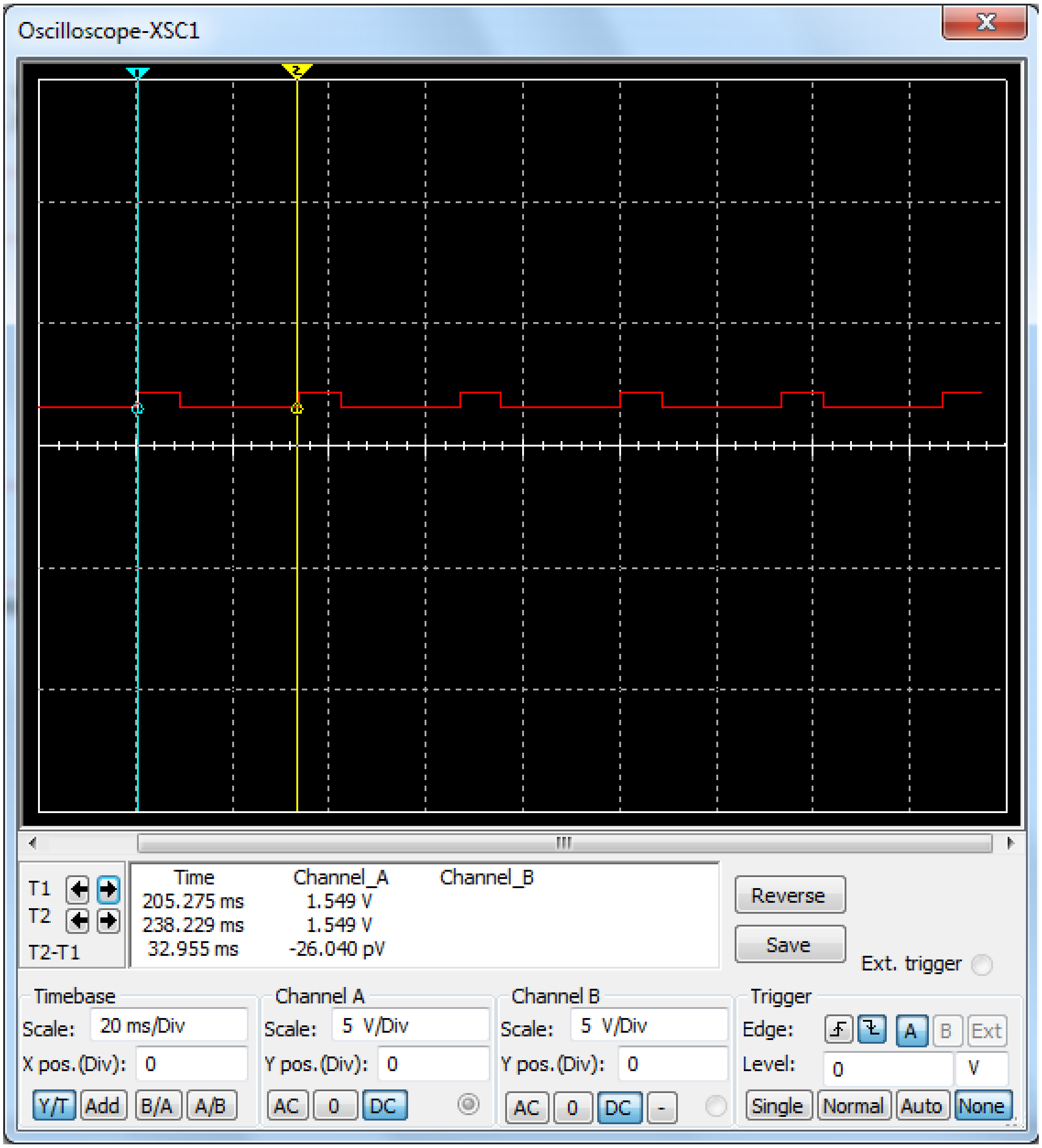
The frequency of the pulse stream depends on the values of R1, R2 and C:

$$f = \frac{1}{\ln(2) \cdot C \cdot (R_1 + 2R_2)}$$

Thus in this case:

F = 1/(ln(2)*100µF*(300Ω+2*56Ω) = 35.02Hz.

Simulation Result Comparison:



According to the snapshot of the simulation, the time period is 32.955ms.
Thus the frequency is:
F = 1/T = 1/32.955ms = 30.34Hz.

