Microsoft Innovation Lab

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Brainchild: A Kinect-VR joint venture

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Abstract

Gait and posture are important parameters of human movement that are impaired in the case of movement disorders, such as cerebral palsy. In such disorders, aspects of motor movement like balance and co-ordination are adversely affected. Cerebral palsy, in particular, can be treated by physical, occupational and speech therapy. But there is no cure. Physiotherapy is often prescribed to affected patients, but the rate of follow through is usually very low as patients find very little incentive to complete their routines. We present a two-fold solution to this problem. We have developed a suite of virtual reality games that aim to gamify the physiotherapy routines, thereby providing incentive for patients to regularly engage in their prescribed exercises. We have also used the data obtained from the player's motions during the game to analyse joint angles and aid in the diagnosis of cerebral palsy. Additionally, the data so obtained was used to track a player's progress in posture and gait through the course of the physiotherapy regimen. This progress chart can be made available to the doctor overseeing the patient, who can then use this information to alter the physiotherapy as per the individual's requirement.

Contents

1 Introduction

1.1 Domain

The emerging technologies of virtual reality and motion capture are being leveraged here. Virtual reality is a way to make an experience more engaging for the user through interaction with a 3D, computer-generated environment. The Kinect motion sensor camera was originally developed for full-body motion capture as a gaming add-on for the Xbox. The software development kits (SDKs) that were subsequently released made it possible for developers to use the Kinect for increasingly innovative applications on PCs and other devices [1]. This combination of cutting-edge technologies looked promising in a wide array of fields. After realising the Kinect had potential for physiotherapy, we decided that we would tackle a healthcare issue: focusing on motor skill disorders like cerebral palsy [2]. The Kinect has proved a valid tool for physiotherapy and gait analysis [3], [4].

1.2 Project

We used Unreal Engine 4, a game engine, to develop a suite of five VR gamified physiotherapy experiences which would provide more incentive for patients to follow through with their prescribed regimens [5]. These games aim to exercise specific motions of the lower body, such as jump motions, kick motions, walking and stepping.

While the player plays a game, relevant data from points of interest on the body such as the positional data of joints and the angles between them (the hip, knee and foot joints, for instance) are collected directly from the Kinect. This data is sent to the cloud. Then it is analysed and the difference between the joint data of a healthy person and one affected by cerebral palsy can be observed on a graph.

We integrated the functionalities of the Kinect with the Unreal Engine by using a plugin called K4U developed by the Opaque Media Group. A plugin called VaRest was used to provide database functionality to the game engine and send the data to the cloud.

1.3 Problem Statement

To record joint movement data with Kinect to diagnose motor skill disorders and monitor patients' progress, and to gamify otherwise tedious exercises with immersive VR, making rehabilitation quicker and more effective.

1.4 Block Diagram

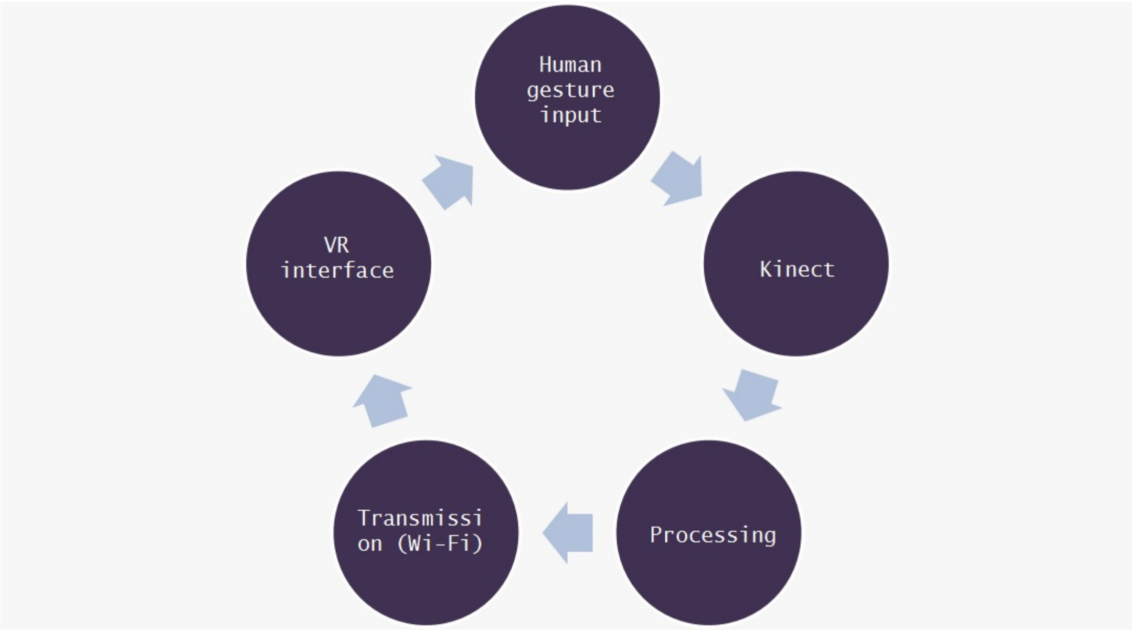


Figure 1: Block Diagram

2 Project Objectives

1. To create immersive VR games to gamify the physiotherapy experience
2. To non-invasively obtain data about joints and their angles for further analysis
3. To provide an analysis of the data so obtained and monitor progress over time with interfaces for doctors and patients

3 Hardware and Software used

3.1 Hardware

- Kinect for Xbox One `http://support.xbox.com/en-US/browse/xbox-one/accessories/Kinect?icid=furl_xboxone-kinect`

  The Kinect is a motion sensing input device manufactured by Microsoft as a peripheral for the Xbox range of gaming consoles and Windows PCs. It incorporates an active infrared sensor which can track without visible light. An improvement on the Kinect v1, it provides full skeletal tracking with six additional joints, an improved time-of-flight sensor, a high-definition camera and the ability to track six people (up from the original two) [6]. It is operated through a Natural User Interface (NUI) consisting of gestures and spoken words. The Kinect for Xbox One is virtually identical to the Kinect v2.

