

ABSTRACT

This paper presents a medical novelty in the field of occupational therapy. Patients diagnosed with stroke or partial paralysis of the arms can undergo therapy of the affected segment of the arm by incorporation of the arm movements in a much aesthetically sound, virtually simulated environment where the human models would be modelled using a 3D modelling platform with appropriate character rigging for associated movements and the posture estimation of the opacity points along the arms such as ball and socket joint, carpels, metacarpels etc would be achieved through infrared sensing of the patient's arm over an interaction space. This would in turn yield the motion parameters in a coordinate system along the X, Y and Z axes which would then be manipulated and scaled as per the customised needs of the patient's paralytic extent in the arm. So the virtual reality applications would specifically involve creative and interesting activities such as games that correspond to different regions of therapeutic activation along the arm. Due to an immersive and interactive simulation environment generated by the head mounted display, the patient would be engrossed in the application and even a minimal movement generated in the arm would correspond to a much sensitively callibrated pair of hands in the virtual environment. This would therefore enable the patient to undergo occupational therapy in a well abstracted manner that belies the actual level of movement and at the same time allows the patient to gradually respond to the therapy over a period of time while continuing this procedure as a part of the treatment.

Keywords: Occupational therapy, Virtual reality, Posture estimation, 3D Modelling, paralysis and stroke.

I. INTRODUCTION

Virtual Reality in occupational therapy is a novel amalgamation which aids the patients suffering from stroke or paralysis in ameliorating their therapeutical approach and thereby function in a manner similar to the normal ones. Virtually aided occupational therapy is able to provide a virtual simulation of natural or real-life environment for the patients in order to have an opportunity to forget about their banal surroundings and situation and focus only on a task in the simulated environment. Virtual reality uses special visual devices and designed environments modelled on 3D modelling platforms and game engines which is customised according to the disabilities of the patients. The rehabilitation is client centered and applications which are made is directly commensurate with the condition of the patient and are mounted on the VR headset for the therapy.

The sequences of action integrated to the device are as follows.

- Simulation of arm movements in various configurations.
- Callibration and exaggeration of real movement to that of virtually observed movement in the VR headset.
- User friendly GUI for the environment
- Mapping the motion of the original arm with that of the virtual arm.
- Integrate with the VR-headset to observe its efficacy.

The major aim is to setup the infrared and depth sensing which can be integrated with the modelling platforms and game engines which in turn can be integrated with the headset easily. The leap motion sensor is available with the required configurations and specifications such as dual cameras with IR LEDs that can be easily used for

posture estimation of the arm movements and scaling of the estimations can be performed to create a deviation from a real time to a virtual scenario, thereby giving the users a mental stimulus about the improvements that are being manifested in front of them.

Intervention is based on the activities assisting the patients to redeem their ability by performing virtual physiotherapy on daily basis and thereby improvising their movements.

II. LITERATURE SURVEY

The literature conveys the proposed research work on immersive environment simulation for occupational therapy in different journals and then discussions about the existing systems that are used around the world.

2.1 Proposals on virtually simulated treatment for occupational therapy :

Virtual reality rehabilitation for unilateral spatial neglect disorder (USN) was explored thoroughly. Limb kinematics and postural deviations had been a scope of improvement in the proposed methodology but preaching of a versatile, virtual environment that enabled a user to interact with an engaging application which may not be possible to replicate in the real world had been stated . [1]

Strength based training with controlled intensity of training sessions was carried out on three subjects. The statistical comparison between the range of motion ,speed of motion etc. before the training sessions and after the training sessions was formulated and it showed a progressive increase in the case of all the three subjects [2]

Leap motion sensor was proposed for gesture recognition and interaction in a VR/AR environment. It proposed an accommodation of infrared sensing setup and cameras as a standalone unit and using the opacity of the bone joints to detect the exact configuration of the arm over the interaction window thereby achieving posture and gesture estimation of points along the arm [3]

