A Novel Force Feedback Haptics System with Applications in Phobia Treatment

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ABSTRACT

It is well known that multi-sensory stimulation can enhance immersion within virtual environments. Whilst there has been rapid development of devices which can enhance the visual immersion, technology to stimulate other senses, such as touch, is still under developed. Currently there is a problem wherein a surface in a virtual environment, such as a wall, cannot replicate the physical properties of a solid object. In this paper a novel system is proposed utilising the HTC VIVE and Rethink Robotics' Baxter Robot to replicate surfaces. A demonstration has been created whereby a user climbs a wall in a virtual environment by grabbing onto ledges which exist as a physical body located on Baxter's end effector. The system uses bi-directional TCP communication between an environment developed in Epic Games' Unreal Engine and the Baxter robot running the Robot Operating System framework. When an ascending user reaches out and grabs a ledge on the virtual wall they will be applying a torque to the Baxter arm which can be measured and the intended movement of the user inferred, resulting in the ledge being moved through a suitable Inverse Kinematics path. This has provided the user with the ability to climb a wall in VR in the absence of any hand tracking methods whilst receiving force feedback from the ledges they grasp onto. Current alternative systems only exist as wearables or operate in small spaces. The increased immersion in this VR demo can be used to assist those with phobias of heights.

Keywords

Encounter Haptics, Baxter, Virtual Reality, Phobia, Psychotherapy, HTC Vive, Unreal;

1 INTRODUCTION

Within recent years there has been a large rise in the popularity of Virtual Reality (VR). This has been due to the release of consumer available VR platforms, HTC Vive[1], Oculus Rift and PlayStation VR, which are now being used by early adopters. This increase in the availability of higher visual quality VR systems has resulted in industries investigating the feasibility of improving processes, such as training or demonstrating solutions. Some usage of VR has been in psychotherapy, where the ability to immerse one into any type of environment has been found to be beneficial [2]. However, it is known that multi sensorial stimulation can enhance presence within a VR environment. In particular, the ability to feel and touch something directly impacts our feeling of immersion. This paper proposes a haptic system with applications for psychotherapy of people with acrophobia (fear of heights). It is desirable to maximise the immersion of an individual during psychotherapy in VR [3]. The motivation is therefore to enable more effective treatment by improving the immersion of the individual into VR through the use of haptic feedback.

The current haptic feedback from both the Oculus Rift and the HTC Vive is limited to vibrations in the handheld controllers. In the event where a user wants to interact with a rigid body in VR, a wall for instance, they will only be able to receive feedback in the form of vibrations when the controller moves through the surface of the object. One significant problem in room-scale VR haptics is that the user is currently not able to receive a force feedback preventing them from moving through the object, therefore replication of the surface's physical presence is not achieved. This force feedback style of haptics, where the user is unable to penetrate a rendered surface, is the style used by the industry standard Sensable Phantom Omni [4] haptics device. The Phantom, commonly used for surgical training [5], provides the desired force feedback, but is limited to a workspace area of 160mm x 120mm x 70mm ($0.001344m^3$), insufficient for room-scale VR. The proposed system will demonstrate the ability to provide force feedback haptics in a workspace volume of over $1m^3$, by utilising Rethink Robotics' Baxter robot's large 7 Degree-Of-Freedom (DOF) arms [6] as a proof of concept.

A second common limitation in VR haptics is the tethering of the user to the haptic device. The Phantom requires that the user be holding a stylus at all times for force feedback. Similarly for vibrational feedback in VR systems the user will need to be holding the controllers. This limits the user's immersion in VR as they are unable to fully interact with the object using their hands. The proposed system is able to provide force feedback in the absence of any tethered objects, such as controllers, wearables or styluses. This is done by creating an encounter haptic system, whereby the Baxter robot will produce force feedback for objects the user will be interacting with in VR.