Figure 2: Kinect v2

- VR headsets

  VR headsets use astigmatic lenses to split the view screen into two to provide a stereoscopic view of VR.

Figure 3: VR headset

- A PC/laptop
- Router 2.6GHz

  A router was required to wirelessly stream the games from the laptop/PC to the mobile phone which was placed in the VR headset.

- Kinect Adapter for Windows

  This was required to connect the Kinect to our computers via USB 3.0 as its proprietary cable is meant for the Xbox's Kinect port.

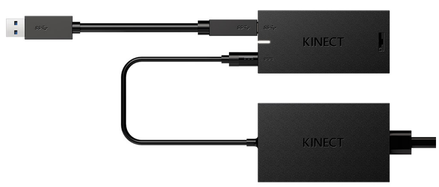


Figure 4: Kinect Adapter

3.2 Software

- Kinect SDK `developer.microsoft.com/en-us/windows/kinect/develop`

  This software development kit enables developers to create applications that support gesture and voice recognition, using Kinect sensor technology on computers running Windows 8, Windows 8.1, and Windows Embedded Standard 8.

- Unreal Engine 4.15.3 `www.unrealengine.com/download`

  Unreal Engine 4 is a suite of integrated tools for game developers to design and build games, simulations, and visualizations.

- K4U plugin `www.opaque.media/download-k4u/`

Figure 5: Unreal Engine

Kinect 4 Unreal (sometimes abbreviated to K4U) is a middleware plugin that allows Unreal Engine 4 developers to use Unreal Engine 4's Blueprint visual scripting system to access the full functionality of Kinect 2 for Windows as seamlessly and as easily as possible.

- Blender `www.blender.org/download/`

Blender is a professional, free and open-source 3D computer graphics software toolset used for creating animated films, visual effects, art, 3D printed models, interactive 3D applications and video games. It further features an integrated game engine.

Figure 6: Blender

- Trinus VR `https://www.trinusvirtualreality.com/`

Trinus VR uses the display and sensors of your own phone to transform it into a portal to your PC games. Requires a smartphone with a gyroscope.It consists of a server application on the Laptop/PC and the screen mirroring application on the Smartphone.

Figure 7: Trinus VR

- Anaconda

  Anaconda is an open source distribution of Python for data processing, predictive analysis and scientific computing.

Figure 8: Anaconda

4 Development Steps

4.1 Deciding on a project

After reading about innovative Kinect projects on the Internet, we decided to make something more than just a game and add VR for extra immersion. A virtual painting studio with a minigame for collecting paint was initially considered. This also led to our augmented reality idea for previewing a user-created, custom paint job on a wall. But since similar things had already been done, this idea was shelved.

The next serious idea was at the intersection of VR, IoT (Internet of Things) and Kinect. We considered modelling a room with its lights and fans in a game engine, and walking though the modelled room remotely with VR and pointing to lights and fans to turn them on and off. It was discarded due to its limited use cases.

Finally, we found that the Kinect could be used for physiotherapy. By helping people, this could be more than simple entertainment. VR would be a relevant add-on as well.

4.2 Kinect version - do we need Kinect for Xbox One?

We decided to upgrade to the Kinect for Xbox One which was much more accurate than the v1 with six extra joints, high-definition recording, a wider field of view and the ability to track in low light with its active infrared sensor [6]. The collection and analysis of data required a high degree of precision and accuracy as it was a medical application, and this was not possible with the Kinect v1.

4.3 Game engine - Unity or Unreal?

We initially started off with another industry standard game engine, Unity. Subsequently, when the switch to a Kinect v2 was in order, it was discovered that the support offered in Unity was sparse. After switching to Unreal Engine, there was a choice between C++ scripting and visual scripting. It was found that the Kinect 4 Unreal plugin was only compatible with Blueprints visual scripting, and thus that was chosen. Blueprints also made for an easier introduction to Unreal's overwhelming set of functions, and visual scripting was sufficient for our games.

4.4 Literature survey to choose exercises

After reading our first Kinect physiotherapy paper on cerebral palsy, the investigation of other gross motor skill disorders (as the Kinect cannot track, for instance, the fine motor skills of fingers) was done. We discovered that our project could be extended to dyspraxia, Down syndrome and autism. We researched common and important rehabilitation exercises and made sure the games covered some of them [7].

4.5 Making our games

The project is centered around a suite of 5 games. The games were built using Unreal Engine 4 which offers a full range of game development tools. It provides support for both C++ code and Blueprints. Blueprints, a node-based visual scripting system, helps develop game logic faster and provides live debugging.

Events, functions, macros, references to variables - all of these are represented by nodes in Blueprints, and these nodes may have input pins, output pins, or both. Nodes are connected by dragging wires between pins. The white pins are execution pins and the order in which they are connected determines the execution sequence. The red nodes on the left are events and they are registered when a component enters the trigger area. In 9 The red F node is a keyboard event and the action of toggling the Spot Light's visibility is performed when the F key is pressed. The blue Spot Light node is a reference to a light in the scene. The blue Toggle Visibility nodes and the Enable/Disable Input nodes are functions. The system also includes decision constructs like Branch (equivalent to 'if') and Switch, and looping constructs like For and While.