It proposed the usage of Wii gaming for stroke rehabilitation. Two groups of stroke patients were evaluated parallelly by making them undergo recreational therapy that involved the arm motor amelioration. The proportion of patients experiencing intervention was noted down . Results were positive and only in cases of extreme ageing intervention became a necessity. The impact scale of various functional tests was monitored over a span of 4 weeks. [4]

High level of control and flexibility in programming was feasible yet the platform independence and operability between disparate VR systems was missing . So utilisation of accessories and files which were often compatible with one platform yet incompatible with another was a persisting problem. However the impact of virtual environment and neuroscience and cognition had been successfully established and understood. [5]

Simulation of a three dimensional virtual environment by offering full visual immersion through both depth as well as breadth immersion has been achieved which in turn has enabled a novelty to the human machine interaction . This salient feature had been introduced to implement the provision of an immersive gameplay environment which can be replicated in a tantamount set of procedures to customise it for occupational therapy as well . [6]

2.2 Virtual Reality Applications For Occupational Therapy Existent In The Contemporary World:

2.2.1. Virtual Reality Health (VRHealth):

Advantages:

- Collaborated modules agglomerated as a unified application.
- Explores gaming based neuroengineering in older adults .
- Usage as a rehabilitation tool has been explored.

Disadvantages:

- Customisation based on the exact affected region along the arm for each and every individual patient has not been accommodated.

2.2.2 Immersive Rehab(IR)

Advantages:

- Interactive physiotherapy sessions for neuro rehabilitation.
- Upper limb rehabilitation is explored.
- Performs physical rehab as well along with neuro rehabilitation

Disadvantages:

- Patient wise customisation is not explored but is crucial as different patients may be different use cases of a different variant of stroke based on the impact region along the arm.
- Accommodation of other regions other than the upper limb could be explored more.

2.2.3. MOTION Live

Advantages:

- Performs motion capture and animations by aggregation of stream of data and drives the hand , body simultaneously.

Disadvantages:

- It fails to perform customisation as per patient's problem specification and only resolves to modelling and character rigging whereas creation and manipulation of scenes is absent .

III. PROPOSED METHOD

3.1 Objective

The objective of the paper is to propose a methodology which could be used to replicate the activities involved in stroke rehabilitation by occupational therapy exercises but in a much immersive ,real time like scenario simulated virtually which would make the outcomes of the therapy as a voluntary amelioration rather than an imposed treatment strategy .It also accounts for the veritability and efficacy of the methodology by monitoring the subject's feedback and improvement post the rehabilitation phase.Based on the findings derived from the observation the feasibility and effectiveness of this methodology can be established .

3.2 Technical specification

The technology accepts of the proposed idea would include:

- Generating 3D human arm models in modelling platforms such as 3DS max, maya or blender and importing the model as a fbx extensions into game engines.
- Game engines such as Unity3D or unreal engine in order to enable scene edition and manipulation..
- Leap motion sensory input for mapping interaction to virtual environment and pose estimation
- Convolutional neural network model to measure the extent of movement presently feasible for individual patients and collecting data for customisation and virtual arm scalability.
- Matterport 3D for importing graphically and aesthetically sound natural environments in the application.
- Head mounted display such as an oculus rift or htc vive .
- Touch controllers and remote
- VR systems which can stream data at high refresh rates to generate the immersive feel of VR.
- A workstation or a higher end notebook with minimum specifications of 8 GB RAM and Nvidia GTX 1080.

Methodology



Figure 1: This represents the series of activities to be performed in order to render a fully immersive virtual environment for patient interaction during rehabilitation . The sequence of steps mentioned above have been ordered according to the timeline of actions to be performed.

3.3 Description of the sequence of activities

Depiction about the proposal in form of flow chart and diagrams becomes much more vivid, descriptive and helps us to comprehend the conceptual depth obscured by the abstractions in much simple manner. The following steps would be utilised for implementation:

Define key activities to be performed to ensure rehab



Figure 2: The above image shows a rehab session from one of our subjects who was exposed to this therapy . The session has been initiated before the mounting procedure and the application serves for finger and wrist rehabilitation on a 2D monitor albeit without the immersiveness of the headset.



