Trackphones

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1. Introduction

1.1 Objective

Commercially, headphones today are able to create the illusion of sound coming from different directions and positions through the use of stereophonic sound. This is commonly achieved by having two different channels of audio with slightly different timing and intensity. In combination, a listener's brain will decode this information by triangulating the position of sounds [1]. However, when a listener rotates his/her head in real-life, sensory input to the brain changes, and a perceptual experience of space occurs. Developing this type of spatial effect in audio is not yet readily accessible and is increasingly necessary in the context of virtual reality.

The goal of this project is to create a device capable of augmenting an existing pair of over-the-ear headphones. This device would allow for the ability to track head orientation so that composers can create music in a 3-D space, while listeners can have a more immersive and realistic experience that varies with the motion of the user's head.

1.2 Background

There are technologies, such as virtual reality (VR), that have implemented the concept of head-tracking. In addition, some museums have even started to integrate 'engaging' experiences in exhibits that entail a walk through tour with sounds. Evidently, this sort of technology and experience is gaining in popularity and is increasingly sought after for development. For this reason and for the sake of innovation, the project we propose combines these ideas: head-tracking for engaging sound experiences.

Currently, such products that use this technology are the Oculus Audio SDK [2] where spatialization and head tracking can modify monophonic sound sources to make them sound as if they were originally from a specific desired location. VR headsets also have volumetric sources, which produce sounds that vary in magnitude depending on your virtual distance from them. The varying magnitude of virtual sources will simulate distance for the use in a virtual space, as the sounds will be spread out and change over the space as one virtually moves.

Another relevant existing project includes the wearable FLORA project. The FLORA project uses a high precision 3-axis accelerometer and compass sensor. In our project, we will also include both the accelerometer and a magnetometer. How the accelerometer works is it will measures the headphone's acceleration forces such as gravity, and most importantly dynamic motion of the user. The acceleration reading is twice integrated in order to achieve information on the change in position of the user. This electromechanical device will be useful for determining how sounds will be perceived by the listener. The function of the magnetometer is to determine the position of the sound system. Since the acceleration readings depend on the orientation of the sensor, the magnetometer data must also be considered when computing the position of the user in order to "de-frame" the acceleration data with respect to the global coordinate system. The accelerometer and the magnetometer must function in unison for this project to be successful.

1.3 High-Level Requirements

- The device should perform head-tracking in “real-time,” i.e. send data a refresh rate that is suitable: at least 30 Hz, but preferably 60 Hz or more.
- The device must have a button to calibrate/reset the system so that the position that the user is facing when the button is pressed is forward-facing. This means that all position data (x,y,z) and angle data (roll, pitch, yaw) should be sent as 0, in the appropriate units.
- The device must be able to send position and angle data accurately up to within a 1 meter radius of the absolute measure for position and the absolute measure ± 3° (or about 0.05 rad) for angles. The absolute measure for position can be measured independently and compared to the output data.

