Feb. 17th, 2014

Andrew H. Rawicz
School of Engineering Science
Simon Fraser University
V5A 1S6

Re: ENSC 440 Functional Specification – SoundHub: Wireless Speaker Module

Dear Dr. Rawicz,

In regards to the course requirements of ENSC 305W/440W, enclosed to this letter is Arimus Audio's functional specification for SoundHub: Wireless Speaker Module. We are designing and implementing a home wireless audio solution that enables music streaming over a Wi-Fi network to multiple speakers.

Our functional specification provides details to the SoundHub's functionality for its various stages of development. In addition, this document covers the overview of the product design, general requirements of the proof of concept model, as well as a detailed test plan on the model functionality.

Arimus Audio is a well balanced team comprised of five senior engineering students: Sherman Siu, Scott Malfesi, George Chang, Dongkai Miao, and David Yin. Their concentrations include an aggregation of computer engineering, electronics engineering, and engineering physics. We will be more than happy to discuss any additional questions or comments you may have regarding the functional specification. Please contact our CEO Sherman Siu at arimus.audio@gmail.com.

Sincerely,

Sherman Siu
CEO
Arimus Audio

FUNCTIONAL SPECIFICATION
WIRELESS SPEAKER MODULE

Project Team : Sherman Siu
Scott Malfesi
George Chang
Dongkai Miao
David Yin

Submitted to : Dr. Andrew Rawicz
Steve Whitmore
School of Engineering Science
Simon Fraser University

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Revision : 1.2

Executive Summary

Team Arimus Audio is founded on the idea that every music lover deserves to enjoy their music with minimum constraints. With this idea in mind, we came up with the SoundHub. The SoundHub is a low cost wireless speaker module that connects your personal device to the sound systems around you. It provides a seamless audio solution, a way for music to be shared freely while retaining its quality and requires minimal setup.

Included in the SoundHub are a number of breakthrough innovations and features focusing on enhancing the user experience. We focused on creating a device which would free users from the messy wires in traditional solutions and brings mobility to the free flowing elegance of music into their realm. No matter if it is a 7.1 surround sound system, a dock or even a small computer speaker, SoundHub will integrate them all into a wireless home audio system.

Having the ability to fit the SoundHub to any existing speaker system, the users gain the benefits of wireless streaming without having to upgrade their entire audio system. The proof of concept model will yield the following key features to impress its audience as much as possible:

- **Quality wireless music**: Transfer the music wirelessly at 16 bit quality through a Wi-Fi network and decode it using a high quality digital to audio converter (DAC) and amplifier
- **SoundHub Array**: When music is broadcasted over the Wi-Fi network, each of the SoundHub device will be able to receive the signal and stream to all speakers in unison
- **Line Through Toggle**: The SoundHub supports a line through that would allow the user to toggle between wireless streaming and their original wired configuration

In addition to the interactive experience featured by the proof of concept model, we have also planned additional functionality that is necessary for the marketable revision and final consumer product. Some of the highlights of these features include:

- **Enclosure:** A stylish enclosure which will keep components safe
- **Mobile Applications:** Specialized applications which can be used to stream music to the configure the SoundHub
- **RoomFlow™**: The RoomFlow feature allows the SoundHub to detect the proximity of the user to the SoundHub itself, and adjust its volume level accordingly

Considering the time and resource limitations, our current targets within the next two months are to meet the proof of concept features. If time permits, additional feature may be added to the system.

This document will describe the functional specifications for the entire SoundHub system, as well as each of the individual components. Several other topics will be covered, including an outline of the proposed test plan, sustainability considerations, as well as the associated engineering standards. Please refer to individual sections for more detailed descriptions of the functional specification of the SoundHub system.

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Glossary

AP	Access Point, a device that allows wireless devices to connect to a network using Wi-Fi
App	Short for application; a program which runs in user space for humans to interact with
Android	A science fiction robot with human appearance; also a mobile operating system developed and open sourced by Google
CPU	Canadian Standards Association
CSA	Light Emitting Diode
DAC	Digital to Analog Converter
FCC	Federal Communications Commission
LED	Light Emitting Diode: a lighting device made from a semiconductor diode
ICES	Industry Canada Electric Standards
I2S	Inter-IC Sound: an audio interconnect common between chips [1]
iOS	A Cisco router operating system; also an embedded operating system created by Apple to run on their phones and some music players
PCB	Printed circuit board
RoomFlow	A proprietary algorithm developed by Arimus Audio which the SoundHub uses
SNR	Signal to Noise Ratio: a measure of signal integrity
SoundHub	A WiFi audio receiving device which is being developed by Arimus Audio
SPDIF	Sony/Philips Digital Interface Format: a typical commercial audio interconnect
Stream	A steady and continuous flow of information often over the internet
THD+N	Total Harmonic Distortion: a measure of harmonic distortion
Wi-Fi	A popular technology that allows an electronic device to exchange data or connect to the internet wirelessly using radio waves
WPS	Wi-Fi Protected Setup: A method of connecting to an AP using a physical button or pin rather than the usual password