The novel force feedback haptic system with 1:1 mapping of objects between VR and the physical world is presented in this paper. This system is comprised of an HTC Vive Head Mounted Display(HMD), Rethink Robitics' Baxter robot and two workstations. Additional functionality in the form of hand tremor measurements, measured by the Baxter robot, is explored. Applications for phobia treatment through a wall climbing demonstration are discussed, with suitability of the system explained.

2 BACKGROUND

Current Haptic Systems

One of the most popular force feedback haptic systems for professionals is the Omni Phantom. The phantom is best suited when the intention is to interact with a small object where fine manipulation and accuracy are essential. The Phantom will not permit the user to move through surfaces, applying a maximum resistive force of 3.3N. As previously mentioned the Phantom is limited to a small workspace. This is far from ideal when the user wants to perform tasks that are performed with great ranges of movement, such as scaling a wall or throwing a ball. The Phantom also requires that the user constantly holds a stylus. This stylus is attached to a series of mechanical linkages which is where the force feedback is provided. This is acceptable in the case where a surgeon will be training with a scalpel being replicated by the stylus. This does not however allow the user to contact surfaces with their hands alone. This haptic interface provided by the Phantom is common, i.e. using an intermediary object to transfer force feedback, such as in the Novint Falcon Haptic System. The Falcon has had successful results from users [7], but again is also not room scale.

The Dexmo F2 VR exoskeleton [8] is an electromechanical device attached to the hand of a user to allow haptics by means of holding virtual objects. The Dexmo is mounted onto the backside of the hand and fixed to each of the fingers. This system applies a mechanical brake on the finger joints when the user attempts to close their hand through a surface. This is effective in replicating the physical boundaries of an object held in the hand, i.e. one cannot close their fingers through a virtual ball being held. There is also no limited workspace using this design technique, it is theoretically room-scale. The force feedback of the device is limited to objects' surfaces which are held within the hand. This means that the braking system on the Dexmo will not be able to replicate a wall being pushed against by the user. The Dexmo is also a tethered device, requiring that the user must wear it at all times to receive force feedback.

In the work of Covarrubias and Bordegoni [9] researchers created a haptic device which is able to replicate curved geometry in a VE by manipulating a servo-actuated metallic strip with mechatronics mounted to a desk. In their work the geometry of a shape existing in the Unity game engine was passed through to an Arduino board connected to a series of servo motors. This enabled the curvature of shapes in Unity to be mimicked by the metallic strip. The results of this proposed system was the ability to feel the curvature of surfaces. This is a system which is also free hand, there are no intermediary objects such as a stylus or controller, increasing the haptic immersion. This system is however limited in a couple of ways. Though the curvature of a shape can be replicated, it can only be done over the narrow metallic strip, therefore the full geometry is not realized. Similar to other systems the workspace is limited, it is clear the system is only suitable for small objects and is not room scale.

Both the HTC Vive and Oculus Rift utilise vibrations in controllers to stimulate the sense of touch to the user. In the case of the user interacting with an object in VR they will be made aware of the contact between their hands and an object in a virtual environment (VE) through the use of these vibrations. This is sufficient in indicating the collision of surfaces in VR, but does not prevent users from moving their hands through surfaces they shouldn't be able to using force feedback. The users are also required to constantly be tethered to the controller to be able to feel any of these vibrations, denying the freedom of movement of the hand.

Current Phobia Treatment

Clinical psychology describes a phobia as an anxiety disorder, characterized by intense irrational fear of specific objects or situations. Many researchers have shown their progress in performing psychotherapy with the assistance of VR, to treating these phobias

[10]. The majority of treatments involve creating 3d models related to the phobia, such as city skylines in the case of acrophobia, 360 degree panorama images and sounds or videos in VR.

