A Multi-interface VR Platform For Rehabilitation Research

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Abstract
With the introduction of new Virtual Reality (VR) devices such as Microsoft HoloLens, Oculus, HTC Vive etc., one cannot ignore the fact that research related to Human and VR interaction is bound to take a big leap. One of the main areas that has already gain momentum, is the area of VR based stroke rehabilitation research. Although many VR based research studies have been performed for lower and upper extremity training purposes, very few research studies are related to development of VR based research platforms. However, these platforms are usually single device dedicated, and therefore cannot be used to add another device. This study contributes to the field of HCI by achieving three major goals– 1) explore the design aspects of VR based training research; 2) innovate the field of VR based training research by developing a multi-interface platform; and 3) inspire future researchers by providing an open source SDK so as to expand the horizon for human VR interaction. A pilot study was conducted in order to test the applicability of our platform, using 25 healthy subjects across four different interfaces. From the promising results achieved during the pilot study we are currently in the process of evaluating our platform using stroke patients at the Spain Rehabilitation Center at the University of Alabama, in Birmingham. Our findings and insights could inform future VR based rehabilitation system designs and help researchers and other stakeholders to assess the viability of using VR based scenarios for training purposes.

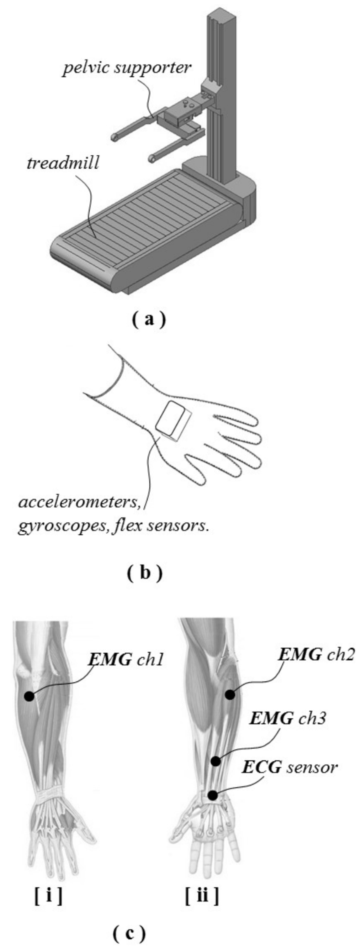

Figure 1: Different control interfaces used for our platform development: (a) KAMX, (b) Digital glove, (c) position of biomedical sensors – EMG and ECG [i] posterior view for right hand, [ii] anterior view for right hand

Author Keywords
Rehabilitation; operant conditioning; compensatory motion.

ACM Classification Keywords
H.5.0 [Information interfaces and presentation (e.g., HCI)]: General

Introduction
As per Goldman Sachs Inc., 2016 report [1], "Virtual Reality (VR) has the potential to become the next big computing platform, as we saw with the PC and smartphones". It is true that there is no shortage of examples on how VR can reshape the existing ways of doing research studies related to the field of education, military, space, architecture, and healthcare. One of the VR based research areas that has already started to gain momentum, is the domain of stroke rehabilitation research. Recent years have shown various technological advances in the field of VR based rehabilitation systems. A possible reason that may have initiated these changes, is due to the drawbacks offered by conventional rehabilitation methods. The most common drawback reported for the conventional rehabilitation technique is its repetitive style of therapy sessions. The repetitive nature of the therapy, may be a demotivating factor for the patient and the patient might eventually lose interest in the therapy [2]. In order to motivate patient during rehabilitation sessions, VR games are now being introduced for different therapy purposes. The main idea behind VR based rehabilitation research is to control the game play by performing certain therapy related exercises. Despite many advances in VR based rehabilitation research, none are related to the implementation of a multi-interface platform for the purpose of rehabilitation related to both upper and lower extremity.

In order to circumvent this limitation, we propose an open source VR based multi-interface platform called as Operant Conditioning based Virtual Reality (OCVR) platform. We build our platform as a multi-interface system for two main reasons–

1) After a stroke or major accident, rehabilitation is required either for upper extremity or lower extremity or both. There are different types of equipment available for rehabilitation purposes of upper and lower extremity. In order to accommodate these equipment, we propose a multi-interface platform.
2) Novel devices are constantly being introduced for rehabilitation purposes. In order to add these new devices and connect with different VR scenarios, we design a multi-interface platform.