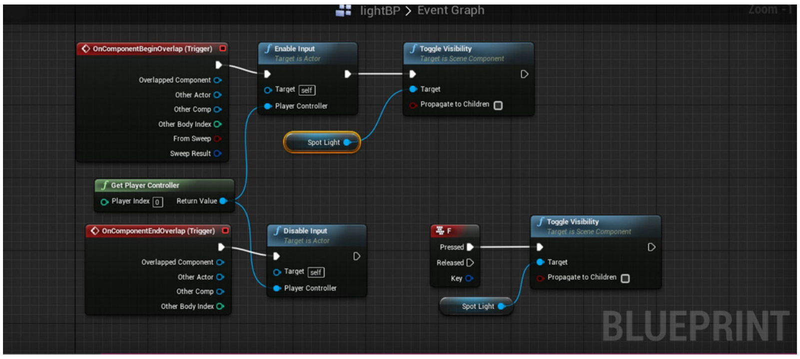


Figure 9: An example from Unreal's own tutorials

Unreal Engine 4 provided various meshes and textures that we used to build our game environments and assets. The 3D models not part of Unreal's Starter Content were developed using Blender, a free and open-source tool for 3D modelling. The meshes developed in Blender were then imported into the Unreal Engine as .fbx files.

The input for the games developed was taken in through the Kinect. This integration was accomplished with the Kinect4Unreal (K4U) plugin. This plugin provided an easy way to access the input of each tracked joint, and simple gestures could be built from the ground up using Blueprints. The plugin also provided Kinect poseable meshes which were already rigged.

The games we have developed are:

Forest Jump

The jump motion of the lower limbs is exercised in this exciting, fast-paced game. Revel in the ethereal sights of the dreamscape. The player jumps until he gets a chance to shoot at mystic treasure and rack up points. But, beware! Everything is not as it seems. Trapped on an ever rotating platform, the scenery is constantly changing. For every 5 jump combo that is achieved, a chance to shoot at treasures for 10 seconds is unlocked, thereby exercising the arms with invigorating stretches.

Scoring Accumulate 5 points for every coin you hit, and lose one for the other treasures you hit.

Figure 10: Forest Jump

Jumping exercises all the muscles in the legs, especially the hamstrings. For patients affected with a motor disability, the jumping motion is one that is most frequently impaired. The nature of this impairment can be both diagnosed and remedied through the course of playing this game. This game also engages the hands by involving stretching motions for every five jumps done.

Wax-A-Mole

This game is a variant of Whack-A-Mole with trick candles spread out over an arena. One candle lights up randomly and the player has 30 seconds to find it and put it out with a water gun. The player has enough water for five shots at the beginning, and must head to the water room for refills (while the countdown continues). Walking and jumping perform the same actions in the game. To shoot, the player must push out with his/her arm. To refill the water gun in the water room, the player must sit down and stand up for every bar in the meter.

Scoring The player scores one point for every candle extinguished. Every squat in the water room gets the player another bar in the water level meter, each bar being 20% by default but adjustable.

Figure 11: Wax-a-Mole

This game incorporates four gestures - walking, jumping, squatting, and pushing with your arm - making it a bit more involved than the others. If squatting is too strenuous, the patient can sit down on a chair and stand up. The exercise of sitting and standing helps increase lower body strength and stability [7].

Timestamp

A sense of rhythm is important in everyday life. Even in a regular walk, the ability to hold a stable gait is important for one to maintain their balance. This game allows a player to step on specific VR markers to the beat of a song, with a customisable regime where the frequency of the steps can be set by the physiotherapist themselves and updated as required. The game comprises a transparent stage on which the player character stands, with footprint-shaped markers rising up to the stage from below. The player has to step on the markers at the correct time with the correct foot to score points.

Scoring Every successful step earns a single point, which is boosted by the score multiplier which starts at 1 and increments by 1 up to 10 for every consecutive step the player gets correctly.