Figure 3: The above image shows a rehab session from one of our subjects who was exposed to this therapy . The session has been initiated before the mounting procedure and the application serves for shoulder , wrist and elbow rehabilitation on a 2D monitor albeit without the immersiveness of the headset.

The pre definitions prior to performance of rehab was the selection of appropriate subjects which was inclusive of hemiplegia and brunnstorm stages of motor recovery with a MOCA score of 25 or above and exclusive of patients with rheumatoid arthritis and aphasia.

Montreal Cognitive assessment and Fugl Meyer assessment of motor recovery were the considerations for outcome measure based on which the activities for each region along the arm were defined and verified as a standard measure for ensuring successful rehabilitation. Bowling while playing skittles and throwing an object were considered as the activities involved in shoulder and elbow rehabilitation. Plucking a flower was employed for finger and wrist rehabilitation and shooting the bugs in a game that we had built and customised which we called the spiders of mars was employed for shoulder and elbow rehabilitation procedures . Other than that we had also imported the in built games which are made available as examples for a particular game engine for the rehabilitation procedures and the following data had been recorded.

Table 1: . Table depicts the treatment protocol for experimental groups

S.No	Activity	Repetition	Details
1	picking & placing blocks	10-15	pinching action in different directions
2	picking & placing blocks	10-15	same as above
3	plucking	10-15	stretch out and pinch
4	plucking	10-15	same as above
5	spiders of mars	5-8	hand stretched out with jerky movement
6	spiders of mars	5-8	same as above
7	bowling	repetitions until level 5	supination and pronation
8	bowling	repetitions until level 5	same as above
9	Spider escape	5 -8	Finger controls

			action
10	pulling a rope	5 -8	stretch elbow & finger movement
11	1.bowling 2.spider escape	1. until 5 levels 2 .5-8 games	Similar to previous cases as done
12	escape velocity	5	Combined upper extremity limb movement

3D Modelling and creation of scenes and prefabs

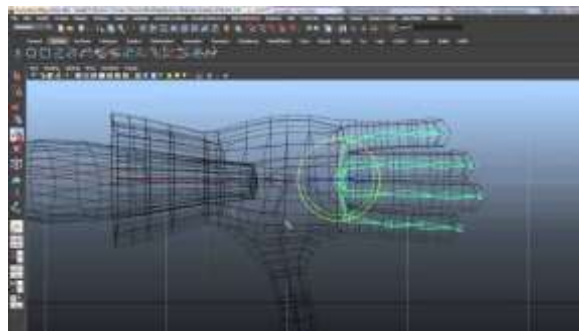


Figure 4. Character rigging of human hands in the wireframe mode of the model . Character rigging facilitates as well as constraints the movement



Figure 5. Character rigging is performed for each segment of the arm . Fig 5. represents the character rigging performed for a single finger in the arm.

Virtual hands need to be modelled before importing and using in the scene editor of the game engine. 3D modelling platforms such as 3DS Max or Autodesk Maya can be used for this purpose.

Several bone animation techniques are employed during modelling to generate the model consistent with the original human arm . The extent of rotation along the three axes for each minuscule segment of the arm needs to be preset to avoid any bizarre or impossible arm configurations. After the segments have been constrained to specific extremities of range of movements , the values ought to be saved and the wireframe model must be converted to a solid model . These steps form the character rigging procedure to be performed for all the objects in a model .

Thereafter skin overlays ought to be added to make the solid arm resemble the human arm texture and color .Once the skin overlays have been added , the model is ready to be exported from the modelling platform to the game engine's scene editor . While 3DS Max supports exporting through .3ds format , other modelling platforms prefer a more commonly used .fbx format .

Measure the range of movement for each subject

For patient wise customisation it is important to understand the affected region and extent of movement possible in that region. In order to achieve that we use a convolutional neural network model that is integrated with the input of the leap motion sensor . The hand movement path is retraced over the interaction window and the range of movement is stored as coordinates in a json file which is used to adjust the scaling parameters later on in the procedure and customise the application and exaggeration of the arm movement for each and every subject who will be using the application for rehabilitation.

