Quantifying and eliminating clinical tremor in VR

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***Abstract*— We present a VR-based tremor-free experience for patients who live with upper limb tremor, that simultaneously creates a research-grade benchmark assessment of tremor. There exists an opportunity and a setback for VR being useful for patients experiencing tremor. First, VR and gaming at large offer an opportunity for patients to explore worlds and experiences apart from their disabled reality. The setback for tremor patients is, however, is how a systematic tremor movement can make user input untenable, thoroughly limiting the interactions that can be used in VR due to the 'noise' of the user's input. Using a commercially available VR system, we designed a challenging balloon-popping task that mimics a commonly-used reaching test that practitioners use to evaluate reaching capability. Within this environment, we offer a mode which low-pass filters the hand position and orientation over a series of past data points, thereby creating a smoothing function for hand movement that can completely remove tremorous movement from the VR hand representation. This visuomotor manipulation allows the patient to more easily reach the balloon targets, thereby enabling the collection of quantitative task data. With the speed, accuracy, and the tremor components computed across 3 axes of movement, patients can be evaluated for their tremor amplitudes in a quantitative, replicable, and enjoyable manner.**

I. Introduction

For patients living with Parkinson's Disease (PD) and Essential Tremor (ET), manipulating objects and interfaces pose new challenges to their ability (and disability) and to their identity (and agency). In this work, we explore two areas of interest to this patient group with respect to Virtual Reality (VR) experiences; first, we examine whether a simple reaching task that is used across disease rating scales can be automated in VR, and second, we explore whether the patient's tremor can be visually negated while performing that test (to provide a unique experience). Rating scales, such as the UPDRSIII and the Fahn-Tolosa-Marin have been effective, and a variety of EMG-based measurement approaches have advanced the tools researchers are developing to classify PD and ET patients \ref{povalej2017new}. And prior work has explored the use of 3D tracking of patient hand position over the course of functional movements \ref{su2001three}. However, these solutions require the installation of a custom-designed system of electromyographic (EMG) sensors, or 3D position tracking—a system with a level of complexity that may not be conducive to widespread implementation. Furthermore, it's important to incorporate the experimental paradigm and proctorship within the experience itself, thereby lending itself to higher replicability and consistency across subjects \ref{belk2013extended}. As VR systems need low-latency high-precision tracking, even the simplest of VR systems on the market today allow for immersive experiences. In parallel, a high-quality, high-accessibility tracking system is ideal for a rehabilitative or clinical measurement system that could be deployed to outpatient clinics to enhance the quality of care for PD and ET patients \ref{rizzo2005swot,dockx2016virtual}.

II. Methods

We produced a VR environment (Unity 2018, San Francisco, CA, USA) for use with an inside-out tracked head mounted display (HMD) and one controllers (HMD update rate of 90Hz; HTC Vive, Xindian, New Taipei City, Taiwan). Hand position and orientation for one controller was saved to RAM during the course of the experiment, and saved to a comma-separated-value (CSV) file after the trial is complete. The second hand is tested in a separate experiment with the same controller.

A. Task

The subject is instructed to keep their torso stationery against a high-backed chair while wearing the HMD and holding the controller in one of their hands.

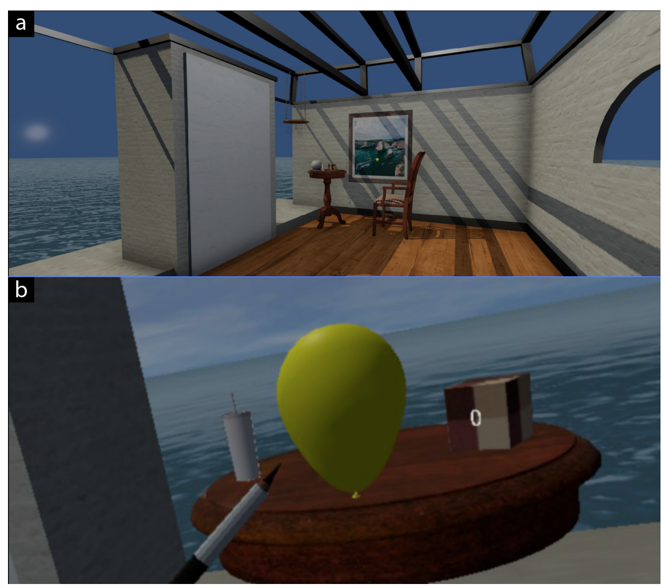

Figure 1. In-game view of the environment balloon task. In reality, the seated subject reaches repeatedly from their nose to a target suspended ahead of them, and 3D tracking is achieved through inside-out HMD and controller tracking with two infrared-light-emitting base stations. (a) The room is a dimly-lit room with a virtual chair that is lined up with a stationary physical chair in reality. (b) The balloon is popped by holding the pencil tip in the balloon's volume. The score thus far is visible to the user.

In VR, the subject sees one balloon at a time, one that appears in the same relative position in front of their nose, and a reach target spawned along a line at a comfortable

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reaching distance for the subject (Figure 1). The patient moves between the two, popping each balloon with a pencil tip that is affixed to their VR-hand avatar. The length and position of the 'reach balloon' line can be adjusted and saved, allowing for a subject-specific and replicable test environment. Axes are illustrated in Figure 2.

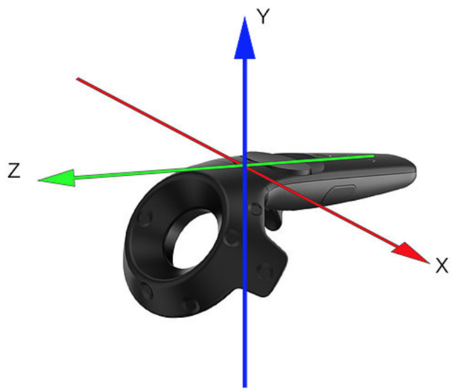

Figure 2. Orientation of the three axes of interest for this study. The pencil tip was placed along the Z dimension, central to the controller.

