iFeel: Vibrotactile Feedback Using the iPhone to Identify Objects in Augmented Reality

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With new developments in haptics, rather than just seeing virtual objects, touch can now be implemented in augmented and virtual environments. Existing applications of haptic technology, such as the vibrotactile glove, are bulky and inaccessible to the public. Alternatively, we wanted to create haptic feedback on a device owned by millions: the iPhone. We built a pipeline for haptics feedback using the Taptic Engine. We used the proximity sensor to trigger an action sequence that used CoreHaptics. With the pipeline, our informal study attempted to emulate prior studies with other haptic technologies. The study centered around the recognition of the number and shape for cubes, and spheres, while also seeing if there is an optimal size. Participants were able to identify the number of objects at a high rate while struggling to identify the cube. Our model was a successful first step into building a baseline for utilizing the iPhone Taptic Engine but is yet to become as effective as prior haptic devices, as users successfully recognized object number.

Keywords: Mixed Reality, Haptic Rendering, Physical Computing, 3D Graphics, Application Design

I. INTRODUCTION

Virtual reality now enables us to experience a virtual environment with touch along with visual and auditory senses. The applications of augmented and virtual reality continue to expand into a variety of industries. To better understand haptics, a haptic interface generates signals which are sent to trigger kinesthetic and touch channels while allowing physical human interaction with the environment [1].

An early haptics study by Lederman and Klatsky [2] determined that various exploratory procedures, such as lateral motion, pressure, static contact, and unsupported holding, were deemed optimal and necessary for determining various features of objects, such as texture, hardness, temperature, and weight. The techniques used in this study would be critical to future studies involving object recognition.

Studies continue to develop more realistic haptic devices. The vibrotactile glove is a common haptic device that consists of a wearable glove with multiple tactors, which are small actuators that vibrate against the skin to provide a physical stimulus. Studies such as the one by Martinez et al. [3] asked subjects to identify cubes, spheres, cylinders, and cones, yielding results well above the chance percentage. Different methods such as vertex and face-based techniques have been used as modes of haptic rendering. Even as many studies attempt to produce low-cost haptic devices [4–6], mid-air haptics is still widely unavailable to the public, which is why we want to create a simple system. A challenge of our study will be using only a single tactor system. However, as seen in Han's work [7], we know that similar results can be achieved for a single tactor vibrotactile glove.

There have been attempts made to produce a smaller device by eliminating the hand-held aspect. The PUMAH model created a mechanism where a plate was rotated for a user to feel with improved positional accuracy [8]. Despite this, the technology can still be simplified into a smaller device to experience haptics in a less bulky fashion, as the model contains various pieces of specialized equipment.

We will use a device available to millions: the iPhone. Prior studies have utilized a bulky phone case with various add-on sensors to produce haptic feedback [9]. However, In recent years, Apple has been shifting towards creating more Augmented Reality applications, creating new capabilities for developers. We incorporated this with the built-in Taptic Engine to produce haptic feedback. Reality Composer was introduced as a tool in Xcode to be used to create an augmented scene which contains behaviors that define the function in the form of a trigger and action [10, 11].

The goal of our project was to create a pipeline for haptic feedback by using the iPhone Taptic Engine, which was used to generate vibrations for notifications with a linear actuator consisting of a vibratory and a touch sensor. Often, the Taptic Engine is used in unison with the speakers to create more realistic sound effects. Core Haptics implementation was utilized to generate haptic vibrations from an AHAP file [12–14]. With the pipeline, we ran studies for object recognition. Our end goal was to achieve similar results as prior studies with displays containing multiple tactors.

II. METHODS

2.1 Building the Pipeline

The overarching goal of our pipeline was to connect the aspects of haptics and augmented reality to allow a subject to move an iPhone around an augmented object, which generates vibrations when interacting with the borders of a 3D object. The application was created for the iPhone 7 or newer running iOS 13.0+ to have access to the Taptic Engine and AR. The code was implemented using Xcode 11 and Reality Composer. ARKit and RealityKit documentation were used to create an Augmented Reality environment for the application based upon the default code given from generating an AR app in Xcode.

