Hapto-Visual Game Design through Mid-Air Haptics and Virtual Reality

Lal Miksham Purushottam
MD16MDES11010

Guided by
Dr. Prasad Onkar

A Thesis Submitted to
Indian Institute of Technology Hyderabad
In Partial Fulfilment of the Requirements for
The Degree of Master of Design

Department of Design
May, 2018

Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/ data/ fact/ source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Miksham Purushottam Lal
MD16MDES11010

Supervisor's Certificate

This is to certify that the work entitled **"Hapto-Visual Game Design through Mid-Air Haptics and Virtual Reality"** is a bonafide of thesis work by **Lal Miksham Purushottam** under my supervision for his M.Design degree.

Dr. Prasad Onkar
Assistant Professor
Department of Design
IIT Hyderabad

Approval Sheet

This thesis entitled "Hapto-Visual Game Design through Mid-Air Haptics and Virtual Reality" by Miksham Purushottam Lal is approved for the degree of Master of Design from IIT Hyderabad.

Signature

Project Guide
Dr. Prasad Onkar

Signature

Chairman
Dr. Deepak John Mathew

Signature

External

Acknowledgements

I would like to express my special thanks of gratitude to my Professor Dr.Deepak John Mathew, Dr.Prasad Onkar, Mr.Neelkantan, Mr.Delwyn Remedios for providing an insightful opportunity and mentorship to work on exploratory thesis project, which helped me greatly improve my design learnings and also gave me a first hand experience to cutting edge technology related to design. Also, I would like to thank my teachers, parents, friends and all well-wishers for their constant support and motivation for fulfilling my dreams and aspiration

Table of Contents

1. Abstract

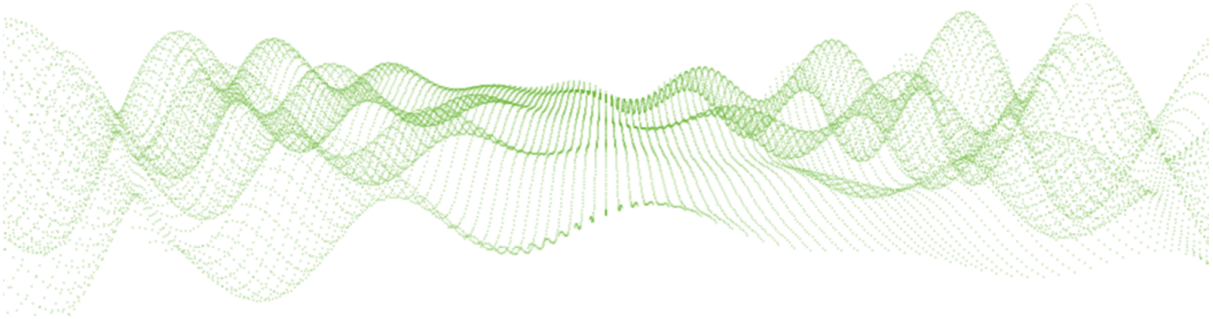
This master thesis covers the design stages of Hapto-Dot, A Haptic - Visual Game, an application that explores the future of new media interactive gaming through mid-air haptic and virtual reality, Game design as a process and game elements as variety of motivating tools are applied in the design process. The purpose of this thesis is to find out how to implement game design process and game elements in multi-sensory immersive new media environments.

The study has been conducted within the frames of design research and it consists of two main stages: concept and elaboration. Before conducting the design stages an overview about approaches of game design process and game elements is presented.

Concept of Hapto-Dot was evaluated via interviewing sessions with representatives of target group. Results of interviews gave the input for refining the concept and defining game elements in the next elaboration stage.

During elaboration stage two iterations were conducted: the first with simulated prototype and the second with functional prototype. Prototypes were play-tested for getting feedback to the design in realistic conditions and for evaluating whether the mobile application is found playful and engaging enough for being popular among target group.

As the result of research it could be stated that implementing game design process and game elements in Hapto-Dot was successful and the development of the application.



2. Introduction

Screen based technologies have advanced to a fascinating extent and the explored capabilities, which include multi-finger input, vibrational feedback, intuitive graphic visuals that supposedly mimic the real world interactions. Also, screen interfaces have been involving in a fashion that it is trying to create interactions that feel three dimensional, and real, but this has it's threshold. interactions in screens cannot be penetrated, which acts as a limitation; and thus a new medium is needed that can overcome this threshold and might be a replacement to screen based interfaces.

The thesis explores the future of screen-less interactions, and how such multimodal interactive interfaces can be designed for a significant purpose. It is focused on a gaming application that could be played in a screen-less environment. The Title of the Thesis is "Hapto-Visual Game Design through Mid-Air Haptics and Virtual Reality".

Mid-Air Haptic technology is new and unexplored, compared to current haptic based technologies. It involves use of phased arrays of ultrasonic speakers which transmit ultrasonic waves that are timed to coincide at a given point in space. The current haptic technology makes use of physical entity in hand that provides a force feedback, and this makes ultrahaptics more flexible and intuitive.

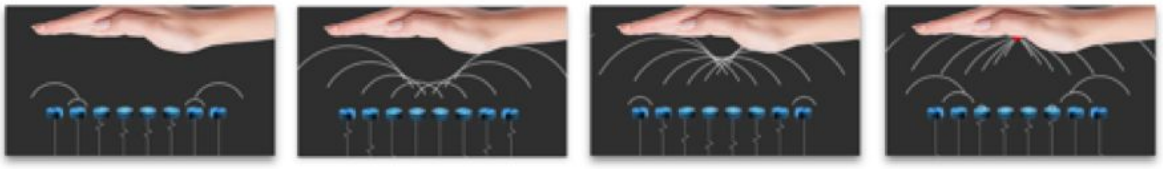
2.1. Literature Review

2.1.1. Understanding Ultrahaptics

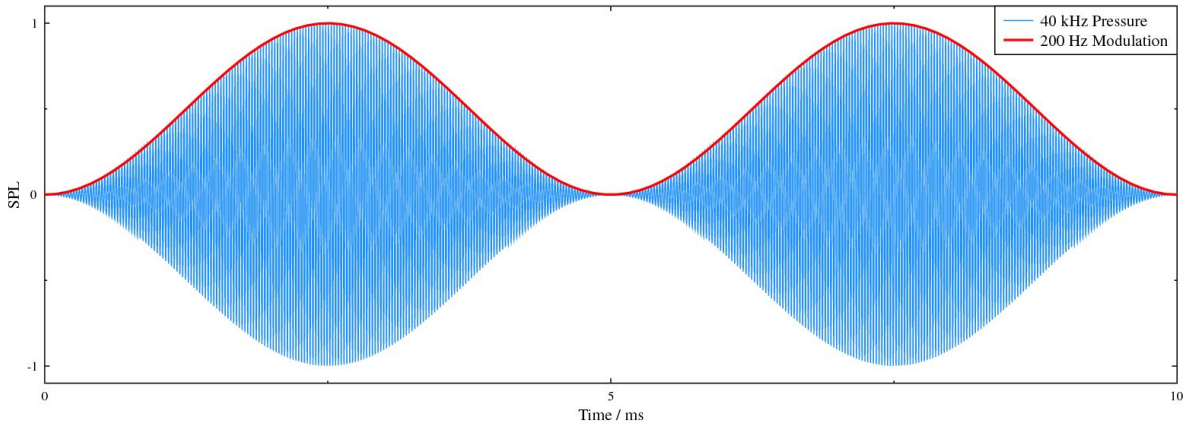
Ultrahaptics is a technology that uses ultrasound waves to construct 3D objects in the air that users can feel. It is primarily a touchless interfaces that go beyond conventional hand-tracking, allowing users to feel haptic feedback so they can tell when they're completing an action. The Ultrahaptics arrays are phased arrays of ultrasonic speakers. They transmit ultrasonic waves that are timed to coincide at a given point in space. By sending a continuous wave the pressure at the focal point can be made to oscillate. Using a hand tracker we can position the focal point on your palm. More complex shapes like lines and circles can be created by rapidly scanning the control point or by using multiple control points simultaneously.

The technology and components in ultrahaptics are illustrated below :

Commercial Ultrahaptics Array



Ultrahaptics uses ultrasound to create and manipulate focused points of high acoustic pressure. These Control points can be moved around in real-time to interact with our hands to create a sensation. The surface of the hands are covered with sensitive nerve endings called mechanoreceptors. Because these are not sensitive to a constant high pressure the control points are manipulated, either by moving them – Spatio-Temporal Modulation – or changing their intensity with a lower frequency wave – Amplitude Modulation.



By sending a continuous wave the pressure at the focal point can be made to oscillate at 40 kHz. However this frequency is too fast to feel. In order to create a haptic point that you can feel, this 40 kHz signal is modulated with a sine wave at 200 Hz, so that the pressure at the focal point also known as a control point in this SDK varies as shown in this graph.

UHEV1 Ultrahaptics Array for academic purposes

(16X16 array with AM and TPS Functionality)

Integrated Leap-motion Sensor

Mini Ultrasound Speaker Array

This sensation is used to signify the starting of a process or action. For example, starting the music on a HiFi. It can also be used to indicate the opening of something (such as a door). 4 focal points start at the centre of user's palm close together, and move away from each other towards the edge of the user's palm.

2.1.2. Virtual Reality as an Immersive medium

In a virtual reality environment, a user experiences immersion, or the feeling of being inside and a part of that world. He is also able to interact with his environment in meaningful ways. The combination of a sense of immersion and interactivity is called telepresence. For immersion to be effective, a user must be able to explore what appears to be a life-sized virtual environment and be able to change perspectives seamlessly. Essentially there are two types Virtual reality devices head mounted displays and cave technology. Mixed reality includes devices like Hololens, which can work well in immersive environment.

immersion can be separated into three main categories:

Tactical immersion - Tactical immersion is experienced when performing tactical operations that involve skill. Players feel "in the zone" while perfecting actions that result in success.

Strategic immersion - Strategic immersion is more cerebral, and is associated with mental challenge. Chess players experience strategic immersion when choosing a correct solution among a broad array of possibilities.

Narrative immersion - Narrative immersion occurs when players become invested in a story, and is similar to what is experienced while reading a book or watching a movie.

