March 30, 2017

Dr. Steve Whitmore
School of Engineering Science
Simon Fraser University
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Re: ENSC 405W Design Specifications for a Voice Controlled Lighting System

Dear Dr. Whitmore,

The attached document, “LightWave System Design Specifications”, outlines the design specifications of our project for the course ENSC 405W/ENSC 440. The document details the design components chosen to build a complete prototype in the next phase of the project. A proof of concept description is shown as well as description of changes and additions to be made to the overall and final design of the product. The system aims to be responsive to voice commands and have features such as a natural wake-up alarm using the home lights.

The specifications outlined in this document are of strict importance for the development phase of the project. These were matched to the system requirements along with each component’s desired behavior and performance. The information outlined in this document will facilitate the building and assembly of the final prototype. The design specifications are divided into hardware and software and present sustainability measures to be implemented during development stages. The system’s user interaction analysis is being presented in appendix B, along with a testing plan in Appendix A.

Light Matters consists of five talented and hard-working Engineering students: Alicia Pavan, Kevin He, Yifan Chen, Haining Yu, and Yuchen Ding. Please feel free to contact us if you have any questions or concerns about our proposal via e-mail at avpavan@sfu.ca.

Sincerely,

Alicia Pavan
CEO
Light Matters

Enclosure: *Design Specifications for a Voice Controlled Lighting System*

LIGHTWAVE SYSTEM

DESIGN SPECIFICATIONS FOR A

VOICE CONTROLLED LIGHTING SYSTEM

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Issue Date
March 30, 2017
Revision: 1.0

Executive Summary

Every morning, from the moment we wake up to the time we hit the pillow at night, we are surrounded by technology. Over the years, the word “smart” has had different meanings, especially when it comes to old times. Today, many devices are made to be smart, i.e. smart watches can keep track of one’s heart rate, walking steps and hours of sleep while smart pajamas can read bedtime stories. All these inventions have one thing in common, and it is that they aim to make everyone’s life more interactive and easy with the use of technology. The LightMatters Team goal is to design a smart lighting system to make the target users’ life more convenient and enjoyable at home. With the LightWave System people will have the ability to control any light inside their homes with an easy voice command.

The LightWave System follows a server-client architecture which consists of multiple switch units and a single central unit. Every room can be seen as a switch unit, and the central unit acts like the server of the system that processes the commands. Voice commands will be received in the switch unit, then command will be sent to the central unit through radio frequency signals. The design of system was modified as it will only have one voice recognition module in the central unit. This will allow better traffic control and a significant drop in cost in comparison to having a voice recognition module in every switch unit.

In this document, applicable system design requirements are listed as well as each component specifications. To ensure safety and system reliability, research was made to find the best suitable components. The hardware components shall be chosen to meet the physical, functional and electrical requirements and the software must be efficient and free of bugs that could damage the user’s experience. Furthermore, the safety and environmental standards are introduced to avoid negative environmental effects. In addition, the user interaction will be analyzed Appendix B.

Following the company’s schedule, a one-room basic prototype was successfully built before the presentation date. LightMatters will continue its research to reach a satisfactory, safe and reliable system.

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Glossary

LED: Light Emitting Diode

Environmental Sustainability: when demands from the environment can be met without reducing its living standards capacity

Prototype: early sample, model, or release of a product built to test a concept

Engineering Standard: documents that specify characteristics and technical details that must be met by the products, systems and processes that the standards cover.

Automation: the technique of making an apparatus, a process, or a system operate automatically

Server-Client: specific model of a computer network that partitions tasks or workloads between the providers of a resource or service, called servers, and service requesters, called clients

CSA: Canadian Standards Association

IEEE: Institute of Electrical and Electronics Engineers

NESC: National Electrical Safety Code

UL: Underwriters Laboratories

PET: Polyethylene terephthalate

ABS: Acrylonitrile butadiene styrene

RoHS: Restriction of Hazardous Substances

RF: Radio Frequency

1. Introduction and Background

The goal of the Lightwave system who is produced by LightMatters provides the users a new home/office illuminating experience by voice recognition and controlling. The Lightwave system is comprised of a central unit and a number of switch units. All the switch units under the same system are available to be manipulated by the users' voice commands. Meanwhile, the switch units have the ability to control the light bulbs in a variety of ways. In other words, the users can control any light bulbs conveniently and precisely in any system coverage areas. This system also contains several security and alarm features, which realize the function multiplication of the home/office illuminating system. In this document, the components and the design specifications of the Lightwave system are clearly described.

This document describes the design of Lightwave system, and explains how the functional requirements in the Functional Specifications document of Lightwave system are met. This document includes a technical analysis of the Lightwave system, and a detailed explanation for the decisions of choosing components according to the comparisons. Meanwhile, as the Lightwave system is an ongoing project, verifications and revisions are essential. To ensure that all the functional requirements mentioned in the Functional Specifications are still entirely met, possible improvements of the system design have been made.

The document is intended to use by all members of the LightMatters Team. The design specifications outlined next will be used throughout the entire project development until completion and will be subject to further changes. By following the research and comparison done in this document, the finished prototype shall fall within the design requirements previously detailed.

2. High-Level System Overview

In this section, an overview of the system is introduced. The main objective of the LightWave System is to facilitate the light system usage across a home using voice controlled capabilities. Users are able to control multiple lights inside of a building, typically for houses. The system also aims to provide the ability to adjust the brightness as well as to flash the lights.

A complete proof of concept device (Figure 1) is in place right now and consists of a mix between the central and switch unit. The system does not communicate wireless yet and it has limited command training.

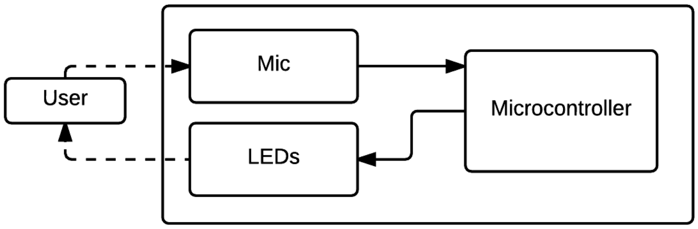


FIGURE 1. PROOF OF CONCEPT DIAGRAM

The final prototype will consist of two switch units and one central unit that works as a bridge between them. The LightWave System follows a single server to multiple clients architecture. The central unit works as the "server", as it controls the communication between the "clients" and performs other important functions. The central unit will be the one processing all the commands and the switch units will be the ones receiving the voice signals. The central unit will also be important for the initial setup of the system given that as of now the voice recognition module only works when the user trains it first. Each switch contains an RF module such that they can send and receive commands to the central unit.

A microphone and two LED lights are installed inside of every switch unit, they handle the I/O and provide feedback to the end users. Figure 2 shows the overview of the components needed inside a switch unit.