The time period of the real circuit is 28.2ms.
Thus the frequency is:
F = 1/T = 1/28.2ms = 35.46Hz.
The frequency obtained according to the measurement of the oscilloscope, 35.46Hz, is fairly close to the frequency calculated from the simulation result above, 30.34Hz.

2.5 Performance Requirements

1. Present at least 4 groups of LEDs that blink at brain-distinguishable frequencies without visual interference among different regions
2. Sufficient amplification on raw signals in order to differentiate blinks/commands
3. Nearly instantaneous (< 2.5 second) response on a single selection from brain to display
4. Bluetooth communication module supports sufficient communication distance (~ 25 feet)
5. Accurate and fast transmission of data and information
6. Considerable battery life time (> 4 hrs of operation)

3.0 Verification

Module	Requirement	Verification
Display	1. LED lights should interact correctly with user (a) LED light blinks at 31,33,35,37Hz stimulate different signals in human brain which can all be detected by detection module. (b) LED lights in the design layout (surround LCD screen, with a standby LED) can stimulate signals in user brain when user stare at any of them. 2. LCD screen can display correct content (a) It should display specific content that microcontroller sends it (b) The transition between different contents should be smooth.	1. (a) - set up detection module (one human user is required) - connect LED circuit to make it blink at 31Hz - put detector on the user - ask user to stare at LED. Detector should receive a signal in user brain, record it. - modify circuit to make LED flash at 33 Hz - put detector on the user - ask user to stare at LED Detector should receive a signal in user brain, record it. - modify circuit to make LED flash at 35 Hz - put detector on the user - ask user to stare at LED Detector should receive a signal in user brain, record it. - modify circuit to make LED flash at 37 Hz - put detector on the user - ask user to stare at LED

		Detector should receive a signal in user brain, record it. - compare 4 signals, they should be distinguishable. - repeat 10 times. the success rate should be 90%. (b) - set up detection module (one human user is required) - set up LED circuit and put LED lights in the final design style. - turn on all LED lights to make them flash in their own unique frequencies (31,33,35,37Hz) - put detector on user - ask user to stare the top LED - detection module should receive signal from user brain. - check the signal. it should reflect top LED - ask user to stare the left LED - detection module should receive signal from user brain. - check the signal. it should reflect left LED - ask user to stare the right LED - detection module should receive signal from user brain. - check the signal. it should reflect right LED - ask user to stare the bottom LED - detection module should receive signal from user brain. - check the signal. it should reflect bottom LED

		- ask user to stare the standby LED - detection module should receive signal from user brain. - check the signal. it should reflect standby LED 2. (a) - connect LCD screen with Arduino board - write test program to display image on LCD - program on microcontroller - run the program - LCD screen should display the correct image - write test program to display text on LCD - program on microcontroller - run the program - LCD screen should display correct text - repeat for 20 times - the success rate should be more than 95% 2. (b) - connect LCD screen with Arduino board - write test program to display multiple image on the screen - program on microcontroller - run the program - LCD screen should display all images and have no glitch during transition. - write test program to display multiple texts on LCD - program on microcontroller - run the program - LCD screen should display correct texts and have no glitch during transition.

		- write test program to display image-text sequence on LCD - program on microcontroller - run the program - LCD screen should display correct images and texts and have no glitch during transition from image to text and from text to image - repeat for 20 times - the success rate should be more than 95%
Microcontroller	1. Interface on LCD screen provides the correct level of interactions. (a) Software system programmed in microcontroller board has correct logistics and fluent control flow. (b) Content is displayed without significant delay. 2. Accurate and lossless data transmission from the Bluetooth module to the microcontroller. Send data in parallel to both the microcontroller and a separate LED which are both connected to the Bluetooth module, compare the data received.	1. (a) - Attach the microcontroller with the LCD screen only. - Use the touch panel as input to interact with LCD screen. - Start from the main menu. - Touch to select "play music" option. - If jumps to music screen, touch to select "back to main menu" option. - Repeat the above steps 20 times. **Expected result:** The screen reacts to all the control signals as designed in the software flow chart. The main menu screen transits to the music screen with a touch select of "play music" and the music screen transits back to the main menu screen with a touch select of "back to main menu". At least 19 times of the test should have the correct transitions. Thus the tolerance is 5% of error rate. 1. (b) - Same setup as 1(a). - Start from the main menu. - Touch to transit to the music

