A Physiotherapy Toolkit using Video Games and Motion Tracking Technologies

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***Abstract*—This paper proposes a software toolkit that Physiotherapists can use to integrate physical therapy exercises with a variety of video games. The toolkit will support a variety of motion tracking technologies and the data from these sensors will help the therapist monitor the performance of the patients and control parameters to advance the therapy appropriately. This technique will be especially useful for disabled patients in developing nations with little access to quality rehabilitation facilities but where computers and mobile phones have penetrated extensively. Using popular games for therapy helps the patient become motivated enough to perform therapy exercise steps repeatedly.**

Keywords—rehabilitation; virtual reality; games; motion tracking

I. Introduction

The statistics of India's disabled population is compelling. According to the last census around 2% of the Indian population is disabled, and 0.6% has motor disabilities in particular. The UN and many NGOs claim that the actual numbers are much higher at around 7-9% [1]. Few hospitals offer quality rehabilitation services. Making the condition worse is the social stigma associated with having family members born with disabilities that make many families disown or ignore the needs of such people. This leaves a lot of scope for therapy regimes that works on cheap, off the shelf technology that can be taken out to the villages. The Indian government is also in the midst of experimenting with various ICT technologies like the Akash tablet and A-VIEW and there is a lot of scope for leveraging this infrastructure for rehabilitation.

Even in cases where the patient is able to access quality rehabilitation it is difficult for patients to see through the entire therapy. Children suffering from Cerebral Palsy and post-stroke adults lack motivation to perform repetitive rehab exercises and usually find the whole process exhausting. A partially automated therapy system that can compensate for the low therapist to patient ratio in India will have a lot of practical implications in how quality rehabilitation care can be delivered to the masses. This kind of intervention has the potential of even letting patients practice rehab exercises at home or in their villages.

Holden's survey of Virtual Reality in Rehabilitation lists motivation among other factors like repetition and feedback as one of the advantages of using virtual environments for rehabilitation. [2]. Repetition is naturally built into the course of a game session as the patient will have repeated the specified therapy actions multiple times. Feedback in games is usually immediate in the form of points, badges and other game rewards. Jack et al discusses improvements in Activities of Daily Living (ADL) by patients who followed a VR based therapy protocol [3].

Even with promising results over the years the one major shortcoming of VR based rehab research is that it still has not made much of an impact in the world of physical/occupational therapy. One reason might be that this is a niche market with few customers. This is why the rehabilitation research world should consider leveraging the sister field of gaming. This paper explores the feasibility and possible techniques of achieving this. The gaming industry is worth $67 billion as of 2012, and the major players invest heavily in creating compelling gameplay and narratives. Games are known for inducing players into the state of flow that is most conducive to learning [4]. Well designed games ensure that the player is always challenged and engaged with meaningful play being the most important factor that determines how the patient. We contend that this is an effective way for rehabilitation as well, having observed anecdotal evidence of kids learning fine motor skills playing card games. Using games also takes advantage of the brain's neuroplasticity. You et al. have discussed the development of neural motor pathways in a child with hemiparetic Cerebral Palsy who underwent Virtual Reality therapy [5].

Another advantage of creating such a software-based tool is the performance and progress data that the therapist can analyze and interpret. This assessment would prove invaluable for the therapist to track patient progress. This feature will also help in the therapist to monitor the progress of the patient remotely if needed if the data can be uploaded to the Internet.

This toolkit will have a database of common therapy exercise movements covering a spectrum of disabilities caused by Cerebral Palsy, Stroke and other brain disorders that will support popular game titles with options to add support for additional games. Once the therapist chooses the movements required, the software creates mappings from the therapy movements to specific game actions.

In this paper we discuss the challenges and some of the existing approaches to solving this type of problem. We also outline the setup of a prototype that was built to test the feasibility of the technology being proposed here in a non-clinical setting.

II. Related Work

Virtual reality for rehabilitation is an area that has seen extensive research over the decades. Holden provides [2] a detailed survey of the research done in this field showing the state of research in using VR in various kinds of therapy (Upper Extremity, Gait, Parkinson's etc).