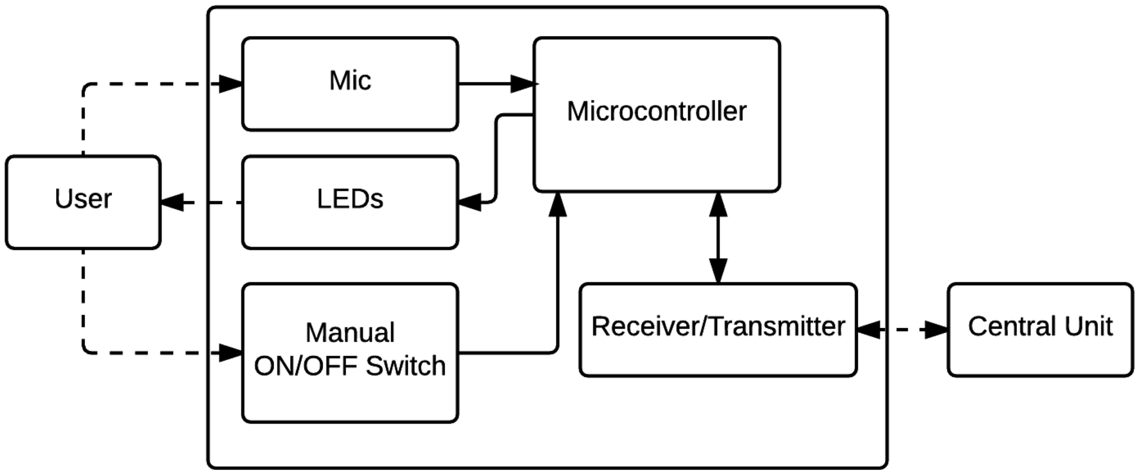


FIGURE 2. PROTOTYPE SWITCH UNIT DIAGRAM

The voice recognition module is installed inside the central unit and processes the commands received from the switch unit. This allows for better traffic control and is a budget friendly solution as this is the most expensive component of the system. Figure 3 shows an overview of the components used inside the central unit.

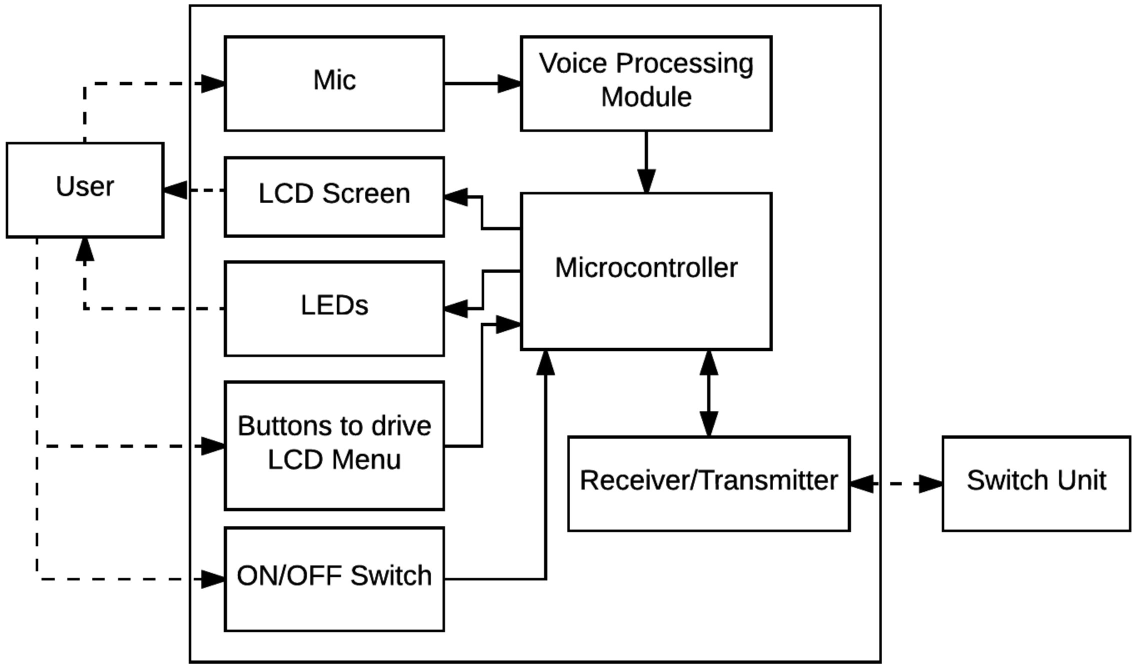


FIGURE 3. PROTOTYPE CENTRAL UNIT DIAGRAM

Overall, when the system is connected wirelessly it will work like the following the diagram in Figure 4. The diagram shows how the system takes an input voice signal, processes it and distributes it if necessary.