A 'debounce' of 100ms was added to the balloon targets; in effect, we did not register a pop of the balloon unless the pencil tip was within the balloon collider for 100ms frames. This was added to prevent the user from slashing into the targets, and promoted accuracy and stability at each of the targets—the default behavior in the existing clinical test.

B. Analysis

Python 3.6 was used to produce visualizations of the recorded data and compute frequency distributions for each of the X, Y, and Z axes for the controller. With the Python script running within the environment, data much like the data shown in this paper are immediately visible on the wall of the virtual environment, and are concatenated into a PDF for a clinical provider's review with the patient.

Fast Fourier Transform (FFT) was applied on data on each axes to provide frequency domain analysis of the tremor. Moreover, the Standard Deviation (SD) of the signal for each axes was calculated and reported.

We produced a metric of 'tremor amplitude', which was inversely proportional to the collective SD across axes, as a first introductory measure to make the report readily comparable to prior test results. We do not perform any further analyses, though we acknowledge that extended techniques are highly applicable (i.e. as with asymmetry analysis, and interpretation of the endpoint velocities and accelerations)\ref{spasojevic2017combined}.

III. Results

We found that tremor is readily visible in the frequency domain when investigating each of the three rotational angles over the course of 15 reaching trials (15 reach balloons, and 15 nose balloons in total). With a hann window of 270 samples over the data collected at 90Hz, and with an overlap of 135 samples, we computed a discrete fourier transform over frequencies from 2-12Hz, a generous range for human-observed tremor frequency bands\ref{povalej2017new}. Performing this analysis for each of the controller rotations in x,y, and z, and across the two conditions of non tremorous and tremorous movement, frequency components in the 4-6Hz band are clearly visible (Figure 3).

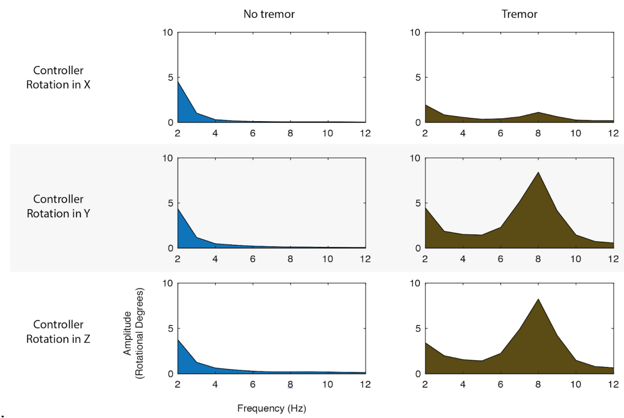

Figure 3. Data collected for a subject creating a patient-like tremorous movement. (a) 3D positions over time are used to generate (b) frequency distribution curves, which illustrate the amplitude of shaking across the different frequencies, along different axes of movement.

IV. Conclusion

We find preliminary evidence that the primary upper limb movements of PD and ET can be quantified through a VR reaching paradigm, and that those frequencies can be adequately negated visually through a moving-average filter. Ultimately this work provides a technical precedent and scientific premise for study with patients.

V. References

@inproceedings{su2001three,
title={Three-dimensional motion system ("data-gloves"): application for Parkinson's disease and essential tremor},
author={Su, Y and Geng, D and Allen, CR and Burn, D and Bell, GD and Rowland, R},
booktitle={Virtual and Intelligent Measurement Systems, 2001, IEEE International Workshop on. VIMS 2001},
pages={28--33},
year={2001},
organization={IEEE}
}

@article{povalej2017new,
title={New perspectives for computer-aided discrimination of parkinson's disease and essential tremor},
author={Povalej Br{\v{z}}an, P and Gallego, Juan Alvaro and Romero, Juan P and Glaser, Vojko and Rocon, Eduardo and Benito-Le{\'o}n, Juli{\'a}n and Bermejo-Pareja, F and Posada, IJ and Holobar, Ales},
journal={Complexity},
volume={2017},
year={2017},

publisher={Hindawi}
}

@article{belk2013extended,
title={Extended self in a digital world},
author={Belk, Russell W},
journal={Journal of Consumer Research},
volume={40},
number={3},
pages={477--500},
year={2013},
publisher={Oxford University Press}
}

@article{spasojevic2017combined,
title={Combined vision and wearable sensors-based system for movement analysis in rehabilitation},
author={Spasojevi{\'c}, Sofija and Ili{\'c}, Tihomir V and Milanovi{\'c}, Sla{\dj}an and Potkonjak, Veljko and Rodi{\'c}, Aleksandar and Santos-Victor, Jos{\'e}},
journal={Methods of information in medicine},
volume={56},
number={02},
pages={95--111},
year={2017},
publisher={Schattauer GmbH}
}

@article{rizzo2005swot,
title={A SWOT analysis of the field of virtual reality rehabilitation and therapy},
author={Rizzo, Albert “Skip” and Kim, Gerard Jounghyun},
journal={Presence: Teleoperators \& Virtual Environments},
volume={14},
number={2},
pages={119--146},
year={2005},
publisher={MIT Press}
}

@article{dockx2016virtual,
title={Virtual reality for rehabilitation in Parkinson's disease},
author={Dockx, Kim and Bekkers, Esther MJ and Van den Bergh, Veerle and Ginis, Pieter and Rochester, Lynn and Hausdorff, Jeffrey M and Mirelman, Anat and Nieuwboer, Alice},
journal={The Cochrane Library},
year={2016},
publisher={Wiley Online Library}
}