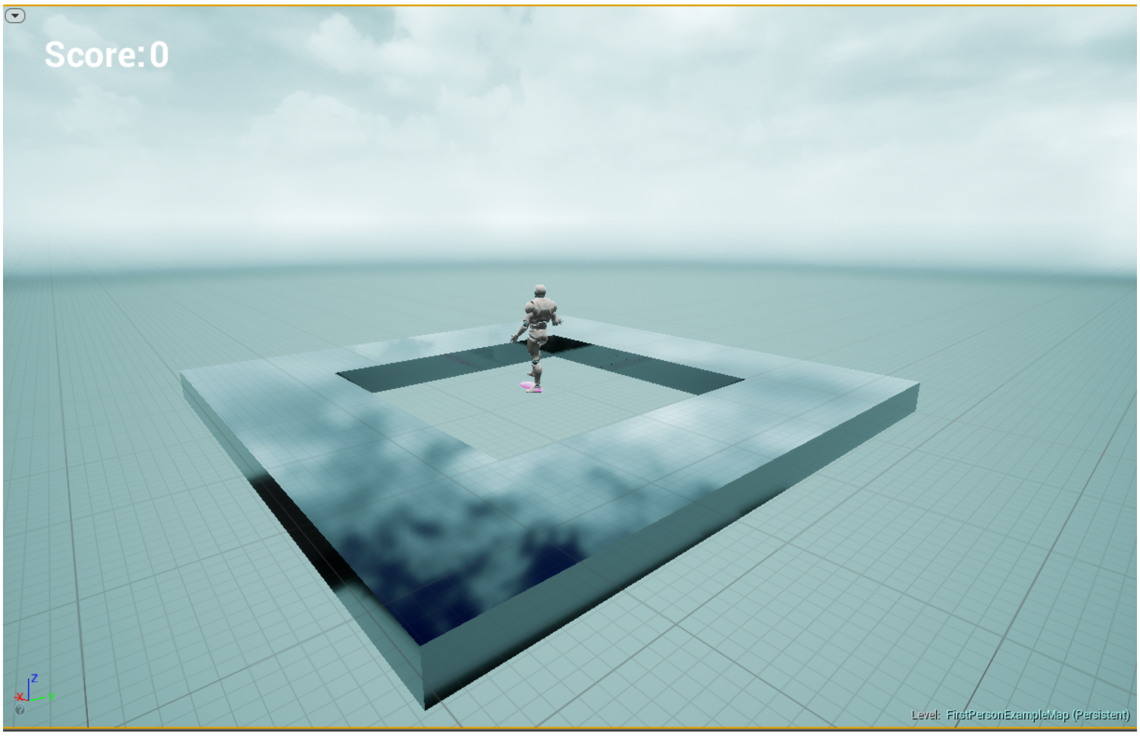


Figure 12: Timestamp

The game is designed to incorporate a sense of rhythm into the player's gait, and at the same time have them stretch their limbs to place their feet in the correct positions. Because the design of the game renders the player's spine a fixed location, any reach the player makes has to come out of their legs, which will ensure that the leg muscles get adequate exercise. The stretching will especially help the hamstrings and calves, muscles which are very likely to atrophy with disuse.

Soccer Kicks

This first-person VR game of football penalty shootouts is played with natural kicking motions. Two targets circle the goal area - a normal target and a 2x multiplier. In this immersive VR environment, players see themselves on the field and hear the crowd cheering for them. Each kick gesture spawns a football. The game uses high-level textures to create an engaging, believable experience. Every kick is monitored, and the data of the stretched limbs are recorded.

Scoring This game was designed with cerebral palsy patients in mind. It improves their

Table 1: Scoring

Region	Score
Target	10
x2	Doubles your score

Figure 13: Soccer Kicks

flexibility by making them stretch in a fun environment. Their legs will move in an arc of up to 120° which is good exercise.

aMaze

Walking - one of the simplest exercises yet often underrated and neglected. aMaze aims to change exactly this by gamifying the entire walking experience. This third-person VR game allows players to immerse themselves in an alternate world where they face several challenges of varying difficulty by walking and occasionally jumping. aMaze, as the name suggests, features a maze. The goal is to get through it and make it all the way to the end to reach the hidden treasure.

Scoring The aim is to clear the floating block area and maze as fast as possible. The player can try to beat the record time.

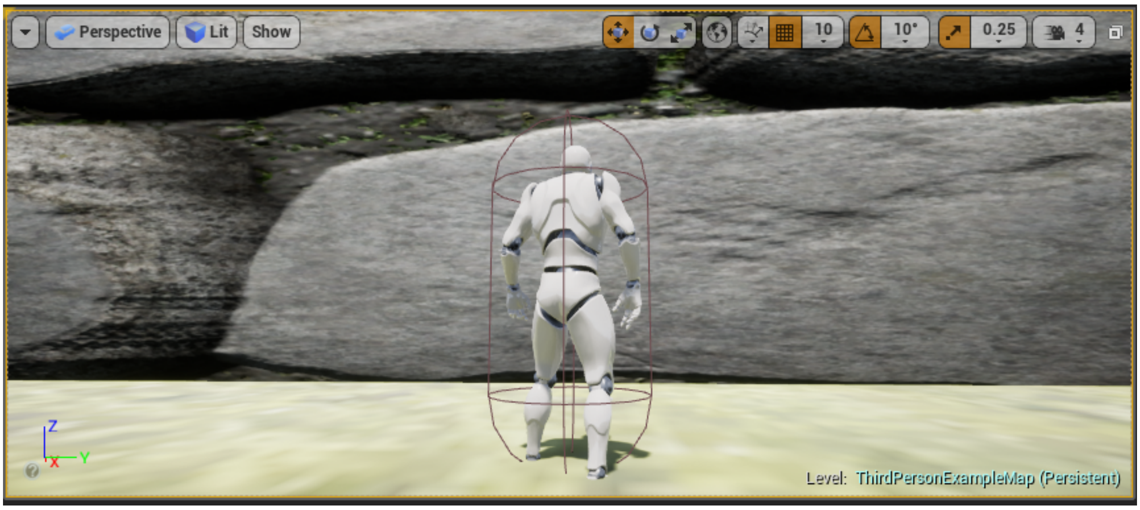


Figure 14: aMaze

The game is designed to improve the motor skills of a person by incorporating basic physiotherapy exercises into a game. aMaze focuses mainly on walking and jumping in position. The intention is to improve mobility in various leg joints (hips, knees and ankle). Walking helps stretch muscles and improves coordination and balance. Jumping helps boost balance and strengthen bones.

4.6 Data analysis, correction and the doctor's UI

We captured joint angles from the K4U plugin and a video stream from the Kinect (with timestamps for the data so that it could be easily understood with the video), and after removing outliers from the data, uploaded it to Google Drive. Drive required the name of the folder to upload to. This folder received videos, images, graphs and an explanatory text file. A plugin called UnrealEnginePython enabled us to run Python scripts from Unreal, including the Python script with Google Drive integration which performed the upload. A graph was drawn comparing the patient's joint angles to those for the ideal movement. This graph and the patient's videos were displayed in the laboratory-like UI we designed for doctors after being downloaded from our Drive folder.

In addition to this, to further better the analysis, Machine Learning was used. To this end, the k Nearest Neighbours Classifier was used. kNN is non-parametric, instance-based and used in a supervised learning setting. The kNN classifier takes a labelled dataset consisting of training observations using which the relationship between the features and the classes is captured. The goal is to learn a function so that given an unseen observation the function can confidently predict the corresponding output, which in this case is to classify it as normal or abnormal. By making use of the Euclidean distance between the test observation and each training observation, k points that are closest to the test observation are found. The conditional probability for each class is then estimated following which the test observation is assigned to the class having the largest probability.