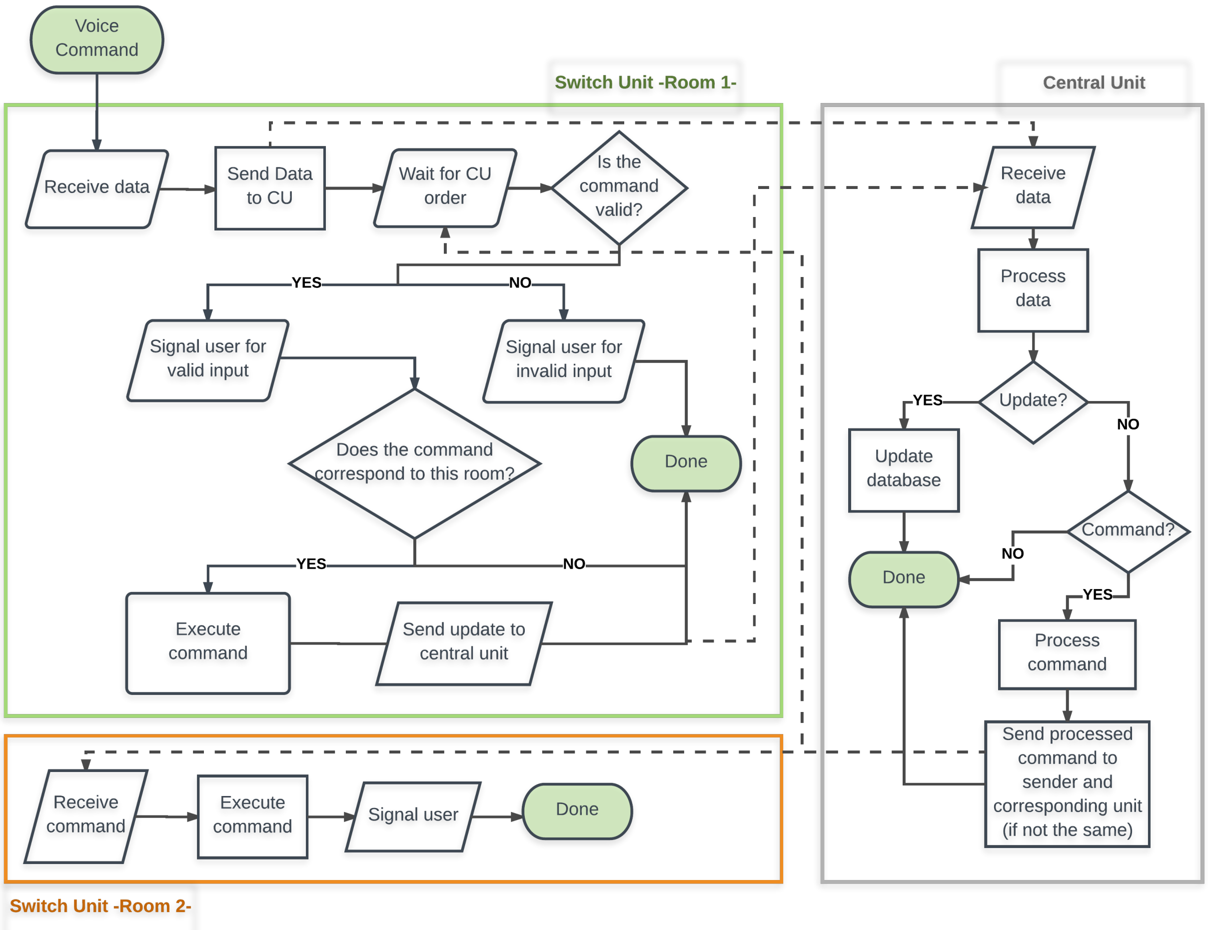


FIGURE 4. OVERALL SYSTEM DIAGRAM

3. Hardware Specifications

The LightWave System consists of two main components: the switch unit and the central unit. Each of these has certain hardware specifications for the product to function as desired. The design of the product was revised and the central unit would be the only one carrying a voice recognition module as this requires a lot of resources being in the switch unit. This revision would also reduce the cost of the system drastically. Measures will be taken in the final prototype to avoid interference for command processing in the product, which will also be discussed in the software section of this document.

As there are duplicated components between the switch unit and the central unit of the product, the following specifications have been organized according to their function. However, it will be clearly specified in the case the component only applies to either the switch or central unit of the LightWave System.

3.1 Communication Specifications

3.1.1. Microphone

The microphone is responsible for collecting the voice commands from the users and converting the commands to analog signals.

The microphone used for the proof of concept device has the following characteristics:

Sensitivity -38 dB

Impedance 2.2 k

Frequency Range 100 Hz - 20 kHz

As for the final design, a more responsive microphone is desired. The following table lists the requirements and the possible microphone options for the final prototype:

Table 1. Microphone Options with Requirements Breakdown

Requirement Number	Requirement Description	MAX9812 Microphone Amplifier Module	MAX9814 Microphone Amplifier Module
R3.12-2	The sensitivity of the microphone shall be -39dB ± 3dB	High Sensitivity Low noise	High Sensitivity Low noise
R3.14-2	The maximum power consumption of the microphone shall be less than 0.8mA	Low supply current 400microA	Higher supply current 3.1mA
R3.15-2	The maximum voltage supply to the microphone shall be less than 4V	3.3V - 5V	2.7V - 5V
Extra	Gain	Fixed 20dB	Auto-adjusting

MAX9812 Microphone Amplifier Module (Figure 1.a): The MAX9812 is a single/dual input microphone with fixed-gain (20dB), tiny packing and a low-noise, integrated microphone bias (Maxim Integrated, n.d.).

MAX9814 Microphone Amplifier Module (Figure 1.b): The MAX9814 has a default 'max gain' of 60dB, but can be set to 40dB or 50dB by changing the Gain pin to VCC or ground (Lady Ada, n.d.). It then has an adjustable gain which can provide better command recognition from a speech that comes further away from the switch unit.

According to the characteristics listed, the MAX9814 microphone-amplifier is the best choice for the LightWave Switch Unit as it will provide a better and cleaner signal to work with for command processing. The higher current for the MAX9814 does not fall within the requirement of 0.8mA. However, after some research the microphone module can work perfectly with the Arduino and will not impact the rest of the design.

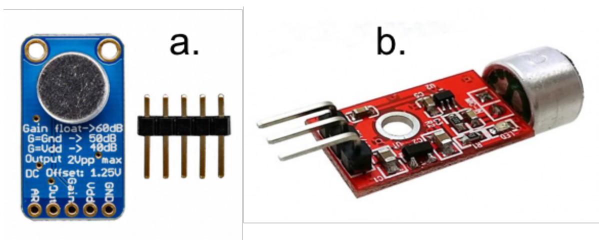


FIGURE 5. CENTRAL UNIT MICROPHONE OPTIONS

3.1.2. Radio Frequency Transmitter and Receiver

The RF component in the central and switch unit shall comply with the following requirements:

R3.40-2 The central unit shall be connected to all the switch units directly through wireless network

R3.41- 2 The central unit shall receive radio signals from the switch units ~~*after the voice commands are processed by the voice recognition system*~~

R3.33- 2 The standard operation voltage of the receiver/transmitter shall be 5V

As it was explained previously, the system’s design was revised and the central unit will not be receiving already processed commands but raw microphone signals.

The transmitter and receiver are the components that allow the LightWave System to have wireless capabilities. The comparison of two transmitter and receiver sets is shown in the following tables.

TABLE 2. RF TRANSMITTER AND RECEIVER COMPARISON

Parameters	RF Link Transmitter 434MHz	RF Link Transmitter 315MHz
Frequency Range	433.92MHz	315MHz
Modulate Mode	ASK	ASK
Circuit Shape	SAW	SAW
Data Rate	8Kbps	8Kbps
Supply Voltage	1.5V~12V	1.5V~12V
Output Power	14dBm	14dBm
Working Temperature	-20~+85℃	-20~+85℃
Parameters	**RF Link Receiver 434MHz**	**RF Link Receiver 315MHz**
Frequency Range	433.92MHz	315MHz
Modulate Mode	ASK	ASK
Circuit Shape	LC	LC
Data Rate	4.8Kbps	4.8Kbps
Supply Voltage	5V	5V
Selectivity	-108dBm	-108dBm
Channel Spacing	±500KHz	±500KHz

Most of the properties of the two sets of transmitter and receiver are the same except the frequency range. As an important reference point, the RF Link with 434MHz costs less. Therefore, we chose the RF Link Transmitter/Receiver 434MHz set as our transmitter and receiver in both units.

3.2 User I/O Specifications

3.2.1. Switch and Buttons (Central Unit)

R3.39- 2 The central unit shall be turned on/off with a manual switch

A simple toggle switch will be used to turn the central unit on and off when desired:

FIGURE 6. CENTRAL UNIT TOGGLE SWITCH

[Added]: Buttons will be controlling the LCD Screen for set-up purposes

For any buttons added to the design, simple 4-pin push buttons will be used.

Dimensions: 6x6x5 mm

FIGURE 7. CENTRAL UNIT PUSH BUTTON

3.2.2. Manual ON/OFF Dimmable Switch (Switch Unit)

R3.251-3 The switch shall have a rotatable knob with the light to turn on/off

R3.26- 2 The switch shall be connected to the light wiring to control the bulb on/off manually

R3.27- 3 The switch shall be able to adjust brightness of the light bulb

FIGURE 8. SWITCH UNIT DIMMABLE SWITCH

The switch chosen is a BQLZR 2 Wire Silver Round Rotatable Knob as it is small, affordable and performs the desired function.

Dimensions 3.7 x 2.5 x 3.1cm/1.46 x 0.98 x 1.22.

3.2.2. LED light

The LED lights are being used in the central and switch to give feedback to the user and should be visible from a distance in the switch unit. The requirement break-down is listed below:

Table 3. LED Options with Requirements Breakdown

Requirement Number	Requirement Description	LED 8mm	LED 5mm
R3.21-2	The LEDs shall consist of one red LED bulb and one green LED bulb	Available in Red and Green	Available in Red and Green
R3.22-2	The standard operation voltage of the LED should be within the range 2V to 4V	3.3V	2V

Given the readily available 5mm LEDs recycled from previous lab components, these will be the ones used in the final product. The 5mm LEDs are visible enough in a dark room and the low voltage consumption is more desirable.