Kizony et al'sTheragame [6] is designed for home use with a webcamera based input system coupled with a suite of games for the patient to play with. Bryanton et al. discusses [4] the results of using games to provide ankle selective motor control exercises onchildren with Spastic Cerebral Palsy.Merians et al's study on virtual reality game based intervention for a child stroke patient reported significant improvements in motor function [8].

Although there are various motion tracking systems available in the market, there are very few frameworks developed that can seamlessly support these technologies to offer an abstraction layer on which developers can create device/system agnostic applications. GlovePie [9] is an open source keyboard/mouse emulator that supports motion tracking devices like the P5 glove, Wiimote, Kinect, etc. with advanced scripting capabilities. However external applications control GlovePie is cumbersome and possible only (indirectly) through the OSC protocol, this toolkit will directly emulate low level keyboard and mouse events by itself.

Suma et al.'s FAAST toolkit (Flexible Action and Articulated Skeleton Toolkit) [10] is a gestural interaction middleware that is built for OpenNI sensors like the Kinect and the NITE sensor. It allows for mapping of whole body movement parameters to keyboard mappings, mouse movements using an "action syntax" framework that gives users an intuitive interface for defining therapy movements.

III. System

To illustrate the functioning of the proposed toolkit we discuss one particular type of rehabilitation exercise, of thumb opposition that is used in many rehabilitation programs to train/retrainpatients in fine motor skills.

A. Design Considerations

There are many design parameters we need to consider while building such a toolkit:

(1) *Building database of games and classifying them.* Since the toolkit calls for the mapping of physical gestures into game specific actions we will need to build a database of supported games with its keymappings listed. These games will then need to be classified.

(2) *Classifying motion tracking sensors*. There are many different motion tracking technologies available out there with differing detection areas, accuracy, accessories etc.

(3) *Classifying exercises*. Here we need to consider exercise specific parameters like the area of detection, accuracy of the detection needed among others. For example a simple stretch exercise may require a large detection region and therefore the toolkit will have to check for motion tracking hardware

Most commercial games especially those in the First Person Shooter category and racing games have little tolerance towards mistakes from the part of the gamer therefore the toolkit should be able to manage with less than accurate gameplayby the patients, filling in game actions where necessary and filtering out noise when needed. To accommodate this, the toolkit will have the therapist input the desired level of accuracy of movement. This factor can be changed (increased) by the therapist as the patient makes progress in therapy.

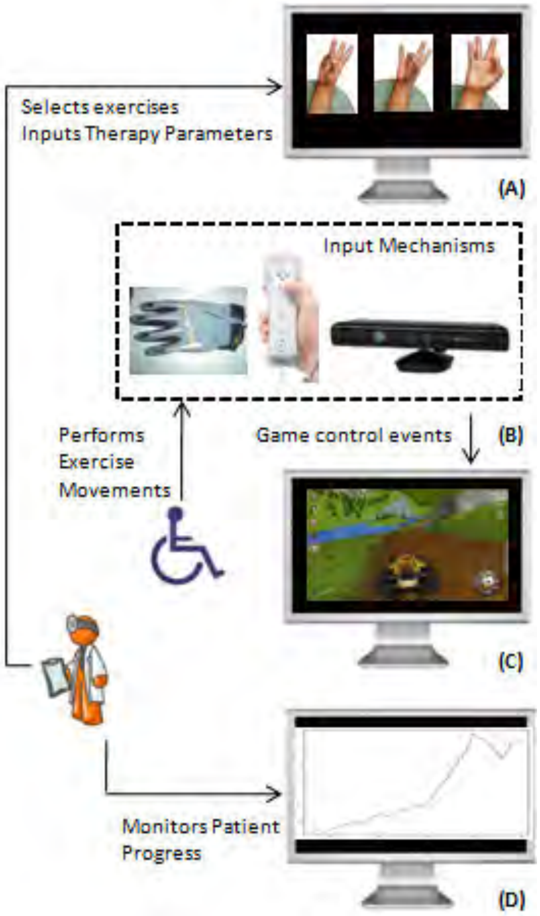

Fig.1. System Use Cases

Figure 1 shows the various use cases that this toolkit will be used and also the main users of the toolkit. One may notice that the programmer/researcher has no place in the use case when the toolkit is being used. Therefore the application has to be designed in such a way that the toolkit is highly configurable and customizable by the therapist.

