SONOS Intercom System

UCSB Capstone 2016-2017
A company that reinvents home audio for the digital age.
SONOS

A high-fidelity audio company that specializes in seamless audio integration over a home WiFi network.
SONOS Ecosystem

- No compromises on sound quality
- Modern aesthetics
- Durable
SONOS COM:1
for play/pause music and microphone.
Market

- SONOS device owners.
- Families.
- SONOS
  - Research and Development regarding **microphones** and **streaming**.
  - Possibility for voice recognition / personal assistant in the future.
Benchmark

Amazon Echo Dot

Senic Nuimo
Functionality

● Communication
  ○ Real time voice broadcasting.
  ○ Allows user to select which “room” to talk to.
    ■ “room” = a group of SONOS devices.

● Music Control
  ○ Play/Pause
  ○ Next
  ○ Previous
  ○ Volume
Music Controls

Change Mode

Mode Button

Living Room

Change Mode
Music Controls

Tap: Volume
Swipe: Next/Previous

Living Room
Music Controls

- Play/Pause
- Action Button
- Living Room
Intercom

Kitchen

Tap: Volume
Swipe: Next/Previous
Technical Details

**Size**
1.5” x 4.25” x 4.25” (38mm x 108mm x 108mm)

**Weight**
6 oz (170 grams)

**Screen**
1.5” (38 mm) Color TFT LCD Display

**Material**
Plastic. Type to be determined.

**Wi-Fi Connectivity**
Wi-Fi module providing fully integrated 2.4 GHz 802.11 b/g/n radio, TCP/IP stack and a 32-bit microcontroller (MCU)

**Audio**
Able to seamlessly connect and control your existing SONOS home network

**System Requirements**
COM:1 comes ready to connect to your Wi-Fi. Requires an iOS or Android device compatible with the SONOS app.

**Power**
5V Supply via wall wart adapter to micro USB

**Operating Temperature**
Heat sink temperature about 55°C
Shell temperature about 28~45°C

**Water Protection**
IP 64 (Dust tight and protection against splashing of water)

* Actual sizes and weight may vary as project develops
Hardware Design

For actual schematic, please see appendix.
Software Design

Music Control Mode
- Action Button Pressed
  - UPnP Play/Pause
  - UPnP Set Volume
  - UPnP Next/Previous
- Volume Up/Down Button Pressed
- Right/Left Button Pressed
- Mode Button Pressed
- Switch Mode
  - Send TCP Packet using BGLib UART to WiFi

Intercom Mode
- Action Button Pressed
  - UPnP Set Stream
  - UPnP Set Volume
  - UPnP Next/Previous
- Volume Up/Down Button Pressed
- Right/Left Button Pressed

Live Streaming Loop
- Read I2S Audio from Mics
- Copy to SW Buffer using DMA
- MP3 Encode Audio
- Ship using BGLib to WiFi module

SONOS Device Discovery
- Issue UPnP Multicast Discovery using BGLib
- Listen for responses
- Update Room List

On timer interval.
What do we have so far?
And What’s Next?
CAD Design

- Exploded Shell View
Physical Tests

- Drop Test.
- Water Resistance Test
- Thermal Test

More information in the Appendix
Text files containing example HTTP UPnP packets for the following actions:

- Get Mute Status
- Get Track Info
- Get Volume
- Next Track
- Previous Track
- Play
- Pause
- Set Mute
- Set Volume
- Set Audio Stream

```
POST /MediaRenderer/AVTransport/Control HTTP/1.1
Host: 172.20.10.7:1400
Content-Type: text/xml; charset="utf-8"
Content-Length: 277
SOAPAction: "urn:schemas-upnp-org:service:AVTransport:1#GetPositionInfo"
Connection: close

<s:Envelope
  xmlns:s="http://schemas.xmlsoap.org/soap/envelope/"
  s:encodingStyle="http://schemas.xmlsoap.org/soap/encoding/">
  <s:Body>
    <u:GetPositionInfo
      xmlns:u="urn:schemas-upnp-org:service:AVTransport:1">
      <InstanceID>0</InstanceID>
    </u:GetPositionInfo>
  </s:Body>
</s:Envelope>
```
API