		menu. - Measure the transition time and record. - Touch to transit back to the main menu. - Measure the transition time and record. - Repeat the above steps for 10 times. **Expected results:** The transition has a reasonable transition time, which is less than 0.5s. Among the 20 records, at least 19 of them should be less than 0.5s. If not, first check the software logic in the code. And then reboot the device and repeat the testing procedure. 2. - Build a simple circuit including a data sender (a PC), Bluetooth module, the microcontroller and a single LED. - Also connect the LED with the Bluetooth receiver so that it reacts to what is received by the Bluetooth module. - Send data from the PC side. - Compare the reactions of both LED element and the microcontroller (which outputs to a LCD screen if necessary). - Wait for 20 seconds. - Repeat the above procedures for 10 times. **Expected result:** Every effective piece of data received from the detection module has the corresponding

		reaction by both the LED and the microcontroller, without the case that the reaction of LED is not reflected on the microcontroller. For each time a data is received from the sender on the LED, the microcontroller should also receive the same data. There is no tolerance on a data transmission failure to the microcontroller. If there is ever a failure, check the connection between the Bluetooth module and the microcontroller on both software and hardware level.
Communication	1. Bluetooth transmitter and receiver should be able to communicate in a quick and reliable manner. (a) Reliable transmission with sufficient distance apart (< 25 feet). (b) Accurate transmission with no or tolerable data loss. 2. Incorporate the response time in the detection phase into total communication cost. (a) Screen regions with distinguishable flashing frequencies can be selected by brain wirelessly. (b) Nearly instantaneous (< 2.5 second) response on a single selection from brain to display.	1. (a) - Connect the Bluetooth receiver to the Arduino board and upload the program to set up serial connection. - Send sample data from a computer using putty or other serial monitors - Increase the distance between the computer (Bluetooth transmitter) and Bluetooth receiver from 1 foot to 30 feet **Expected result:** Data transmission is reliable (no miss or error rates) within 25 feet. 1. (b) - Increase transmission rate (from 1 character per second to 16 character per second) and sample data size, - Transmission distance set at 20 feet **Expected result:**

		Data transmission is accurate up to 16 characters per second with no data loss. 2. (a) - Incorporate the whole detection module (signal collector, amplifier and analyzer) before the transmitter end and make selections by brain **Expected result:** Regions on the screen can be successfully selected as intended. 2. (b) - Record real response time from brain to display for several flashing frequencies **Expected result:** For distinguishable frequencies, response time can be as short as 1 second and at most 2.5 seconds.
Power	1. Supply steady input voltage to the system. (a) Capable to provide steady 9V input voltage to the Arduino board. (b) Capable to provide steady 3.3V input voltage to the LCD screen and the Bluetooth module. 2. Considerable battery time. (a) Capable to last 4 hours for worst case scenario. (i.e. continuously operating mode) (b) Capable to last up to 20 hours for average case scenario. (i.e. reasonably operating time including standby mode, excluding power-off mode)	1. (a) - Build a simple test circuit including the power supply of 9V and resistors of various values. - Control the resistor values to obtain current values, which can be measured correspondingly. - Calculate the resulted voltage values based on the resistance and corresponding current values. **Expected result:** For all different pairs of resistor values and current values, the calculated voltage values should fall in the range: 8.0V to 10.0V.

		1. (b) - Build a simple test circuit including the power supply of 3.3V (output of the embedded regulator on the Arduino board) and resistors of various values. - Control the resistor values to obtain current values, which can be measured correspondingly. - Calculate the resulted voltage values based on the resistance and corresponding current values. **Expected result:** For all different pairs of resistor values and current values, the calculated voltage values should fall in the range: 3.2V to 3.4V. 2. (a) - Connect the power supply to the circuit. - Disable the standby mode so that the device keeps running in the operating mode. **Expected result:** The power does not run out until 4 or more hours later. 2. (b) - The calculation associated with this verification is being implemented with reasonable estimations. - Assume the ratio among fully functioning operation time, standby time is approximately 1:10. - Assume a working LED

		consumes 90% less of the power than a working LCD screen. - Thus by calculation, the power which can support 4 hours of worst case is able to support more than 20 hours of average case. **Expected result:** The power does not run out until 20 or more hours later.