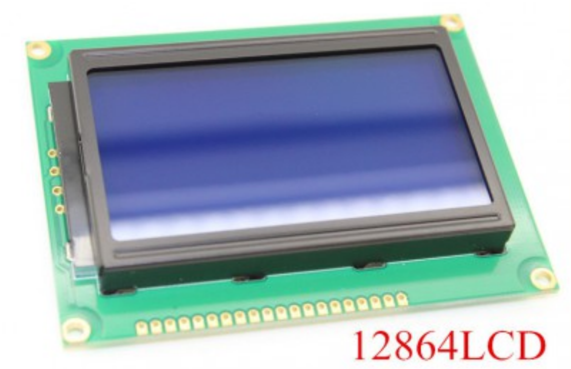
3.2.3. LCD screen (Central Unit)

The LCD screen is used for displaying feedbacks to the users for initial setup of the system settings such as adding devices, training commands, etc. This feature was added to provide users with an easier setup of the system given the limitations of the current voice recognition module. The LCD screen must be easy to read, compatible with the central processor, low power consumption, and have a suitable size. There were two options for the LCD screens: Serial Enabled 16x2 LCD, and 12864 Graphic DIsplay LCD. A comparison is shown in table 3 to make the final choice easier.

TABLE 4. LCD SCREENS COMPARISON

Parameters	SERIAL ENABLED 16X2 LCD	12864 Graphic Display LCD
Supply Voltage	5V	5V
Screen Dimension	71.4mm x 26.4mm	72mm x 40mm
Display Colors	Black on Green	White on Blue
Compatibility	Support Arduino UNO	Support Arduino UNO
Display Construction	16 x 2 characters	128 x 64 dots

Referring to the table, both LCDs have the same power consumption, and support the central module, however, the screen of the 12864 Graphic Display LCD is much larger and functional since it is able to display graphs instead of characters only.



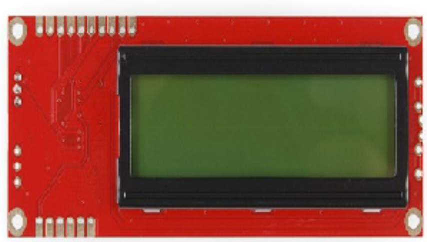


FIGURE 9. 12864 GRAPHIC DISPLAY LCD AND SERIAL ENABLED 16X2 LCD

3.3 Processing Specifications

3.3.1 Microcontroller

Arduino Micro (Switch Unit)

In every switch unit, in order to convert the commands received by the receiver to digital output signal, the Arduino Micro was chosen to be the microcontroller (see Figure 10). The Arduino Micro is a microcontroller board based on the ATmega32U4, developed in conjunction with Adafruit. It has 20 digital input/output pins (of which 7 can be used as PWM outputs and 12 as analog inputs), a 16MHz crystal oscillator, a micro USB connection, an ICSP header, and a reset button (Arduino Micro, n.d.). The physical pin characteristic is shown in Figure 11. The general characteristics of the Arduino Micro chip are listed in the following table:

TABLE 5. ARDUINO MICRO CHARACTERISTICS

Microcontroller	**ATmega32u4**	**Input Voltage**	7-12 V
Architecture	AVR	**Digital I/O Pins**	20
Operating Voltage	5 V	**PWM Output**	7
Flash memory	32 KB of which 4 KB used by bootloader	**Power Consumption**	29 mA
SRAM	2.5 KB	**PCB Size**	18 x 48 mm
Clock Speed	16 MHz	**Weight**	7 g
Analog I/O Pins	12	**EEPROM**	1 KB

TABLE 6. ARDUINO MICRO REQUIREMENT BREAKDOWN

Requirement Number	Requirement Description	Arduino Micro	Arduino UNO
R3.31-2	The maximum operation voltage of the microcontroller shall be 15V	5V	5V

Comparing to another candidate, Arduino Uno, the Arduino Micro chip has a better cost performance and enough processing power for the switch unit. At the same time, AVR based microcontrollers are more functional for the desired tasks.

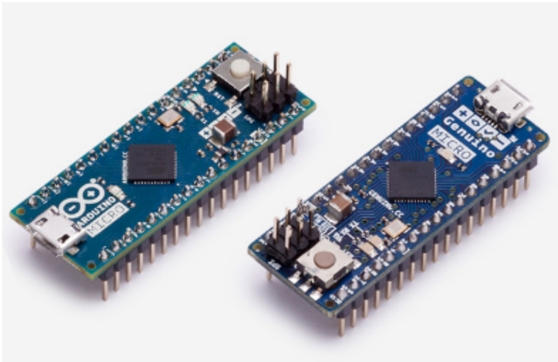


FIGURE 10. ARDUINO MICRO

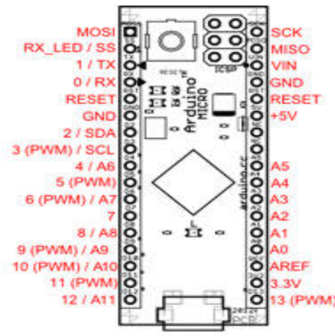


FIGURE 11. ARDUINO MICRO PINS ARCHITECTURE

Arduino UNO (Central Unit)

We chose the Arduino UNO as the central processor. It is responsible for the communication with the voice recognition module, processing and sending the command to the connected transmitter. The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button (Arduino UNO, n.d.). We listed some key parameters of the Arduino UNO board in the following table.

TABLE 7. ARDUINO UNO PARAMETERS OVERVIEW

Microcontroller	ATmega328	**Input Voltage**	7-12 V
Architecture	AVR	**Digital I/O Pins**	20
Operating Voltage	5 V	**PWM Output**	6
Flash memory	32 KB of which 0.5 KB used by bootloader	**Power Consumption**	50 mA
SRAM	2 KB	**PCB Size**	53.4 x 68.6 mm
Clock Speed	16 MHz	**Weight**	25 g
Analog I/O Pins	6	**EEPROM**	1 KB

Comparing to the ATmega328P microchip, the Arduino UNO chip perfectly matches the EasyVR Shield 3 module. On the other hand, the arduino boards is exponentially easier and faster to prototype. Both the Arduino UNO and the ATMega 328 are shown in Figure 12, and Figure 13 (Sakr, 2013) shows the port tags used when the proof of concept device was built.