The convolutional neural network model identifies the pattern of difference in the luminous intensity over the leap motion sensor and recognizes the opacity of the points describing the region of maximal motion of the patient's arm . So the coordinate values recorded in the json file can be used as the threshold coordinates beyond which scaling and exaggeration of hand movement could be achieved.

IV. GESTURE RECOGNITION OF REAL TIME ARM TRACKING AND WITH VIRTUAL ARM

Gesture recognition is used to track motion of the all the joints in the hand . The gesture recognition will be used to map the hand gestures in the real world to the virtual hands on the screen. Gesture recognition can be verified by switching to the visualizer window and verifying the tracking of the hands and monitoring the fps (frames per second) in the visualizer .

A leap motion sensor can attain tracking upto the elbow only and in order to track the other lower limb extremities we can use a full body posture estimation device setup such as the microsoft kinect but the accuracy of the posture estimation must be highly specific to ensure therapeutic effect and attaining such posture estimation of the highest order and clarity requires very high end GPU specifications.

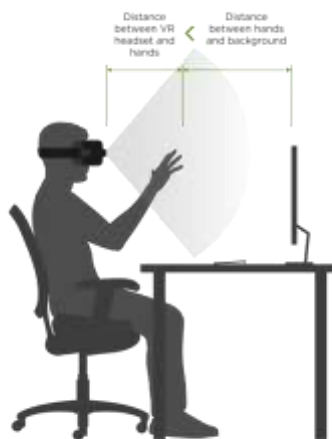


Figure 6. The above figure shows the interaction box in the shaded arc and how the points of opacity of the hands are projected onto the head mounted display from the game engine once the scene is flipped to play mode.

Leap motion sensor is a sensing device that accomodates two cameras and infrared sensors and is available for provision as a standalone unit . It functions over a range referred to as the interaction box or window . The interaction box is an imaginary cuboidal region that is transparent in nature . When the human arm in the real world is brought over the sensor within the interaction box , then a difference in the regularity of the transparency is caused as the bones in the human hands are opaque in nature. Thus these points of opacity are projected onto a grid like space and the shape and size of the hands are mapped accordingly . Any changes in the gesture of the

hands or the posture would variate the points of opacity in the interaction box and hence the projection on the visualizer grid is also consequently changed.

Once the sensing of gestures is successful we must be able to seamlessly integrate the sensor data with the game engine so that we can setup the scene and use our modelled virtual hands instead of the skeletal leap hands available for visualization. To do that we import the SDK of the core assets into the game engine and thereafter we setup the scene in the game engine by either importing the scene or building it and customising it up from the scratch. We need to add object weight and gravity to all the objects included in the scene so that the game or application behaves similar to the real world and considers those gravity values for the objects as an indication of obstruction to the movement in the game or something in the way which needs to be circumvented or crossed.

Once the scene creation and manipulation is completed, the objects with the preset gravity value could be controlled and picked up by our modelled hands while the patient performs gesture commensurate with the movement required to carry out the specific key activities that have been deemed earlier to successfully ensure rehabilitation.

The same can be verified through the Fugl Meyer assessment to make appropriate comparison between the pre and post rehab phases. The subjects were split into two groups namely experimental and control group and rehabilitation was offered in the conventional method to the control group and in the novel VR method to the experimental group.

Scaling the linear and rotational movements of the arm for customisation:

Although, the immersive virtual environment would be ready once the scene is ready to be played in the game engine, the therapeutic essence of the application can only be achieved by the scaling of movement along the rigged joints of the hand. Scaling can be achieved by writing scripts that control the extent of rotation and linear motion along the joints. This in turn is done by mapping the coordinates of the movement in the real world to that of the interaction box of the application. To succeed in the mapping we need to adjust the dimensions of the interaction box. This is termed as frame by frame normalization and dimension shift of the interaction box. This changes the frame of reference of first person view and thereby distorts the original movement by a given magnitude.