B. *Exercise Selection*

The therapist will be shown a screen in the beginning to input patient specific details like expected speed of action, accuracy of gesture matching, and the list of therapy exercise movements the patient needs to practice, as seen in figure 3. Specifying the speed of performing the therapy exercise step is important because patients may initially struggle to perform these actions. The therapist may ask the patient to perform the step, time the action and then feed it into the application. This helps the Game Selection Module to select the right kind of game (something like racing may not be suitable for patients who take a lot of time to perform certain actions). The application can also factor in the game preferences of the patient to help the Game Selection Module pick and configure the right game.

Similarly, accuracy is another important parameter that the therapist needs to feed into the application. This could be in the range of 0% to 100% with 100% referring to an exact match of the current gesture with that of one in the database. Most often the latter is not practical, so the therapist can provide a reasonable accuracy value of say 50% and gradually adjusts the value to accommodate for the progress of the patient's therapy.

The toolkit will a have a database of common physiotherapy exercises from which he can select and create a customized list of therapy movements. The only limitation is that only a limited number of therapy steps can be bound to

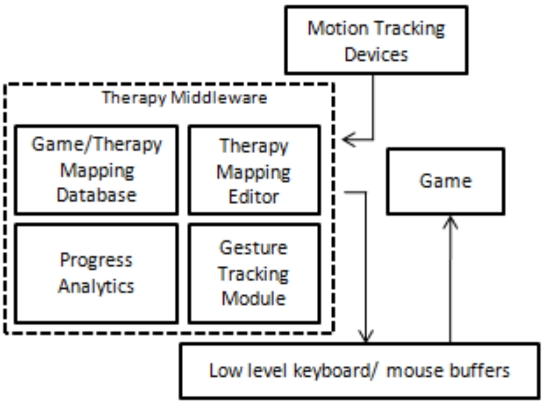

Fig. 2. System Architecture

game actions at a time, but this can be overcome by mixing and matching different therapy steps as the therapy progresses. The toolkit then checks for the list of available motion tracking devices (discussed in next section) based on the kind of movements the patient needs to perform (Ankle, Finger, Lower Body exercises) and depending on the hardware capabilities (the Kinect cannot track finger movements and the Wii and Gloves cannot track leg movements), and the accuracy and speed of motion parameters. The preset values of the capabilities of each game (accuracy, timing of actions, and pace of gameplay) and the supported hardware devices (degrees of freedom, precision needed, etc.) are stored in the toolkit's database. The software then creates key/mouse movements to map each exercise to the required therapy action as shown in figure 3.

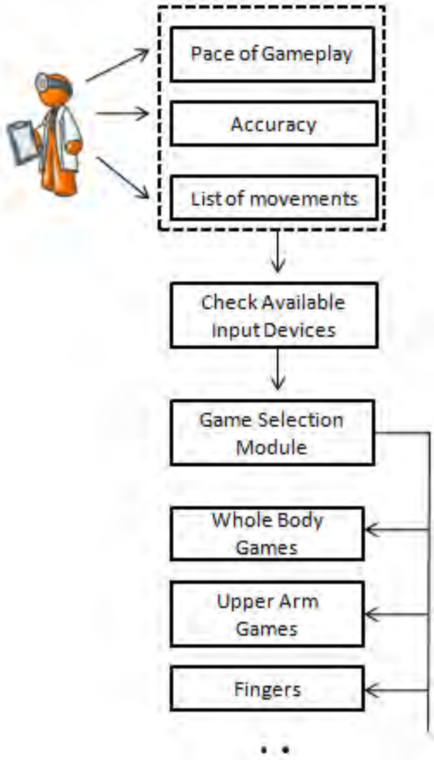

Fig. 3.Initialization Phase

C. *Motion Tracking*

There is a wide variety of motion tracking technologies available in the market right now. The toolkit has to be designed to support various motion tracking solutions available in the market. Zhou et al. surveyed such motion tracking technologies available in the market that can be used for rehabilitation. Recent additions to thislist are the Microsoft Kinect [11] and Wii both of which provide for low-fidelity movement tracking.