1.0 Introduction

The SoundHub is the next revolutionary step in wireless speaker technology. Designed to be sleek and discreet, it allows existing wired speakers to attain wireless freedom by streaming music from other devices to it. Furthermore by utilizing modern Wi-Fi protocols, multiple speakers connected to separate SoundHub devices can be streamed to at the same time. With SoundHub, rooms or entire homes can have access to streamed audio content, with full control through your handheld devices or computers.

The goal is to produce a slim and discreet speaker attachment that will allow music streaming through Wi-Fi, while maintaining a price point much lower than existing competition. This product will allow users to gain the benefits of wireless streaming without having to upgrade their entire audio system. Figure 1 shows an artist's rendering of how the SoundHub will look along with an audio system.

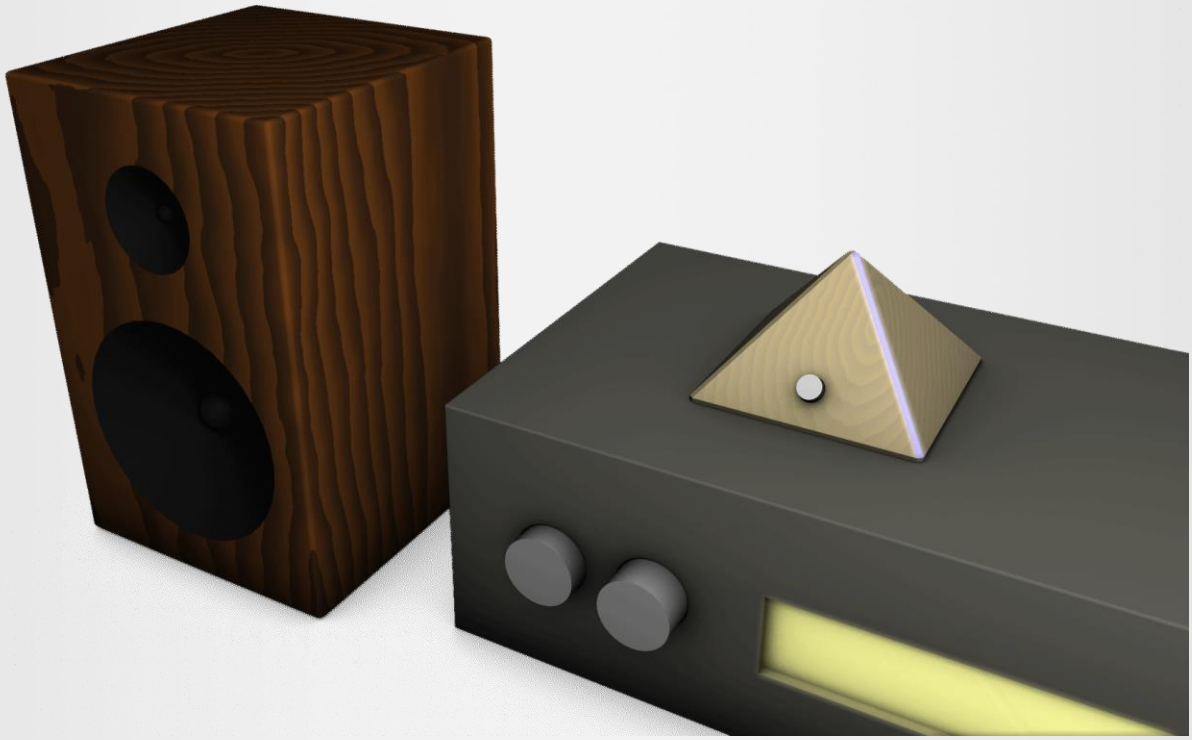

Figure 1: Artist's SoundHub Rendering

With user-friendliness in mind, the SoundHub requires minimal setup and has intuitive user controls. The setup requires the SoundHub to be connected to the user's speakers and will use a Wi-Fi network. Once connected to the network the mobile device will be able to find and wirelessly stream music to the SoundHub.