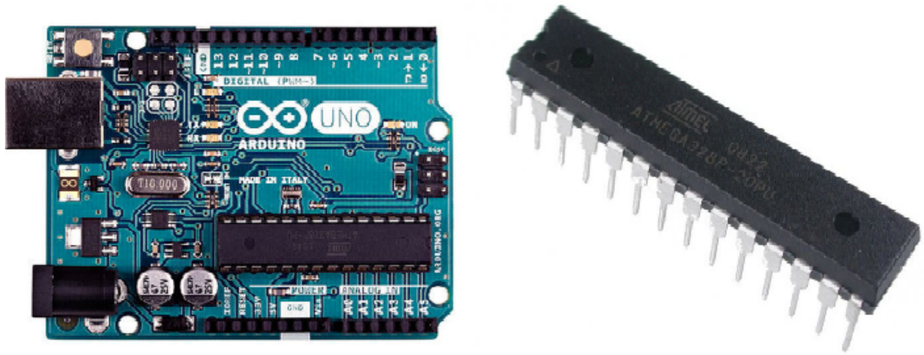


FIGURE 12. ARDUINO UNO AND ATMEGA328

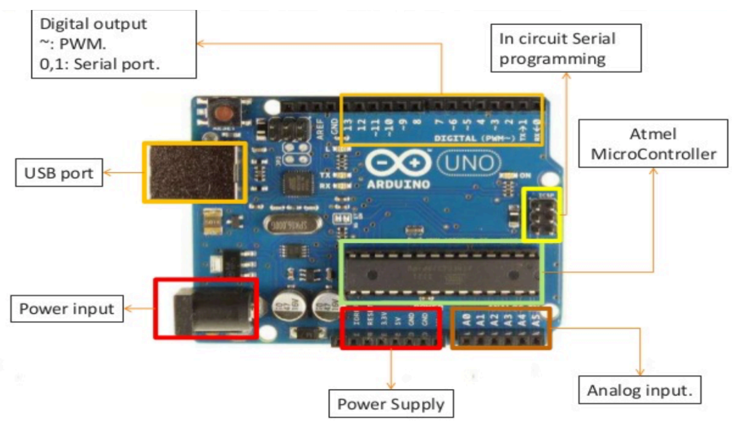


FIGURE 13. ARDUINO UNO PORT TAGS

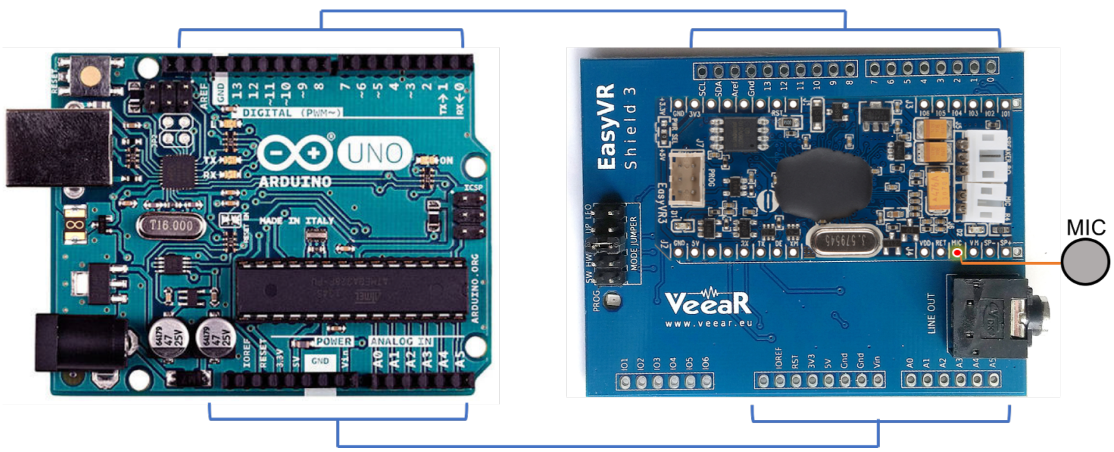
3.3.2 Voice Recognition Module

The voice recognition module oversees the voice commands recognition and identifies the actions that should be operated by the lighting system. After comparing different types of voice recognition modules, the EasyVR SHIELD 3.0 was chosen to be the most appropriate. The "EasyVR is a multi-purpose speech recognition module designed to add versatile, robust and cost effective speech and voice recognition capabilities to virtually any application" (Lees Electronic, n.d.). Especially, the EasyVR SHIELD 3.0 perfectly supports Arduino boards. Meanwhile, EasyVR provides the support to 28 customer Speaker Independent commands, and up to 32 user-defined Speaker Dependent triggers or commands.

The module has a microphone input, 8 ohm speaker output, and headphone jack. Comparing the EasyVR SHIELD 3.0 with other voice recognition modules such as Geeetech, MOVI, and BitVOicer, the advantages of EasyVR are clear. First of all, EasyVR has a built in speaker, which is more convenient to give us feedbacks while testing and debugging. Secondly, EasyVR has many online resources available that facilitate development. Thirdly, EasyVR does not have critical disadvantages such as completely relying on a local computer, having an old API or strictly limited recording.

FIGURE 14. EASYVR SHIELD 3.0

The proof of concept device used the Arduino UNO and EasyVR Shield Module along with the microphone described in section 3.1.1. Figure 14 shows how the pin connection is made to be compatible with the Arduino board, which facilitated the proof of concept device build.



3.3 Electrical Design Specifications

3.3.1 Relay (Switch Unit)

The relay will be the one responsible for managing the electricity between the wall voltage and the Arduino. As the Arduino cannot itself drive a high voltage light bulb, a relay with 5V DC port was chosen. The requirement stated that the standard operation voltage should be 120V, the relay with 250V AC will be capable of handling the wall output voltage and control the light bulbs with ease.

Table 8. Switch Unit Relay Requirement Breakdown

Requirement Number	Requirement Description	Keyestudio 5V Single 1 Channel Relay
R3.23-2	The standard operation voltage of the relay is 120V	5V DC - 250V AC
R3.24-3	The relay shall be able to power up the light bulb to the desired intensity	-

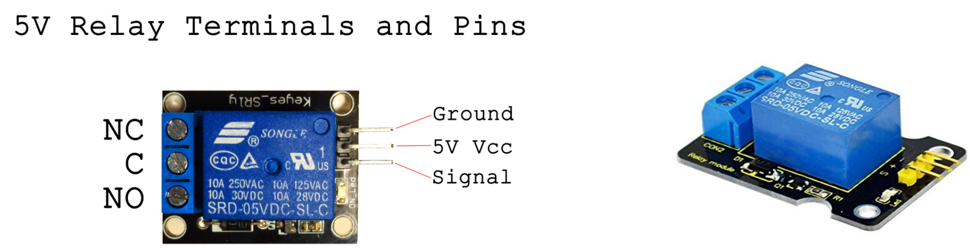


Figure 15. 5V DC Relay with Port Labels

The team chose a regular relay instead of a solid-state relay given that the latter would not be good with bulbs as it does not completely turn off. The relay chosen can perfectly work with the Arduino as it has the 5V port and it can connect to the wall wiring using the 250V AC. As per the dimming capabilities, further research is to be done on this matter to find the easiest and safest way to dim the lights to the desired intensity. The decision on the relay chosen may change in future design revisions based on this research.