2.2. Game Design as a Process

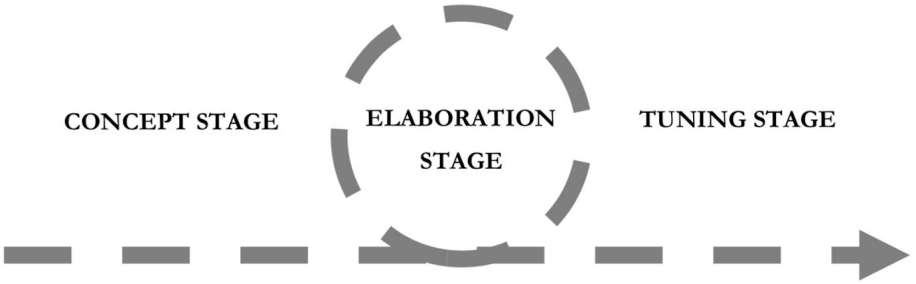
As there are different approaches to design and development process there is also a variety of understandings how games should be created and designed. Here is a review about how our game design process is going to look like.

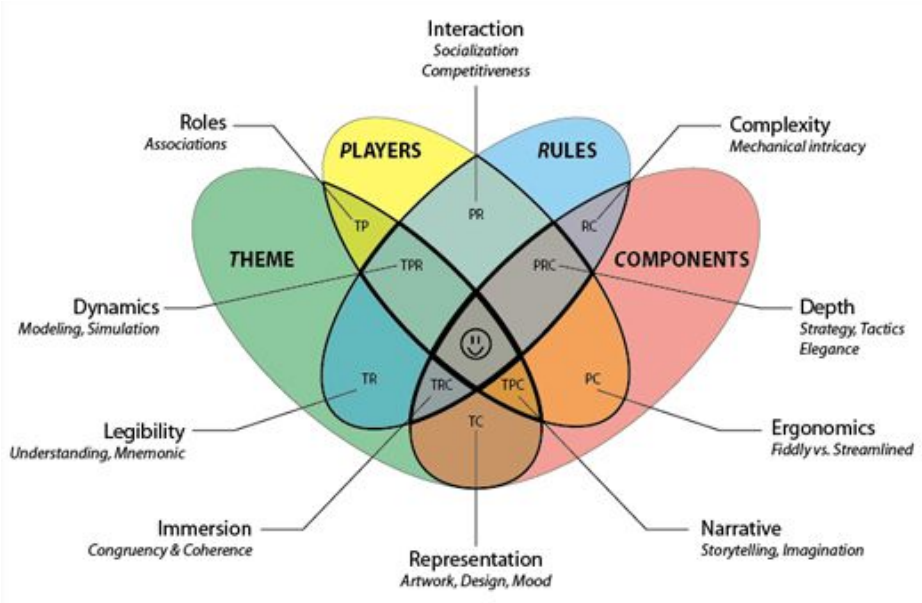
Ernest Adams theory of game design. It includes three stages -

Concept stage – carried out first and its results do not change;

Elaboration stage – most of the design details are added and decisions are refined through

Prototyping and playtesting, tuning stage – no new features added, only small adjustments are made





3. Concept Brief

3.1. Conception about Hapto-Dot

Concept of Hapto-Dot was created based of Adams' approach (Adams, 2010). At first background and assumptions were presented. After that fundamental game concept, game genre, target audience and player's role were defined.

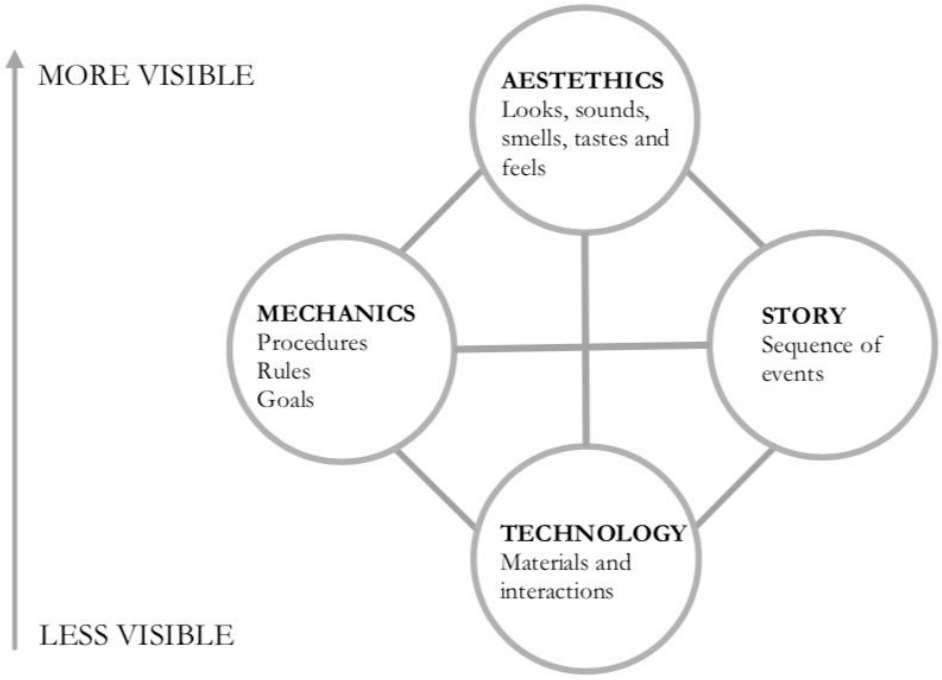
3.2. Background and Assumption

Nowadays, digital technology has taken a step into deeper human engagement, creating paradigms shifts in the way we interact with technology. With screened interfaces in trending existence, it becomes compelling to explore broader dimensions relating to what would our future of interactions be like. For a classic case, gaming industry has made a benchmark progress in human computer interactions. The whole idea in gaming is to make user feel a sense of immersion and evoke appropriate emotions, which can be sectioned into various factors as described below.

The "elemental Tetrad by Schell", defines what matters while analysing the intuitive experience of the game. It can be categorised into less visible and more visible parameters. The fundamental roots of an experience are the visible aspects of Aesthetics, Mechanics and Story. The less-visible aspects is the underlying technology. Though technology is less visible aspect as the user concentrates his mental and visual attention to the visible aspect; the importance of applying apt technology whilst designing an

immersive experience cannot be undermined. Technology determines the interactions and materials that will involve the user's involuntary attention and needs to be intuitive for user to seamlessly sync with the visible aspects of the game. Interactive technology has progressed from simple mouse and keyboard inputs to advanced gestural and tactile inputs. The core differences lies in the flow of interaction. Keyboard and Mice based input relies on a set of relatively fixed rules which determine the outcome of the action, and the interaction space is confined as well. Keyboard and Mice systems specifically enabled objective tasks. The other set of input devices included trackpad, touchscreen and other gesture based input that involved multi-finger interactions with haptic feedback. Haptic feedbacks are provided by keyboard and mouse too, which enables the user to perform the task through spatial and sensation based understanding about the environment. However, such haptic interactions had a planar dimensions and could not be translated to a three dimensional space. The further improvement to spatial input devices include nintendo switch, xbox controller which provide

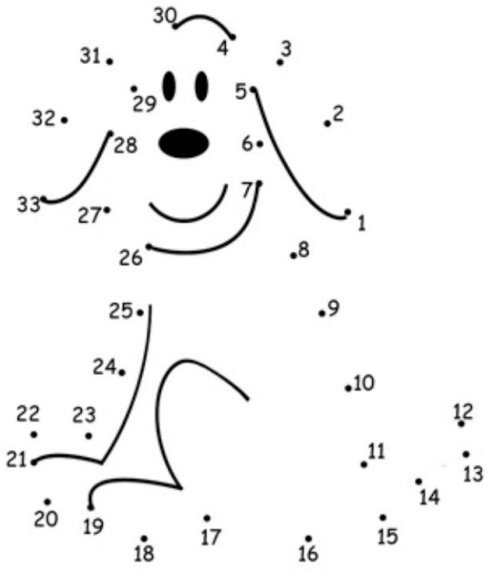
an ability to interact in a spatial environment. All the currently available input devices work through a device in hand, with less degree of freedom.



The assumption is to enable use of ultrahaptics that can provide an enhanced degree of interactive freedom to the user, through mid-air haptic input and interaction. Mid-Air haptics coupled with hand tracker and leap-motion sensor, can effectively make an touchless interface to design immersive application. A game design challenge with ultrahaptics can be a good use-case to explore it's interactivity. Understanding the new media technology from design perspective can prove useful for designing and developing such applications.

3.3. Fundamental game concept

The game Hapto-Dot is essentially derived from a classic game “connecting the dots”, which is a common gaming exercise in schools aimed at training them to learn as well as play whilst they are trying to sequentially connect dots on a sheet of paper and a completion relates to the figure enclosed by the dot. The derived analogy is translated into a new medium that is designed for three dimensional environment. The analogy of visual dot is a haptic dot. Haptic dot is basically a sensation in space that will experientially feel like a dot, and is created through mid air vibrations at a certain point in space with the help of ultrahaptics. The user finds the sensations registers it and finds the next one. Registering all the sensations will reveal the structure fully, thus, rewarding the user with a feelable shape, which is a object of the small scenario. Creations of more shapes will reveal more objects, which can together be experienced as a unified entity. The fundamental behind this is a linear gameplay, which ensures easy learning curve to such new media interaction



Connecting the Dots Puzzle

Above figure shows the example of classic connect the dot games, from which the concept of Hapto-Dot is inspired.

3.4. Game Genre

Hapto-Dot is a casual educational game, that aims to explore and learn about spatial understandings of new media interactions. It involves multi-sensory interactions with haptic and visual entity. The game focuses on providing immersion in free environment, thus helping user understand and intuitively interact.

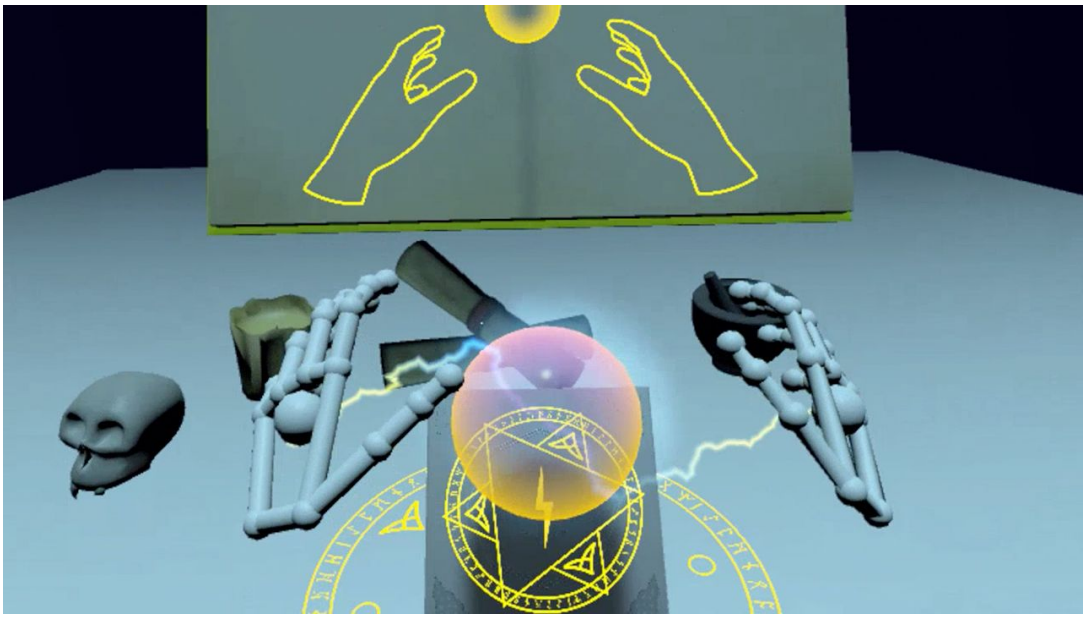
3.5. Target Audience

Target group of Hapto-Dot is adults, kids and teenagers. In comparison there are significantly less entertaining applications for adults. Certainly there can be also users among kids and teenagers, who can learn spatial interactions with improved hand-eye coordination.