This functional specification will outline the following:

- The SoundHub product and its features
- Overall requirements of the proof of concept model
- Detailed test plans
- Sustainability considerations and safety

1.1 Scope

This documentation describes the functional requirements of the wireless speaker adapter system, including the requirements of proof of concept model, the marketable revision, and the final consumer product. These requirements will be used as reference throughout the design and implementation phase and will be referred to in future documents.

1.2 Intended Audience

The intended users of this document include all members of team Arimus Audio and potential stakeholders of the project. The team leads can use this document as a guide to measure the overall progress while the developers can refer this to reflect on the requirements needed for this project. Stakeholders can use this document to verify the model functionality as well as the percentage completion of the project.

1.3 Requirements Classification

The following convention will be used throughout this documentation to represent a functional requirement:

[Req x.y.z P]

where x.y.z indicates the requirement section and number and P number represents priority level. The priority level is divided into three levels

- P1: Requirement that is high priority and is essential to the proof of concept model
- P2: Requirement that is a moderate priority and is aimed for the marketable revision
- P3: Requirement that is low priority and is applicable to the final consumer product

1.4 Intended User

Our intended user is defined as a person of at least 12 years of age and literate. Any persons not fitting in this defined category is beyond the scope of this document.

2.1 Use Case

Our product consists of two systems for the user to interact with, the application on their own mobile devices and the SoundHub device itself. Figure 2 shows a use case diagram which defines how a user may interact with the system.