- MP3 Audio Streaming Test
  - Live
  - Need to fix delay. (Maybe has to do with buffering?)
Hardware

● Current Prototype
  ○ Six button GPIO control
    ■ 1 uF cap with 2.5Kohm
    ■ LED feedback
  ○ Microphone Development Board
    ■ Two I2S Digital Mics
    ■ Bottom Mount

● Winter Quarter Plans
  ○ Capacitive touch interface
    ■ Decrease to four buttons
  ○ Microphone output to Sonos Speaker
Software

● Basic Functional Structure:
  ○ Volume up adds 5 to volume, until maximum is reached
  ○ Volume down subtracts 5 from volume, until minimum is reached
  ○ Change mode switches from intercom to music
  ○ Change room simply states next room selected
  ○ The same button selects next song depending on the current mode
  ○ Similarly the previous button works based on the current mode
PCB Spins

- This PCB artwork (Gerber Files) will be shipped to Laritech to be manufactured and assembled.
PCB Spins

- Prototype vs Final
- Must take enclosure constraints/requirements into account.
- Buttons vs Capacitive touch
Meet the Team

CEs
Subho Choudhury
Brian Sandler
Richard Wei
Brenden Fujishige
Mohammad Cazi
Marcellis Carr-Barfield
Organization

Discipline Leaders

Thermal/Power

DSP & Mic Array

PCB Hardware

Structure/Design

Software
Appendix
Design Constraints

● Experience
  ○ Minimize audio latency.
  ○ Responsive controls.

● Simplicity

● Durability
  ○ Product should withstand home environment (drop/water proof).

● Affordability
  ○ $49.99-$99.99 is acceptable for such a simple device.
Water Protection

IP level: Ingress Protection Marking. classifies and rates the degree of protection provided against intrusion, dust, accidental contact, and water.

It contains two digits: the first for dust protection and the second for water protection.

### Dust Protection

<table>
<thead>
<tr>
<th>Level Sized</th>
<th>Effective Against</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>1</td>
<td>&gt;50mm</td>
</tr>
<tr>
<td>2</td>
<td>&gt;12.5mm</td>
</tr>
<tr>
<td>3</td>
<td>&gt;2.5mm</td>
</tr>
<tr>
<td>4</td>
<td>&gt;1mm</td>
</tr>
<tr>
<td>5</td>
<td>Dust Protected</td>
</tr>
<tr>
<td>6</td>
<td>Dust tight</td>
</tr>
</tbody>
</table>

### Water Protection

<table>
<thead>
<tr>
<th>Level</th>
<th>Protection against</th>
<th>Level</th>
<th>Protection against</th>
<th>Level</th>
<th>Protection against</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>None</td>
<td>3</td>
<td>Spraying water</td>
<td>6</td>
<td>Powerful water jets</td>
</tr>
<tr>
<td>1</td>
<td>Dripping water</td>
<td>4</td>
<td>Splashing of water</td>
<td>7</td>
<td>Immersion, up to 1 m depth</td>
</tr>
<tr>
<td>2</td>
<td>Dripping water when tilted at 15°</td>
<td>5</td>
<td>Water jets</td>
<td>8</td>
<td>Immersion, 1 m or more depth</td>
</tr>
</tbody>
</table>
Solution for the microphone part: acoustic meshes

ePTFE membrane is the newest generation of breathable membrane which has good waterproof and air-ventilating properties.