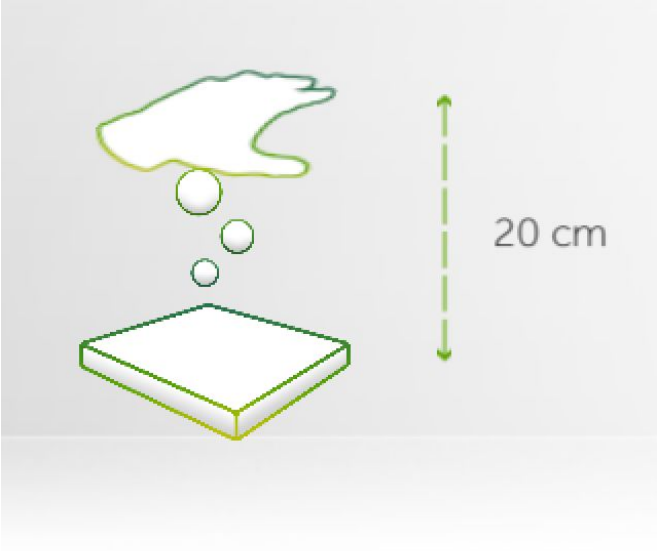
3.6. Player's Role

The player has to sense and connect the haptic dots together to form a shape. The faster he does, the more reward he get. The player is also suppose to guess the shape he is trying to make by connecting. The game also has scenarios, which the player can choose from.

Below is the Concept of player feeling haptic shape on Hapto-Dot :



An representational illustration of hapto-visual experience



Dots will appear ideally from 0-20 cm above device.
The aprox. operating distance is 60 cm

4. Elaboration Stage

4.1. Game Elements

Game elements are building blocks of strategising a particular game. Here is a list essential game elements that will be important while we design an engaging experience.

Goals – the ultimate goal and also sub goals for accomplishing the high level goal; related to and depending on the story of the game.

Gameplay – structure of the game; what the player has to do and how; what makes the player motivated and interested.

Challenges – assignments for the player – pieces of the gameplay; related with time, knowledge, memory, exploration, conflict, competition, cooperation, economic, conceptual reasoning, creation etc.

Rules – regulations and limitations for the gameplay.

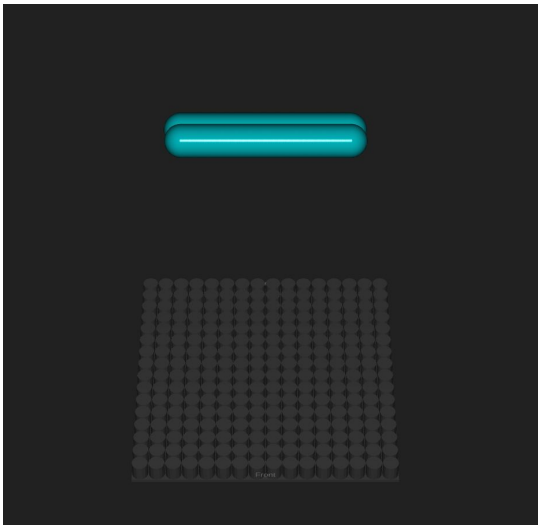
Feedback – communication about the progress, consequences to the actions, rewards and

Facilities – devices, materials, and other objects supporting and mediating the game; visible part of it is considered as game aesthetics.

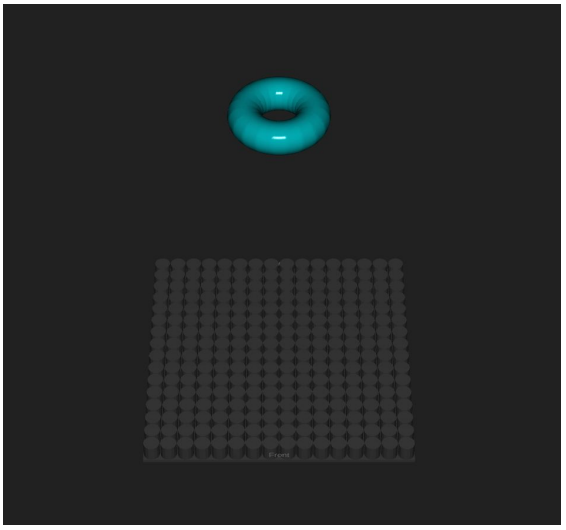
4.2. Interaction Elements and Patterns

Interaction on Mid-Air Haptics was explored and a series of interaction patterns were devised. Interactions can range from static mid air shapes to moving and dynamic feedback. There are two ways, the interactions were designed. Time Point Streaming and Amplitude modulation. Time point streaming is more seamless to look through. Amplitude modulation takes into consideration basic set of interactions and majorly involves static content.

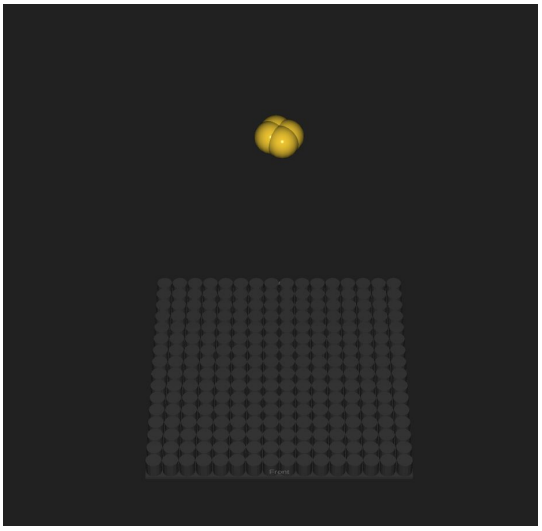
Below are the developed examples of variety of interactions that were designed using sensation editor in ultrahaptics SDK :