Acrophobia is the specific fear of heights, one which can be highly impactful on the quality of life a person can achieve if not treated. Work has been undertaken in the university of Ontario to create a VE room where people could receive treatment [11] . In this treatment patients would train in a small VE room, called the cave, using projectors to create the VE. The patients in this treatment would have physiological sensing equipment attached to them to observe their stress levels. The patients would progress through increasingly stressful acrophobic exercises as their tolerance increased. They would always retain the option to take a break from the VE if anxiety levels were too much to handle. What is notable about this study is that there is a focus on immersion, safety and objective data on the stress levels of the patient. These are aspects which have been retained in the proposed phobia treatment system.

Some have attempted to create games for the treatment of phobias. A system was designed with using the Microsoft Kinect controller with phobia treatment games on a pc for patients to work through [12],[13]. A system such as this with objectives and rewards for movement outside of the comfort zone for the phobic receiving treatment can be highly motivating and have a positive impact on their progress. This concept of measured progress and milestones has also been retained in the proposed phobia treatment system.

Research has shown how critical immersion is for inducing anxiety in patients for psychotherapy of phobias [2]. This need for immersion, alongside the absence of haptics in most VR therapy, is the motivation for the proposed system.

3 WALL CLIMBING DEMONSTRATION

Concept Features

We propose a wall climbing demonstration in VR with haptic force feedback to be used in psychotherapy treatment of those with acrophobia. The primary function of the proposed system is the ability to use the HTC Vive Head Mounted Display (HMD) as a VR viewer into a VE where the user can climb a tall wall, shown in Figure 1. By using VR the effect of ascending a wall and therefore increasing height can be achieved. This is essential in being able to trigger the fear of the phobic for treatment. The Baxter robot's role in this system will be to allow force feedback during wall climbing and enable tremor of the hand to be measured. This demonstration is absent of any hand held controller. Instead the Baxter robot's end effector will be used for input, in the form of hand tremor and torque application. It is similarly used as an output, providing the force feedback of ledges in the VE. The Baxter robot itself is also referred to as a 'safe robot', due to the robots elastic actuators and torque sensing limbs. It can therefore operate alongside humans without the need for cages as most non-compliant robots require. This is what makes it suitable for haptics [6]. The sacrifice with this safety is that the arm is never entirely rigid and can be moved passively by a small amount (<15mm) by the user. This also leads to a tolerance of approx. +-5mm on the end effector accuracy[6].

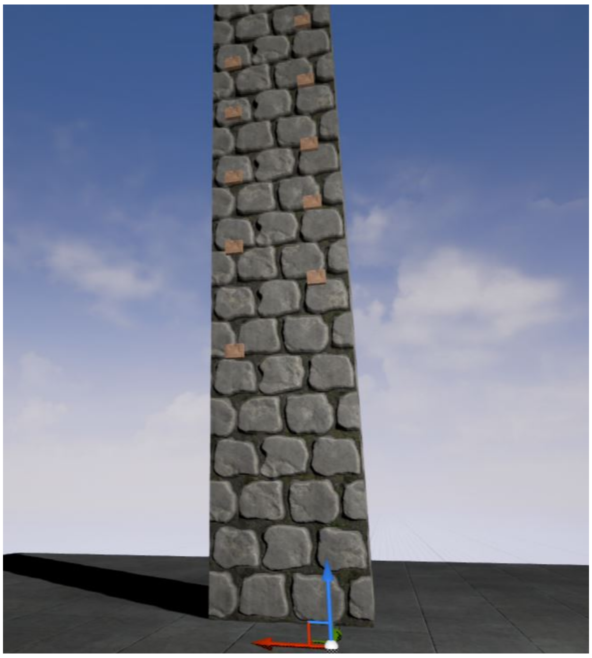
Figure 1: Wall in Unreal.

Using VR allows for data to be collected from treatments, such as the height to which the patient ascends the wall or the time taken to perform a task. The user Point Of View (POV) can also be recorded, using software such as NVIDIA GeForce Experience ShadowPlay, during treatment, alongside external cameras recordings with timestamps. This means that areas of interest during the timestamped data, such as wall height position, can be further analysed by seeing exactly what the participant was seeing at the time. Similarly a camera recording the user allows for their body language to be observed retrospectively. Features such as this can be beneficial in indicating the progress of the users throughout treatment, as well as analysis to identify areas they may have been more or less comfortable with. Using a HMD for VR as opposed to creating a projector powered VE allows the system to exist in a much smaller working volume, though the Baxter is a large robot with reach of 1.21m [6]. This solves one of the big issues clinics have with VR treatment, being the amount of space used for their VE [14].