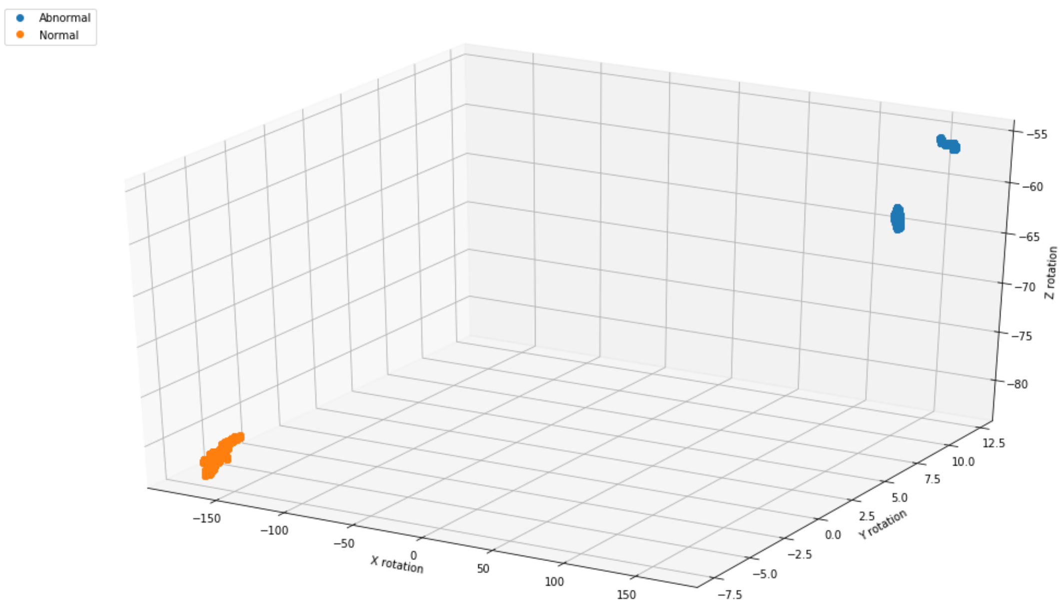


Figure 15: Clustering

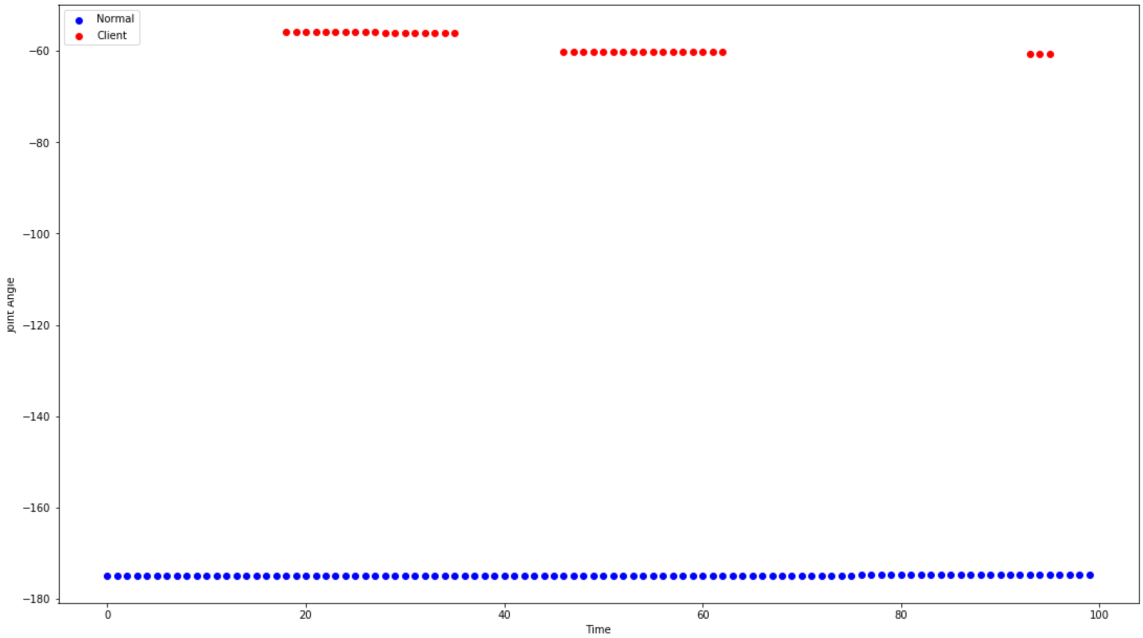


Figure 16: Graph on z axis

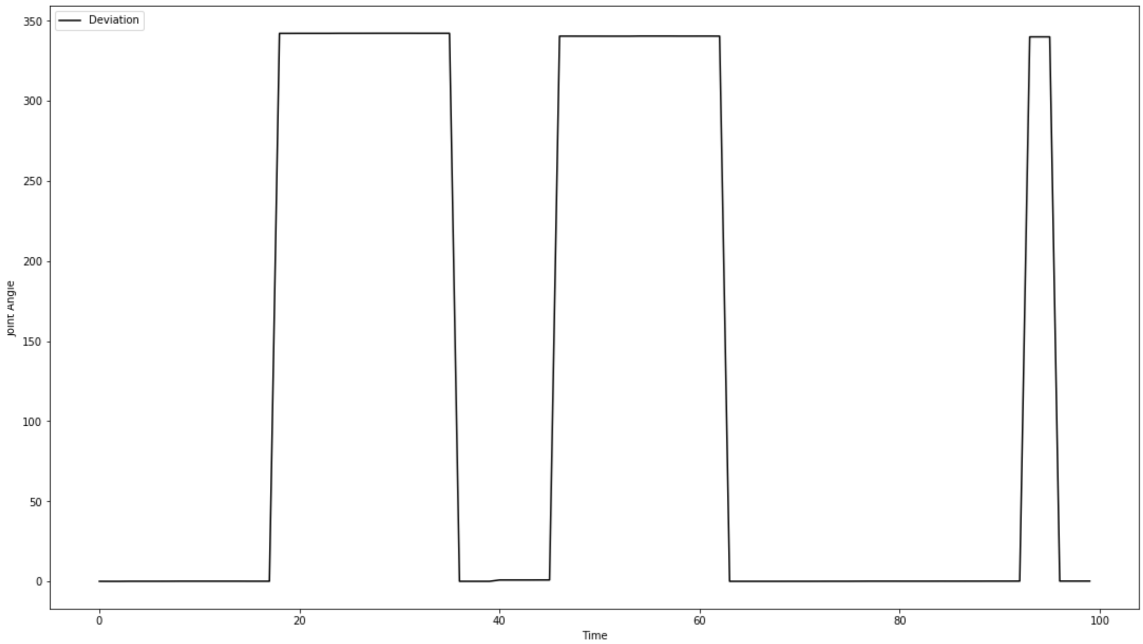


Figure 17: Difference of the values on z axis

5 Challenges Faced

Our choice of game engine had to be careful as Kinect support was an issue. Unity was another leading game engine that we initially considered, but it did not provide free support for the Kinect for Xbox One. Unreal Engine supports the Kinect v2 (and equivalently, the Kinect for Xbox One) with the free K4U plugin developed by Opaque Media Group. We initially started out with the Kinect v1, but the accuracy was low, and thus many functionalities could not be obtained. Our intended medical applications obliged us to order the Kinect for Xbox One.

The K4U plugin was offered only for an older version of the game engine (4.15.3), which meant that some features of the engine had to be compromised on. Weak community support for UE4 was another roadblock we encountered. We hope to contribute to the community ourselves in the future. Difficulties with Unreal Engine were resolved by reading forum posts and watching tutorials on YouTube by Virtus Learning Hub and the Unreal Engine developers themselves. Blender, a 3D modelling software used for rigging the skeletal meshes and modelling assets, had a steep learning curve. We had to fine-tune the gesture blueprints to work in different environments and to be independent of the Kinect's height from the ground.

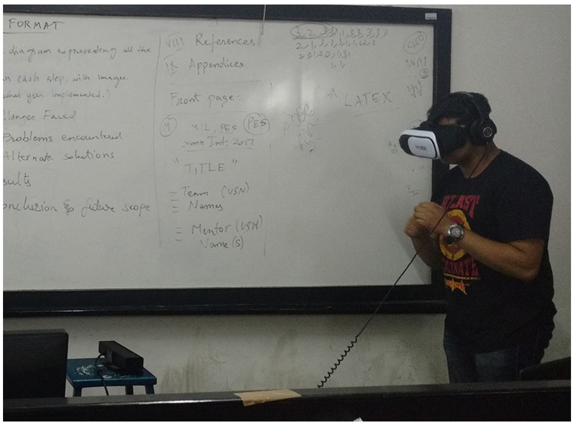
Some of our laptops had basic GPUs and low RAM capacity, which meant that the older version of the engine could not be supported. This was finally resolved by using a different system. Unreal Engine does not offer backward compatibility. Also, we cannot package the games with Kinect functionality into a unit without an expensive source license.

6 Results

We managed to develop 5 individual games, each exercising a different lower body motion. The joint movement data can be collected and analysed by doctors to provide highly personalized treatment. Unlike human observation, the Kinect's joint data are objective feedback. The Kinect can be intuitively used by those with disabilities and does not require a controller. Kinect therapy may be an affordable option in countries where healthcare is expensive. Also, patients need not travel back and forth between their homes and the therapy facility [5].