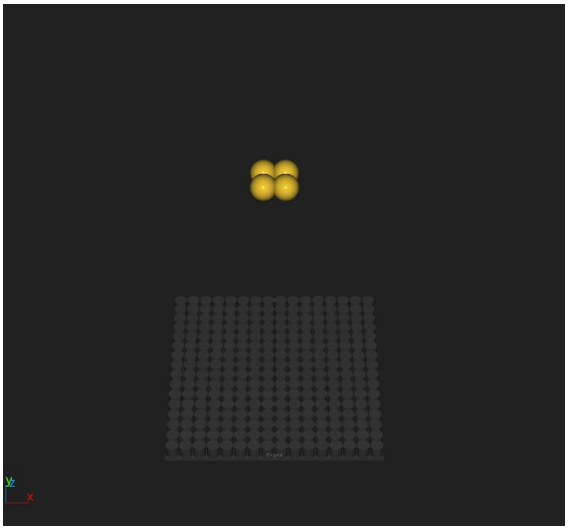
Line vibrations, TPS



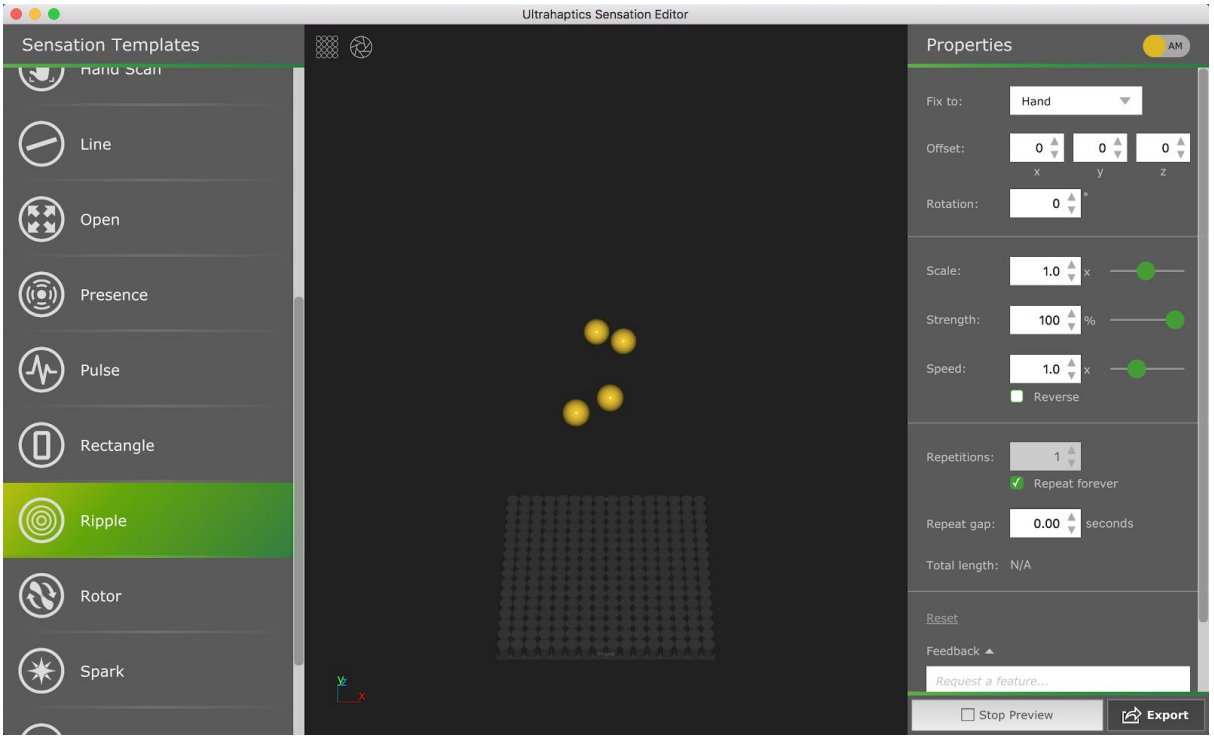
Circle, Time point Streaming



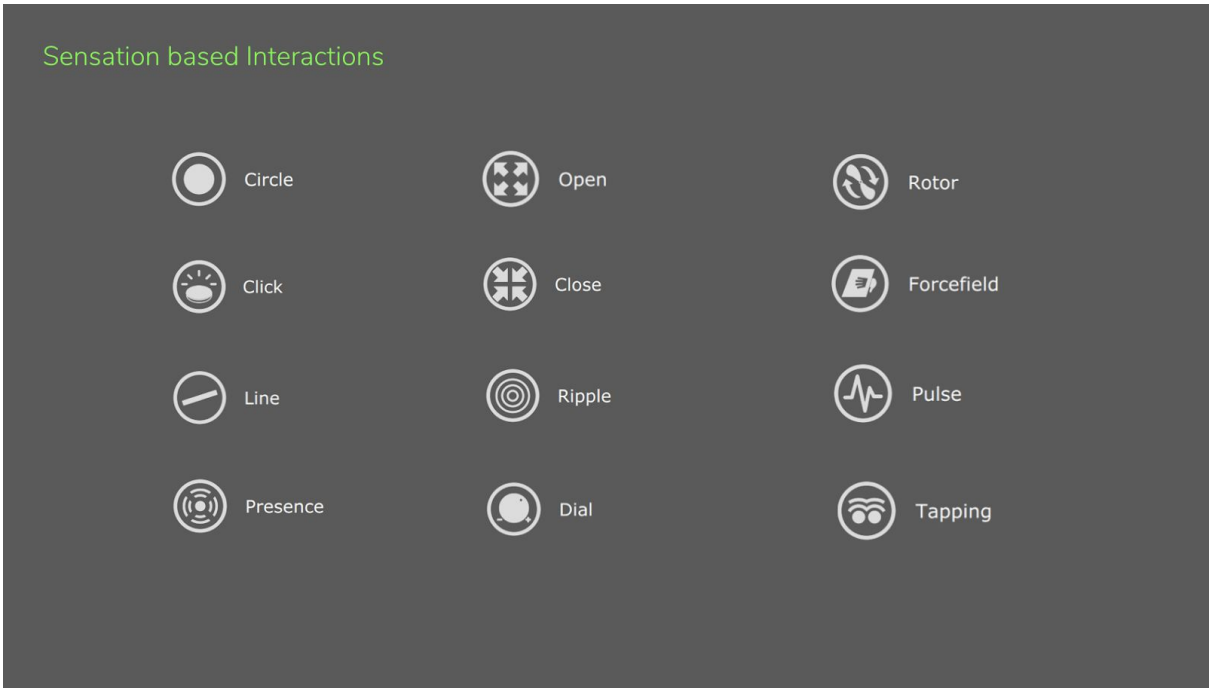
Point Vibration, AM



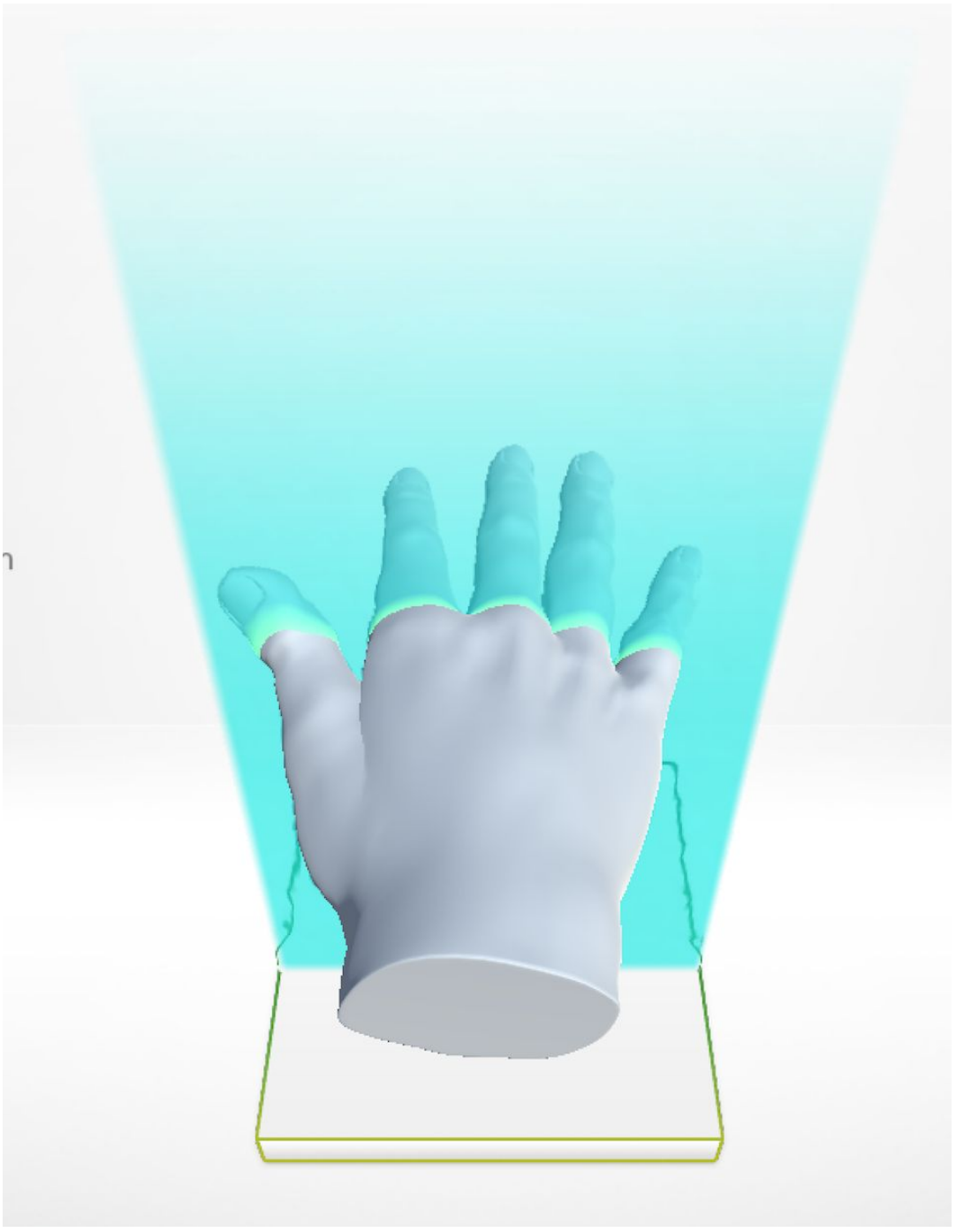
Pulse Point, Amplitude Modulation



Software Parameters to Design a particular sensation, through sensation editor.



List of more sensations that were explored through the sensation editor



Forcefield tactile Feedback through ultrahaptics.

4.3. Goal

The most important game element in Hapto-Dot is the goal. This is what makes the difference between a two dimensional games and hapto-dot. The game provides a life and immersion to simple gaming activity. The ultimate goal is to create a deeper sense of spatial interactivity, and provide intuitive engagement.

4.4. Gameplay

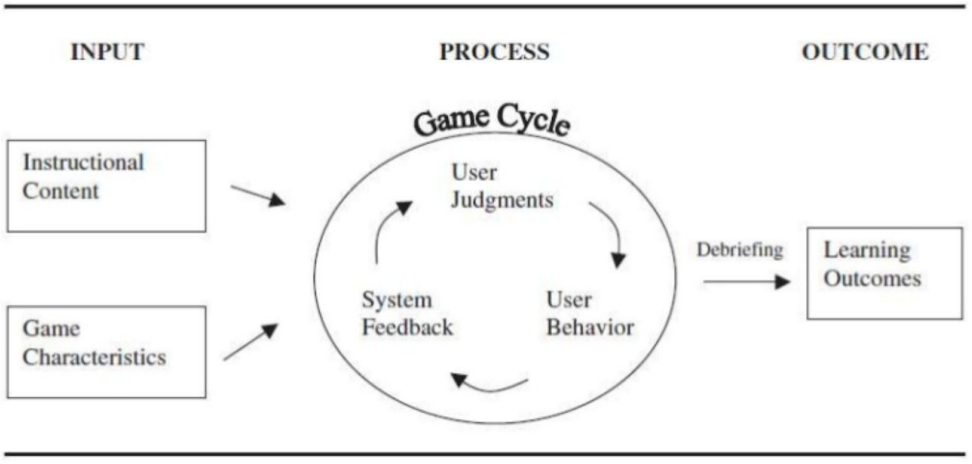
The following steps are involved in the gameplay. First step, sets of game modes to interact - Time based, sensation based, freeform. Next step is to Choose the desired mode -