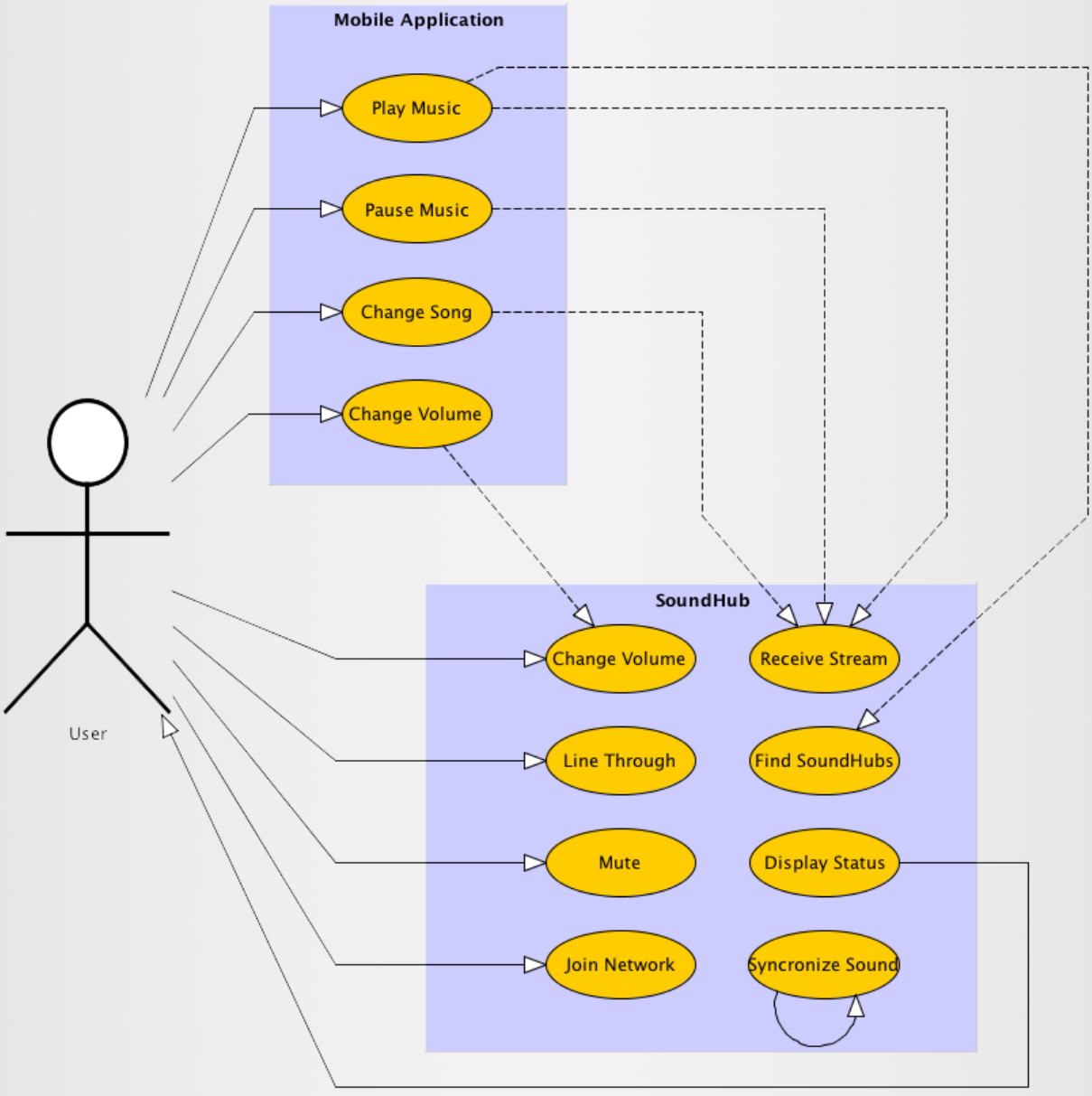

Figure 2: Use Case Diagram for the SoundHub System

2.2 Top level Design

The SoundHub consists of a central processing unit (CPU) which is running an embedded Linux kernel and custom firmware. The peripherals of the CPU include a Wi-Fi module, a volume knob, status lights and circuitry to decode the digital audio stream and through a DAC to produce an analog signal which can be played out of the speakers. A high level block diagram of wireless speaker adapter is shown below in Figure 3.

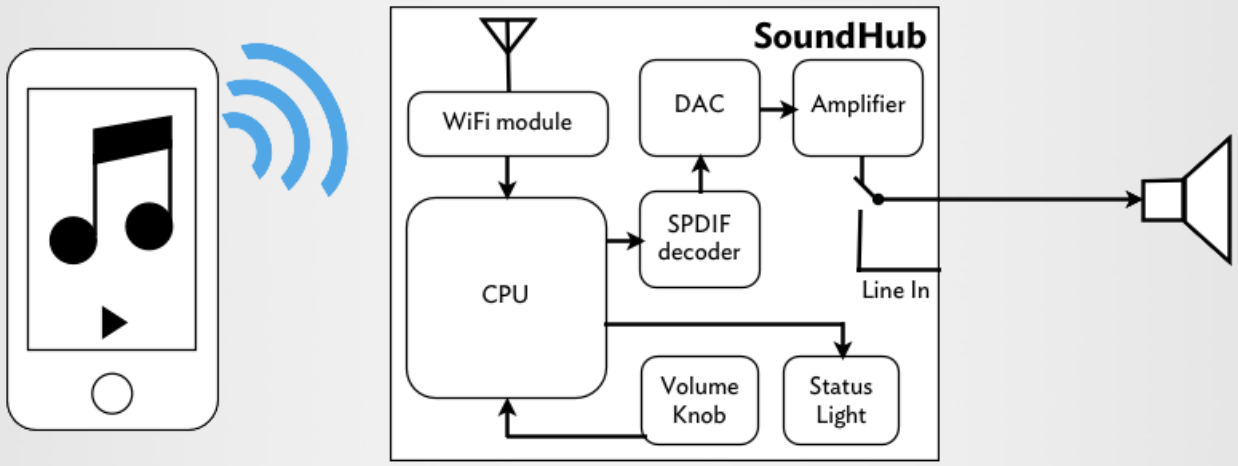

Figure 3: Block Diagram of Wireless Speaker Adapter

The system design consists of three major sections:

- Hardware development aimed to provide high quality audio transmission through the design and implement a customized DAC system
- Firmware development on the evaluation board to achieve audio streaming through a Wi-Fi network to multiple speaker systems
- Software development aimed to develop an android application which is capable of controlling playback over a mobile device.

The requirements of the above sections will be discussed in section 3.

2.3 Functionality Justification

Functionality was chosen based on the user demand for a wireless speaker system that is capable of streaming music to multiple devices to create a whole house audio experience. The goal for the SoundHub is to be a low cost, sustainable, quality music device. With this in mind, the functionality and design decisions were made to balance each of the three objectives. The choice of adopting open source materials allows interested individuals in the open source community to develop more functions and features into the SoundHub. Also, by selecting a higher quality DAC, the SoundHub can be future proofed by supporting higher specifications than consumer grade audio formats. This allows the SoundHub to be kept by a user for longer periods without having to pre-emptively replace it. To be even more sustainable the SoundHub incorporates exclusively recyclable materials for its enclosure.