This magnitude would be determined by the threshold value measured by the convolutional neural network model which we had used to retrace the range of motion for each patient in order to be flexible in customisation. We need to specify the coordinates for the hands in the application greater than the maximum range of the coordinate upto which the patient can move his joint. This would cause an exaggerated movement of the gestures in the application.

The above steps needed to be done for both the hands individually to complete the procedure. Also the sensitivity of the device can be altered as per needs, however if the value were to cross the optimal value the functioning becomes erratic.

Comparison between the control group and experimental group :

The following data represents the comparison between both the groups prior to rehabilitation and after the completion of the rehabilitation procedure.

Table 2. The above table shows effectiveness of conventional therapy on voluntary motor control among stroke patients.

Control group	Mean	Std deviation	U Test	p value
pre test	23.75	0.5	-1.89	0.059
post test	26.5	1.732	-1.89	0.059

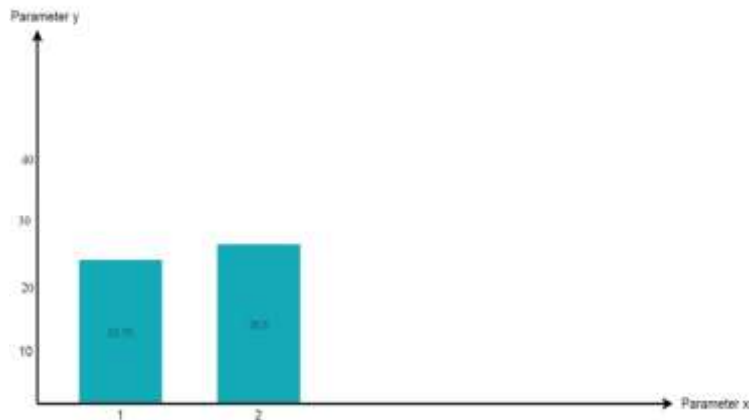


Figure 7 : The graphical representation shows that there is no significant difference in the mean value of the pre-test and post- test scores of the control group . (23.75 & 26.5 respectively)

Table 3. The above table shows effectiveness of functional activity based therapy on voluntary motor control among stroke patients

Control group	Mean	Std deviation	U Test	p value
pre test	24.40	5.413	-2.023	0.043
post test	43.40	4.980	-2.023	0.043

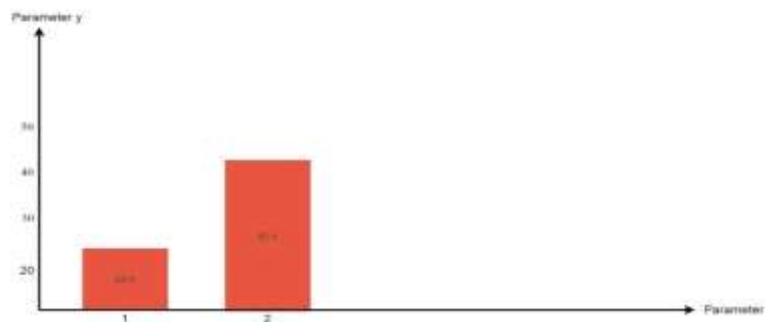


Figure 8 : The graphical representation shows that there was significant difference in the mean value of the pre-test and post- test scores of the experimental group . (24.4 & 43.4 respectively)

Mounting the 2d application on a head mounted display:



Figure 9. The above figure shows the complete oculus rift setup with the headset , IR sensors ,controllers, remote and joystick.

Head mounted display or a VR headset is a device that provides a 3D immersive display for the application being played. It offers depth sensing of the real world environment to get the immersive feel of virtual reality. The device consists of two IR sensors which read the room or environment in which the device will be put to use . This is done through room configuration setup for the device .During the room configuration, the two sensors are kept in 2 corners of the room on opposite ends while the user goes around the room with the controller and set markers for boundary over the region in which the device would be operated .The same room dimensions are set as the enclosed region for the skybox of the headset. The audio of the application is played in the ear using a pair of headphones and the combined depth sensing and application audio renders an immersive feel to the application.