Saati Acoustex B090HY

<table>
<thead>
<tr>
<th>Item Name</th>
<th>Pore size(µm)</th>
<th>Open area(%)</th>
<th>Thickness (µm)</th>
<th>Weight (g/m²)</th>
<th>Air permeability (L/m²@20mm WG)</th>
<th>Specific Airflow Resistance [MKS rayls]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustex090</td>
<td>41</td>
<td>24</td>
<td>125</td>
<td>85</td>
<td>2125</td>
<td>90</td>
</tr>
</tbody>
</table>

Backup Choice (See Appendix)

Sumitomo Electric Industries  
Poreflon™ Air Vent  
Sterlitech Corporation  
PTFE LAMINATED FILTER
Test of the membrane
Survey result of where people will use this product

Where will you put this device?

- Living room: 1 (11.1%)
- Bedroom: 3 (33.3%)
- Kitchen: 5 (55.6%)
- Bathroom: 1 (11.1%)
- I want this device at: 4 (44.4%)
# Detail of dust protection

<table>
<thead>
<tr>
<th>Level sized</th>
<th>Effective against</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>—</td>
<td>No protection against contact and ingress of objects</td>
</tr>
<tr>
<td>1</td>
<td>&gt;50 mm</td>
<td>Any large surface of the body, such as the back of a hand, but no protection against deliberate contact with a body part</td>
</tr>
<tr>
<td>2</td>
<td>&gt;12.5 mm</td>
<td>Fingers or similar objects</td>
</tr>
<tr>
<td>3</td>
<td>&gt;2.5 mm</td>
<td>Tools, thick wires, etc.</td>
</tr>
<tr>
<td>4</td>
<td>&gt;1 mm</td>
<td>Most wires, slender screws, large ants etc.</td>
</tr>
<tr>
<td>5</td>
<td>Dust protected</td>
<td>Ingress of dust is not entirely prevented, but it must not enter in sufficient quantity to interfere with the satisfactory operation of the equipment.</td>
</tr>
<tr>
<td>6</td>
<td>Dust tight</td>
<td>No ingress of dust; complete protection against contact (dust tight). A vacuum must be applied. Test duration of up to 8 hours based on air flow.</td>
</tr>
</tbody>
</table>
## Detail of water protection