All the functionality has been tailored to make SoundHub a household electronic that will last. By making it versatile and able to be incorporated into any existing sound system, it discourages wasteful purchases of entirely new systems simply for the wireless capabilities. Its simple design and ease of use will make it an essential addition to home audio systems.

3.0 System Requirements

This section details the requirements for the SoundHub system. As mentioned in section 2.2 the system consists of three main design components.

- Firmware: which includes the code that runs on the SoundHub CPU
- Hardware: which includes the electronic and physical enclosure requirements
- Software: which includes the app that users use to stream music to the SoundHub

Each of these components will have a separate section describing their specific requirements. In addition there is a set of general requirements which apply for the entire SoundHub system which is included below:

General Requirements

[Req 3.0.1 - P1]	The system is designed for consumer indoor use
[Req 3.0.2 - P1]	The system is turned on when the power supply is plugged in
[Req 3.0.3 - P2]	75% of the users should find the system intuitive to use and be able to configure the entire system in under 20 minutes
[Req 3.0.4 - P3]	Retail price of the SoundHub system must not exceed $100

Environmental Requirements

[Req 3.0.5 - P2]	The system uses only RoHS compliant materials under category 3: Computing & Communications Equipment [2]
[Req 3.0.6 - P2]	Highly recyclable outer enclosure
[Req 3.0.7 - P2]	The electrical hardware contains only lead free components and solder

Safety Requirements

[Req 3.0.8 - P1]	All components must not emit radiation known to be harmful to humans
[Req 3.0.9 - P1]	All components must not cause destructive interference with the functionality of other common devices
[Req 3.0.10 - P1]	All components must not melt or emit toxic fumes under operational and storage temperatures
[Req 3.0.11 - P2]	The vertices and edges of the enclosure must be reasonably harmless to users when handled
[Req 3.0.12 - P2]	The hardware components inside the enclosure should be secured to prevent loose parts

Standards

[Req 3.0.13 - P2]	The device will meet all Canadian Standards Association (CSA) electrical standards [3]
[Req 3.0.14 - P2]	The device will meet all Federal Communication Commission (FCC) regulations on Wi-Fi (limitation of maximum amount of power the device can transmit, FCC part 15 in US) [4]
[Req 3.0.15 - P2]	The device will comply with Industry Canada Electric Standards (ICES) ICES-003 rules [5]
[Req 3.0.16 - P2]	This device will comply with the IEEE (Institute of Electrical and Electronics Engineers) 802.11n-2009 standards [6]

3.1 Firmware Requirements

This section identifies the firmware requirements of the wireless speaker adapter system. For the proof of concept model the firmware will be run on the evaluation board and it is expected that streaming to single device will be completed before developing multi-device streaming. The RoomFlow feature is also developed during this stage, if time permits. In a marketable revision the firmware will be run on the custom hardware.

General Requirements

[Req 3.1.1 - P3] The system should be responsive 5 minutes after being plugged in

Setup Requirements

[Req 3.1.2 - P2] The system will attempt to connect to wireless router using Wi-Fi Protected Setup (WPS) when button is pressed [7]

[Req 3.1.3 - P2] The system will time out of WPS connection after 2 minutes

[Req 3.1.4 - P2] The system automatically reconnects to network it has been connected to previously known wireless networks

Network Requirements

[Req 3.1.5 - P1] The system will transfer data using a Wi-Fi network

[Req 3.1.6 - P1] The system broadcasts presence to mobile device

[Req 3.1.7 - P1] The system is able to receive and play an audio stream of at least 16 bit audio at 44.1 kHz

[Req 3.1.8 - P1] The system is capable to perform real time streaming with less than five seconds lag from the source

[Req 3.1.9 - P2] Music rarely skips due to dropped packets with no more than a second of audio lost over 5 minutes of playback under good network conditions

[Req 3.1.10 - P2] The system is able to synchronize music playback with other SoundHub devices

[Req 3.1.11 - P3] The system is capable to perform real time streaming with less than a second lag from the source

[Req 3.1.12 - P3] RoomFlow: individual SoundHubs are able to detect their own distance from the music source and dynamically adjust their own volume based on that distance and the proximity of other SoundHubs

3.2. Hardware Requirements

This section will describe the hardware requirements for the SoundHub system which includes electrical hardware and the enclosure. A sample enclosure is planned to be included with the proof of concept model and a more refined version will be on the marketable revision. Figure 4 shows the front and back view of an enclosure.