Time Based - Connect the dots in space in given time

Sensation based - connect the dots based on type of sensation

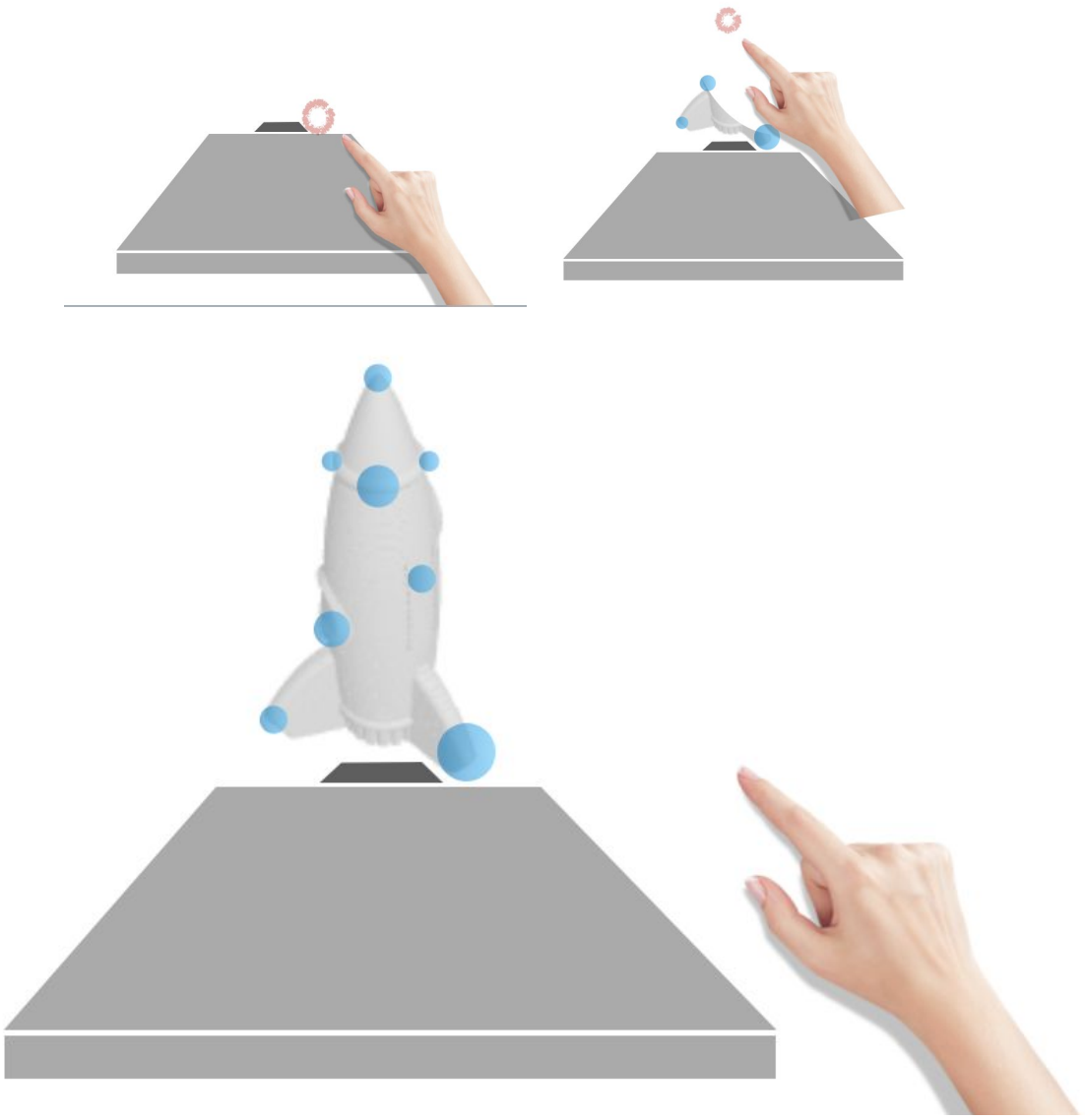
Freeform challenge - Create your own dots and shapes

According to Garris, Ahlers and Driskell, gameplay largely depends on input that engages user in the game cycle and thus creates opportunities for learning outcomes.



(Garris, Ahlers, & Driskell, 2002) 4

With the first game input sensations, the user follows the following flow in the game cycle and completes it, as shown in the illustrative diagram below -



Player Playing Hapto-Dot with rocket shape. When the player connects all the dot, he is able to visualise and feel the rocket in space. This gets added to his inventory of accomplished objects.

4.5. Challenges

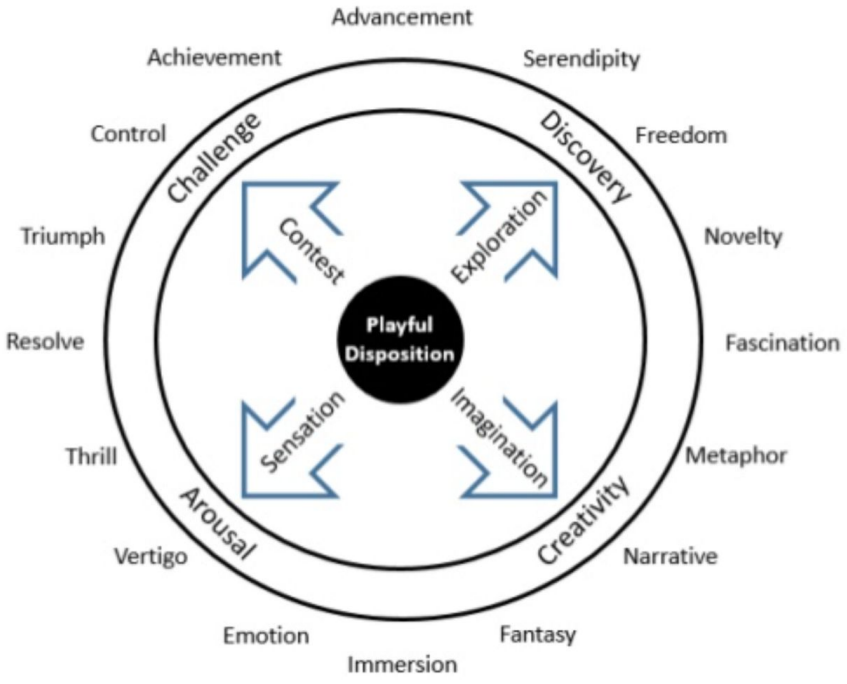
Challenges in Hapto-Dot are designed with respect to following parameters

Knowledge challenges – formulated as quiz questions after connecting the dots about the shape.

Exploration challenges – Formulated as finding and exploring dots in space, with various game modes as described in gameplay.

Creation challenges – Formulated for self learning and exploration, enables user to create his own spatial shapes and iterations by placing dots in the environment.

The challenges are a part of a playful disposition cycle as shown below :



.

4.6. Rules and Caution

For playing Hapto-Dot the player in Hapto-Dot should follow the main rules:

- Player should identify the sensation and register it by pinching the dot. This is necessary to make sure player gets the next dot. The dot is visible on the virtual reality space only when the player confirms that he has found the haptic dot.

- Player is only allowed to search for one dot at a time. Multiple dots cannot be searched at a particular time. The next dot appears only after finding the next dot.

- Player can use only one hand to search the dot. Use of multiple hands is not allowed whilst playing the game.

- Player is allowed to move his hand only in a specified workable area. Ultrahaptics works only 60 cm in vertical direction and 15 square centimeter planar area.

- Player should not put other body parts on the device as it might be harmful for his health. The game is meant to be played standing in front of the device or by sitting on a chair afixed in the environment.

- Player is allowed to skip a level or ask for hints only after 3 tries of not finding the dot in the space. Tries are registered by showing a pass gesture. Pass gesture is defined as open down facing palm over the device.

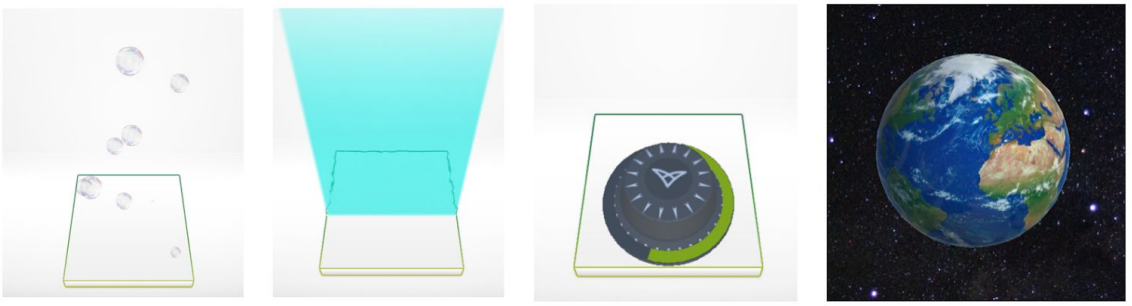
- Player can quit the game anytime he wishes to. Quitting the game requires player to choose the option from the right bottom of the environment as a cross.

- Player can choose his custom interaction sensation as a part of customisation. Customisation can be done to change the dot density, dot feel and the easiness of gaming.

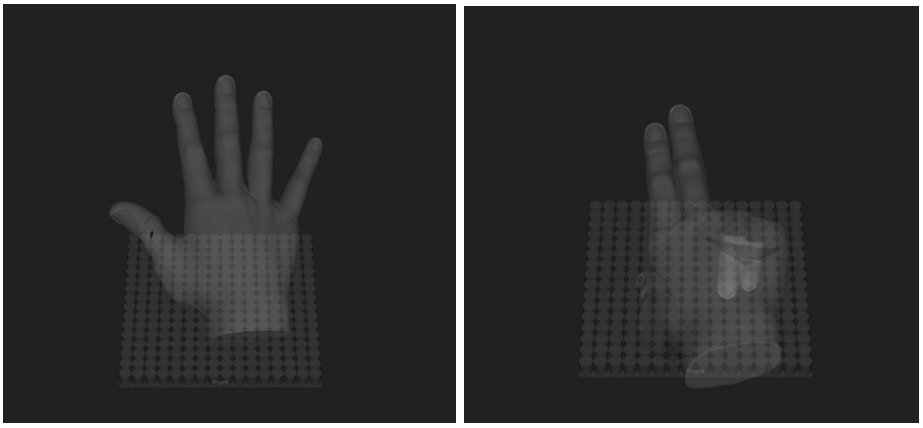
- Player should not play the game for more than 10 mins, and is recommended to avoid prolonged game usage, as it can cause visual and sensation fatique.

4.7. Types of Interactions

A comprehensive set of mid-air interactions were explored and designed through ultrahaptics SDK. These included designing both finger sensitive interaction and palm sensitive interactions. Palm sensitive interactions could enable user to get three dimensional feedback. Finger interactions primarily involved motion based mid-air feedback, specifically dot based.