For this, code was taken from Apple Developer's Haptic Sampler application code, which plays code from an AHAP file [14]. The Haptic Sampler provides implementation shown in the pseudocode below, which sets up the haptic engine and plays from the AHAP file.

```
function createEngine
  configure HapticEngine
  if (supports haptics)
    startEngine
    else throw error
function playHapticsFile
  do
    retrieve fileName: from input String
    filePath: locate fileName
    if(engine = idle)
      startEngine
    playPattern(filePath, "ahap")
  catch error
```

In the Reality Composer environment, the default scene was used, while creating a custom behavior with the preset proximity sensor, connected with an action sequence which will play a sound and a notify action. The notify action was then taken into Xcode and implemented to play a haptics sound using Core Haptics implementation as shown in the pseudocode below, as AR scene setup starts in viewDidLoad, while the connection of the proximity sensor to haptics occurs in setupNotifyActions.

```
function viewDidLoad
  createEngine
  boxAnchor: loadBox from Experience
  setupARConfiguration for application
  arView.session.run
  arView.append(boxAnchor)
  enable collision handling in boxAnchor
  setupNotifyActions
```

Figure 1: A user is shown conducting the study, feeling out a virtual sphere, while to the right, the initial test file is displayed, where users are able to see the objects.

```
function setupNotifyActions
  allActions.filter(prefix: "Tapped")
  for action : allActions
    if(proximity sensor triggered)
      playHapticsFile
```

2.2 Testing the Pipeline

We conducted an informal study to test the effectiveness of our pipeline. Users were asked to identify different features—number and shape—while we varied sizes to attempt to find the optimal size to achieve the correct answer.

2.2.1 Experimental Setup. For testing purposes, we created an arrow pointer object at the origin of the augmented environment to signify where the objects could be found. With this, we hid the objects from the start so the subject would not have any way to cheat the system.

Prior to conducting our studies, we conducted a survey, which can be seen in Appendix 1, of the individuals confirming they would be able to conduct the study. Participants were either sent the code to run themselves on Xcode or utilized technology provided by us, connecting the laptop to the phone.

During the studies, subjects were asked to find a 2 m by 2 m desk or floor space to conduct each of the experiments, Subjects not tested in person were monitored through a Zoom call on their laptop to ensure that they were following the proper steps during the experiment. Participants were asked to use earbuds in order to limit outside auditory distractions. For the study, we were able to test 5 participants.

2.2.2 Object Number Recognition. Our first informal experiment tested individuals by asking them to identify the number of a given 3D object, shown in an environment. The number of objects varied from 1-5. For the study, we

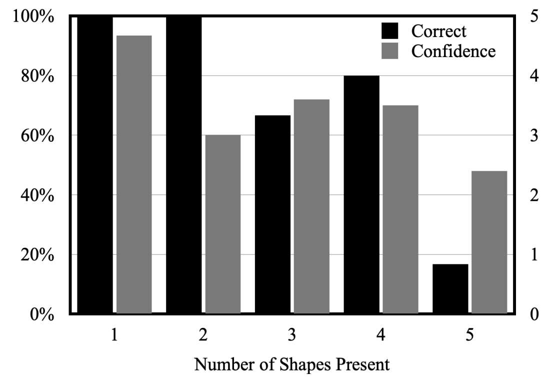

Figure 2: The correct rates and confidence levels for the participants identifying the number of shapes present in an environment, which ranged from 1 to 5 are shown.