2. Design

2.1 Block Diagram

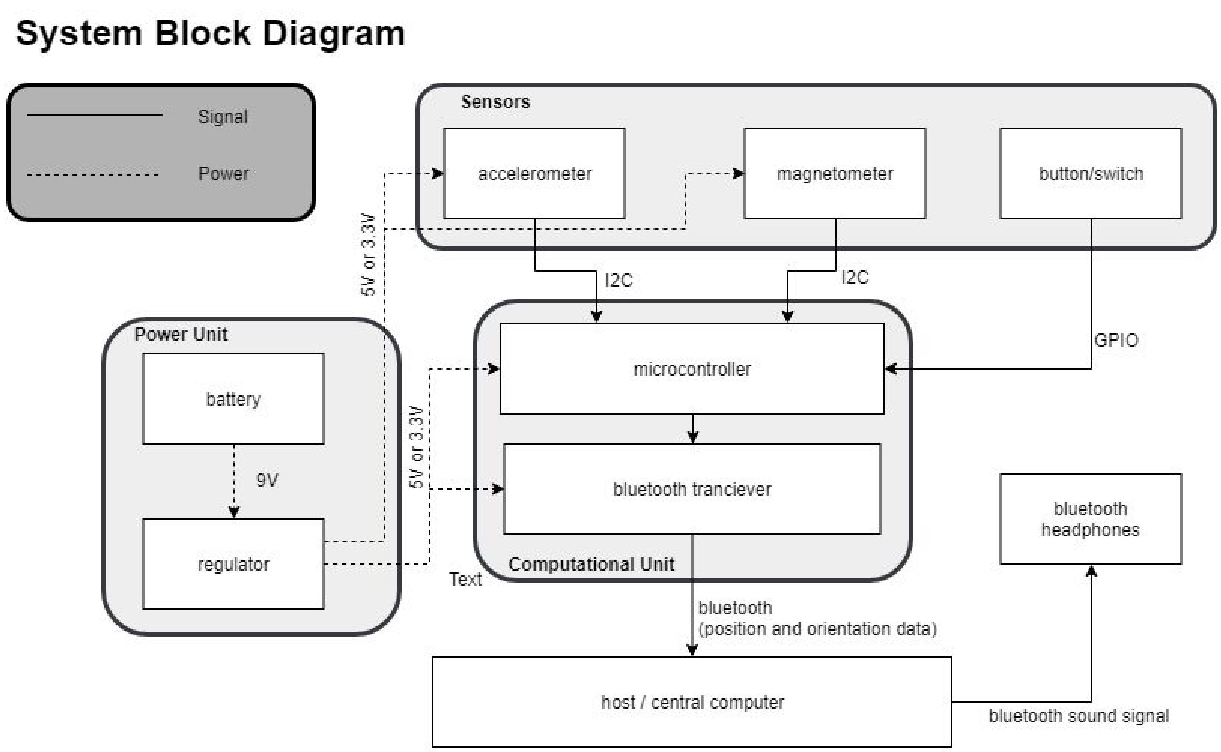

Figure 1. Block Diagram

2.2 Physical Design

The computational unit, the power unit, and the sensor unit will all exist in one chassis attached to the top of a pair of off-the-shelf, over-the-ear, bluetooth headphones. The headphones and the box will not interact electronically; they will communicate with the host computer using separate bluetooth signals. Somewhere in the same room the user is wearing the headphones, there will be the host computer. The host computer receives position and orientation information about the head from the sensor box and sends a sound signal to the bluetooth headphones.

Figure 2. Physical Design

2.3 Functional Overview

2.3.1 Computational Unit

2.3.1.1 Microcontroller

The microcontroller receives and processes data from the accelerometer, magnetometer, and button to produce the relative position and orientation of the headphones to relay back to the host computer. The button status is used to set the origin state of all six position and orientation data points. If the button is pressed, the current orientation and position of the headphones becomes the new zero from which to measure all deviations from that initial state. The orientation vector (roll, pitch, and yaw) of the headphones is deduced by the data from the magnetometer. The magnetometer acts as a 3-axis digital compass and relays information about the direction of magnetic north relative to the orientation of the sensor on 3 axes. The position vector is obtained by integrating over the acceleration data from the accelerometer with reference to the current orientation of the headphones as deduced by the magnetometer. A Kalman filter, a signal processing technique, will be utilized to ensure the position data information is stable and as accurate as possible. The position data (x, y, z) relative to the set origin and the orientation data (yaw, pitch, roll) in radians as floating point values. This data is sent to the bluetooth transceiver.

Requirement 1: The microcontroller must return frames of data at frequency with minimum 30 Hz (may be greater frequency) to bluetooth transceiver.
Requirement 2: The microcontroller must facilitate two I2C connections.
Requirement 3: The microcontroller must facilitate one GPIO connection.

Requirement 4: The microcontroller must be able to program and drive bluetooth transceiver with connection with baud rate of at least 11520 (6 float-64 values per frame with a frame rate of 30Hz).

2.3.1.2 Bluetooth Transceiver

Relays position and orientation information from the computational unit to the host computer over wireless bluetooth connection.

Requirement 1: The bluetooth transceiver must sustain a connection with the host computer for distance at least 5 meters away in a standard indoor room environment.
Requirement 2: The bluetooth transceiver should be able to send data with baud rate of at least 11520 (6 float-64 values per frame with a frame rate of 30Hz).

2.3.2 Sensor Unit

2.3.2.1 Accelerometer

Records data on 3-axis acceleration of the sensor box and relays information to the microcontroller over an I2C connection.

Requirement 1: The accelerometer should measure acceleration over 3 perpendicular axes.
Requirement 2: The accelerometer should return data with a frame rate of at least 30 Hz.
Requirement 3: The accelerometer must work over range of at least ± 2g.
Requirement 4: The accelerometer must accept DC power source of 3.3 ± 0.3V or 5 ± 0.3V.
Requirement 5: The accelerometer must have sensitivity of at least 1024 counts per g.
Requirement 6: The accelerometer must communicate over I2C connection.