It should be noted that our platform is designed for three types of user – an **application developer**, **an editor**, and **an operator**. An application developer can add new functionalities to the existing platform, and can also add and then test his or her own pieces of software. An editor is the one that can modify existing VR scenarios or can add new levels to the existing VR games. Finally, an operator would generally be considered a clinician or a practitioner who simply runs the pre-built applications. We hope our proposed system architecture for OCVR may serve as a basic building ground for future VR based rehabilitation studies. We keep our design principles simple so that new users can easily modify and add new modules, so as to further strengthen the VR based research domain.

Related Work
A range of prior research studies demonstrates the feasibility of VR based platform for rehabilitation and training

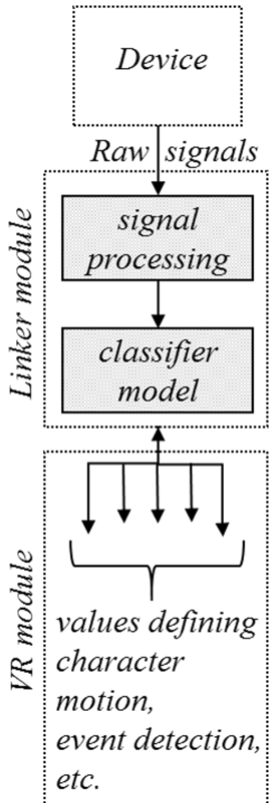

Figure 2: Design principal for connecting a single interface to VR. The Linker module converts raw signal from rehab device to single numbers. These single numbers are then interpreted by VR module to implement character, pawn motion, etc. We design both Linker and VR module for four different devices or interfaces.

purposes. The Gesture therapy (GT) [3] is a virtual reality-based platform, developed for upper limb rehabilitation purpose. The main component in the platform consists of a webcam that tracks a handheld device, known as a gripper. A tracker module constantly locates the handheld device and sends information to the game module. Although the study claims the ability of the proposed system to detect compensatory motions, such claims are not properly discussed in the results. OpenViBE [4] is a free and open-source platform for the design, test and use of Brain-Computer Interface research studies. The platform consists of a set of software modules that can be easily and efficiently integrated to design BCI for both real and VR applications. However, the platform is dedicated only for BCI applications and the author does not make it clear on how it can be extended to other interfaces. The Supervised Care and Rehabilitation Involving Personal Tele-robotics (SCRIPT) platform [5] is intended to provide distal arm training to chronic stroke patients at their homes. The games are controlled using haptic device that tracks the hand and wrist movement and implements appropriate actions in the VR scenario. Although the games are designed using operant conditioning technique, they are designed specifically for the upper-limb motor rehabilitation purpose only. BioPatRec [6] is a research platform that allows the user to control artificial limbs via decoding bioelectric signals. BioPatRec also includes virtual reality environments for a training and performance evaluation purpose. It is released with all the necessary routines for the myoelectric control of a virtual hand and multifunctional prosthetic devices.
Considering previous research studies related to development of VR based platform, we introduce our multi-interface platform design and experimental findings that incorporates operant conditioning based VR scenarios for rehabilitation or training purposes.

As such, development of VR based rehabilitation research platforms are a complex process which has not yet reached maturity, we present our efforts to contribute to this field by introducing our platform.

Design and Novelty of Research

We validate the applicability of our platform using the most commonly used devices in rehabilitation research such as– KineAssist machine or KAMX, Electromyogram (EMG), Electrocardiogram (ECG), Digital Glove (Figure 1). A KAMX is commonly used for lower extremity training of post stroke patients. For upper extremity training purpose, EMG and Digital glove have been previously used. We add ECG as one of the interface to continuously monitor patient's health status. The design principal for constructing a single layer or in other words – connecting a single interface to VR is shown in Figure 2. Our proposed platform can easily house '*n*' number of such layers. The working principle for each layer is simple – first obtain raw signals from the device or interface, then apply signal processing and machine learning algorithms to extract relevant information, and finally code the relevant information and pass on to the VR module in order to control character motion, or detect an event, etc [7, 8, 9]. For example, in case of digital glove, we design an algorithm to extract useful information from accelerometers, gyroscopes and magnetometers raw signals, in order to determine which of the hand exercises the user is currently performing. The recognized hand exercise or gesture is then translated into a number, which is later on passed on to the VR module as an instruction for VR character (or pawn) movement purpose. This is similar to translating of pressing the **W**-key or ' ↑ ' (up-arrow key) on the computer keyboard by a game into forward direction motion of a game character or pawn. Instead of translating the pressing of key, our platform transforms the hand motion capture by different sensors during training into instruction for con-