<table>
<thead>
<tr>
<th>Level</th>
<th>Protection against</th>
<th>Effective against</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>None</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1</td>
<td>Dripping water</td>
<td>Dripping water (vertically falling drops) shall have no harmful effect on the specimen when mounted in an upright position onto a turntable and rotated at 1 RPM.</td>
<td>Test duration: 10 minutes Water equivalent to 1 mm rainfall per minute</td>
</tr>
<tr>
<td>2</td>
<td>Dripping water when tilted at 15°</td>
<td>Vertically dripping water shall have no harmful effect when the enclosure is tilted at an angle of 15° from its normal position. A total of four positions are tested within two axes.</td>
<td>Test duration: 2.5 minutes for every direction of tilt (10 minutes total) Water equivalent to 3 mm rainfall per minute</td>
</tr>
<tr>
<td>3</td>
<td>Spraying water</td>
<td>Water falling as a spray at any angle up to 60° from the vertical shall have no harmful effect, utilizing either a) an oscillating fixture, or b) A spray nozzle with a counterbalanced shield. Test a) is conducted for 5 minutes, then repeated with the specimen tilted 90° for the second 5-minute test. Test b) is conducted (with shield in place) for 5 minutes minimum.</td>
<td>For a Spray Nozzle: Test duration: 1 minute per square meter for at least 5 minutes Pressure: 50–150 kPa Water volume: 10 litres per minute For an oscillating tube: Test duration: 10 minutes Water Volume: 0.07 l/min per hole</td>
</tr>
<tr>
<td>4</td>
<td>Splashing of water</td>
<td>Water splashing against the enclosure from any direction shall have no harmful effect, utilizing either a) an oscillating fixture, or b) A spray nozzle with no shield. Test a) is conducted for 10 minutes. Test b) is conducted (without shield) for 5 minutes minimum.</td>
<td>Oscillating tube: Test duration: 10 minutes, or spray nozzle (same as IPX3 spray nozzle with the shield removed)</td>
</tr>
</tbody>
</table>
**Detail of water protection (2)**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Water jets</td>
<td>Water projected by a nozzle (6.3 mm) against enclosure from any direction shall have no harmful effects.</td>
</tr>
</tbody>
</table>
|   |   | Test duration: 1 minute per square meter for at least 3 minutes  
|   |   | Water volume: 12.5 litres per minute  
|   |   | Pressure: 30 kPa at distance of 3 m |
| 6 | Powerful water jets | Water projected in powerful jets (12.5 mm nozzle) against the enclosure from any direction shall have no harmful effects. |
|   |   | Test duration: 1 minute per square meter for at least 3 minutes  
|   |   | Water volume: 100 litres per minute  
|   |   | Pressure: 100 kPa at distance of 3 m |
| 6K | Powerful water jets with increased pressure | Water projected in powerful jets (6.3 mm nozzle) against the enclosure from any direction, under elevated pressure, shall have no harmful effects. Found in DIN 40050, and not IEC 60529. |
|   |   | Test duration: at least 3 minutes (rotation needed)  
|   |   | Water volume: 75 litres per minute  
|   |   | Pressure: 1000 kPa at distance of 3 m |
| 7 | Immersion, up to 1 m depth | Ingress of water in harmful quantity shall not be possible when the enclosure is immersed in water under defined conditions of pressure and time (up to 1 m of submersion). |
|   |   | Test duration: 30 minutes - ref IEC 60529, table 8.  
|   |   | Tested with the lowest point of the enclosure 1000 mm below the surface of the water, or the highest point 160 mm below the surface, whichever is deeper. |
| 8 | Immersion, 1 m or more depth | The equipment is suitable for continuous immersion in water under conditions which shall be specified by the manufacturer. However, with certain types of equipment, it can mean that water can enter but only in such a manner that it produces no harmful effects. The test depth and/or duration is expected to be greater than the requirements for IPx7, and other environmental effects may be added, such as temperature cycling before immersion. |
|   |   | Test duration: Agreement with Manufacturer  
|   |   | Depth specified by manufacturer, generally up to 3 m |
Microphone Protection

Sumitomo Electric Industries
Poreflon™ Air Vent

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Pore Size (µm)</th>
<th>Thickness (µm)</th>
<th>IPA Bubble Point (kPa)</th>
<th>Waterproof Pressure (kPa)</th>
<th>Flow Rate Liquid (ml/min,cm²)</th>
<th>Flow Rate Air (L/min,cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP-010-60</td>
<td>0.1</td>
<td>60</td>
<td>150</td>
<td>220</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>PP-022-60</td>
<td>0.22</td>
<td>60</td>
<td>120</td>
<td>180</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>PP-045-60</td>
<td>0.45</td>
<td>80</td>
<td>80</td>
<td>120</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>PP-100-100</td>
<td>1</td>
<td>100</td>
<td>40</td>
<td>60</td>
<td>60</td>
<td>8</td>
</tr>
<tr>
<td>PP-500-100</td>
<td>5</td>
<td>100</td>
<td>15</td>
<td>20</td>
<td>120</td>
<td>15</td>
</tr>
</tbody>
</table>

Sterlitech Corporation
PTFE LAMINATED FILTER

<table>
<thead>
<tr>
<th>SKU</th>
<th>PTFE_Laminated_Sample_Pack</th>
<th>Pore Size (µm)</th>
<th>0.1-1.0 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>13 - 47</td>
<td>10</td>
</tr>
</tbody>
</table>

