# PROJECT V.I.E.W: AUGMENTING HUMAN SPATIAL NAVIGATION VIA SENSORY SUBSTITUTION

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## ABSTRACT

Humans primarily use their sense of sight for spatial awareness and to navigate their surroundings, but lack the ability to employ their other senses as guidance systems. This report details the design of a wearable feedback device which makes visionless navigation possible, and has potential uses in low light environments when artificial light is not an option, situations where 360° awareness is important (such as riding a bike on a busy road) and applications where a user is piloting a system remotely. Visually impaired persons could be positively impacted by an affordable device which allows them to sense their surroundings in greater detail than other solutions on the market today.

The feedback platform developed during this research has shown the ability to assist individuals with recognizing and avoiding walls. This has been tested in a virtual maze with a joystick controller and a virtual reality headset. In a majority of cases, users were able to successfully navigate an unknown maze without vision, using the wearable as their primary method for navigation.

***Index Terms*—** Virtual Reality (VR), Sensory Substitution, Augmented Cognition, Vision-less Navigation

## 1. INTRODUCTION

### 1.1. Study Motivation

The VIEW project aimed to create a device that would allow users to acquire detailed information about their surroundings, without using their sense of sight. This could be achieved through sensory substitution by replacing a user's sense of sight with information from physical contact or vibrational patterns. Information communicated utilizing the sense of touch is referred to as haptic feedback.

The applications for such a device could include: aiding the visually impaired, helping a pilot sense their surroundings when their vehicle restricts their line of sight, enhancing awareness when light is restricted, and improving immersive video games. The work done on this project is supported by Northeastern University's Augmented Cognition Laboratory. The results will be used to study human learning patterns in the area of sensory substitution. The continuation of this research will lead to the further development of the device for certain applications listed above, and to discover new applications for the device.

### 1.2. Related Works

Several devices have been designed and constructed which have similar functions and use cases to the VIEW platform. Many of the existing devices differ in their mounting locations, feedback methods, and sensor technology.

Curham and Wolfe [1] have developed a wrist mounted system which uses an ultrasonic transducer to detect objects indoors. This is a device with a single sensor and motor, and thus limits the amount of data that can be transferred to the user. Testing with the device did not see an improvement over traditional methods of navigation using this device.

Sharma [2] created a haptic device installed in a shoe, which is less intrusive than most other designs. It uses four motors to guide the user and linked to the wearers smart phone to access direction. A proximity sensor in the shoe can also provide information, but because of the mounting position it can only work with low objects directly in front of the user.

### 1.3. Our Contribution

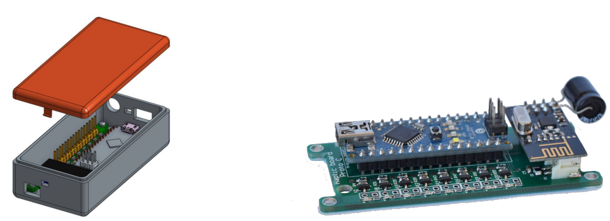

**Fig. 1**: VIEW Wearable

The research team has designed a wearable device that guides users through a space using haptic feedback. The feedback device is a headband with an array of haptic motors that vibrate at varied intensities. By mounting the device on the

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head, the feedback being received intuitively rotates in the same way as the human sense of sight. The mode, intensity, and pattern with which the motors vibrate is programmable. The current iteration uses a program which activates the motors based on the users distance to an object, with each motor representing a 45° field of view. The wearable device also incorporates an RF receiver. This is helpful as the device does not have to contain a processing system or sensor array.

The operating and test platform is a virtual environment. The users position is simulated in a game engine software, which also collects data about the artificial space surrounding the representation of the user in game. Platforms were developed using both a 2-dimensional environment and a VR environment. This tests a users ability to navigate using the VIEW device. The lack of a sensor suite allows future development to include testing with a variety of vibration patterns and feedback cues. This data is transmitted to the wearable which provides the haptic feedback to the user.