Using a VE allows for panoramic images to be stitched onto the Unreal Skybox, the VR background behind the wall. This means that patients can perform their treatment in urban city conditions with tall buildings, or more outdoor environments. This can be used for more specific treatment of participants, some of whom may be more acrophobic in certain settings.

The Baxter robot's end effector is used in an encounter haptics system, providing the ledges that the participants will be grasping onto, as shown in Figure 2. This will enable the users to move up and down the wall. The users are not required to be tethered to a device, other than the HMD for viewing purposes. This enables more natural and intuitive interactions between user and ledges. Another reason for designing the system where the users hands are free is to increase the immersion of the participant by providing them full sense of touch on their hands. One drawback of this design choice where the users hands directly contact objects is that the geometry of the object in a VE must match the geometry and scale of the physical object on the Baxter end effector.

Shaking or trembling of the hands is a common physical symptom experienced by people with phobias during anxiety inducing tasks. Links between tremor and anxiety have been made in a number of studies and it has also been recognized in a study of phobics in VR treatment [15], [3]. The Baxter is capable of both positional feedback, in the form of Cartesian coordinates, and torque sensing at the end effector. Using this torque feedback from the end effector hand tremor can be measured throughout the treatment of the user, providing objective feedback of stress levels. This can show not only progress throughout an entire treatment program, but also indicate the exact parts of the demonstration where the phobia was most stressful.

Safety and comfort are essential when performing any form of psychotherapy. By allowing free hand haptics absent of any tethering to a device the user is able to completely remove themselves from the environment simply by taking off their headset. The fact that the treatment is delivered through a VE allows users to push themselves to accomplish anxiety inducing tasks whilst retaining the option to completely remove themselves from the scene at any moment. As the participants are inside a VE they are also in no physical danger when performing tasks, such as wall climbing, as they would be if they were to perform the task outside of VR.

It is proposed that a user study be conducted, whereby people with acrophobia experience the demo with haptic feedback, as well as without haptic feedback (using controllers to climb the VR wall). Comparisons of the system with and without the haptic feedback can be made subjectively from user opinion as well as observed behaviour to validate the impact of the immersion, through haptics, on the anxiety levels of the phobic.

4 CONCEPT IMPLEMENTATION

The entire system, shown in Figure 4, is physically comprised of a Baxter robot, a Vive HMD and a Windows development machine, with a guest Ubuntu Virtual Machine (VM). The software used within the system are Ubuntu 14.04, Windows 10, ROS Indigo , MoveIt!, Unreal Engine 4 and Steam VR. The Ubuntu VM is the machine within which communication to the Baxter Robot is undertaken. The Windows PC is where the VR is controlled, using a VE created in Unreal with a plugin for the HTC Vive to be used as a viewer.

Figure 2: Example of user interacting with ledge.

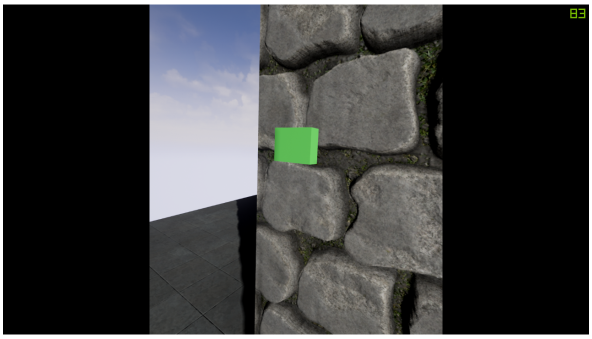

Figure 3: Example of user's view of ledge.

