Progress report

Project Title: Indoor Mapping and Asset Tracking System

Project Code: FYP E14

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Executive Summary

This project aims to develop software for a device that improves the well-being of employees and the ergonomics of office spaces. The project will add new feathers of an indoor mapping system using audio technology to an existing prototype called Limpet.

The hardware design for the Limpets has already been done with the most cost-effective hardware components. In theory, this Limpet should work to detect distance using sound. Tests are needed to prove that the hardwires work to the specification.

While the project progress, the research area covered acoustic distance measurement, 3D distance mapping, Wireless mesh network, MEMs microphone, digital PDM signal output, and convert PDM signal to PCM signal. The hardware design of the PDM breakout board has been made by design the schematic and the PCB using Altium Designer. Hardware modification of the I2S breakout board has been made to swap the PDM microphone onto the I2S breakout board. By testing the modified PDM breakout board, it was not working. The breakout board under testing changed to the I2S breakout board. I2S MEMs microphone is similar to the PDM microphone. Tests for the I2S breakout has not yet been undertaken.

The project is currently one week behind, according to the Gannt chart. According to the plan, this project should be in the experiment stage, but the microphone model for the microphone has not been successfully tested yet. The plan for the project is described in a Gannt chart shown in the remaining task section.

Three sections are used to analyze the sustainability of this project. The environmental impact section discusses the life cycle analysis in base component procurement, production, distribution, usage, and end of life. The effect of the Limpet on making the office environment better was discussed in the social impact section. The impact of the Limpet on saving more energy for the company was discussed in the energy impact section. More detail can be seen in the sustainability part of the report.

Contents

Project overview

Wellnomics is a company that develops systems to improve the health, well-being, and productivity of people who works in an office environment. The systems designed by Wellnomics primarily are software solutions to improve the ergonomics of the office environment.

Wellnomics has been developing several hardware solutions that integrate with electric sit-stand workstations and measure presence and equipment utilization. The hardware comes in several versions, including a plugged-in version shown in figure 1 for sit-stand workstations and a battery-powered version shown in figure 2 for standard desks.

Figure 1: Plug-in Limpet.

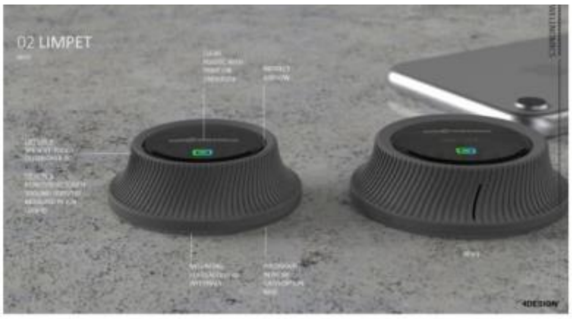

Figure 2: Battery Powered Limpet.

Covid-19 caused people in an office environment need to have physical distancing, as shown in figure 3. Wellnomics wants to create a hot-desking system for the office environment with new feathers of an indoor mapping system using audio technology. “Hot desking is a trend in which workers take whatever desk is available, instead of having one assigned space” [1].

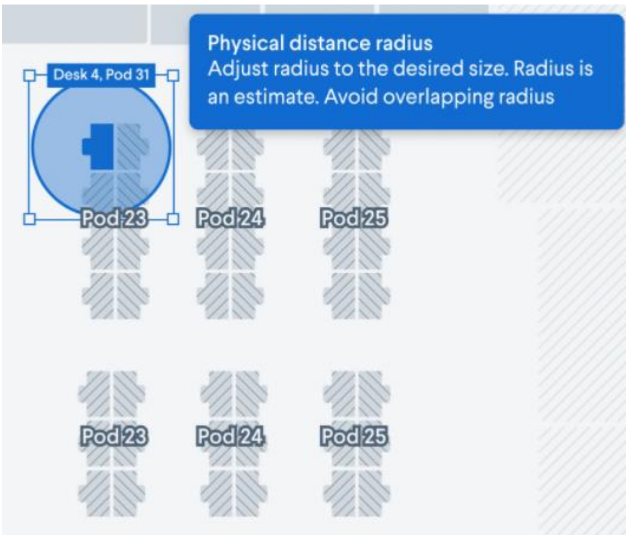

Figure 3: Physical distancing between disks in an office environment.