For installation and use of the relay, the following diagram will be used as a reference (Circuit Basics, n.d.):

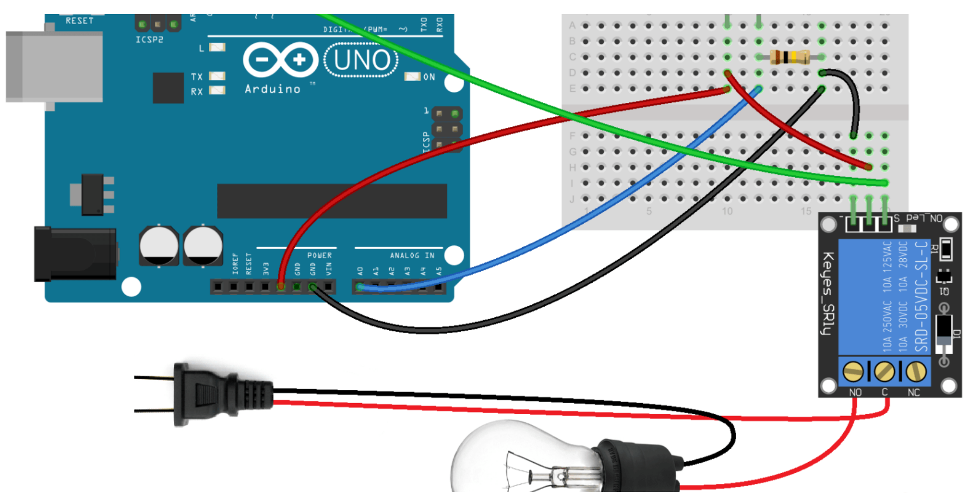


Figure 16. Arduino and Relay Connection

3.4 Enclosure Specifications

The casing of the LightWave System will be made with PET 3D printing material using the ESSS 3D printer, as it is low cost and easily accessible.

R3.43-3 The dimensions of the central unit case shall be smaller than 120x120x40 mm

To satisfy requirement R3.43-3, the arduino UNO size is 68.6 mmx53.4mm and the other components required are small enough for the central unit to be within the limits required.

3.5 Environmental Specifications

R3.44- 3 The central unit shall be functional within the temperatures of -30°C to 85°C

R3.45- 3 The central unit shall be functional in the humidity range of 4% to 50%

To comply with requirements R3.44-3 and R3.45-3, all the components listed above are functional within the temperature range of -30°C to 85°C and humidity range of 4% to 50%.

4. Software Specifications

In this project, the software design is a critical part of the product. It involves communication between device units, voice processing, user interface as well as feedback control. In this section, software aspect of individual modules will be discussed separately.

4.1 Switch Unit

4.1.1 Communication and network protocols

Since the architecture of this product is similar to Server-Client architecture, the devices communicate using wireless radio transmitter and receiver modules.The networking protocol is the key to avoid wireless interference. By doing user analysis, the switch units are likely to occupy the shared frequency channel at the same time, i.e. Two users try to control lights in their room respectively causing traffic collision. In order to avoid the signal collision and properly distribute the channel use into each of the switch unit devices. The system shall implement Medium Access Control (MAC) to avoid channel collision. The following protocols shall be compared during the testing phase of the project.

4.1.1.1 ALOHA

ALOHA is the simplest networking protocol explained in this document:

- If the switch unit receives user command, send it immediately to central unit
- If the central unit does not reply with acknowledged signal, resend the command after a random period of time

This networking protocol has the lowest delay, however its throughput when having a large collision rate is not efficient. The throughput (S) can be calculated by the following formula:

$$S=Ge2G \qquad (1)$$

Whereas G is the average transmission attempts per frame time. (Wireless Communication, 1995)

4.1.1.2 CSMA/CA

CSMA/CA is the acronym for Carrier Sensing Multiple Access with Collision Avoidance. It is the most popular networking protocol nowadays, Wi-Fi uses this protocol to serve local network devices. The theory of this protocol is:

- Before transmitting, the switch units try to sense the shared channel, if the channel is occupied, it waits for a random period of time and waits for a CTS (Clear to Send) signal
- While transmitting, the switch unit send a RTS (Request to Send) signal to take the ownership of the shared channel
- The central unit only issue CTS to one switch unit at a time to avoid collision

(“Carrier sense multiple access with collision avoidance”, n.d.)

4.1.2 Command/Feedbacks

Each switch unit has a microphone to receive the user’s input. The software controls the LED light on switch units as a feedback to the users. There are four states of the LED lights:

- Green light on: this means the switch unit received user’s input and is in transmitting and processing stage.
- Red light flashes: this means input is not recognized.
- Red light on: this means the communication between switch unit and central unit failed.

- Light Off: this means the switch unit is in idle state.

4.2 Central Unit

4.2.1 User interface

The central unit has four buttons and a LCD screen for user settings. The buttons are mainly used to navigate through the menu. The menu has many options including train, set timer, add switch unit, etc.

4.2.2 Command processing

EasyVR Shield voice recognition chip provides a useful library for implementing voice recognition applications, the following C library functions are used in order to perform the desired functionalities of the product:

TABLE 9. EASYVR FUNCTION LIST

Function Name	Description
addCommand (int8_t group, int8_t index)	Adds a new custom command to a group.
bridgeLoop (Stream &port)	Performs bridge mode between the EasyVR serial port and the specified port in a continuous loop.
changeBaudrate (int8_t baud)	Sets the new communication speed.
detect ()	Detects an EasyVR module, waking it from sleep mode and checking it responds correctly.
dumpCommand (int8_t group, int8_t index, char *name, uint8_t &training)	Retrieves the name and training data of a custom command.
dumpMessage (int8_t index, int8_t &type, int32_t &length)	Retrieves the type and length of a recorded message.
eraseCommand (int8_t group, int8_t index)	Erases the training data of a custom command.
eraseMessageAsync (int8_t index)	Erases a recorded message.
getCommand ()	Gets the recognised command index if any.
getCommandCount (int8_t group)	Gets the number of commands in the specified group.
getError ()	Gets the last error code if any.
hasFinished ()	Polls the status of on-going recognition, training or asynchronous playback tasks.

recognizeCommand (int8_t group)	Starts recognition of a custom command.
removeCommand (int8_t group, int8_t index)	Removes a custom command from a group.
resetAll (bool wait=true)	Empties internal memory for custom commands/groups and messages.
setLanguage (int8_t lang)	Sets the language to use for recognition of built-in words.
setMicDistance (int8_t dist)	Sets the operating distance of the microphone.
sleep (int8_t mode)	Puts the module in sleep mode.
trainCommand (int8_t group, int8_t index)	Starts training of a custom command.
verifyCommand (int8_t group, int8_t index)	Verifies training of a custom command (useful after import).

(EasyVR Arduino, n.d.)

5. Sustainability and Safety

To avoid significant damage to the environment and in case of disposal of the parts used, the team will be using parts that comply with the "Restriction of Hazardous Substances" (RoHS) regulations. For the disposal of electronic scrap and other materials during the prototype and product build process the parts will be taken to a "Return-it" recycling facility for proper handling.

For the proof of concept and final prototype's wiring the team will use components and tools from previous project classes. The materials used in the prototype will be easily recycled and used for the final product assembly. Regarding the casing, a model will be 3D printed using PET filaments as described in the enclosure specifications.

6. Conclusion

The goal of the Lightwave development team is to build an affordable, convenient and revolutionary home automation product. The product converges voice recognition and lighting system. In this design specification document, the high-level design scheme is presented with diagrams. Many technical and user interface related issues and design choices are discussed. Along with hardware and software specifications, test plan was designed to insure the sufficient coverage of the product functional and non-functional requirements. A nicely designed user interface is the key to the success of all home automation products. User analysis was carefully researched with surveys and online statistics, it was used to choose the main components and design the user interface in software aspect. Finally, usability testing IS planned after the delivery of phase one prototype.