Setup

There were a small number of calibrations in preparing the haptic system. Initially an end effector, Figure 5,was manufactured of a pine wood cut (100mm x 130mm x 40mm), this geometry was mapped 1:1 with a corresponding Unreal model which would act as the ledges for users to grab onto on the wall. Once this was attached to the Baxter robot the robot gripper's weight was recalibrated to handle the additional mass.

To use the HTC Vive a Steam VR room setup was required. This calibration procedure was done carefully

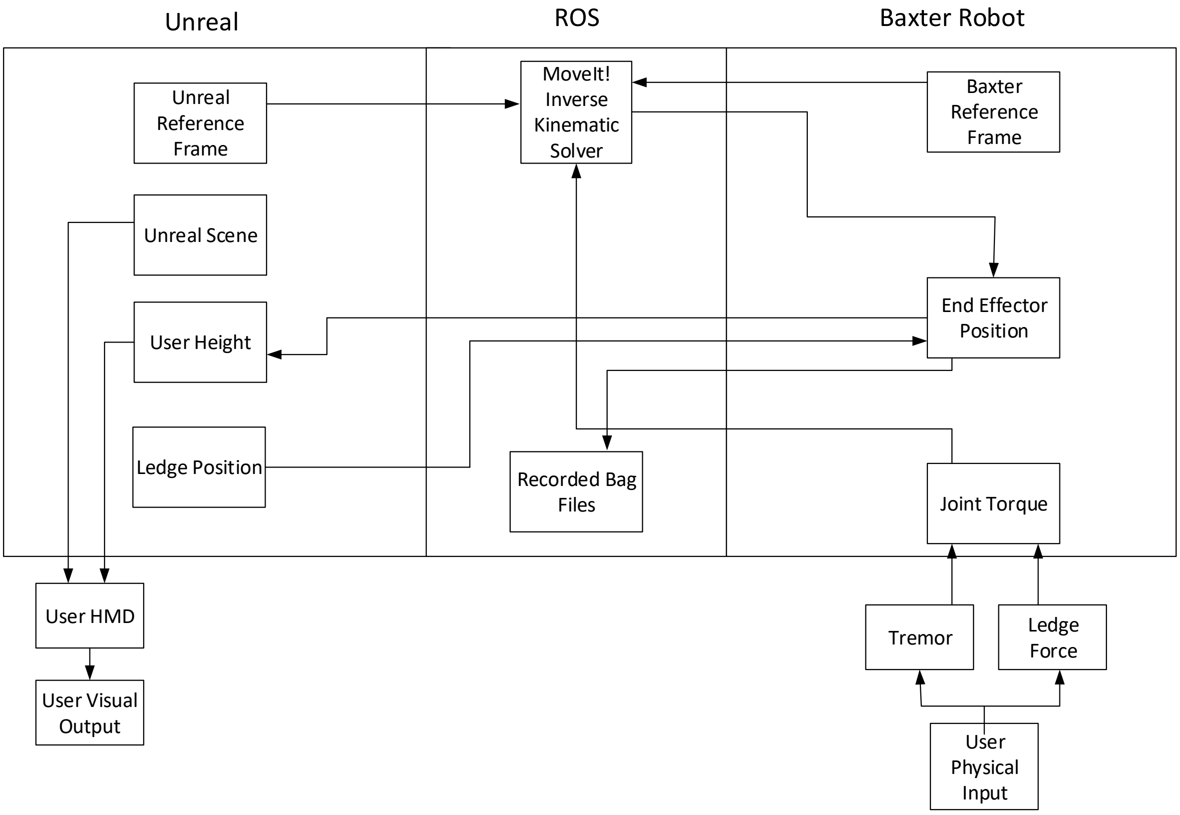

Figure 4: Information flow for Unreal, ROS and the Baxter Robot.

in an effort to align the coordinate reference frame of the Baxter with the coordinate reference frame of the HTC Vive. The distances between these axes were then derived using the Vive controllers in Unreal and sending the Baxter arm end effector to a known Cartesian coordinate, where this would be compared to a corresponding Cartesian coordinate sent to the PC by the controller occupying the same space.