2.3.2.2 Magnetometer

Records data on 3-axis direction of magnetic north relative to the orientation of the sensor box and relays information to the microcontroller over an I2C connection.

Requirement 1: The magnetometer should measure magnetic field over 3 perpendicular axes.
Requirement 2: The magnetometer should return data with a frame rate of at least 30 Hz.
Requirement 3: The magnetometer must accept DC power source of 3.3 ± 0.3V or 5 ± 0.3V.
Requirement 4: The magnetometer must communicate over I2C connection.

2.3.2.3 Button

Sends a signal on its state (pressed or not pressed) to the microcontroller over GPIO connection.

Requirement 1: The button must be easily-pressible.

2.3.3 Power Unit

2.3.3.1 Battery

A standard, off-the-shelf 9V battery as the supply for the regulator.

Requirement 1: The battery must supply at least 0.5Ah.
Requirement 2: The battery must deliver at least 0.25A.
Requirement 3: The battery must hold 9 ± 1V DC supply.

2.3.3.2 Regulator

The regulator will take the 9 volts from the battery and produce a stable 5 and 3.3 volts power supplies for the devices within the sensor box (accelerometer, magnetometer, bluetooth transceiver, and microcontroller).

Requirement 1: The regulator must supply at least 0.5Ah.
Requirement 2: The regulator must be capable of delivering at least 0.25A.
Requirement 3: The regulator must hold 3.3 ± 0.3 DC supply.
Requirement 4: The regulator must hold 5.0 ± 0.5 DC supply.

2.3.4 Host/ Central Computer

The Host Computer will receive position and orientation data from the computational unit over bluetooth signal. Using position and orientation data, the Host Computer will produce and process the appropriate audio signal according the composer's soundscape. The host computer sends this audio signal to the bluetooth headphones.

Requirement 1: The Host Computer must maintain 2 bluetooth connections.
Requirement 2: The Host Computer must be capable of streaming audio over bluetooth.
Requirement 3: The Host Computer must be capable of running SuperCollider development platform.

2.3.5 Bluetooth Headphones

The Bluetooth Headphones will be a pair of off-the-shelf, over-the-ear headphones with bluetooth streaming capability. These headphones will simply play the signal from the host computer into the user's ears.

Requirement 1: The Bluetooth Headphones must be able to stream bluetooth audio to your ears.
Requirement 2: The Bluetooth Headphones must be be over-the-ear headphones.

2.4 Risk Analysis

Although all interfaces are important to make this project successful, arguably the most important component is the one that ties all the interfaces into a complete marriage - the computational interface. The reason for the computational interface being the most important for the success of this project is because the microcontroller is the component that receives and sends data to the rest of the modules. Based on the signals received from the accelerometer, the microcontroller is the brain to determine what sounds the bluetooth headphones will send. A good PCB design will be needed for the microcontroller to communicate effectively with the accelerometer and magnetometer. These requirements are difficult but important to implement because they give the dimensions, PCB design, and functionality of the headset.

3. Ethics and Safety

The system we propose to create involves creating a product that will attach to existing headphones. Should there be poor power management, a malfunction could pose a large safety risk, as the user would be wearing the product, and could potentially damage the user's headphones. To adhere to the IEEE Code of Ethics, we would disclose this fact in its release to the public as a potential risk with the use of this product [3]. Additionally, the risk of injury should be minimized with the design being low power.

Based on our current design, we will be using a 9V battery. If metals or any conductive materials come in contact with the batteries, then a short circuit can occur and lead to safety hazards, such as a fire. Our design would ensure that the battery will be in its own compartment, so as not to come in accidental contact with other materials.

Another safety risk this design may pose may stem from the fact that it is to be mounted on top of over-the-ear headphones. Poor mounting may cause the whole assembly to fall off the user, causing unpredictable damages or outcomes depending on the environment the user is in. Again, this risk should be communicated with the release of the product to adhere to the IEEE Code of Ethics: "to disclose promptly factors that might endanger the public […]" [3].

Since the completed project will likely be physically small, the device could become a choking hazard should it come in contact with infants. We will make sure that any mounted pieces on the headphones will be securely intact, so that no small pieces come loose, to minimize this risk.

4. References

[1] R. A. Dobie and V. H. S. B., Hearing loss: determining eligibility for Social Security benefits. Washington, DC: National Academies Press, 2005.

[2] Introduction to VR Audio. [Online]. Available: https://developer.oculus.com/audio/. [Accessed: 08-Feb-2019].

[3] Ieee.org, "IEEE Code of Ethics", 2019. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 7- Feb- 2019].