Performance by Pore Size

<table>
<thead>
<tr>
<th>Pore Size</th>
<th>Thickness</th>
<th>Air Permeability</th>
<th>Water Entry Pressure</th>
<th>IPA Bubble Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 µm</td>
<td>6.10 ml (122-254 µm)</td>
<td>0.05</td>
<td>&gt;65 psi</td>
<td>&gt;25 psi</td>
</tr>
<tr>
<td>0.22 µm</td>
<td>4.6 ml (102-142 µm)</td>
<td>0.2-0.4</td>
<td>&gt;14.5 psi</td>
<td>&gt;20 psi</td>
</tr>
<tr>
<td>0.45 µm</td>
<td>3.5 ml (76-127 µm)</td>
<td>0.4-0.8</td>
<td>&gt;10 psi</td>
<td>&gt;10 psi</td>
</tr>
<tr>
<td>1 µm</td>
<td>3.5 ml (76-127 µm)</td>
<td>1.5-3.5</td>
<td>&gt;4 psi</td>
<td>&gt;8 psi</td>
</tr>
</tbody>
</table>
Thermal Analysis

Assumptions:
1. Average heat power on PCB
2. PCB efficiency is zero
3. 25°C Ambient Temperature
4. PCB Power is 10W

<table>
<thead>
<tr>
<th></th>
<th>Thermal conductivity (W/(m*K))</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCB</td>
<td>&gt;0.81</td>
<td>55</td>
</tr>
<tr>
<td>Heat Sink</td>
<td>108.89</td>
<td>55</td>
</tr>
<tr>
<td>Shell</td>
<td>&gt;0.2256</td>
<td>24~45</td>
</tr>
<tr>
<td>LCD</td>
<td>0.74976</td>
<td>48</td>
</tr>
<tr>
<td>Natural Convection coefficient</td>
<td>~ 4.3 (W/m² K)</td>
<td></td>
</tr>
</tbody>
</table>
Needs and Engineering Characteristics

- **Needs**
  - Technical
  - Customer

- **Engineering Characteristics**
  - Power
  - Appearance
  - Material

<table>
<thead>
<tr>
<th>List of technical needs</th>
<th>Engineering Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td>Power Supply(W)</td>
</tr>
<tr>
<td>Clarity of Microphone Input and Output</td>
<td>Noise cancellation (dB)</td>
</tr>
<tr>
<td>Water Resistant</td>
<td>Volume (dB)</td>
</tr>
<tr>
<td>Not Hot to the touch</td>
<td>Gaskets, light tolerances (mm)</td>
</tr>
<tr>
<td>Drop Resistant</td>
<td>Temperature (F, C, J/S)</td>
</tr>
<tr>
<td>Get good WIFI reception</td>
<td>Toughness(J)</td>
</tr>
<tr>
<td>Fit Sonos Design Guidelines</td>
<td>USB cable powered</td>
</tr>
<tr>
<td>Can be powered by a cell phone wall wart.</td>
<td>Simple Button Layout</td>
</tr>
<tr>
<td>List of customers' consideration</td>
<td>Appearance(mm. &amp; $$$)</td>
</tr>
<tr>
<td>Some Mobility</td>
<td>antenna(1-10)</td>
</tr>
<tr>
<td>Easy to Use</td>
<td>Material</td>
</tr>
<tr>
<td>Suitable Size</td>
<td></td>
</tr>
<tr>
<td>Good Weight</td>
<td></td>
</tr>
<tr>
<td>Less Wires</td>
<td></td>
</tr>
<tr>
<td>Affordable</td>
<td></td>
</tr>
</tbody>
</table>
Power Requirement

- The WIFI module power requirement is about 1.5W(max).
- Mic power requirement is about 25mW (max) each, hence the power for mic array should be about 100mW.
- LCD display takes about 0.5W.
- For CPU, the max supply current for each pin is 100 mA. With supply voltage 3.3 V, the max power would be about 5-6W, which is the worst case, depending on the number of driving pins.

The ideal power requirement is 6w at work. In case more are in need, we would take the worst case at first for testing to find out the more appropriated value. The power requirement at work would be taken as 10W.