Figure 5: Manufactured physical ledge.

MoveIt! is a common library used in robotics for path planning. In this case the library is used for its Inverse Kinematics (IK) solver. In such a solver cartesian coordinates with quaternions can be provided as input. These are used to determine joint angles resulting in the robot end effector being in the desired place. Not all IK solutions paths can be achieved smoothly by the Baxter robot. It is therefore important that the VEs be designed with consideration to the optimal workspace of the Baxter and movement of the Baxter end effectors be similarly limited to optimal IK solution paths.

A bi-directional TCP socket connection is formed between Unreal and ROS on the Ubuntu VM, using Rosserial Windows, a library required for ROS communication over Microsoft Windows. This permits the passing of messages from Unreal to ROS, such as ledge positions, to be used with the robot. There are a number of different types of ROS messages being passed between the Ubuntu and Windows workstations, in the form of Booleans, ROS Pose messages (Cartesian coordinates in the form of floats) and ROS Publishers and Subscribers, to enable positional data to be taken from Unreal and have the Baxter robot's end effector move to the same location in space.

Runtime

At start up a VE developed within Unreal is shown to the user through the Vive headset, shown in Figure 3.

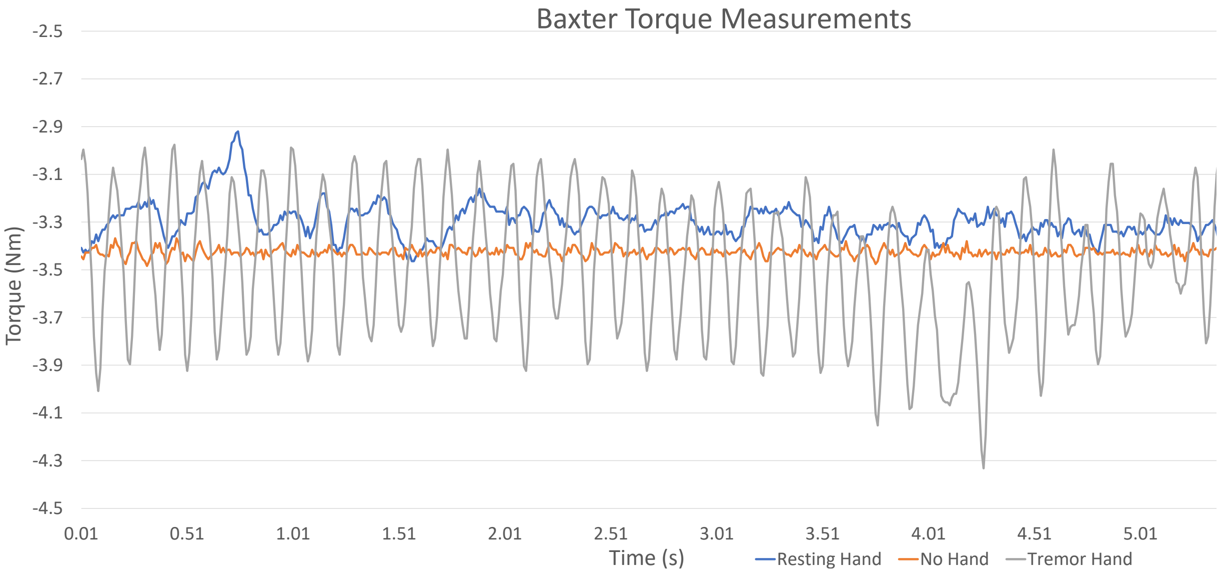

Figure 6: Tremor detection data plot.