The Limpets can track physical distancing between disks for people who work in an office environment. The purpose of this is to keep them healthy and avoid catching Covid-19 or any other airborne diseases.

The Limpets generate the 3D-distance mesh assists the company to discover the most popular seat area, such as near the windows. The company can rearrange the office space set up to allow more employee to work more efficiently. The employee who sits in their preferred seats works happier in the office. When the employees work happier, it also prompts their health and well-being both psychologically and physically.

This project adds new feathers of an indoor mapping system using audio technology to an existing prototype called Limpet. The hardware design for the Limpets has already been done with the most cost-effective hardware components. In theory, this Limpet should work to detect distance using sound. Tests are needed to prove that the hardwires work to the specification.

To test all the components works according to the specification, this project has been divided between 4 group members. For measuring sound, a speaker and a microphone are needed for the Limpet. The project was divided according to four aspects of the project, the microphone part, the speaker part, the signal shape and frequency used to suit the office environment, the 3D-distance mesh development.

Progress to Date

The first understanding of the project

The project started on the 1st of March when groups are assigned and confirmed by our lecturer. This project was defined as building a prototype with a Nordic nrf52840 embedded microprocessor, a digital MEMs microphone, and a tiny 80dB speaker from reading the project requirements. Write embedded firmware to synchronize and perform measurements between prototypes in a multi-dimensional mesh network using sound. Collect measurements wirelessly from multiple devices to a central point. Research and develop appropriate mathematical techniques to combine noisy distance data into 3-dimensional maps of device location has been done.

Research the project with first understanding of the project

Brainstorming and background research has been done on acoustic distance measurement. The idea of distance measurement was defined as the distance between two objects can be calculated as the velocity of sound travels times the time taken for sound to travel (Distance = Velocity * time). The velocity of sound is defined as 343 (meter/second) under 20 degrees Celsius [2].

The second understanding of the project

Acoustic distance measurement

The first meeting with our sponsor, Kevin was taken place on the 5th of March. This meeting has changed some of our understanding of the project. A prototype/Limpet has already been made. We need to write embedded firmware to synchronize and perform measurements between prototypes in a multi-dimensional mesh network using sound; Collect measurements wirelessly from multiple devices to a central point.

Research the project with a second understanding of the project

3D mapping

Background research of the 3D mapping has been done. To calculate the 3D position of an existing node, four other known position nodes are needed to calculate the relative 3D location without knowing the orientation of the 3D system [3].

Wireless mesh network

Background research of mesh network has been done. A mesh network is a local network topology, as shown in Figure 1 below. The infrastructure nodes connect directly, dynamically, and non-hierarchically to as many other nodes as possible. All nodes cooperate to route data efficiently.

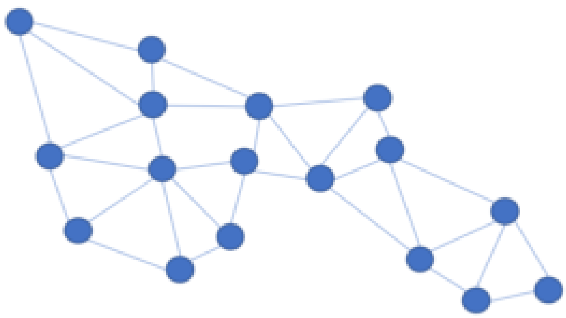

Figure 1: Mesh network.

There are two kinds of mesh network suitable for this project, Bluetooth and Zigbee. Bluetooth mesh has four advantages.

- Bluetooth mesh network can be supported with just a software upgrade from any Bluetooth low energy (BLE) version since version BLE4.0.
- Bluetooth mesh network is the first worldwide mesh standard specified up to the application layer, and there are mesh models build for Bluetooth mesh.
- Bluetooth low energy allows the Bluetooth mesh to save energy compare to other mesh networks.
- All Bluetooth mesh network messages are encrypted and authenticated at both the network layer and application layer [4].

Zigbee mesh network has specific advantage and disadvantages shown in Table 1 below. Compare Bluetooth mesh with Zigbee, Bluetooth mesh would be more suitable than Zigbee for the project because the implementation cost is low and more secure.