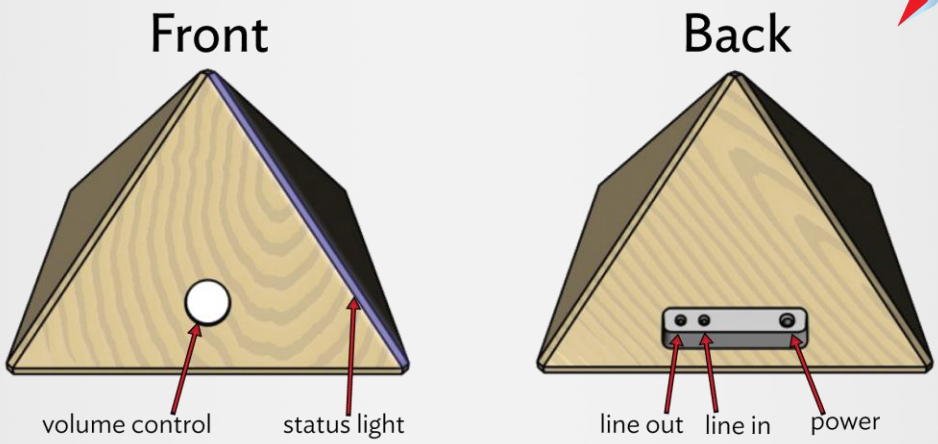

Figure 4: Front and Back View of SoundHub with Major Features Labeled

On a marketable revision, there will be a complete custom printed circuit board (PCB) for the system. However given time constraints and how much of the PCB is expected to closely resemble the evaluation board we will be focusing on the most customized systems of the hardware for the proof of concept model. The main objective for the proof of concept model is to design and implement a high quality DAC that replaces the pre-existing DAC on the evaluation board to allow for a better listening experience. The new DAC is expected to give significant improvements in signal specifications such as signal to noise ratio (SNR), dynamic range, and total harmonic distortion (THD+N) over the original DAC.

Electrical Requirements

[Req 3.2.1 - P1]	The hardware circuitry will run off wall 100-240V at 50-60 Hz AC
[Req 3.2.2 - P1]	The power plug using North American standard
[Req 3.2.3 - P1]	The hardware circuitry is capable to decode digital signal from the CPU and converts to an analog output
[Req 3.2.4 - P1]	DAC designed produces SNR of more than 115dB from a standard 3.5mm jack output at peak performance
[Req 3.2.5 - P1]	DAC designed produces THD+N of less than -95dB from a standard 3.5mm jack output at peak performance
[Req 3.2.6 - P1]	The hardware has one 3.5mm audio jack line out receptacle
[Req 3.2.7 - P1]	The hardware has one 3.5mm audio jack line in receptacle
[Req 3.2.8 - P1]	The LED is able to indicate states such as streaming, connecting to Wi-Fi network, potentially with varying colors and pulsating lights.
[Req 3.2.9 - P2]	The power cord is detachable
[Req 3.2.10 - P2]	DAC designed to be compatible with 24 bit audio at 96 kHz

Operation Requirements

[Req 3.2.11 - P2]	Storage temperature: -40 to 70 degrees
[Req 3.2.12 - P2]	Operational temperature: from -25 to 60 degrees
[Req 3.2.13 - P2]	The device will operate at under a noise level under 30dB in normal conditions

Enclosure Requirements

[Req 3.2.14 - P2]	The hardware must be enclosed to prevent unintentional damage
[Req 3.2.15 - P2]	All connection ports and buttons should be easily accessible
[Req 3.2.16 - P2]	LED status lighting on one of enclosure edges
[Req 3.2.17 - P2]	Line through Toggle Switch located in the rear panel
[Req 3.2.18 - P2]	Volume control knob located in the front panel
[Req 3.2.19 - P2]	The product must have openings for heat dispersion
[Req 3.2.20 - P3]	All ports and switches must have accompanying labels
[Req 3.2.21 - P3]	The product must weigh less than 2 kg excluding the power supply
[Req 3.2.22 - P3]	The enclosure dimensions are not larger than 20cm x 20cm x 20cm, and can be carried with one adult hand

3.3. Software Requirements

The mobile application is the primary interface between the system and user. Control functions such as playback control and volume control are displayed on the main screen of the application. An example of how the GUI may look is shown below in Figure 5.

Figure 5: Artist's Rendering of the Main Playback Screen. Image based on Apollo App [8]

For the proof of concept model we are only implementing an Android version of the app as this is all that is necessary to show that our system works. However for the production model we will also have an iOS version available so that users have their choice of device. The detail requirements for the proposed software application are listed below.