## 2. METHODOLOGY

### 2.1. System Architecture Overview

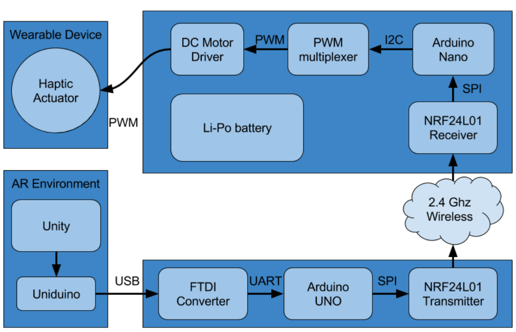



**Fig. 2**: System Overview

In the software simulation, a user navigates a virtual sprite around a maze. Data is collected with raycasts, which are vectors that shoot from the user to the closest object encountered in a given direction. This information is collected at a rate of 50Hz and sent to the user. The raycasts are spaced evenly such that the sum of angles is 360° and they are coplanar to the axial plane of the user's head. The data gathered is converted to distance in feet, and each distance is then further processed to a single byte (0 - 255) that represents the power applied to the corresponding haptic motor. During testing, eight of these raycast events are measured, each offset 45° from one another. It is important to note that more raycast directions could be captured, giving higher resolution data to the haptic device if desired. For that reason, the distances output by the raycast vectors in unity will be referred to as array K.

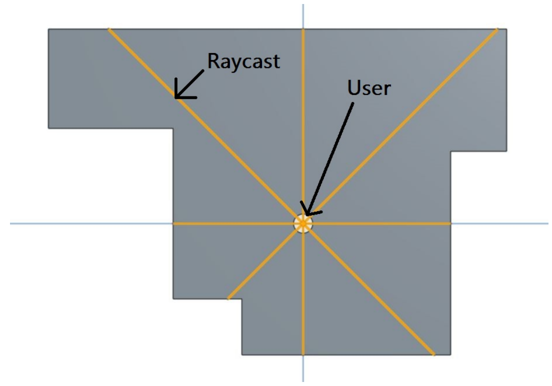
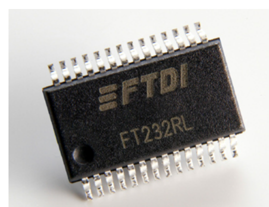
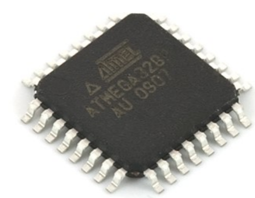



**Fig. 3**: Raycast

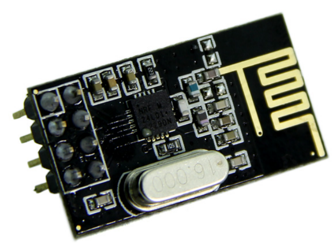
After calculations have been completed, Unity uses a library, Uniduino, to connect to a serial port. This data is transmitted by USB 2.0 to a serial adapter on the Arduino PCB. This converter changes the USB signal to a universal asynchronous receiver/transmitter (UART) signal, which is readable by the Arduino UNO.




(a) USB to UART converter



(b) ATMEGA328-AU MCU



(c) NRF24L01 Tranciever

**Fig. 4**: Transmitter Dongle

The data transmitted to the microcontroller is placed into an object called dataStruct. This structure has the public variables val0 though K, and _micros for timestamps. Using various open source libraries, it sends this object via serial perihperal interface (SPI) to a NRF24L01 wireless transceiver.

The transceiver functions as a transmitter, and sends the aforementioned data via 2.4Ghz electromagnetic radiation to the wearable receiver.

Data is received by another NRF24L01 receiver that has been calibrated to the correct channel (81) to receive the signal of the transmitter. After properly receiving the signal, the component transmits it via SPI to an Arduino NANO.

The NANO takes the data and rebuilds the dataStruct object with K values. This is then processed by more open source libraries that send it via inter-integrated circuit (I2C) to a connected pulse width modulation (PWM) multiplexer. The NXP PCA9685PW multiplexer takes in the I2C signals for each of the K values and matches each to a PWM signal on one of its 16 ports. The device is latching and holds the PWM state sent to a port until overwritten, or if the chip is power cycled.