Advantage of Zigbee	Disadvantage of Zigbee

• Zigbee has a flexible network structure • It has a very long battery life • Zigbee has a mesh network topology with low cost, multi hope data transmission and is power effective • It is less complex than Bluetooth • It is easy to install • Zigbee support a large number of nodes • Zigbee is more reliable • It is a short working period result in power saving and power consumption of communication	• Zigbee disadvantages mainly include short-range • Low complexity and low data speed • Its high maintenance cost, lack of total solution, and slow materialization, • Low transmission, as well as low network stability, are also some of its disadvantages that takes it a step back as compared to others • Replacement with Zigbee compliant appliances can be costly • Zigbee is not secure like a Wi-Fi-based secured system • It does not have end devices available yet

Table 1: advantage and disadvantage of Zigbee [5].

The final understanding of the project

After the meeting on the 16th of March, the requirement for the project was redefined. The mesh network in the project specification was a 3D-physical mesh network instead of a Bluetooth mesh network. The components were assumed to be working in theory, but there was no evidence that the components work in reality as well as the datasheet specified. Tests for the components were needed. Therefore, the project was split into four parts, speaker, microphone, 3D-physical mesh network, and signal processing.

Research the project with the final understanding of the project

MEMs microphone

During the time between 16th of March to 12th of April, background research has been done for the microphone part. The microphone supplied for the project was a MEMs microphone [6]. The specific microphone for this project is SPH0644LM4H-1 [7]. MEMS stands for micro-electro-mechanical systems, technology to microphones that have led to small microphones with very high performance.

MEMS microphones use acoustic sensors, as shown in figure 2 below, fabricated on semiconductor production lines using silicon wafers and highly automated processes. Layers of different materials are deposited on top of a silicon wafer. Then the unwanted material is then etched away, creating a moveable membrane and a fixed backplate over a cavity in the base wafer. The sensor backplate is a stiff perforated structure that allows air to move quickly through it, while the membrane is a thin solid structure that flexes in response to the change in air pressure caused by sound waves. Changes in air pressure created by sound waves cause the thin membrane to turn while the thicker backplate remains stationary as the air moves through its perforations. Movements of the membrane create a change between the membrane and the backplate, translated into an electrical signal by the ASIC.

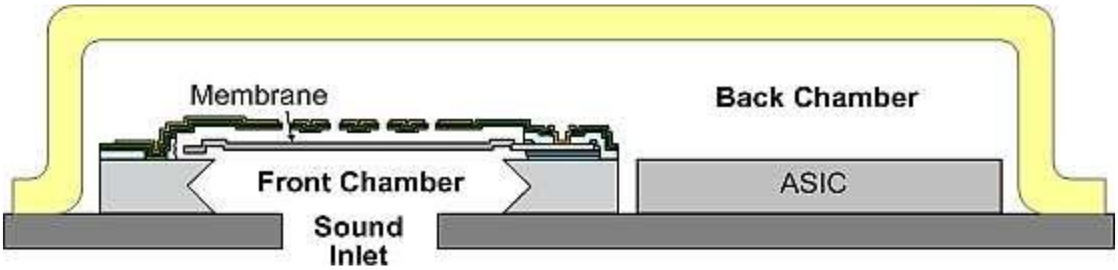

Figure 2: Cross-section diagram of a typical bottom port MEMS microphone.

Digital PDM signal output

SPH0644LM4H-1 is a digital PDM microphone. PDM stands for pulse density modulation, which produces a highly oversampled single-bit data stream. Figure 3 below shows what digital PDM in graph view and binary view.