[Req 3.3.1 - P2]	The application is compatible with Android (2.3 and above) mobile devices
[Req 3.3.2 - P2]	The application is able to detect SoundHub devices
[Req 3.3.3 - P2]	The application has control over the Playback (pause, play, skip)
[Req 3.3.4 - P2]	The application has control over the stream volume
[Req 3.3.5 - P3]	The application has control over individual SoundHub's volume
[Req 3.3.6 - P3]	Works with iOS (7.0 and above) mobile devices

3.4 Documentation Requirements

This section describes the requirements of the user documentation that will accompany the SoundHub system in the production model and will assist the customers in setting up their system.

[Req 3.4.1 - P3]	User Manual will be provided along with the consumer product
[Req 3.4.2 - P3]	The user manual demonstrates setup procedure using pictures and short concise sentences
[Req 3.4.3 - P3]	The contents of the user manual can be understood by a person with post-elementary reading comprehension

4.0 Test Plan

Team Arimus Audio has developed a set of preliminary test procedures to ensure proper system functionality. The test plan is divided into two parts: individual component testing and an evaluation of the integrated system. Detailed testing procedures for each part to be followed throughout the design and implementation are outlined in the following sections:

4.1 Individual Component Test

4.1.1 Firmware

The firmware test plan section will be split up to three major categories, networks, system, and audio. The network section will detail the specific test plan procedures used to handle all the networking and connectivity issues with SoundHub. The system section will cover the general software controlled devices and user interaction with SoundHub. The audio test plan section will detail the streaming and audio playback functionalities. All of these sections will be tested individually. The software code that will be developed to run on the SoundHub will also be modularly tested. By testing each section of software independently we can easily identify the source of the bug and make necessary corrections before the marriage of hardware and software. The agile development process will be adopted throughout the project to help minimize the overall errors and increase productivity.

Networks:

- Connectivity between the wireless Access Point (AP) with a SoundHub
- Utilizing WPS as an alternative method to connect the SoundHub to the wireless AP
- Connection to the wireless AP will remain active within the signal range
- Identify the network connection between the source and the sink

System:

- Time to boot up and start up applications after power is connected takes less than five minutes
- Varying the volume knob will change the system volume
- Status is indicated by LED

Audio:

- Able to transfer the music packets from a single source to a single sink on a single machine
- Different support for audio format and sampling frequencies
- One music source device to one speaker system streaming through Wi-Fi network
- One music source device to multiple speaker systems streaming through Wi-Fi network
- Multiple music source devices to multiple speaker systems streaming through Wi-Fi network
- Handling of multiple music sources to a single speaker system and later to multiple speaker systems
- Able to perform playback functionality (play, pause, music seek, up and down volume controls) within the required minimum lag duration.
- Multiple devices to multiple speaker systems streaming with RoomFlow function
- Active handling of Wi-Fi connectivity when dropped or lost

4.1.2 Hardware

The hardware test plan is divided into several sections focused on the output of each major component. Especially for the proof of concept stage, the test plan is focused on the custom audio processing hardware. There are two major audio processing blocks: the decoder block and DAC block. The decoder block first receives the digital Sony/Philips Digital Interface Format (SPDIF) signal from the CPU, then converts the signal into Inter-IC Sound (I2S) format [1] and feeds it into the DAC block. The DAC block produces two set of differential signals from the I2S inputs, and post-processing amplifier circuit will output the stereo signal with high audio quality. See Figure 6 below for a hardware block diagram:

Figure 6: Block Diagram of the Custom Audio Processing Hardware

Unit tests will be conducted to ensure they pass criteria specified below:

3.5mm Line in:

- The 3.5mm enable switch block should function properly without noise generation

Volume Knob:

- Quadrature signal is produced when knob is turned indicating the direction of rotation

SPDIF to I2S converter/decoder circuitry:

- The SPDIF decoder should produce the I2S signal with synchronization between bit and channel clock
- The produced left/right channel clock should be in the same phase with the system clock

DAC circuitry:

- The DAC shall produce accurate audio stream with signal to noise ratio of at least 115dB

In addition, we plan on testing major components individually prior to use in the protoboard. Note that the test plan for each individual component may vary, and not all components can be pre-tested given their functionality, and package type (ie. surface mount components). Software simulators will be also used to help understanding the circuit.