3.1 Tolerance Analysis

The most critical part in our design is the interaction between the brain and the display. The response time from brain signals to the display should be as fast as 0.5 second. However, due to detection errors and signal integrity issues, this response time might be longer than expected. We decide to set the tolerance level of response time to 2.5 seconds. Under different environmental conditions or human attention levels, we should always see a response of less than 2.5 seconds. This is achieved by setting largely distinguishable flashing frequencies.

3.2 Ethical Issues

As electrical engineers, we always regard IEEE code of Ethics as our professional guideline. In all the stages of this project, from initial design to final implementation, we will strictly comply with the IEEE code of Ethics and inspect ourselves regularly to make sure we don't violate any of the requirements. Following are the ethical issues that we encounter in the project.

1. To accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;

The purpose of our project is to give people an alternate way of interacting with machines, that is, by brain. It can make people's life more convenient, especially for the disables. The product uses flashing light source as stimulates, which may do harm to people's eyes. We are aware of that and will do various experiments on it until we get the proper flashing frequency and brightness. Also we will make it clearly in our instruction document.

3. To be honest and realistic in stating claims or estimates based on available data;

All the testing data will be recorded honestly and we will adjust our product based on it. If current implementation doesn't give us satisfying experimental data, we will improve it instead of hiding the problem and pretending nothing goes wrong.

5. To improve the understanding of technology; its appropriate application, and potential consequences;

Our project is based on the progress in EEG technology, which detects signals generated in human brains. We did a reasonable amount of research on it and understand how the technology works from a high level perspective. We have also seen its laboratory demonstration. In our project, we are focusing on applying the original lab application to our daily life, and exposing the potential value of the EEG technology to the world.

6. To maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;

We are aware that our current experience and competence are only enough for building the prototype of our design. We will introduce the products to markets only after we gain more training and knowledge.

7. To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;

We are eager to ask for opinions about our product from both instructors and fellow students and we will credit the contributions of them. For advices which we think are valuable we will definitely take them. If other groups are seeking advice from our group, we will treat them with complete honesty.

9. To avoid injuring others, their property, reputation, or employment by false or malicious action;

We have taken the safety training online and have read through all the tutorials and we will strictly follow them all the time when we are in the lab.

10. To assist colleagues and co-workers in their professional development and to support them in following this code of ethics.

Everyone in our group values teamwork highly. Although each person has his own assignments for every week, we are willing to help any member who has difficulties in the project. Also we always remind each other of the importance of following the code of ethics.

3.3 Safety Issues

In order to make a valuable and trustworthy product, we need to be able to guarantee the consumer that this product will be safe enough for the consumer to own. When introducing the flashing LEDs around the main LCD display to be visually interacted by the users in order to generate the EEG signals along the scalp, the engineer has to keep in mind that the flashing frequencies of all the LEDs (both LED arrays and the single LED for standby usage) should have relatively higher frequencies than human's visual range, considering that even if the user cannot visually recognize or distinguish a high frequency, the EEG signal at the same frequency can still be generated along the surface of the brain. This will comply with the safety of the users so that they will not find the LED to be annoying and it also avoids the visual fatigue.

The battery used for this product contains battery acid. Thus it should be properly placed (preferably away from the device), so that even there is a battery acid leak, it will not cause damage of the rest parts of the device, or to the user who is interacting with the device.

In order to guarantee the safety of the engineer who is building the main circuit as well as the rest parts of the device, the engineer should keep in mind that the correct and appropriate components and parts should be used. For example, several 100µF capacitors are being used in the development. If a wrong capacitor is used or it is not connected in the correct way, there is the possibility of explosion for the part either during the experimentation or the producing process.

Besides, the device will also use proper grounding for safety of both engineers and users. It serves as the purpose of safety insurance since it will prevent shocks in case that the electrical insulation fails. In addition, in order to guarantee that this device is free of hazardous materials, all the parts and components used in this device are compliance with the Restriction of Hazardous Substances (RoHS) directive.