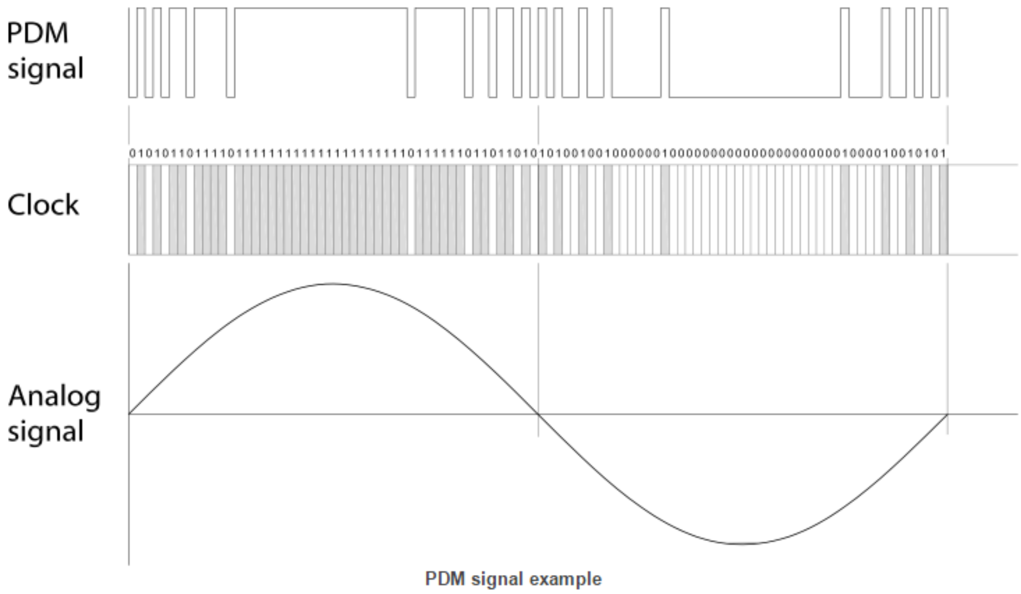

Figure 3: PDM signal example.

Convert PDM to PCM signal

The digital MEMS microphone outputs a PDM signal, a stream of 1-bit digital samples with the sampling frequency of 1MHz to 3.25MHz [8]. The data is acquired by the DFSDM serial transceiver that connects to the external Sigma-Delta modulator of the digital microphone. The digital filters perform CPU-free filtering that averages the 1-bit input data stream from the Sigma-Delta modulator into a higher resolution and a lower sample rate. This data is transferred through DMA to a RAM buffer to be further filtered. After that, the PCM raw data can be handled additionally. The process is shown below as a block diagram in figure 4.

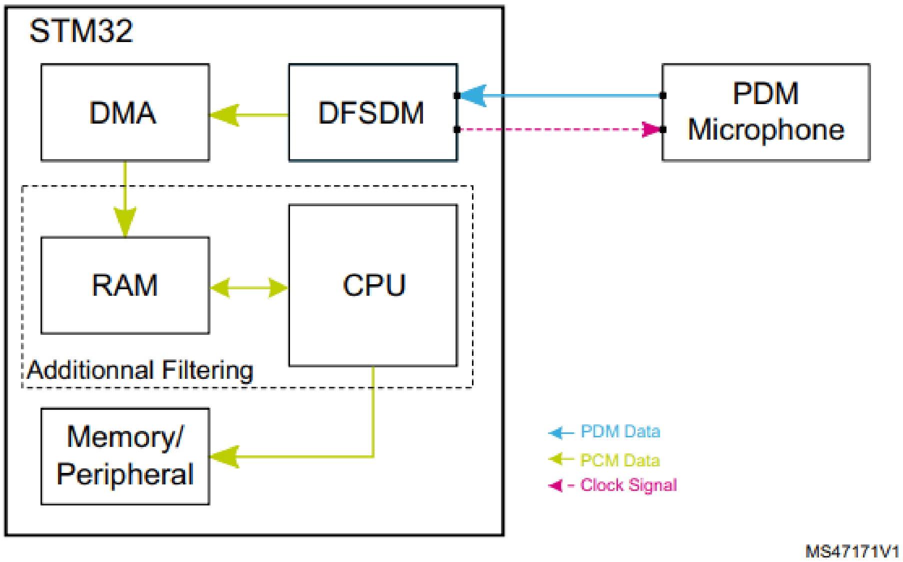

Figure 4: Digital data acquisition and processing using DFSDM (block diagram).

Design a Microphone breakout

A microphone breakout board is needed for testing the MEMs PDM microphone. Although some breakout board has been ordered, the shipping time has been extended by the Covid-19 situation. With most of the research done, the breakout board is needed as soon as possible for testing. A breakout board has been designed based on the schematic provided by the Adafruit [9], as shown in figure 5 below. The PCB of the break has been designed, as figure 6 shown below, based on the schematic.