There is an initial ledge shown through colour indication for the user grasp. As soon as this VE starts positional data is stored in ROS Pose messages which are then altered in Unreal for offsets calculated during the calibration procedure. These messages are then passed to ROS on the Ubuntu VM containing information regarding the location of the ledge. A ROS Node, an executable on ROS, will receive these Pose messages, using functions and scripts from the MoveIt! libraries to produce an IK solution which is forwarded to the Baxter robot. This results in the initial ledge which the user sees in VR being matched by a physical ledge held by the Baxter arm at the same location in space.

Once the IK solution has been met and the Baxter robot end effector is in the correct location the user is notified by a colour change in the VE, this is when they can grasp the ledge. When the user holds and moves the ledge downward torque sensing in the joints of the Baxter robot arm is used to deduce which direction the user is attempting to move the ledge in, currently limited to 2-DOF, as well as the magnitude of torque applied to each joint. With the direction of movement deduced an IK solution is provided for a new set of Cartesian coordinates, translated by 1mm in the direction of desired movement. The translation distance is adjusted in runtime based on the torque measured from the end effector, with a greater torque resulting in larger IK coordinate changes. The overall effect of this is that as the user moves the ledge the robot arm will move with them at the desired speed, whilst retaining the correct orientation of its end effector. The user is unable to move the end effector in other DOFs, such as towards or away from themselves, as the Baxter robot will be in a control mode called Positional Mode which requires IK solutions to be published for the arm to move.

As the user moves a ledge the Pose messages, containing the coordinates for the end effector, are passed from ROS to Unreal through the use of the ROS network. These are then used to adjust the height of the user in the VE, resulting in a 1:1 mapping of the ledge maintained between real world and VE during transit. At the same time torque measurements of the end effector are saved in timestamped logs. Both wall height and small tremor forces can be later analysed, inferring times when the user was most anxious and how high up the wall they were at the time. Throughout this movement of the ledge the robot arm will constantly be providing the rigid body of the ledge with force feedback. It should be noted that the force feedback will never be greater than 5N at the end effector.

Whilst one end effector is being moved downwards the other robot arm aligns itself to the next ledge for the user to grasp. This second ledge will then be ready to be grabbed irrelevant of the position of the first ledge due to the continuous 1:1 mapping and height changes of end effector and VR user height in the VE.

Measuring Hand Tremor

Hand tremor is measured through torque sensing in the Baxter robot's joints. As a user's hand tremors whilst holding the ledge they apply a force to the robot's end effector. This is then transmitted as a torque through to the closest joint. This can be recorded at 95Hz. Corresponding timestamps can then be used to align the tremor data with the Unreal recording.

To evaluate tremor detecting capabilities of the system a simple test was performed. Torques were recorded in three scenarios:(1) no user contact with the ledge; (2) when the user held the ledge with minimum hand tremor; (3) when the user replicated mild hand tremor.

With the naked eye the tremoring hand was not visibly distinguishable from the resting hand, it was however very distinguishable in the data, Figure 6. The smallest tremor amplitude during the test corresponded to a torque change of approx. 0.2Nm, which could still be defined from the resting hand or no hand contact. In the case where a user's hand will tremor more during high levels of anxiety it will be clearly identifiable from the regions of lighter tremor. To more effectively evaluate the capabilities of the proposed system in determining stress levels. Results of the hand tremor will be compared to heart rate recordings for a participant during a future user study.

5 CONCLUSION

A novel, large volume, encounter haptics system is proposed. The system has features suitable for VR psychotherapy, in the form of offering the ability to record the POV of a user during treatment and objective feedback of anxiety levels. This haptic system is limited by the shapes available to add to the end effector of the Baxter robot and is most effective when VEs are designed with optimal IK solutions for the Baxter in mind. The increased immersion of the treatment through the use of haptic force feedback could help improve current VR treatment. The author believes that the most suitable users of such a system would be a VR treatment clinic wanting to conduct highly immersive and interactive phobia treatment. A user study to analyse the impact of these haptics in a VR treatment by comparing anxiety levels, objectively and subjectively inferred, is necessary in future work to compare a VR treatment with and without haptics.

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