4.0 Cost and Schedule

4.1 Cost Analysis

4.1.1 Labor

Name	Hourly Rate	Total Hours	Total = Hourly Rate x 2.5 x Total Hours
Yujie Chen	$40.00	120	$12,000
Shiyang Liu	$40.00	120	$12,000
Xuanyu Zhong	$40.00	120	$12,000
Total			$36,000

4.1.2 Parts

Item	Quantity	Cost($)
Arduino Mega 2560	1	45.69
SainSmart 3.2'' TFT LCD display and touch panel	1	17.99
Arduino Bluetooth Transceiver Module RS232	1	8.91
9V power adaptor	1	5.99
9V battery	4	9.45
555 Timer IC	4	5.00
LED array – 10 Greens	6	3.60
100µF capacitor	4	2.40
300Ω resistor	4	1.64
10Ω resistor	4	1.60
47Ω resistor	1	0.47
56Ω resistor	1	0.38
68Ω resistor	1	0.49
82Ω resistor	1	0.76
Total		104.37

4.1.3 Grand Total

Section	Total
Labor	$36,000
Parts	$104.37
Total	**$36104.37**

4.2 Schedule

Week	Task	Responsibility
2/4	Design overall block diagram	Yujie Chen
	Finalize and hand in proposal	Shiyang Liu
	Look for parts needed	Xuanyu Zhong
2/11	Order Arduino Mega 2560 and TFT display	Yujie Chen
	Prepare for Design Review	Xuanyu Zhong
	Install Arduino development kit and look into datasheet	Shiyang Liu
2/18	Design connection interface between the microcontroller board and display	Yujie Chen
	Learn to set up bluetooth connection	Xuanyu Zhong
	Learn to program the displays	Shiyang Liu
2/25	Assemble microcontroller and display unit for test Learn to program touch panel on the screen	Xuanyu Zhong
	Write simple test program for controller and display	Shiyang Liu
	Design specific control flow for software system	Yujie Chen
3/4	Order parts for wireless module	Xuanyu Zhong
	Integrate and embedded software system into microcontroller	Shiyang Liu
	Design the frequency generator circuit	Yujie Chen
3/11	Go to James Norton's lab and learn more about the detection device	Shiyang Liu
	Design wireless interface to realize wireless data transmission between the detection module and control module	Yujie Chen
	Use the frequency generator to drive LED arrays	Xuanyu Zhong
3/18	Search for the frequencies that will trigger peak response	Yujie Chen
	Test wireless communication module alone	Shiyang Liu
	Design and integrate communication software module into software system of controller	Xuanyu Zhong
3/25	Assemble control and display modules with communication module	Shiyang Liu
	Test over TFT display and signal detection module	Xuanyu Zhong
	Test over the software system using touch screen	Yujie Chen
4/1	Connect detection module with other modules of the portable device	Yujie Chen
	Test/Debug over the assembled modules	Shiyang Liu
	Do overall testing and debugging	Xuanyu Zhong
4/8	Thoroughly test the software state flow	Yujie Chen
	Thoroughly test the control flow of the microcontroller	Shiyang Liu
	Cooperate with Jamie and look for further improvements	Xuanyu Zhong
4/15	Improve performance of software system	Shiyang Liu
	Improve performance of wireless communication interface	Xuanyu Zhong

	Optimize the device with better appearance	Yujie Chen
4/22	Prepare for demo	Yujie Chen
	Prepare for presentation	Shiyang Liu
	Write skeleton of the final paper	Xuanyu Zhong
4/29	Presentation and write final paper	Xuanyu Zhong
	Review the final paper	Shiyang Liu
	Return parts	Yujie Chen

5.0 References

1. Documentation of SainSmart 3.2" TFT LCD Display+SainSmart TFT LCD Adjustable Shield For Arduino 2560 R3 1280 A082 Plug.
Retrieved from http://www.sainsmart.com/zen/documents/20-011-918/ITDB02_Graph16.rar.