The difficulty of each game we have developed can be easily adjusted by modifying variables. For example, in Wax-A-Mole, we can increase the countdown to 60 seconds, give the player more water and increase the player's walking speed to make it easier. Though the Kinect games are motivating enough, our VR headsets transport the users into even more stimulating, explorable 3D worlds. If the user is not comfortable with VR, the games can be tweaked to work without it.

(a) Testing the Kinect



(b) Testing the VR headset

Figure 18: Testing the project

7 Future work and scope

- This system can be extended to other motor development diseases. Cerebral palsy is one of the most common congenital disorders and one for which Kinect therapy exists, so we started with it.
- Machine learning can be incorporated to dynamically personalise each exercise regimen according to the progress made by the player in posture and gait.
- Methods of data representation and visualisation can be improved.
- Wearable devices can be added for greater accuracy, augmenting the data that the Kinect currently provides.
- The games currently focus on the lower body. Actions exercising arms could be introduced.
- We intend to overlay the onscreen character with a phantom that performs the motions perfectly. This way, patients can correct their movements themselves.

8 Conclusions

With its accurate detection of human movement, the Kinect was bound to inspire new projects and supplement existing ones. Though the Kinect was intended for gaming, creative hobbyists have repurposed it for applications ranging from music creation to aiding surgeons in consulting medical images with simple gestures. This goes to show that new technology may end up in unexpected places, like a gaming device in our physiotherapy project.

It's not just cerebral palsy - clinics are stressed with the elderly population going up, and we need a way for them to stay fit at home while having fun [5]. With our interface, doctors can see if patients are doing their daily quota of exercises and track their progress over time.

Notwithstanding, our data analysis needs to be developed further. Though two of our games require arm gestures to shoot, every other gesture is performed by the lower body. The Kinect's limitations include not being able to detect individual fingers for fine motor skill exercises and being a little inaccurate when it comes to detecting people in wheelchairs or with deformities. Tracking is also jittery when the player is stationary (though very accurate when the player is moving).