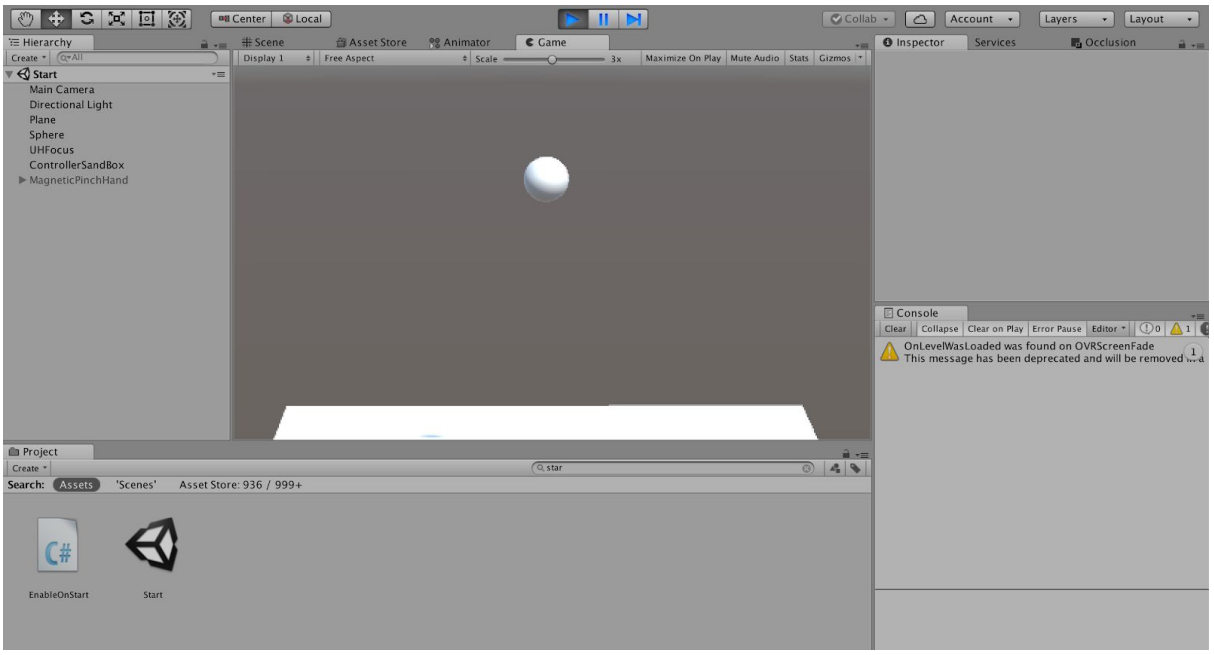
Set of primary spatial interactions with ultrahaptics



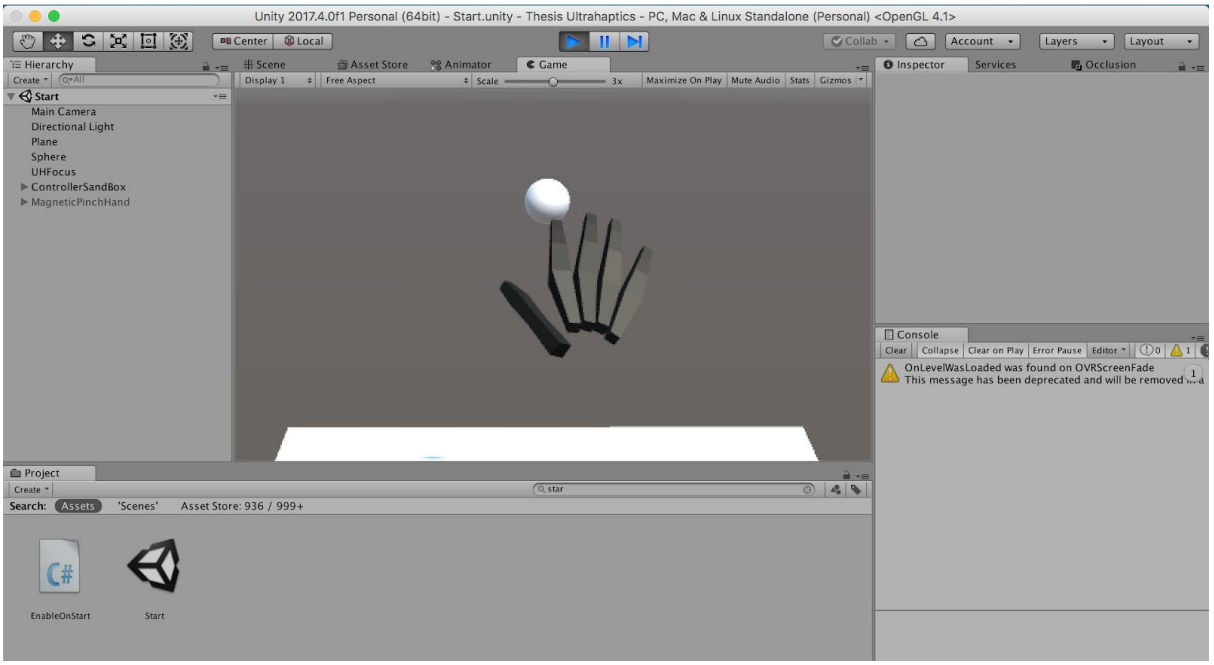
Open hand Interaction Type Finger Interaction Type

4.8. Game Prototyping Process

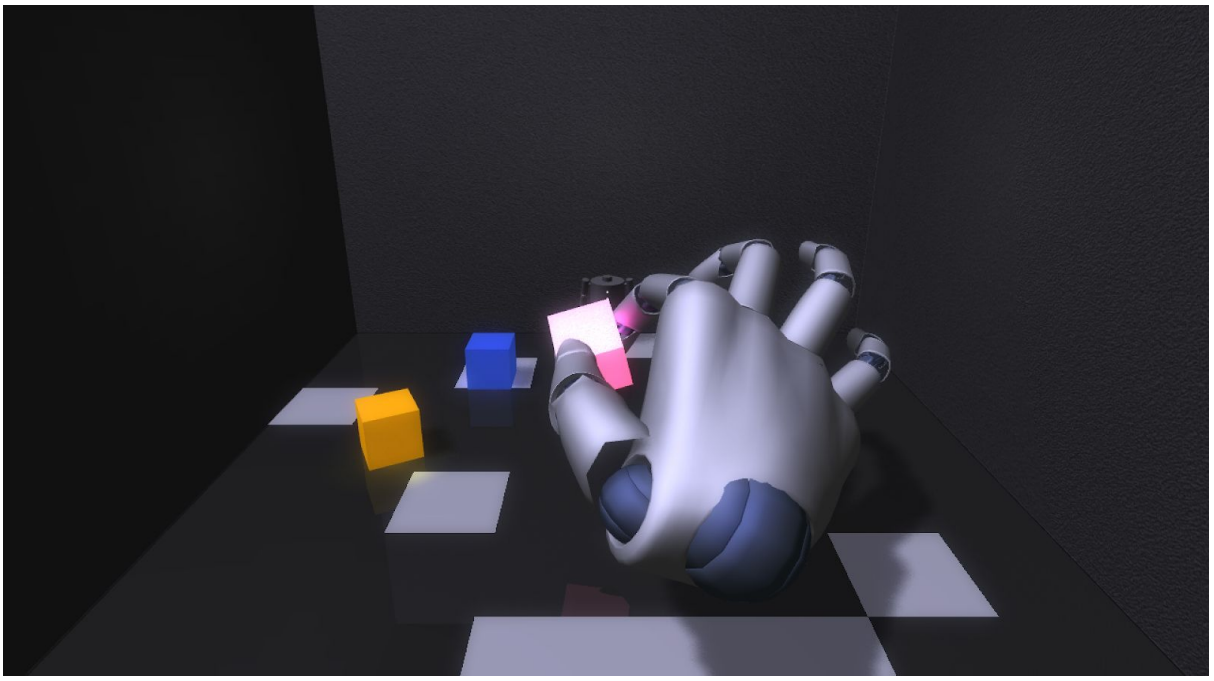
The Game was prototyped on Unity 3D with the help of Ultrahaptics SDK and Leap Motion SDK. The following steps were involved in the prototyping process :



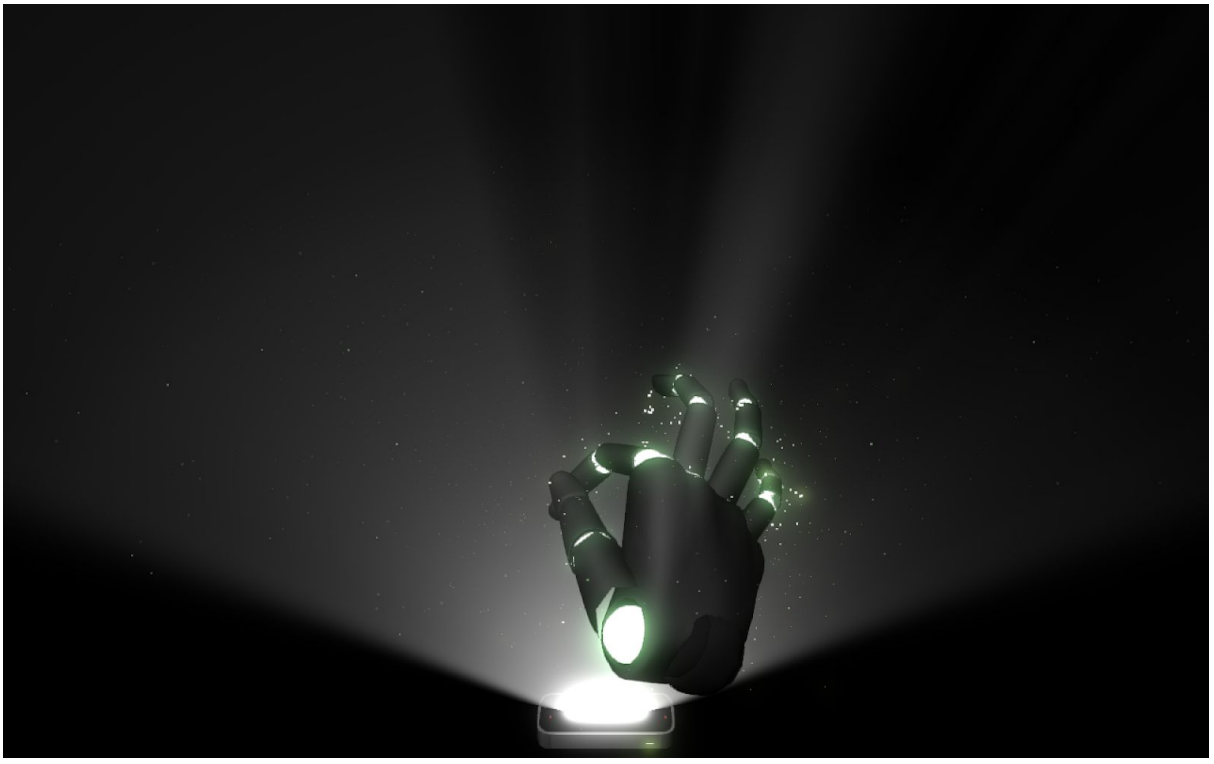
Basic environment Prototype in Unity 3D - Dot 20 cm above the surface at (0,0,20)