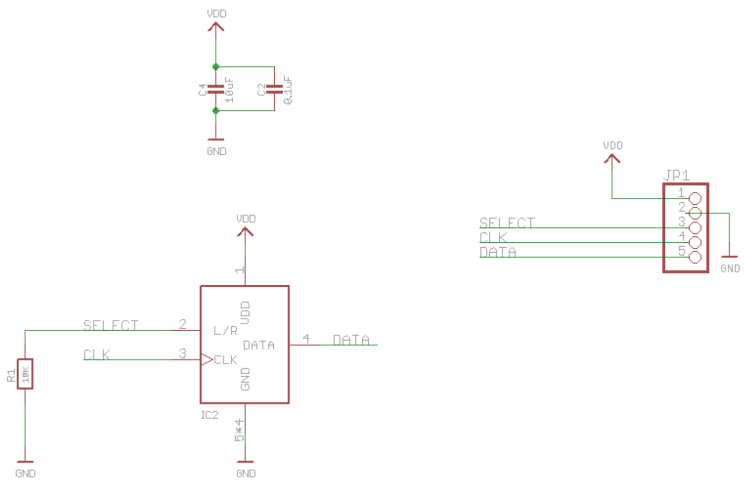

Figure 5: Microphone breakout schematic.

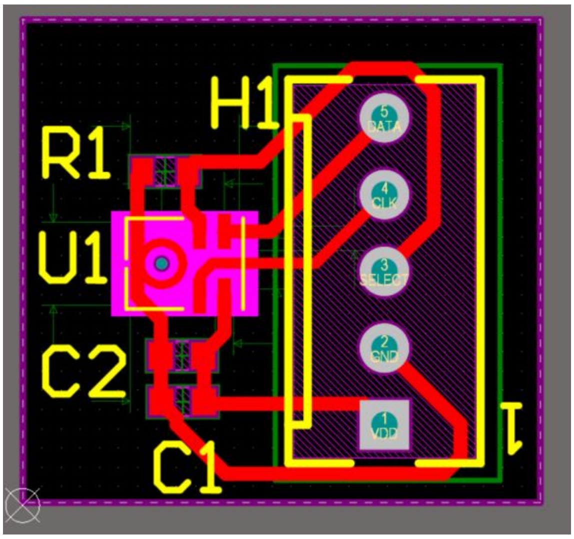

Figure 6: PCB design of the breakout board.

Testing for breakout board

Just after the PCB breakout board has been designed and checked with the technician Diego, the PCB breakout board we ordered has arrived. The breakout board we ordered is a MEMs digital I2S microphone. Some modification to the breakout is needed to swap the microphone, as shown in figure7 below.

Figure 7: Modified breakout.

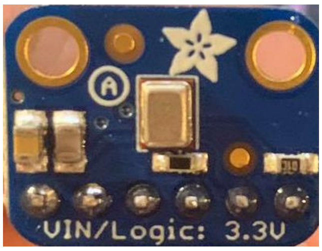

Figure 8: I2S breakout.

After changing the microphone, the breakout board was tested to determine if the breakout board had been modified correctly. For testing, Teensy 4.0 is used to supply enough clock speed (600MHz maximum) for the high sampling rate that the PDM microphone requires. The breakout board was not working. The output of the data out pin was 0 all the time with noise and the generated sound. By rechecking the schematic of the breakout board, the connection was made correctly.

The difficulty was troubleshooting the problem. The problem could be in hardware, or the problem could be in software. Our supervisor, Shayne, has recommended that we use the I2S microphone to do primary testing because it was not worth the time to troubleshoot the problem. The I2S microphone breakout is shown in figure 8 above.

Remaining Tasks

Gannt chart

The project has come to week 14, as shown on the Gannt chart below, as figure 9. The current progress is a week behind on the microphone part. It should get to the first week of testing, but it is still on the modelling part as described in progress to date part.