Here we discuss various hardware devices that the framework should support. These are available commercially, made primarily for games and business. This ensures that the technologies are widespread and cheaply available.

- *Nintendo Wiimote*: The Wiimote has proved to be a success among different age groups and has been used in rehabilitation [12]. It provides sensor data (Yaw, Pitch, Roll) from its inbuilt accelerometer plus position data (X,Y,Z). The device is good for fast paced Upper Extremity rehabilitation exercises that does not need much accuracy.
- *Microsoft Kinect*: The Kinect is good for games that involve whole body motion. The Kinect SDK provides 3D position data for 20 joints. The system relies on markerless IR based depth sensing, the patient need not wear any extra attachment for tracking. Rizzo et al. showed promising results comparing the performance of the Kinect to the Optitrack systemover a series of motor tasks

performed in a virtual environment by patients with Spinal Cord Injury patients [13].

- *Glove based tracking*: The Dataglove, the CyberGlove and various other glove based input devices are useful for tracking user hand pose (position and orientation) & finger flexion [14].
- *Leap Motion*: The upcoming Leap Motion sensor is promising with its highly accurate tracking of hand/finger pose [15]. In addition to being inexpensive, it is also being integrated into many computers and mobile devices. This technology holds great promise for the field of rehabilitation since it doesn't require the patient to wear any gloves which is an important factor in the therapy of patients who has had hand surgery.

Once the data is received (accelerometer data for the Wiimote, joint data for the Kinect), it has to be classified into different gestures. Lee et al [16] & Liu et al. [17] discuss the use of Hidden Markov Model (HMM) techniques to classify gestural actions. Barbič et al. achieved 90% precision [18] with few false positives with a Probabilistic PCA method to classify gestures. Liu et al. managed a recognition rate of 97%. We can use any of these or a combination of these to classify the different exercise steps that is important for the game event-mapping phase.

The alternative to automated gesture recognition systems is to specify specific spatio-temporal parameters as in Suma et al.'s FAAST toolkit. This technique is easier to implement but it doesn't tolerate mistakes on the part of the patients as much as the automated classifying techniques does. For ease of development we adopted a similar strategy while developing the prototype.

D. *Game Play*

The toolkit creates low-level keyboard & mouse events that most games treat as input from a real peripheral device (see Figure 2). Figure 4 shows a possible scenario where different configurations of the thumb opposition exercise are mapped to different actions in a driving game. This helps the toolkit accommodate most commercial and open source games (except for those which employ anti-cheating measures). This also means that access to existing game source code is not needed.

E. *Progress Analysis*

The therapist monitors the progress of the patient in terms of reports after a game or session depending on which he can tweak the parameters to make it more challenging or identify specific problems that can be alleviated using other techniques. The therapist can track the progress of the patient over days, weeks and months that provide data that is of great clinical value. The therapist may further adjust different parameters including pace of gameplay, accuracy of movements and may add or remove certain exercise steps from the list.

IV. PROTOTYPE

We set up a technology demonstrator to test the efficacy of the technical principles.