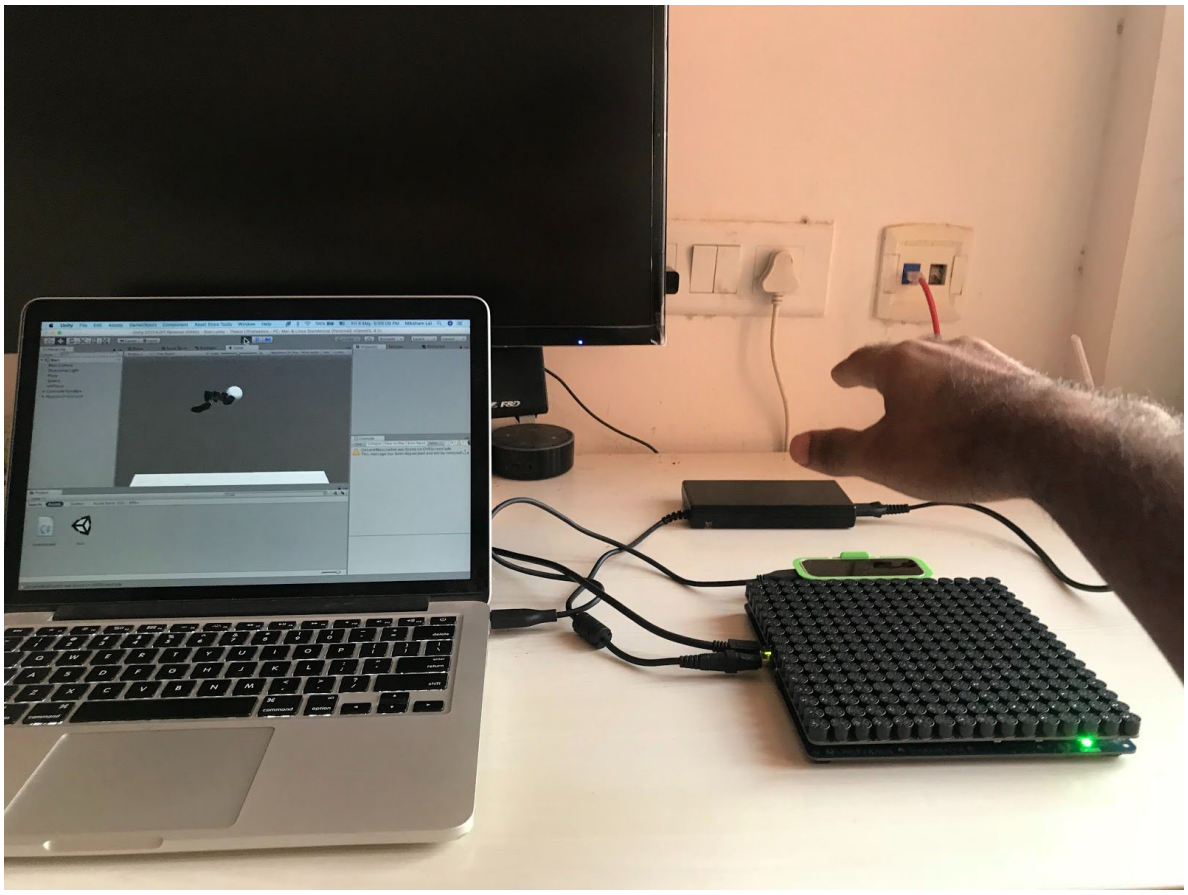
Hand Tracking through Unity 3D, Leap Motion Sensor, Use of skeletal HandTracking.



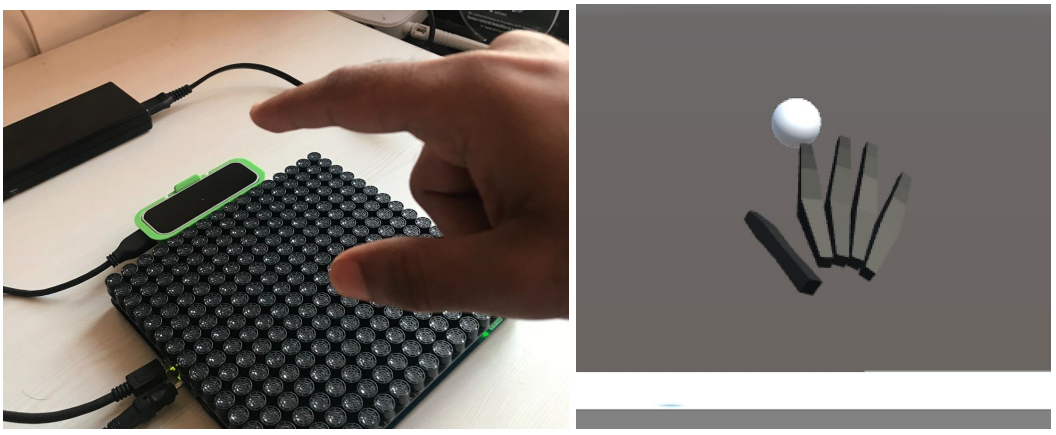
Leap-motion integration with interactive objects, register a dot in space with pinch



Merging Ultrahaptics and Leap-motion for Hapto-Visual Feedback



Testing dot Interaction through Ultrahaptics connected to Unity on Laptop



Fine Calibrating Leap-motion and Sensing Device output

C-Sharp script to make use of amplitude modulation for a point creation 20 cm above the device surface

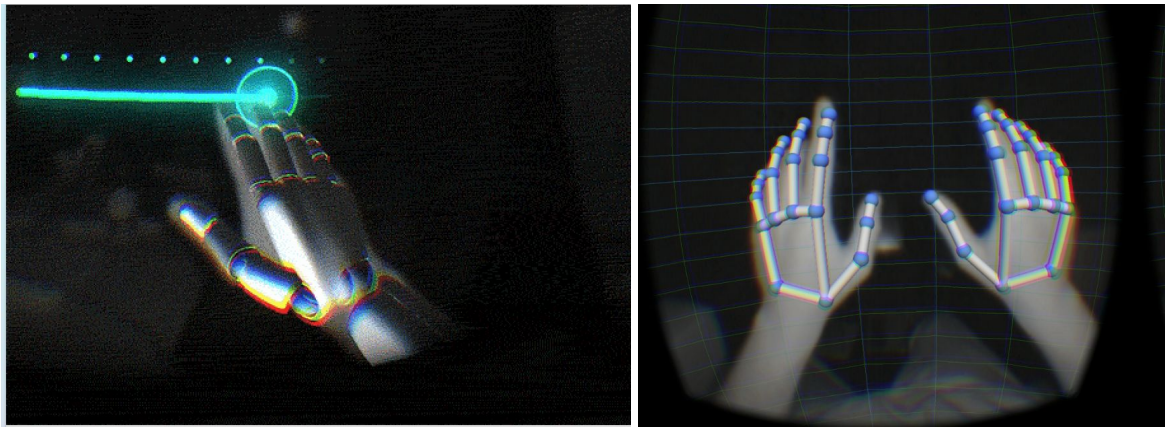
```
using UnityEngine;
using System;
using System.Collections;
using System.Collections.Generic;
using System.Linq;
using Ultrahaptics;

public class Unity_AMFocus : MonoBehaviour
{
    AmplitudeModulationEmitter _emitter;

    void Start()
    {
        // Initialize the emitter
        _emitter = new AmplitudeModulationEmitter();
        _emitter.initialize();
    }


    // Update on every frame
    void Update()
    {
        // Set the position to be 20cm above the centre of the array
        Ultrahaptics.Vector3 position = new Ultrahaptics.Vector3(0.0f, 0.0f, 0.2f);
        // Create a control point object using this position, with full intensity, at 200Hz
        AmplitudeModulationControlPoint point = new AmplitudeModulationControlPoint(position, 1.0f, 200.0f);
        // Output this point; technically we don't need to do this every update since nothing is changing.
        _emitter.update(new List<AmplitudeModulationControlPoint> { point });
    }


    // Ensure the emitter is stopped on exit
    void OnDisable()
    {
        _emitter.stop();
    }

    // Ensure the emitter is immediately disposed when destroyed
    void OnDestroy()
    {
        _emitter.Dispose();
        _emitter = null;
    }
}

```

4.9. Experience Interface for Hapto-Dot

The interface has three screens, onboarding, in - game and settings.

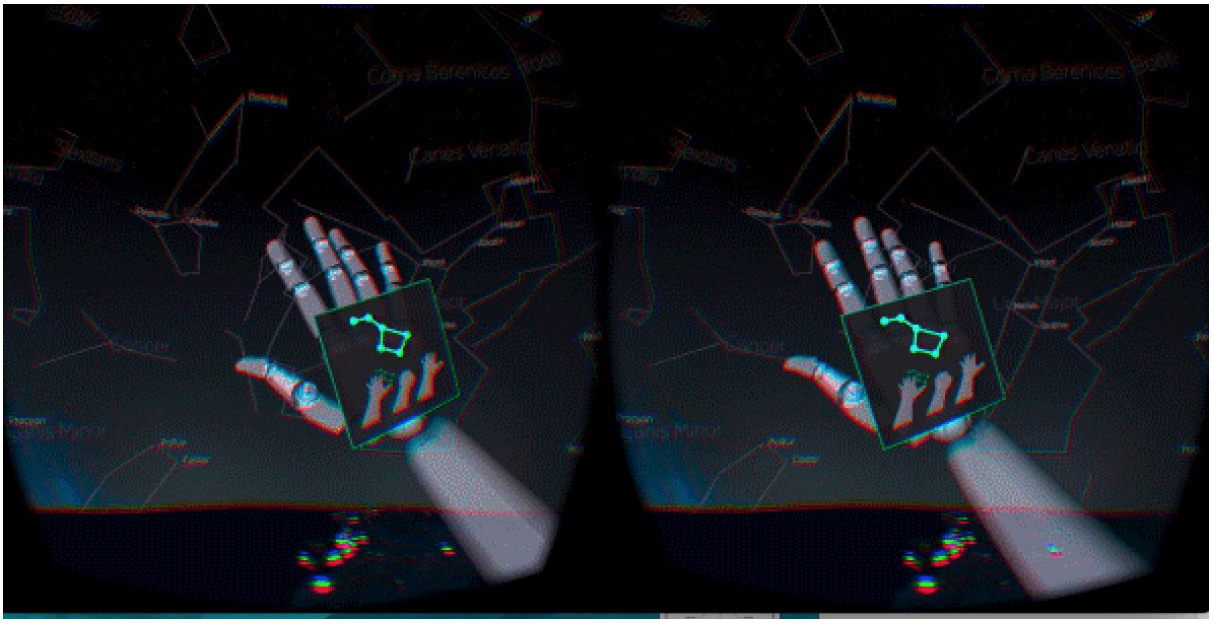
Onboarding - Onboarding screens specifically concentrates on the the game mode types. Player can choose from the desired mode and move to play the game.This is primarily a finger based menu interaction.

Finger based menu interaction, interact with circular elements.