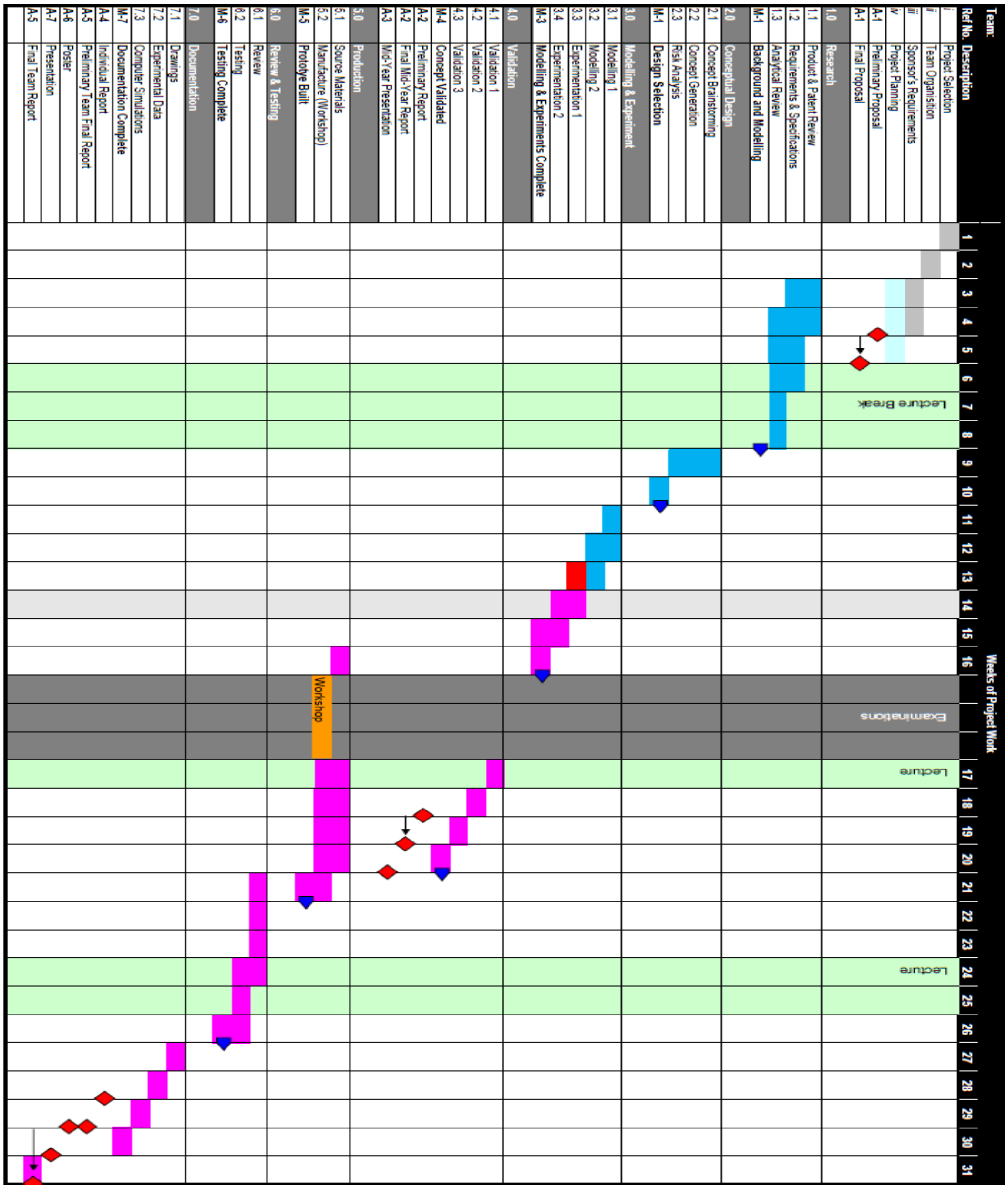

Figure 9: Gantt chart.

Detailed explanation for some Gannt chart points

Finish modelling

Program the I2S microphone breakout with teensy and start testing the ability of the microphone to detect sound. Take the output of the microphone and turn it into the waveform received.

Testing for microphone

Once the I2S microphone can successfully detect sound, tests will be implemented. Tests include:

- testing microphone's ability to perform edge detection; testing microphone's ability to measure distance.
- Testing the microphone's ability to receive a signal in a quiet environment.
- Testing the microphone's ability to receive a signal in a noisy environment.
- Testing the microphone's ability to receive a signal in an anechoic environment.
- Testing the microphone's ability to receive a signal in a reflective environment.
- Testing the microphone's ability to receive a signal in an absorptive climate.

Validation

Finish testing with results and start working together with other group members on developing methods that measure distance accurately. Once some methods are developed, start testing with multiple devices and get the 3D-distance mesh to work.

Sustainability Analysis

Environmental impact of the Limpet

Life cycle analysis is used to analyze the environmental impact on the planet of this project. This section discusses the life cycle analysis in base component procurement, production, distribution, usage, and end of life. All the aspects are discussed below.