9 References

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10 Appendix

Blueprints & Macros

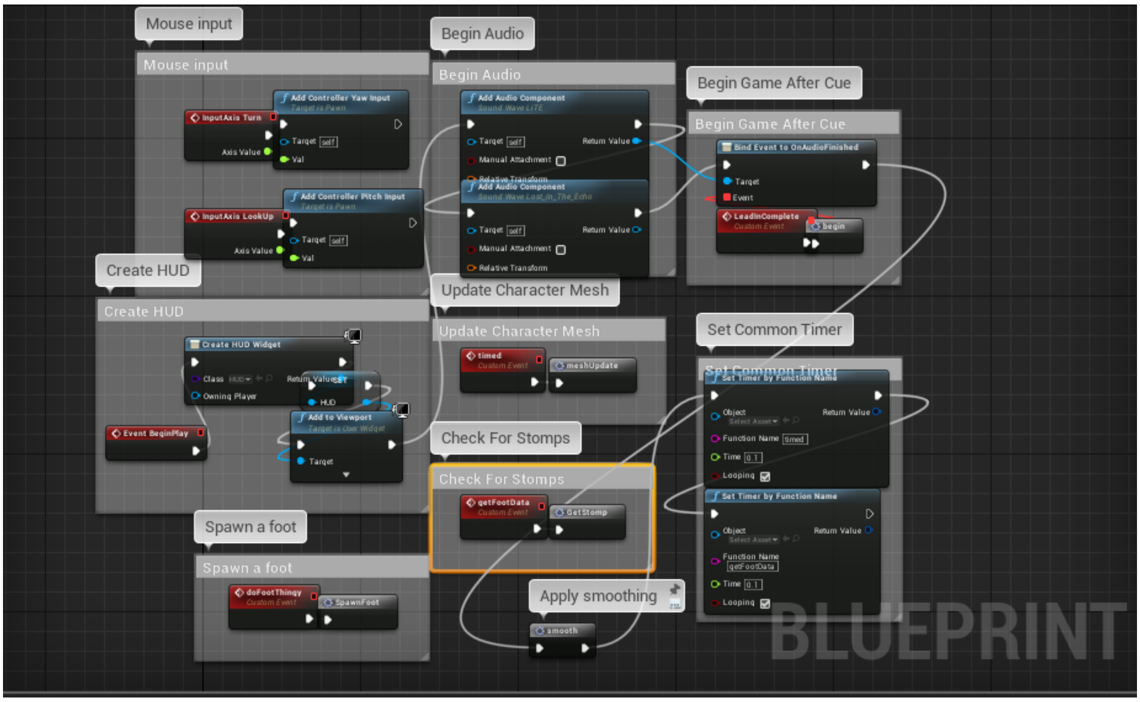

Figure 19: Timestamp Blueprint

Blueprints and Macros are a way of enabling functionality for the game actions and events. For interfacing these actions with the Kinect, the gestures were each abstracted into a macro, which was called as and when required. Below are some examples of such macros. 21 is one such example which defines the actions that take place when a candle is hit in the game Wax-a-Mole.