4.1.3 Software

The software application is the primary interface between the user and the system. Therefore the GUI of the application must be straightforward and fulfill the requirements listed in section 3.3. The features of the application will be tested as an individual component without considering the SoundHub system:

- Successfully run on android devices without frequent crashing
- Correct layout of GUI and each button corresponds to its functionality
- Automatic identifies the SoundHub device once the mobile device and the SoundHub is on the same Wi-Fi network
- Stream to a separate device other than the SoundHub known to implement the sink protocol

4.2 Integration Tests

The integrated system can be evaluated in different categories once the individual components are examined to be working properly and the integration has been completed. In the proof of concept stage, the highest priorities are the audio quality and the latency response during the streaming. Therefore the following tests will be done and future adjustments will make accordingly.

Perceived audio quality:

- The wireless streamed music through the system should be of noticeably better quality compared to non-processed music through line in from the same source. This subjective measurement will be conducted and judged by experienced individual.
- The wireless streamed music should retain its quality over different frequency range, sample music such as heavy bass and soprano will be used to test

Latency Test:

- The wireless streamed music should respond to user's command through the mobile application within five seconds. The latency will be evaluated based on different circumstances such as the relative signal strength of the source and the sink, and the actual command (tuning volume, play/pause, queuing new songs). The results will be handed over to the development team for future improvements.

Power Consumption Test:

- The system should not exceed the power rating on the AC converter

Stress Test:

- Stream music to the SoundHub for a period of twelve hours and determine the rate of dropped music during that duration

5.0 Sustainability/Safety

At Arimus Audio we are focused on making sure that our product is both sustainable and safe for users. We designed our product with the idealized goal of a cradle to cradle design in mind. However given the current nature of consumer electronics, this was not possible; still we focused on making sure our product to have as little negative impacts on the environment and peoples' lives as possible.

The enclosure is to be made primarily of wood to maximize recycled material and reduce the environmental impact. Electronic components are to be easily separable from the enclosure to allow simple recycling procedures. In addition, RoHS compliant materials [2] have been selected to ensure there are no heavy metals such as lead found. By following this requirement throughout the project, this sets the standard for a lead-free device in future prototyping and production phases.

In regards the safety, the enclosure is to be designed without harmful sharp edges and corners while retaining an overall pyramidal shape. Components inside the enclosure are secured with standoffs against the pyramid shell to prevent movement and damage to parts. Screws will be placed on the opening plate preventing unintended access to electronic components. The SoundHub will also follow the guidelines of FCC's section 15 Class B Digital Device [4]. Section 15 Class B digital Device indicates that this, "digital device that is marketed for use in a residential environment notwithstanding use in commercial, business and industrial environments." [9]. Examples of such devices includes, but are not limited to, personal computers, calculators, and similar electronics devices that are marketed for use by the general public. We intend on supporting wireless standards such as IEEE 802.11n-2009 [6] and also more recent IEEE standards to promote the longevity of SoundHub as we develop the product into its further stages.

Future SoundHub roadmaps will be more focused on its safety and sustainability. Plans for certifications and assessment various safety and environmental standards are being discussed. Strategies for the SoundHub's components and enclosure's redesign to target energy efficiency and cost reduction are also going to be formulated during the prototyping development cycle.

Combining the SoundHub with a home's pre-existing audio systems allows users to forego purchases of entirely new speakers and promotes speaker re-use.

6.0 Conclusions

This documentation has laid out the functional specification for the SoundHub wireless speaker adapter system and will act as the guidance and reference as team Arimus Audio moves into the design and implementation phase. The system design consists of three major sections:

- Hardware development aimed to provide high quality audio transmission through the design and implement a customized DAC system
- Firmware development on the evaluation board to achieve audio streaming through a Wi-Fi network to multiple speaker systems
- Software development aimed to develop an android application which is capable of controlling playback over a mobile device.

The functional requirements have been divided into five main categories with several sub-options under each category. The prioritization system will allow the development team to efficiently allocate resources accordingly. We have put high priority on the features which are necessary for the device to have basic functionality. Some of these high priority features include the ability to stream music wirelessly, line through capability, synchronized output for multiple devices and high quality music output. Whereas we have put lower priority on features which add extra polish to the SoundHub but are not as necessary such as the enclosure, the mobile application and the RoomFlow feature.

Our product will be tested throughout the design and implementation stage referred to the test plan section of this documentation. Each module will be tested individually for functionality, and then an integration test will be examined for system compatibility and also for overall evaluation.

At Arimus Audio, we keep sustainability and safety in mind during the design of our product. The proof of concept model will meet all the safety standards as well as consider sustainability topics outlined in the document.

References

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