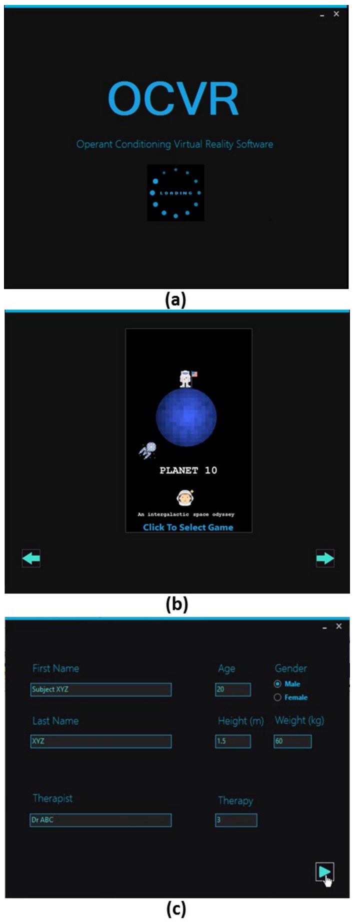

Figure 3: User interface for our platform–(a) loading page, (b) page to select game, (c) page to enter patient's information.

trolling VR character motions. In order to add new device, the application developer simply needs to place his or her algorithm to the Linker module. We believe by keeping our platform design principle simple, future researchers or developer will be able to modify our platform according to their own use.
Our platform is designed in such a way that it focuses on four major design aspects related to VR based rehabilitation research –

1 Easy to connect different types of devices with different types of VR scenarios,
2 Design of VR scenarios such that it acts as a trainer to the patient,
3 Control of VR scenarios depending upon the health status of the patient,
4 Collection of patient's performance data during training session for evaluation purpose.

In order to achieve first goal, we design "an easy to use" user interface that allows an operator to connect four commonly used rehabilitation devices with VR scenarios. The user interface is design using C#, which calls a batch-file every time an operator presses connection button on the user interface. The batch file executes certain set of commands in order to initiate connection between the interface and the VR scenario.
Before proceeding towards the second design aspect, it necessary to understand the concept of compensatory motions and operant conditioning technique. Usually during rehab sessions, it is observed that patients rely more on unaffected limb to do exercises as compared to the affected one. In order words, patients *compensate* one part of their body with other, so as to ease stress. However, in order to improve motor skills, it is necessary to prevent compensatory motions and perform exercises using both – affected and unaffected limbs. The operant conditioning technique seems to be an appropriate technique to address the compensatory motion issue. Operant conditioning is a type of teaching method, in which a particular behavior is controlled by an external stimuli. Any moment, the patient performs compensatory motions, an external stimulus (in the form of punishment) is initiated so as to minimize or put an end to the behavior of performing compensatory motions.
In our study the VR game progress or task progress acts as an external stimulus, which tries to control the compensatory motion behavior of an individual through rewards or punishments. Some of the key concepts of operant conditioning that we incorporate in our platform design are – positive reinforcement (rewarding game points for correctly performing the task), positive punishment (penalizing with something which seems less harsh, i.e. reduce game points) and negative punishment (penalizing with something which seems harsh, i.e. restarting the game level). In case of lower extremity training using KAMX, we design a time-limit drag race game using operant conditioning technique. Raw signal from treadmill and pelvic mechanism of the KAMX (Device) are obtain and passed on to the Linker module consisting of signal processing and classifier model. The Linker module classifies the user walking patterns into compensatory or normal walk. If the Linker module classifies the walk as compensatory then the user loses the control of race car and the car is steered to the edge of the road, eventually losing new track record (negative punishment). If the patient avoids walking, then the patient loses some amount of time (positive punishment). This type of game play scenarios causes participants to associate their motion behavior with punishments or rewards and thus eventually makes them to perform correct exercises. Similarly, for hand and arm exercise we design a car race, a first person shooter game and space flight controller game [9]. All of these games can be control using EMG,

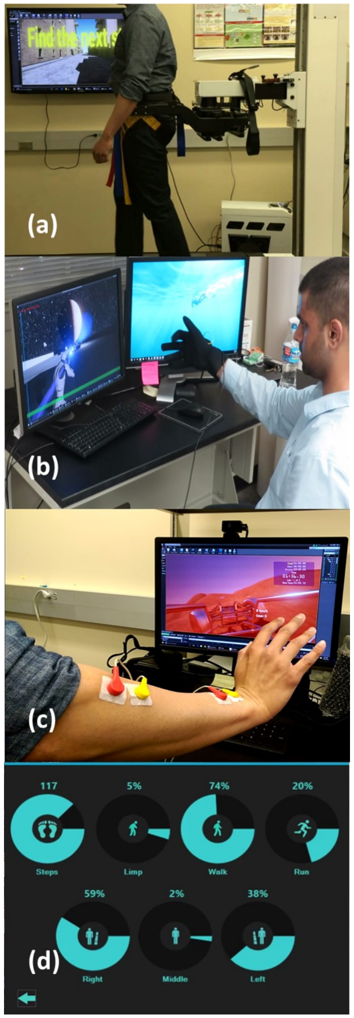

Figure 4: Our multi-interface VR platform designed for the purpose of rehabilitation and training research. VR scenario controlled using – (a) KAMX, (b) Digital Glove, (c) EMG. We design– (d) user interface for data collection and visualization