An N-Channel MOSFET, specifically the DMG3420U-7, receives the PWM signal of one of the K signals. This signal controls power to the haptic actuator and is active high. There is also an LED resistor circuit parallel to the haptic motor that indicates the motor power level.

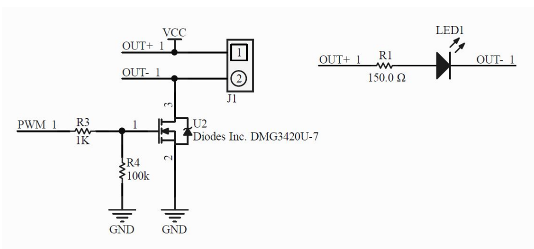
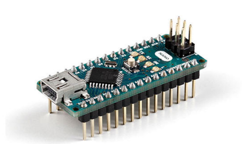
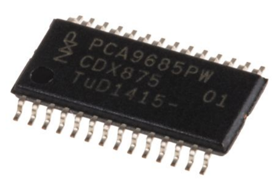


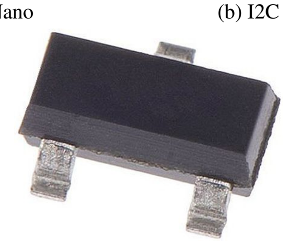

**Fig. 5**: Driver Schematic



(a) Arduino Nano




(b) I2C to PWM multiplexer



(c) NMOS FET Motor Driver

**Fig. 6**: Haptic Wearable

## 2.2. Feedback Design

The haptic actuator used in the design is a linear resonant actuator (LRA). It functions similar to that of a speaker voice coil. There is a magnet in the center of the LRA and a coil wrapped around it. When current flows through the coil, a magnetic field is induced which pushes the magnet to the side of the case. A spring forces it back to return to the electromagnetic field of the coil. This movement of mass in the case of the actuator creates one dimensional vibrations that can be felt on the outside of the case. Due to the spring in the system this actuator is very easy to power, a DC current is all that is necessary.

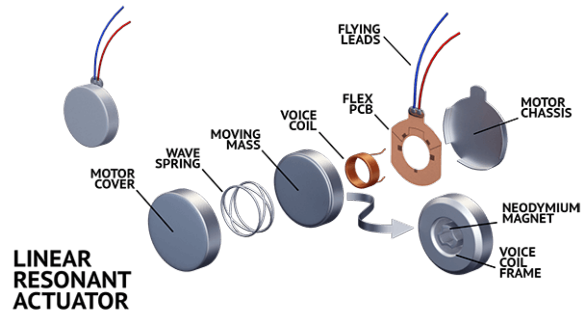



**Fig. 7**: Linear Resonant Actuator

## 2.3. Software Design

In order to create a controlled testing environment, both Unity and Arduino software environments were utilized. Unity was used in order to create virtual environments for users to explore. This also gave the team the ability to easily modify the environments by changing wall positions and scales. A player object was added to the scenes in Unity and could be controlled via a joystick controller or virtual reality headset. When a joystick is used as control input, audio signals are added for ”footsteps” to give the user a feeling of presence in the virtual environment.

In the virtual environment, feedback data was generated at every physics update of the game, which occurred at a rate of 50 Hz. The feedback data was calculated in a C# script which had access to the player location and orientation. For each direction that feedback was calculated, sensory data began at a scaled distance of 2.5 feet from a wall. Data would increase exponentially as a user approached a wall and would reach a max value when the user was within 1 foot of a given wall. The sensory data was calculated as a single byte value for each motor on the haptic feedback device. This gave a range of 0-255 for possible feedback values. As an additional special case, an audio signal would notify the user of a collision with a wall.

Once all of the data was calculated for a specific time point in the virtual environment, the data was sent to an Arduino connected to the computer. This was managed by using a Unity library, Uniduino, to connect to the Arduino and open a serial port. The team developed a function to send the desired data and format via the C# serial port object. At this point, the Arduino software took over and placed all of the data in a C++ structure, using an RF transmitter to forward the data to the haptic wearable.