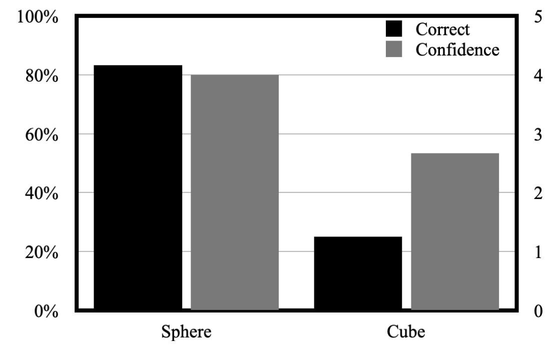

Figure 3: The correct rates and confidence levels for the participants identifying shapes—a sphere or a cube—in an environment are shown. In this study, the shapes ranged in various sizes.

created 5 test files for each of the possible numbers of objects as well as a control file. The files were tested in random order during the experiment process. Subjects would first go through a sample file while being able to see the objects, to understand better what to expect during the experiment. Next, the objects were hidden, as participants were tasked with determining the number of objects present in the scene. In each file, there was one object in the center as a control shape. Each object in the scene had its own vibration pattern. Upon the completion of each test case file, the subject's confidence level was reported on a scale of 1-5, 5 being the highest confidence, 1 being extremely uncertain.

2.2.3 Object Shape Recognition. Our second informal experiment tested individuals by asking them to identify the type of a given 3D object, shown in an environment. The identified objects were spheres and cubes.

For the study, we created 5 test files for each of the possible 3D objects. Once again, the files were tested in random order. The subjects cycled through the files while being asked to identify the object that was being felt. After each test case, the subjects were again asked to respond to the same confidence scale.

2.2.4 Object Size Recognition. Our final informal experiment tested individuals by conducting the previous shape studies with varying sizes for the object to see which size was optimal for recognition rates. For the study, the 5 copies of the sphere and cube from the previous study represented ranging sizes of 10 cm, 20 cm, 30 cm, 40 cm, and 50 cm.

III. RESULTS AND DISCUSSION

3.1 Object Number Recognition

3.1.1 Results. Figure 2 depicts that for environments with 1 or 2 objects, individuals identified the number of objects at a rate of 100%. As the number of objects increased, the correct rates declined, with 5 objects being only identified correctly once. When 1 to 4 objects are present, participants answered correctly at rates well above the chance percentage of 20%, with correct rates from 60% to 100%. Except for when 2 objects were present, the user confidence rate correlates with the correct rate.

3.1.2 Discussion. A potential explanation for why individuals were much more confident for 1 than 2 could be the fact that users were only feeling one type of vibration throughout in the first case, but feeling two different vibrations in the second case could confuse the individual to think that there could have been more present. As noticed from users answers for 3 or 4, they would often overestimate, potentially validating the theory of confusing sounds together.

Low correct rates for the higher number of objects can be caused by the higher number of distinct vibrations to remember, as the fewer objects the easier to remember. An observation made during the study was that different individuals used different techniques. Most scanned the entire area multiple times to ensure no missed objects, while others randomly tapped around the region, which often yielded lower correct rates. Overall, for low numbers of objects, our model was effective for individuals to identify the number of objects present in a scene.

3.2 Object Shape Recognition

3.2.1 Results. Figure 3 illustrates that spheres are recognized at a much higher rate than the cubes, with spheres being recognized at 83.3%, while cubes just 25%. With the confidence levels, spheres had a high average confidence level, while users were unsure when given cubes.

3.2.2 Discussion. During the study, it was observed that individuals were able to identify spheres extremely quickly, but had a difficult time identifying cubes, often guessing

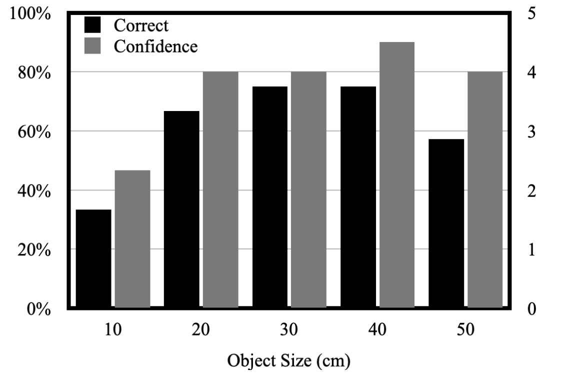

Figure 4: The correct rates and confidence levels for the object size recognition study are shown. In this study, individuals were asked to identify shapes of varying sizes to find an optimal size.

the shape, reporting low confidence. The low recognition rate of the cube may be caused by the default proximity sensor, which uses spherical shapes to build the border for the cube.