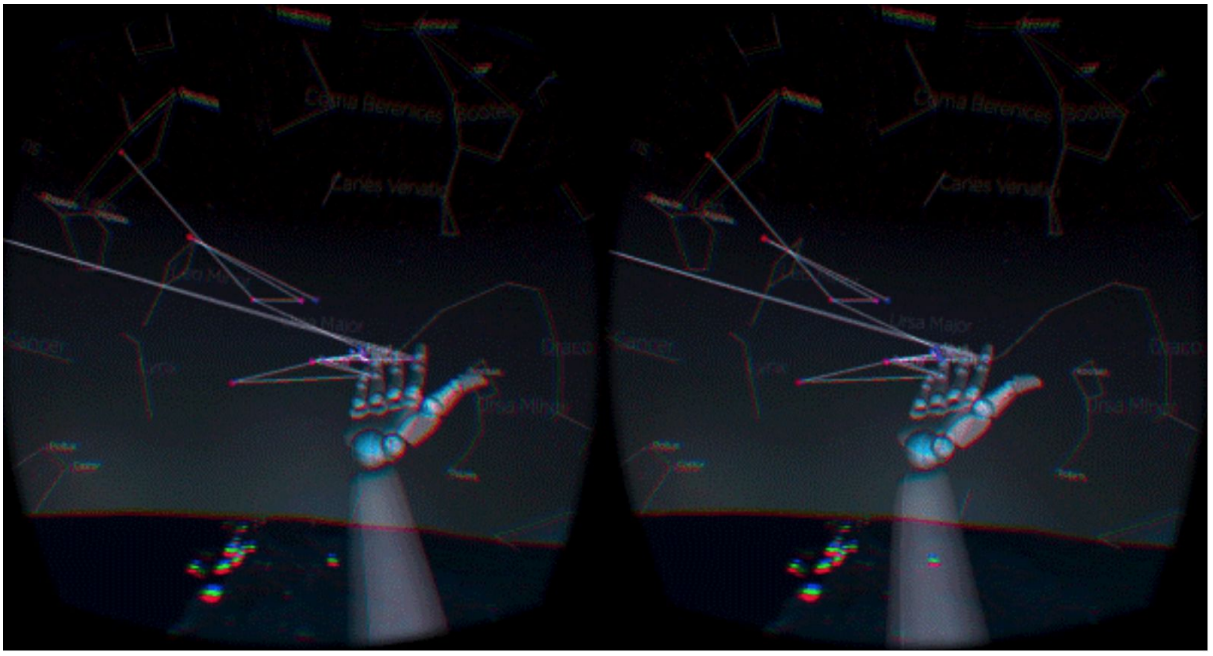


Dot trace line, shows visual feedback component of path traced when in game, with hand in view.

In-Game - This screen is a game screen, where the player plays with the dot. The screen is minimal and consists of elements relating to the particular game mode. A dashboard on the back of the hand tells user about the progress of the game.



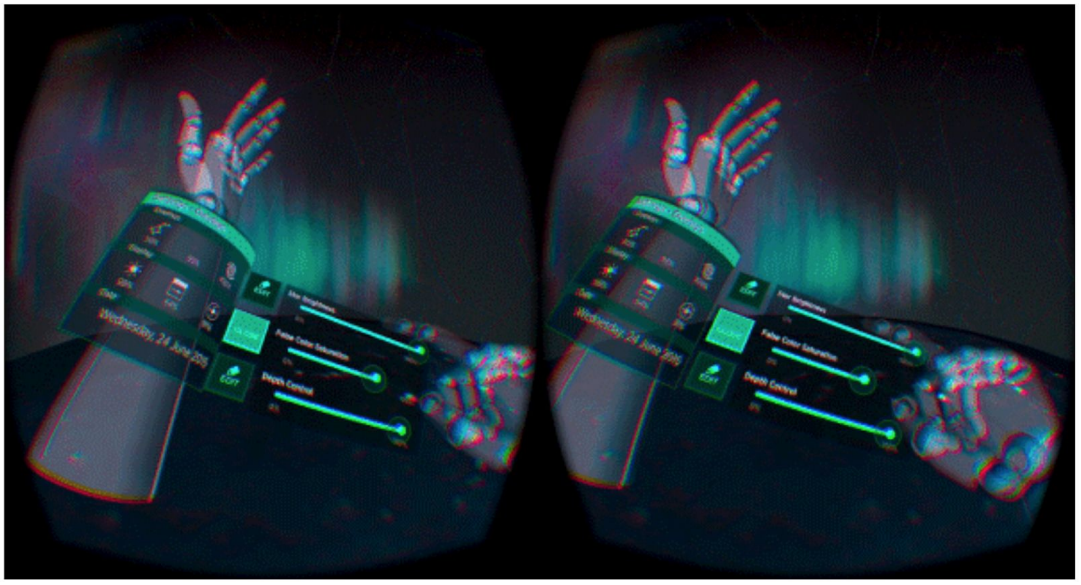
Palm Back for Live game progress bar visualisation

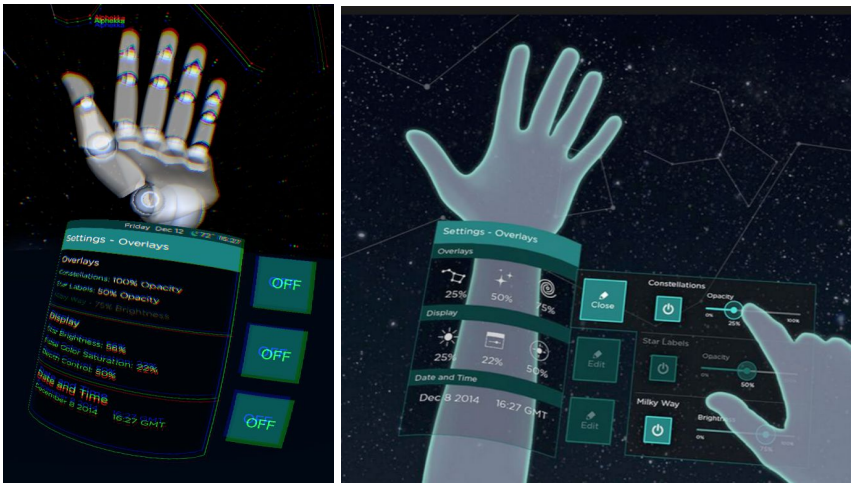


Hands interacting with Dots in VR Split Screen.

Settings - The settings panel will help user gain access to various setting instances related to the game, from sound to dot type etc.This is a arm based interaction, which can be used from palm. Hence, the whole game can be hand controlled through this ARM HUD

ARM HUD for settings in Hapto-Dot





Arm interaction Model for Settings

4.10. User Testing and Results

An initial user testing was conducted on a set of 5 users between age group 22-28. The users were subjected to a single game module that included a dot in space 20 cm above the ground, and were asked to rate on the scale of 5 on experience parameters such as degree of immersion, accuracy, presence, engagement, spatial awareness, etc. The table below shows the results for only visual, only haptic and both haptic and visual feedback.

	Visual	Haptic	Haptic-Visual
Sense of Presence	3	3	4
Immersion	3	2	3
Accuracy	2	3	4
Engagement	3	2	4
Spatial awareness	3	3	4

5. Conclusion

This thesis has explored dimensions of new media interaction. Interactions based on spatial input with mid-air tactile feedback has opened new possibilities of high fidelity immersive experiences. With the help of Hapto-Dot, an immersive multi-sensory high fidelity application has been conceptualised for future of gaming and common interactivity with the environment. Though the concept is far fetched and will require technological advances. The fidelity of current ultrahaptics technology is low, and might need further generations to launch before the sensations become lifelike. The broad concept of touchless sensations, improve in combination with virtual reality, and the greater sense of immersion ensures improved spatial performance. Hapto-Dot provides with an insight to spatial perception being improved in gaming through use of 3 dimensional immersive visual input couple with mid-air haptic feedback. Designing intuitive Interactions play an important role in the development of such games. The thesis has also taken into consideration the interface interactions, and through the explored concepts, games can be recreated for better experiences.

6. References

- Subramanian, Sriram, Thomas Andrew Carter, and Benjamin John Oliver Long. "Method and apparatus for providing tactile sensations." U.S. Patent No. 9,612,658. 4 Apr. 2017.

- Schiavullo, Raffaele. "ULTRAHAPTICS TOUCH VIRTUAL OBJECTS IN MID-AIR." *Virtual Reality* 11 (2018): 01.

- Carter, Tom, et al. "UltraHaptics: multi-point mid-air haptic feedback for touch surfaces." *Proceedings of the 26th annual ACM symposium on User interface software and technology*. ACM, 2013.

- Kervegant, Cédric, et al. "Touch hologram in mid-air." *ACM SIGGRAPH 2017 Emerging Technologies*. ACM, 2017.

- Carter, Thomas Andrew, Benjamin John Oliver Long, and Sriram Subramanian. "Metamaterials and Acoustic Lenses in Haptic Systems." U.S. Patent Application No. 15/671,107.

- Long, Benjamin John Oliver, Thomas Andrew Carter, and Sriram Subramanian. "Method and Apparatus for Modulating Haptic Feedback." U.S. Patent Application No. 14/916,179.

- Jackowski-Ashley, Louis, et al. "Haptics and directional audio using acoustic metasurfaces." *Proceedings of the 2017 ACM International Conference on Interactive Surfaces and Spaces*. ACM, 2017.

- Corenthy, Loic, et al. "Touchless Tactile Displays for Digital Signage: Mid-air Haptics meets Large Screens." *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, 2018.

- Georgiou, Orestis, et al. "Haptic In-Vehicle Gesture Controls." *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct*. ACM, 2017.

- Kugler, Logan. "Touching the virtual." *Communications of the ACM* 58.8 (2015): 16-18.

- Schell, Jesse. *The Art of Game Design: A book of lenses*. AK Peters/CRC Press, 2014.

- Deterding, Sebastian, et al. "From game design elements to gamefulness: defining gamification." *Proceedings of the 15th international academic MindTrek conference: Envisioning future media environments*. ACM, 2011.

- Fullerton, Tracy, Chris Swain, and Steven Hoffman. *Game design workshop: Designing, prototyping, & playtesting games*. CRC Press, 2004.

- Malaby, Thomas M. "Anthropology and play: The contours of playful experience." *New Literary History* 40.1 (2009): 205-218.

- Moreno-Ger, Pablo, et al. "Educational game design for education." *Computers in Human Behavior* 24.6 (2008): 2530-2540.

- Ryan, Marie-Laure. *Narrative as virtual reality: Immersion and interactivity in literature and electronic media*. Johns Hopkins University Press, 2001.

- Ryan, Marie-Laure. "Immersion vs. interactivity: Virtual reality and literary theory." *SubStance* 28.2 (1999): 110-137.

- Sites Source and Images - Ultrahaptics.com, Leapmotion.com, developer.ultrahaptics.com. Unity Hub, Unity 2017.f1, Leap-motion SDK, Ultrahaptics SDK, Github.com