digital glove and also by KAMX. The signal processing and classifier models are designed in such a way that patient needs to perform complete hand exercise or else the game won't respond properly to their hand motions. Thus by implementing the concepts of operant conditioning we ensure the patient is performing correct exercises.

As discussed previously we apply operant conditioning technique for designing our VR modules and implementing proper training. However, care must be taken to avoid over stressful situations using operant conditioning technique, especially during lower extremity training. To tackle this problem we include an ECG to monitor cardio activity of the patient. In case of abnormal cardio activity, as detected by our Linker module from raw ECG signals, the VR module immediately stops and initiates emergency stop message to the therapist.

For the purpose of evaluating patient's progress, we design a data collection and visualization technique using our user interface. The data collected can be analyzed and later on use to determine the progress of the patient.

Study Design

In order to test the applicability of our platform across the four VR interfaces, we conducted a pilot study using healthy subjects. In all 25 subjects were recruited from the campus of the University of Alabama at Tuscaloosa, over a period of two months. In case of KAMX, 8 subjects (5 males, 3 females) under test were asked to perform four types of behavior – stop, normal walk (or symmetric gait), and compensatory walk (or asymmetric gait) using left and right leg alternatively. In case of compensatory walk, subjects performed motions, where the stance phase of gait is abnormally shortened relative to the swing phase. The similar types of motion that one performs to avoid pain due to weight-bearing.

In case of EMG and digital glove, 8 different subjects (4 males and 4 females) and 9 individuals (4 males and 5 females) were recruited respectively. The subjects were asked to perform seven different types of (therapist recommended) hand exercises and data was collected accordingly. In case of ECG, data was collected from the same subjects that were used for EMG data collection. In each case, data was stored along with the time stamp and class labels, and later on used for building a classifier model.

We propose our own algorithm to classify different types of motions performed by the subject. For a given device, raw signals within a time-window of $3secs$ were processed sequentially. For each $3sec$ window, first Butterworth filtering technique was applied to remove noise from signal. Then spatio-temporal features were extracted and then applied to a classifier, so as to recognize the subject's current state of motion. We perform a comparative study between two classifiers – Support Vector Machine (SVM) and Artificial Neural Networks (ANN), so as to determine which classifier is better for recognition purpose. In case of KAMX the raw signals were obtained from treadmill and pelvic mechanism. In case of EMG and ECG the raw signals were obtained from 4-channels placed on the subject's hand (Figure 1). The raw signals obtained from accelerometers, gyroscopes and flex sensors of digital glove were processed to determine subject's current hand motions.

Results and Discussion

In order to understand the working state of our platform, please watch: (short video) https://www.youtube.com/watch?v=UMQUieoKAUs or (long video) https://www.youtube.com/watch?v=Sdh43sKrMXI&feature=youtu.be. We will soon post our entire SDK and video tutorials on how to modify the source code on: http://ocvr-p10.com/.

The reason behind pilot study was to check the real time performance of our proposed signal processing and classification technique in recognizing subject's current state of motion or movements. Real time evaluation of our platform demonstrated that the classifier model were able to correctly classify subject's movements. Subjects were able to easily control the VR scenario using different interfaces (KAMX, EMG, ECG, Digital Glove). The SVM classifier outperform ANN in classification purposes. After getting promising results from healthy subjects, we will be soon conducting a two-month field research at the Spain Rehabilitation Center located on the University of Alabama, Birmingham campus. Since, we are currently in the process of finalizing data collection from stroke patients, we are not yet to draw any final conclusions regarding the overall platform design aspects.

Future Work and Conclusion

Our system will be evaluated soon using stroke patients at the Spain Rehabilitation Center at University of Alabama, Birmingham campus. Our findings and insights could validate the design and implementation of VR based rehabilitation systems and help researchers and other stakeholders to assess the viability of using VR based scenarios for training purposes. Our platform will be made as an open source with the hope to accelerate the development of human VR interaction.

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