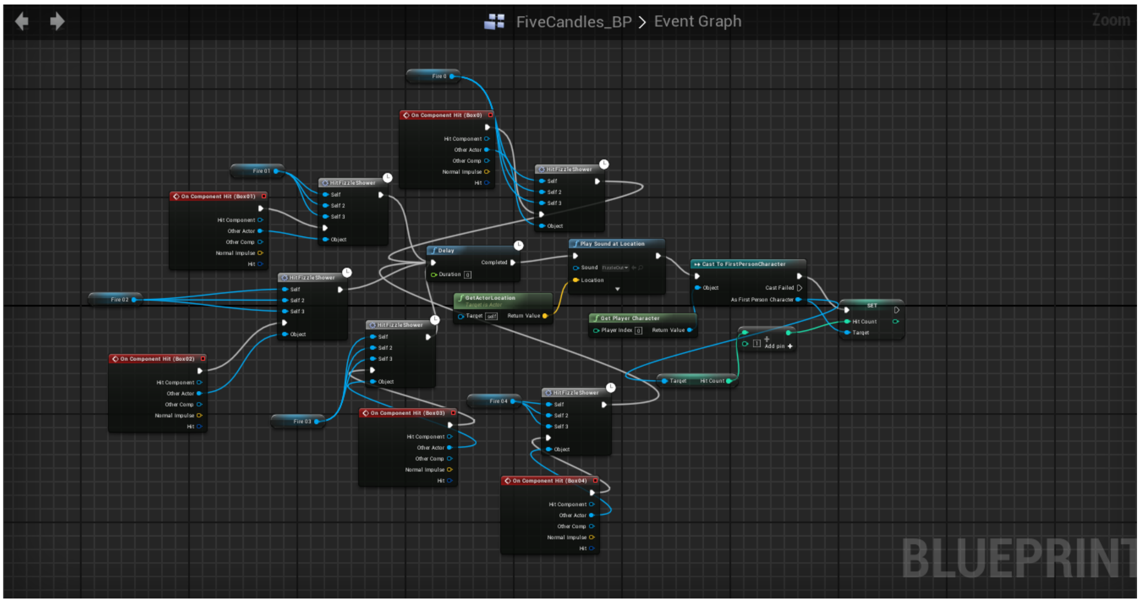

Figure 20: Shoot Candle Blueprint

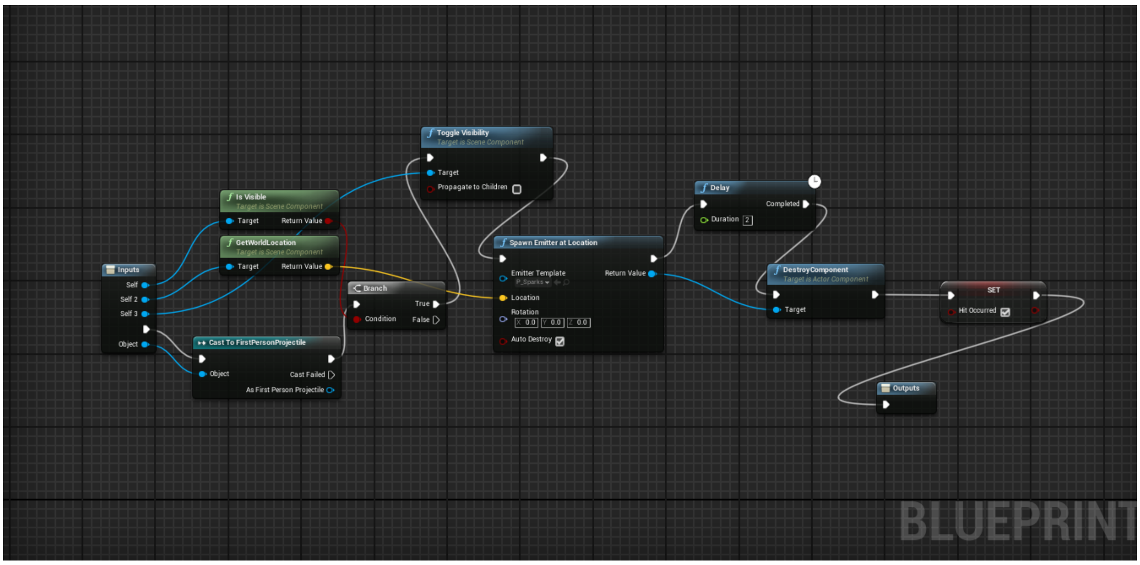

Figure 21: Hit Macro

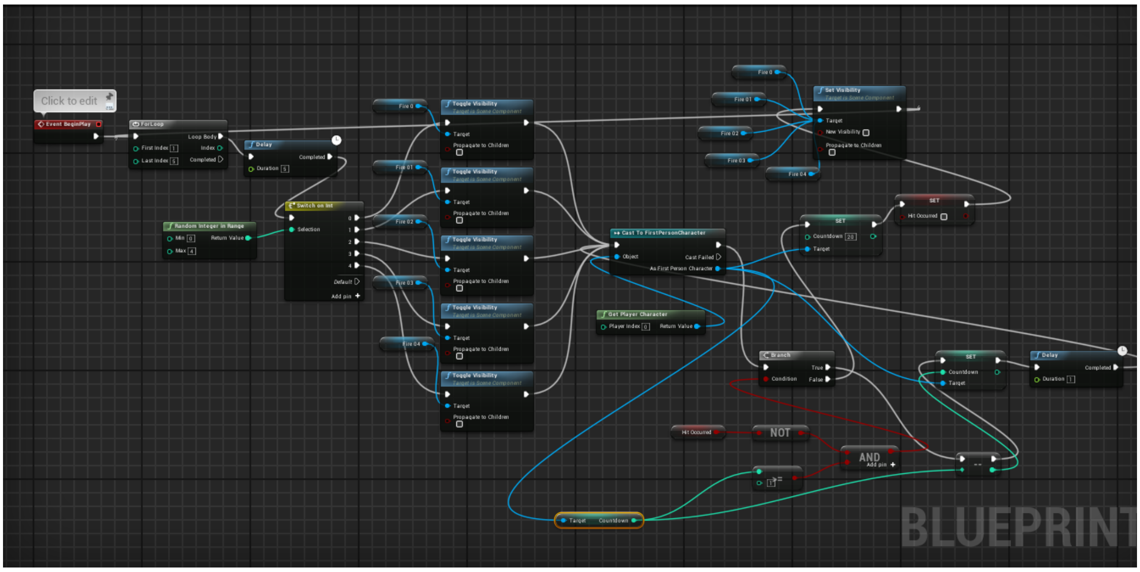

Figure 22: Set Random Candle Blueprint

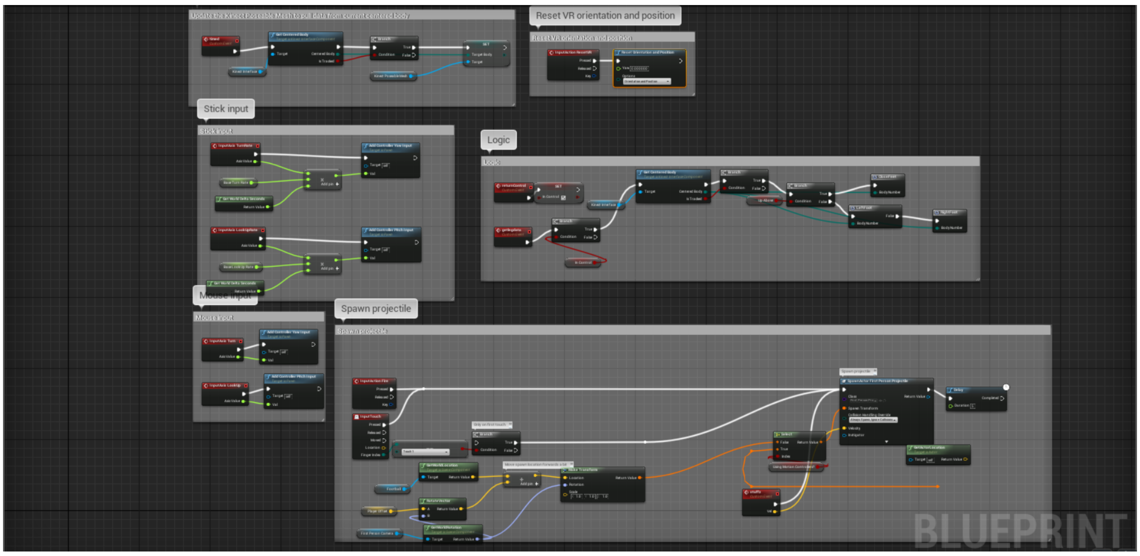

Figure 23: First Person Character Blueprint