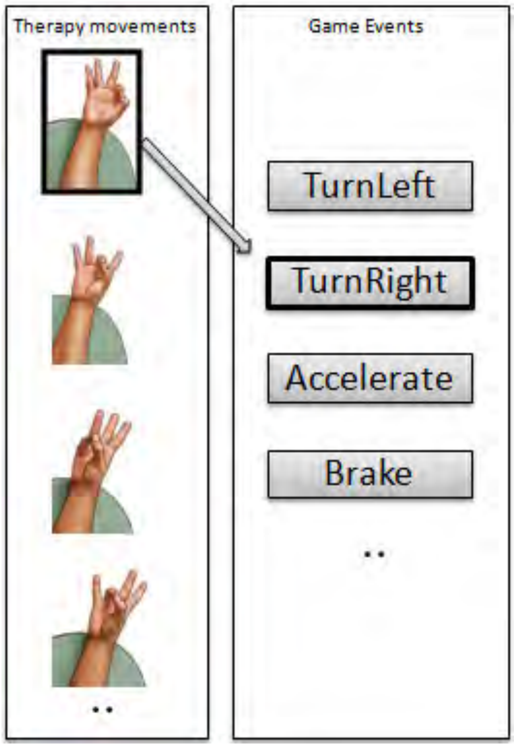

Fig. 4. The software maps thumb opposition exercise actions to game events

A. *Setup*

We used a Kinect depth sensor, Leap motion controller and the Wiimote as motion tracking devices as shown in figure 5. The games tested were the open source Tuxracer [19], SuperTuxKart [20] games and the indie game, Skydive [21]. We selected different kinds of stretch exercises that demanded varying levels of accuracy and detection regions.

Stretching sideways. In TuxRacer the player controls a penguin avatar that slides down a ski slope controlled by <left>, <right> and <forward> buttons.

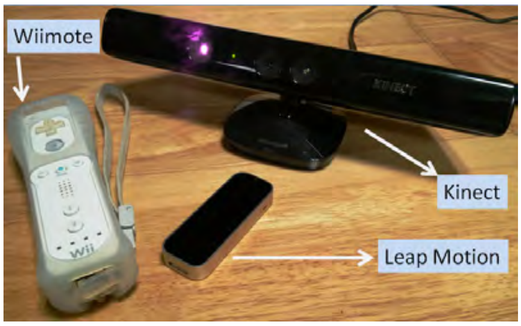

Fig. 5. Sensors used in the prototype

Since the primary input to the TuxRacer game is binary (<left>,<right>) the program chooses this and checks for the availability of a suitable sensor which in this case would mean both the Kinect and the Wiimote both of which offers a way of tracking whole body movements seen in figure 6.

Fig. 6. Sideways stretch controlling game avatar in TuxRacer

Wrist Flexion. This exercise is mapped directly between the Wiimote sensor and the SuperTuxCart, seen in figure 7, since wrist flexion cannot be measured accurately with the Kinect and the Leap does not provide any non-finger tracking. Here we also specify additional keybindings for the Wiimote because of the added complexity of the racing game.

Fig. 7. Wrist flexion controlling game avatar in SuperTuxCart

Shifting Hand Orientation. The Skydive game has the user control the orientation of the virtual skydiver using the <left>, <right>, <forward>&<backward> buttons.

This exercise also looks for devices that deliver the capability of tracking the orientation of the hand accurately. Only the Leap motion and the Wiimote are capable of this. Figure 8 shows the Leap Motion sensor being used as a motion-tracking device along with the game Skydive where the objective is guide a Skydiver through obstacles by changing orientation.

B. Observations

The current prototype that realizes a few of the ideas outlined in this paper, demonstrated the utility of a video game based toolkit for physiotherapy. The next step is to remove the hard coding of the control parameters and let the software offer the user a user interface to select exercises and specify parameters.

Fig. 8.Hand orientation controlling game avatar in SkyDive

V. CONCLUSION

This technique may prove effective in offering solutions for India’s huge disabled populationby accommodating the low patient-doctor ratios as well as offering the possibility of remote management of therapy sessions.

This type of a toolkit will compensate for the lack of commercial therapy focused games. Further conclusions regarding the efficacy can only be verified after user studies and medical validation are done. The concept of having a versatile toolkit for rehabilitation can be extended to having the software working over the network letting therapists perform remote monitoring of patient performance.

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