Base component procurement and production

Silicon Semiconductors

Battery

Housing

The housing for this project is constructed using a 3D printer with PLA. PLA is made from fermented plant starch such as corn or sugar cane. The growth of these plants requires land preparation, maintenance and harvesting. The impacts of growing fermented planets on the environment is through power usage or chemicals. For sugarcane grown PLA, the total CO_2 emissions from growth to production is 501kg/ton PLA [12]. PLA plastic emits less CO_2 than other types of 3D printer materials at the transportation stage [13].

Distribution

The developed devices could be sold individually or attached to desk shipped via freight ships. The environmental impact would then be dependent on the number of devices shipped together. Freight ships have a wide range of ecological effects, including air pollution, spillage, ship-strikes on marine megafauna and ballast water containing aquatic invasive species [14].

Individually sold devices would need to be manually installed by the customer. Shipping these would be best done in bulk to the office. The practical impact per device can be kept down if the devices are sent together. Shipping many devices to a distributor would be the best option. From the distributor, the devices could be placed onto a desk and reshipped.

Usage

The Limpets are going to be used in offices. It has both operational requirements and maintenance requirement for usability.

A primary operational requirement for the Limpet is energy. Energy for the Limpet comes in the form of a Lithium button battery. Ten years is the operational lifespan of a Lithium button battery [15]. Using a battery instead of an external energy source means that the Limpet has no effect on energy consumption during operation. Due to the batteries require replacement instead of charging. Limpets' features mean that energy use improvements can be implemented, reducing overall energy use even with increased use of the Limpets.

In the case of a Limpet requiring repairs, the device would be replaced. Replacement instead of repairing is due to the Limpets being a low-cost device, and incurred costs of repairing a Limpet may be more than the Limpet's worth.

End of life

The batteries are taken off the Limpet at the end of life and ship to the battery recycling place. The battery recycling place removes all the non-metal parts and ships the mixed metal to the metal separation factory [16]. The housing of the Limpet is collected and recycled at a PLA recycle factory. PCB of the Limpet can be recycled in three ways at the end of life, thermal recovering, chemical recovering, and physical recovering [17].

For the thermal recovering process, PCB must be heated to a high temperature to recover the metals present on the board. FR-4 is a composite material composed of woven fibreglass cloth with an epoxy resin binder that is flame resistant. Thermal recovery will incinerate the FR-4 but retain the copper. This process creates harmful gases in the air like lead and dioxin.

For the chemical recovering process, a bed of acid to recover the metal from the PCB. The PCB board is put into the acid, destroys the FR-4. This process creates a large quantity of wastewater that needs treatment before disposing of into the ocean.

The physical recovering process involves shredding, smashing, breaking, and separating the metal from non-metal components. This method has the most negligible environmental impact. It is a hazard for everyone working around the PCB. This process sends dust, metal, and glass particles into the air, leading to respiratory issues if exposed for prolonged periods. This method does retain all the metal components from the PCB.

Social impact of the Limpet

The work environment is reshaped into a more efficient, more employee loveable environment with the effect of the Limpet. The environment changes as employees need by using the 3D-mapping system. The Limpet system allows companies to builds the most comfortable and most efficient working environment for their employees. This project's aim of developing software for a device that improves the well-being of employees and the ergonomics of office spaces is achieved. The effect of the Limpet is not limited to the office space. Happier employee becomes happier parents, happier flatmates, which has a significant impact on social environments.

Energy impacts of the Limpets

Energy impacts of the Limpets are stated below. Lighting can be controlled by the hot-desking of the Limpets. If nobody is in an office area, lights can be turned off. With the 3D distance mesh system, some office structure analysis can analyze the position of the air-condition placement. Air conditioning can be placed in the places of most usage. This can minimize the cost of using the air conditioning.

Conclusions

The understanding of the project has changed three times as the project progress. Our supervisor and our sponsor approved the final knowledge of the project. Research of the mesh network does not affect the project, and the time was wasted. The breakout of I2S should be used for testing in the first place as it has more chance to work than the modified PDM breakout board. The microphone test for the I2S microphone needed to be undertaking soon. An unmodified breakout board should be working, and implementing the code to program the breakout board needs to take place soon. More than 8 hours per week worth of work will be done during week 18 to week 20 to compensate for the loss of progress for the project's experiment.

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