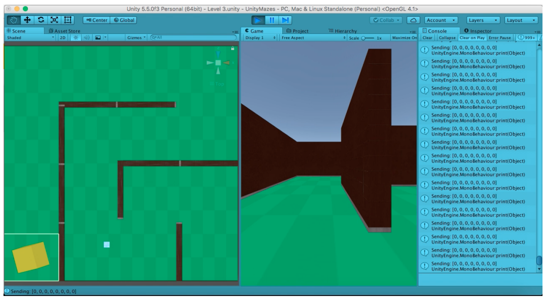


**Fig. 8**: VR Software environment

## 2.4. Testing Environments

While designing the testing environment for the haptic feedback platform, the team chose to have eight feedback motors with which to convey data to a user. The C# script calculating data in Unity was updated to match this decision and as a result, eight values were calculated for the K array in each data transmission. As an example a single transmission could include this data: $\{75, 0, 0, 33, 33, 35, 35, 75\}$ and over time the data can be graphed to store the information sent to the user.

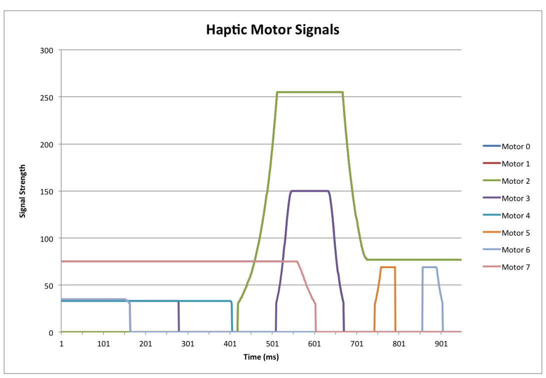



**Fig. 9**: Graph of Sent Data over Time

The directions chosen for raycasts and calculations started at 22.5° clockwise from the back of the player's head orientation and were spaced 45° apart in a circle on the axial plane of the user's head. This gave the testing environment augmented feedback by scanning a 360° range of vision instead of a normal field of view, which is approximately 190° for humans if peripherals are included.

In order to find distances to objects in the virtual game, the Unity Physics.Raycast() functionality was used. This returned the shortest distance between the user and an object in a straight line in each of the eight directions chosen. The methods chosen could be updated in order to match different configurations, such as more or less than eight directions, or searching for small objects with a Unity collider component rather than many straight lines. In this way, the software would not limit the feedback platform in terms of data collection.

# 3. EXPERIMENTAL RESULTS

## 3.1. Experiment Setup

To test the feedback system participants were presented with two experiments. The first experiment was a 2D Unity maze. The user would be tasked with navigating through the maze using a joystick controller. The second experiment was a 3D VR Unity maze. The user would be tasked with navigating through this type of maze using a HTC Vive headset. In each of these experiments the participants were given three scenarios. In the first scenario the user would navigate through a maze with no visual restrictions. In the second scenario the user was blindfolded and tasked with navigating through a maze with only an audio cue when they collided with a wall. In the final scenario the user was blindfolded and wore the feedback device to aid them with navigating through the maze. During testing, mazes were randomly chosen from a pool so that the user would not be able to rely on their memory.

### *3.1.1. Participants*

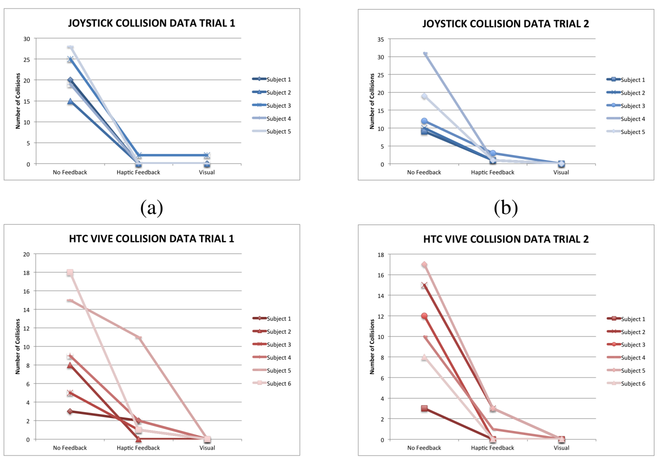
During the two different experiments for which data was recorded, there were a total of eight individuals who volunteered to participate. The participants tested were between the ages of 21 and 30. All participants noticed a decrease in collisions while using the haptic feedback platform as compared to having only audio cues and showed an extremely fast learning curve. From the data gathered, there was a slight trend in better collision avoidance for participants who had previous experience with video games due to the familiarity with the methods of control.