2. Documentation of Arduino Mega 2560.
Retrieved from http://arduino.cc/en/Main/ArduinoBoardMega2560.

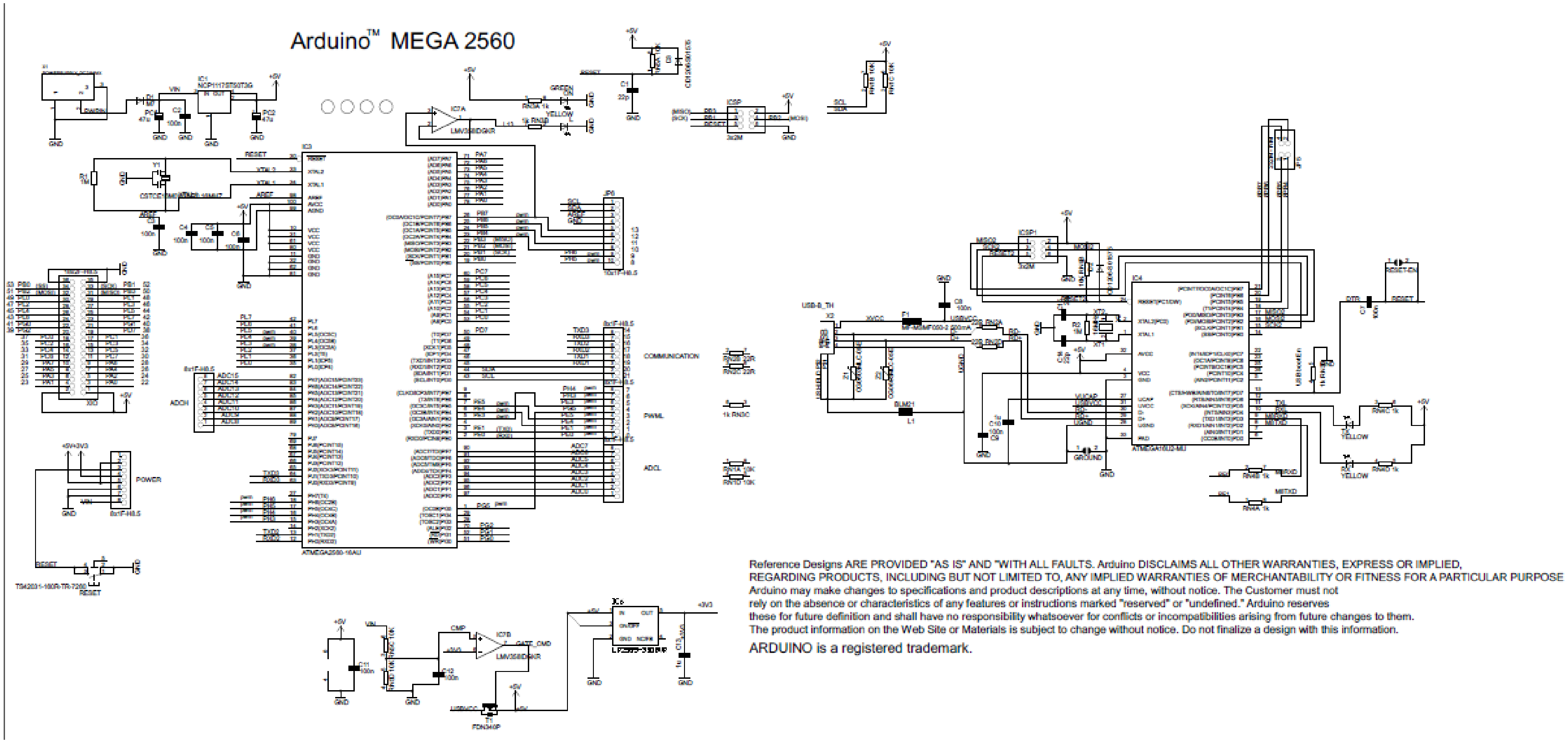
3. Library of UTFT.
Retrieved from http://www.henningkarlsen.com/electronics/library.php?id=51.

4. Pin connection between TFT 3.2" LCD and Arduino Mega 2560.
Retrieved from http://www.urel.feec.vutbr.cz/MIA/2011/Matyas/dl/240374PQ.pdf.

5. 555 Timer IC documentation.
Retrieved from http://en.wikipedia.org/wiki/555_timer_IC.

6.0 Appendix


www.sainsmart.com
•SD Card
•TFT LCD
•Touch Screen
TFT LCD Mega Shield V1.0
MEGA


Arduino™ MEGA 2560
Reference Designs ARE PROVIDED "AS IS" AND "WITH ALL FAULTS. Arduino DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED,
REGARDING PRODUCTS, INCLUDING BUT NOT LIMITED TO, ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE
Arduino may make changes to specifications and product descriptions at any time, without notice. The Customer must not
rely on the absence or characteristics of any features or instructions marked "reserved" or "undefined." Arduino reserves
these for future definition and shall have no responsibility whatsoever for conflicts or incompatibilities arising from future changes to them.
The product information on the Web Site or Materials is subject to change without notice. Do not finalize a design with this information.
ARDUINO is a registered trademark.