3.3 Object Size Recognition

3.3.1 Results. In Figure 4, individuals struggled with small objects of size 10 cm, only identifying them at a rate of 33.3%. Each of the remaining sizes yields correct rates around 60%, showing that as long as it is greater than 10cm, it is relatively easy for individuals to identify shapes. The confidence rates directly correlate with the correct rates for each of the sizes, as individuals accurately reflected their confidence.

3.3.2 Discussion. 50 cm has the second-lowest correct rate, which may be explained by the fact that individuals struggled to locate the object in space. With the graph, it can be seen that around sizes of 20 cm-40 cm yields similar results as anything smaller will be too small to differentiate and anything larger will be hard to find in space.

3.4 General Discussion

For all three studies, users never reported a confidence level of 1, meaning they all had some idea they answered correctly. In Figure 5, user confidence levels accurately reflected their answer as those who reported 4s and 5s were most often correct. Meanwhile, those who reported 2s were nearly always wrong, while those who reported 3s were sometimes right and sometimes wrong. Additionally, the individuals who participated in the study all reported familiarity with Augmented Reality systems, which means that a study conducted with a more general population will potentially yield lower correct rates.

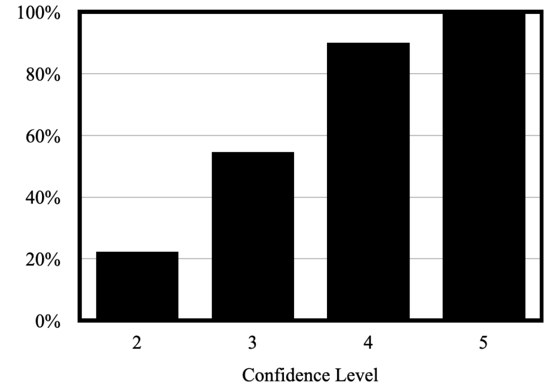

Figure 5: The correct rates compared to the confidence levels are shown. Individuals accurately report their confidence based on how often they are correct.

IV. CONCLUSION

Our study was based on the previous vibrotactile glove studies, which have individuals identify various 3D objects in space, yielded results well above the chance percentage [3-6]. Rather than using multiple tactors, we used a single tactor similar to the study conducted by Han [7]. For our study, we built a pipeline from Xcode onto the iPhone, via Reality Composer and Core Haptics implementation by creating a custom behavior. As the user interacts with the border of an object, they will be able to feel a vibration [11-13].

With the pipeline constructed, we tested 5 participants on various tasks involving our pipeline. First, we asked participants to identify the number of shapes present as well as the type of shape, while varying the size.. Participants were able to identify the scenes with 1-4 objects at extremely high rates well over the chance percentage, while 5 objects were only identified correctly once. Additionally, we noticed that spheres were recognized extremely accurately and quickly, but cubes were difficult to identify, potentially due to the curved edges that we used to construct the cube. It was seen that 10 cm was far too small to identify objects accurately in and 50 cm was too large, making it difficult to locate the object. Any size from 20 cm-40 cm yielded similar results in terms of the correct percentage.

In the future, we will expand our study to test more individuals to have results more representative of a general population. Additionally, we will use more shapes, starting with cones and cylinders, eventually reaching our end goal of creating a tactile music sculpture. To accomplish this, we will code our own proximity sensor with adjustable parameters to enable vertex-based and volume-based approaches.

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APPENDIX

1. Survey Questions

Pretest:

1. What is your age?
2. In this study, you will be sensing vibrations in your hand and moving your hand around in an environment. Is there any reason you would not be able to participate in this task?
3. What is your iPhone model?
4. Are you familiar with Augmented Reality?

Test:

1. (Number) You will be asked to identify the number of objects present from 1 to 5. How many objects are present in this environment?
2. (Size) The shape present can be a sphere or a cube. You may respond with unknown if you aren't sure. Is the object in this environment a sphere or a cube?
3. (Confidence) On a scale of 1-5, 5 being complete confidence and 1 being uncertain, how confident are you in your answer?