The document describes the overview of the automation system by providing useful flow diagrams and component lists. The system primarily consists of a single central unit along with countable switch units. The central unit works as the brain of the distributed system, it communicates with switch units to perform voice processing jobs. Switch units are to be installed at light switches located in every room of the facility. The main functionality is to capture users' commands and send them to the central unit.

The hardware specification lists necessary components including Arduino UNO, EasyVR Shield voice recognition module, 433MHz radio transmitters and receivers, and user interaction components such as LCD screens, buttons, and microphones. Arduino was the choice for central unit because it is capable of processing the voice commands and it is financial friendly. In this section, the pros and cons of the voice recognition modules are discussed. The microphone must be able to capture sound that spans different frequencies as well as it shall be able to capture user's' command for long distances. Thus, specific microphone amplifier that gives the desired gain is chosen.

The software specification contains three aspects: communication, voice processing and user interface. Two wireless network protocols are presented as choices for the system. They are ALOHA and CSMA/CA, both protocols give different level of balance between delay and throughput. The final decision will be made during the testing phase of the development life cycle. Moreover, the pre-defined EasyVR voice processing library is used.

Finally, user analysis and test plan is discussed. User and technical analysis of the product deliveries the design of the user interface. A complete list of usability testing is shown in the appendix, it follows the most important user interface principles: simplicity, visibility and user interaction feedback. The included technical test plan will be used for quality assurance and to ensure the product deliveries every requirement listed in the requirement documentation. This document will be reviewed and revised during the testing phase. As the development continues, LightWave home automation lighting system will be improved and it is the future of indoor lighting systems.

Appendix A

Prototype Test Plan

The following tables describe the tests to be executed on the final prototype to ensure the device fulfills its functional requirements. Further tests will be developed once more features are added to the device and its expected functionality is known, i.e. timer setup, light alarm, etc.

Microphone Reach Test			
Environment: System is connected to an external bulb in a low-noise contaminated room Description: To ensure the sensitivity of the microphone is able to receive commands from 30, 60, 100, 200 and 300 cms away			
Procedure	**Result**	**P**	**F**
Execute the command to turn on the light from 30cms away	The light bulb turns on after less than 2 seconds and the green light flashes		
Execute the command to turn off the light from 30cms away	The light bulb turns off after less than 2 seconds and the green light flashes		
Execute the command to turn on the light from 60cms away	The light bulb turns on after less than 2 seconds and the green light flashes		
Execute the command to turn off the light from 60cms away	The light bulb turns off after less than 2 seconds and the green light flashes		
Execute the command to turn on the light from 100cms away	The light bulb turns on after less than 2 seconds and the green light flashes		
Execute the command to turn off the light from 100cms away	The light bulb turns off after less than 2 seconds and the green light flashes		
Execute the command to turn on the light from 200cms away	The light bulb turns on after less than 2 seconds and the green light flashes		
Execute the command to turn off the light from 200cms away	The light bulb turns off after less than 2 seconds and the green light flashes		
Execute the command to turn on the light from 300cms away	The light bulb turns on after less than 2 seconds and the green light flashes		
Execute the command to turn off the light from 300cms away	The light bulb turns off after less than 2 seconds and the green light flashes		

LEDs Test			
Environment: System is connected to an external bulb in a low-noise contaminated room Description: To ensure the LEDs are triggered to right and wrong commands			
Procedure	**Result**	**P**	**F**
Execute a valid command to turn on the light	The light bulb turns on and the green light flashes		
Execute a wrong command to turn off the light	The light bulb does not turn off and the red light flashes		

Electrical Test			
Environment: System is connected to an external bulb in a low-noise contaminated room Description: To ensure the electrical connection to the bulb is working correctly			
Procedure	**Result**	**P**	**F**
Execute the command to turn on the light and leave the system idle for 10 minutes.	The light bulb turns on and stays on a steady brightness.		

Software Test - Turn on/off			
Environment: System has two switch units and is connected to two external bulbs in a low-noise contaminated room Description: To ensure the software turns on and off the correct light			
Procedure	**Result**	**P**	**F**
Execute the command to turn on light 1 (same room)	Light bulb 1 turns on. Light bulb 2 stays off		
Execute the command to turn off light 1 (same room)	Light bulb 1 turns off. Light bulb 2 stays off		
Execute the command to turn on light 2 (other room)	Light bulb 2 turns on. Light bulb 1 stays off		
Execute the command to turn off light 2 (other room)	Light bulb 2 turns on. Light bulb 1 stays off		

Appendix B

User Interface

1. Introduction

The user interface allows users to setup and voice control lights in different rooms, including set and modify voice commands, turn on and off lights, change the brightness of lights, and wake up light (delayed time control). The interface consists of 4 buttons and 1 LCD display connect with central unit for displaying message and allow users to select command list during the initial setup; each switch unit will also come with a button and a LED to allow user to active the the initial setup sequence. The central unit user interface will be mounted on the wall of the “main room (usually the master bedroom)”, buttons and LEDs of switch units will be mounted on the wall of each room, near the light.

2. User Analysis

The product is targeting customers at all ages and both genders. It is especially helpful for disabled people. However, proficient language skill for any of the following languages is required: English, French, Italian, Japanese, German and Spanish. The users need to be able to record their voice sound in order to train and give command to the light system. The system is required to have simple user interface with minimum setting steps for elders and disabled people. It should be easily understood by users with the central unit menu and navigation buttons. The user interface shall follow the standard and common patterns such that the users can easily identify the usage of the product. By the result of the research and user analysis, a large group of the customers will be using this product in a large indoor environment such as single house owner and office infrastructure manager. The product is less likely to be purchased for outdoor environment or small apartment units whose area is less than 1500 sq ft. Thus, the communication and microphone receivable distance are critical requirements for the project.

3. Technical Analysis

3.1 Discoverability

It is easy for users to understand how the product is used daily and what steps are necessary in order to setup the system for the first time. There is only one action is required for the user to control the system, which is “say the command”, nothing more; and there are only 2 steps for customers to set up the system for the first time: name the rooms and record the commands.

3.2 Feedback

The LCD screen will display command list and allow user to select different command in order to do the modification, it will also display status and messages to show the user whether a modification is successful or not. LEDs will indicate whether an action is accepted during the initial setup with switches.