From the banality of 2D monitor screens we move our rehab application to the immersive skybox.The application is loaded into the home folder of the desktop application of the headset and it takes time for the headset to render the application into the display from as low as few minutes to as far as few days depending on the application and availability of resources such as a higher end RAM and graphic card.

Advantages

- The results and feedback showed that VR therapy was more entertaining than conventional therapy and the progress was quickly noticeable..
- The environment could be changed in accordance to the patient's need and applications could be used according to the customized needs of the motion.
- The participants were able to perform the interactive and task-oriented activity with the leap motion sensors .
- The VR therapy was able to provide an exclusive audio cum visual experience which helped in motivating the participants.
- The key activities of rehab once guided upon could be performed independently in the future by the patients on their own without any professional intervention.
- The real time immersive experience was the key as it played with the mindset of the patients and help them to recover faster compare to conventional methods.
- The repetitive activities can be performed on a diurnal basis in a less tedious manner and the patients could also relax and enjoy the virtual world while simultaneously working to regain their motory movements in a short span of time.

Our unique approach to the solution, planning and execution

This proposal mainly focuses on the accomodation of concomitant features such as immersiveness of the application, efficacy of the activities chosen for the section wise therapy of the arm and emulation of the same through the game engines. The most salient feature however remains the customisation of the gesture control based on the specific stroke condition of the subjects in the experimental group.

To measure quantitative parameters we compare the level of significance of the change amongst both the controlled and the experimental group of subjects. If a significant difference is spotted between the pre rehab and post rehab phases then the functional therapy using VR has been successful when compared to the conventional therapy.



V. POSSIBLE FUTURE DEVELOPMENT SCOPE

- The work was carried out on a system that supported the bare minimum specification of graphics which is a nvidia GTX 1080 graphic card. Greater support to graphical intensity will yield a much smoother interface .
- Room configuration was preset to the dimensions of the lab and reconfiguring it for another room would require technical support and cannot be done by a naive user..
- Our proposed and tested applications only offered rehab to upper limb extremities and not the complete human body .Posture estimation through openpose or densepose libraries in tensorflow could be employed in future increments of the product to cover the complete body extremities.
- While adjusting the sensitivity of the leap motion sensor we faced a lag by few milliseconds as the motion over the device was not incessant enough .Thus we had to select an optimal sensitivity value for all the subjects .
- The portion of arm from elbow to shoulder could not be tracked by the leap motion sensor due to absence of joints like those present in the elbow and wrists .Thereby we could not employ any quantitative measures in that region.
- Applications requiring change of directions for navigation had to be achieved by the VR headset controller and could not be integrated with the leap motion sensor which in turn prevented the control of gameplay through mere head movement.So the patient had to focus on controller for navigation and do therapeutic activity using the leap motion sensor .

VI. CONCLUSION

The output of the process showed a prodigious improvisation in the movements of the stroke patients along the affected regions of the arm.The response of the patients towards this virtual reality therapy showed more inclination and predilection compared to that of the conventional therapy as it included more mundane and soporific activities.Scaling the virtual arms was the major challenge involved in the process but we adjusted the scale factor and sensitivity in the script files of the character rigged arms and were able to achieve it .The range of leap motion sensor is limited to the arms and to achieve full body posture estimation we explored the openpose and densepose libraries using a convolutional neural network model and trained the sample posture estimations of the complete body based on COCO and MPII datasets which have been made available. Tracking occurs in real time with negligible lag time of about 10 milliseconds.

The drawback of our model is the non scalability to the other parts of the body as the interaction space is a limited region covering a brief zone over the sensing device and scaling the arm movement does not resolve the paralysis associated with the other parts of the body. The scope of improvement would be gradual in the motor functioning of the patients but is definitely guaranteed as the response obtained during the therapy showed a positive and consistent improvement and hence this zeitgeist method facilitates an efficient and efficacious recovery than the currently employed methods.

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