### *3.1.2. Data Collection Procedure*

Each test subject was able to see and able to complete a tutorial maze without collisions before he or she was given visual restriction. Afterwards, in each testing scenario a user would complete one maze. Upon completion, the number of total wall collisions as well as the time it took to complete the maze were recorded. During data collection each user completed all three scenarios twice. In addition to this, to prevent users from learning and predicting the maze layout, the mazes were randomly assigned from a preset list. The maze numbers were also recorded in case it was required to determine if any of the mazes had a quantifiable difference in difficulty.

### 3.2. Performance Evaluation Results

Blindfolded users experienced drastic improvements navigating through the course with haptic feedback. While navigating through a two-dimensional space, users found difficulty monitoring their speed. As a result they were given audio feedback when moving. Subjects with more experience playing video games were able to complete the two-dimensional tests with less difficulty than those who did not play games. However, subjects globally completed three-dimensional mazes with fewer collisions using the feedback system. Once in a three-dimensional test, test subjects were able to navigate with more comfort. In the virtual test setting, users had a much stronger sense of speed and spacial awareness when walking in real life instead of using a controller.




(a) (b) (c) (d)

**Fig. 10**: Testing Collision Data

### 3.3. Discussion

This preliminary study must be followed by similar experiments with more subjects. Future experiments should include visually impaired test subjects to further test the applications effectiveness for said users. The test could include moving objects in the virtual environment once the users are comfortable navigating through a room. The number of sensors on the headband could increase or decrease as some users may be overwhelmed by the increased spacial awareness or conversely desire more information. The intensity and precision of the haptic feedback could also be customized during configuration to ensure comfort and ease of navigation.

Training systems in virtual reality allow a user to safely practice performing an action multiple times, and build the users muscle memory after physically performing motions in real life. Once there is enough confidence in the virtual experiments, a user could then attempt to use an external sensor in the real world to navigate in a safe environment. The VIEW feedback system has been interfaced with a 360° LIDAR scanner using the same range of feedback as in the simulation. A user is able to obtain information about the environment with higher efficiency in virtual reality than the real world due to current limitations of sensors. The 2D test can apply to navigating a maze with a remote controlled robot attached to a LIDAR sensor. The 3D test would translate to navigating through a room in the real world with more advanced sensors.

## 4. CONCLUSION AND FUTURE WORK

The research has demonstrated the effectiveness of the platform in conveying data to the user with haptic feedback. Users have seen immediate results when using haptic feedback in the form of recognizing the presence of nearby walls in a maze and avoiding collisions with said walls. Navigation with haptic feedback is not as fast or reliable as navigating with vision, although this research has proven to be a means of visionless navigation.

This platform has gone through three PCB iterations over it's design process. It is now more streamlined that the first iteration and can be worn on a user's person as a belt attachment. An area of future improvement would be shrinking down the PCB, building a microcontroller directly into it, and adding a Li-Po battery charge circuit.

Another area of improvement would be the drive circuitry for the haptic actuators. A PWM signal is primitive way of controlling an actuator of this type. In the future, it would make sense to purchase proper drive circuitry, with added haptic capability.

The final area with the largest improvement available is the haptic motors and headband itself. From making the headband thinner and subtler, to having more haptic actuators that give a higher resolution of data to the head.

Finally, the research has also proven the effectiveness of this feedback testing platform. Using a VR environment for testing has allowed for a controllable testing environment. This testing environment can be adjusted easily to match physical metrics on the feedback device. This method of testing also stresses safety; users were able to walk around an empty room and experience virtual collisions with no harm to his or her person.

## 5. REFERENCES

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