3.3 Conceptual Models

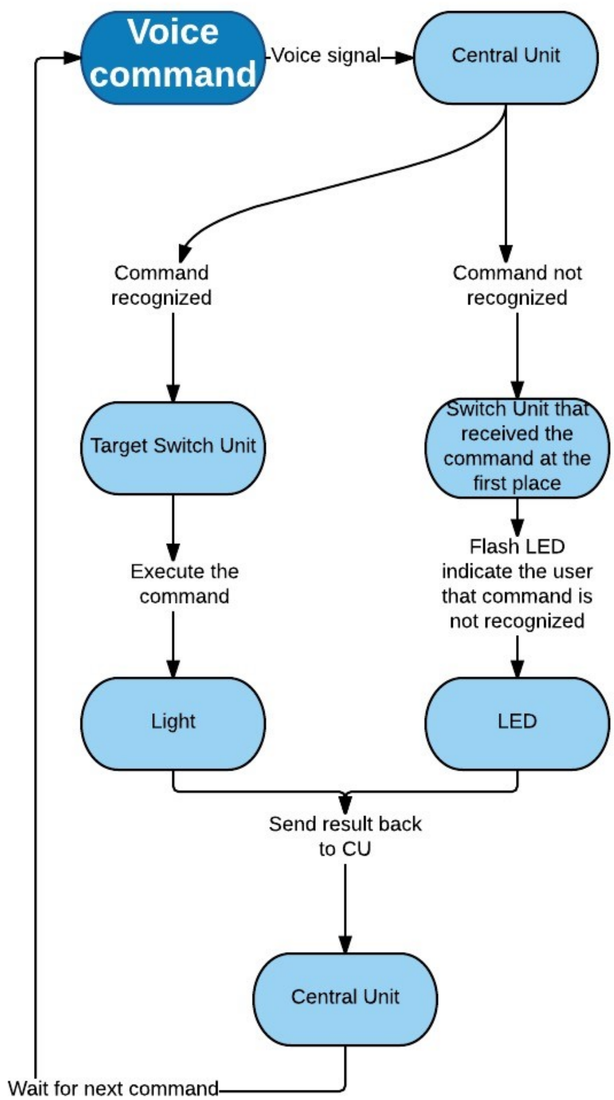


FIGURE 17. UI DIAGRAM

3.4 Affordances

Affordance is clear, say the word and the product will execute it, the LEDs will let the user know what the results are.

3.5 Signifiers

For the design of current stage, there will be arrow icons on the buttons of LCD display, and LEDs on switch units are signifiers as well that indicate the user whether a command is executed or not.

3.6 Mappings

The goal of this system is to be as user friendly as possible, therefore, at this stage of the project, the system does not require a lot of users' memory to perform a task. Users are encouraged to use common phrases as commands, such as "light on" or "turn on the light", so it could be easier for user to remember the command words. However, the system does require users to memorize the sequences of how the command should be spoken to avoid accident triggering.

3.7 Constraints

In order to not accidentally trigger the command during users' daily conversation, there are certain constraints that how the command is spoken. The command must follow the format: [keyword] + [room name] + [action command]. The 3 elements in the command must be spoken in the exact order and they are recorded and stored in the system at the initial setup.

4. Engineering Standards

A good user interface design is to help users finishing tasks without drawing unnecessary attention to itself ("User Interface Design, n.d.). Therefore, graphic design and the correct choice of words printed on the device is important to support its usability. An LCD is going to be placed on the central unit for setup of the device and there are three principles to follow:

1. The simplicity principle. Steps to finish common tasks should be easy to follow and repetitive.
2. The visibility principle. User interface should be professional without distracting user attention.
3. The feedback principle. Keep users informed of any system interpretations, changes of state or condition

Engineering standards:

1. IEC 102290 (Graphic standard)

2. IEC 102287(Word choice)
3. IEC 129090(Guidance on Usability)

IEC stand for (IEEE International Committee, n.d.).

5. Analytical Usability Testing

The system requires little education for users to understand and perform tasks, however, the system requires users to give commands in certain formats, whoever is not familiar with the system might have trouble giving the right commands. Moreover, at this early stage of the project, users with different speech styles than the host might not be recognized by the system, the voice recognition system will be improved in the future. Since the system is voice control, user with physically inconvenience will have no trouble interacting with the system.

Due to signal transmitting, there might be time delay between receiving commands and executing them. Normally users would assume that the execution will happen immediately after the command is given, however, due to budget consideration, there is only 1 voice recognition chip in the system, therefore, all command will be converted to digital signals and send to the central unit, then they will be processed there, which cause delays. Whether the delay will be significant needs further test.

Generally, there is no safety concerns in the system, all wires and chips are mounted in the wall, and users, by design, will rarely interact with the hardware interface, only during the initial setup or when the setup needs to be modified.

6. Empirical Testing

Although the project continues to be in its early stages and the proof of concept only covers around 30% of the final prototype, some important details were observed while the team, friends and staff were using the device. Previous user experience comes from using voice activated functions from smartphones or smart TVs in which the user gives instructions in a straightforward manner. However, these instructions can vary in a few ways:

6.1 Difference in Speech

The EasyVR Shield managed to work with three different speech speeds during the product demo, but it is still facing an inconvenience when a person other than the one that trained the product tries to execute the commands. The team is currently researching to come up with a way to reduce the harsh voice match of the product using filters to allow more users to use it without them all having to go through the initial training.

Future tests in this area will cover:

- Interaction with the system using three different speech speeds
- Interaction with the system using different accents and pronuntiations

6.2 Command Format

Command recognition is currently limited to certain formats and does not allow for too much variability, i.e. “Bedroom lights turn on” is not the same as “Turn on bedroom lights” and only the one programmed in the internal setup will be recognized. However, the team wants to improve this feature and a workaround may be in place in other versions of the prototype.

Future tests in this area will cover:

- Executing a valid command and await proper behavior
- Executing an invalid command and await proper behavior

In case fixes are in place for flexibility:

- Executing a command by reorganizing the words and await proper behavior

6.3 Memorizing Commands

Part of the use of this product requires the user to remember the commands to interact with the home lights. Although the flexibility of the commands is quite limited as of now, the ones pre-programmed are easy and intuitive enough that the user will not feel the burden of memorizing commands, and they will come naturally. Another aspect that was observed was the use of the action words, some people like to say, “bedroom lights on” instead of using the verb “turn on”. Therefore, for the commands to be the easiest the team will have to adjust to the results of the following tests:

- Ask a new user to turn on the lights without any command format reference and evaluate the success rate comparing to the built-in format
- Record the intuitive commands from the users: adjust the existing product if the previous success rate is low

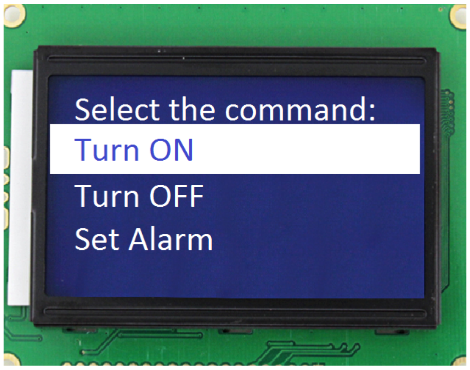
6.4 Errors

Making errors while using the product has a non-fatal effect. Getting the wrong command will result in no response from the system but will not provoke any dangerous behavior. The area which can be risky is installation, and a manual will be included that will also recommend the installation to be in hands of an electrician that knows how to work with higher voltages.

6.5 LCD Setup

Once the LCD programming is done, it will look like the representations shown in figure 18. The setup will be accompanied by a user manual and will have to be tested with different users to make it easy to follow. A successful setup will give the user the best experience with the product usage, therefore its importance is critical.

Main menu



Training menu

FIGURE 18. LCD SETUP REPRESENTATION

7. Conclusion

The LightWave System is a high performance, safe and simple system that aims to offer users a great experience at home when it comes to light. At this stage of the project, users can start to control the lights with simple voice command easily, and the learning process will not take a lot of memory from users, once learned, anyone including children and elders will be able to handle the system perfectly. In the next development stages the system will be subject to testing with different types of users and the feedback will be considered to improve the intuitive factor of its usage as well as diminishing command execution errors, increasing performance in voice recognition while also aiming for the minimal response delay.

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