A virtual reality-based training system for error-augmented treatment in patients with stroke

Lily Sror
Department of Industrial Engineering and Management
Ben-Gurion University of the Negev
Beer Sheva, Israel
lilys@post.bgu.ac.il

Michal Vered
Rehabilitation Department
Soroka Medical Center
Beer Sheva, Israel
MichalVe@clalit.org.il

Iuly Treger
Rehabilitation Department
Soroka Medical Center
Beer Sheva, Israel
iulyt@clalit.org.il

Shelly Levy-Tzedek
Physical Therapy Department
Ben-Gurion University of the Negev
Beer Sheva, Israel
shelly@bgu.ac.il

Mindy F. Levin
School of Physical and Occupational Therapy
McGill University
Montreal, Canada
mindy.levin@mcgill.ca

Sigal Berman
Department of Industrial Engineering and Management
Ben-Gurion University of the Negev
Beer Sheva, Israel
sigalbe@bgu.ac.il

***Abstract*— Stroke is a leading cause of long-term sensori- motor deficits in upper limb function and current upper limb interventions have limited effectiveness. Joint-level augmentation treatment, grounded in referent control theory, prescribes insertion of error at the joint level for inducing a dynamic re-mapping of muscle-level control mechanisms. We hypothesize that this will lead to an increase in the control range of the joint and consequently to improved performance of voluntary motion. In the current presentation we describe a system harnessing virtual reality developed for upper-limb training based on joint level error augmentation. The system comprises three components, a passive arm rest supporting the arm against gravity, a Kinect motion tracking system, and a virtual-reality training environment. The visualization of the entire arm is a critical system component which should invoke a high degree of presence. For the method to be effective, the participant should accept the visualized arm position as representing his/her actual arm location, despite conflicting input from his/her proprioception. A pilot test is currently under way for assessing the method's effectiveness.**

***Keywords*—virtual reality, error augmentation, stroke, motor rehabilitation**

I. Introduction

Stroke is a leading cause of long-term sensorimotor disability. Deficits in upper-limb functionality following stroke persist into the chronic stage in a large proportion of stoke survivors [1]. This is partly due to the limited effectiveness of current rehabilitation interventions for the upper limb [2]. Repetition is a key post-stroke rehabilitation element. Accordingly, multiple efforts have been directed at augmenting rehabilitation following stroke with advanced technologies, such as robotics and virtual reality (VR) [3-4]. Such advanced technologies can support and motivate motion repetition. More specifically, VR facilitates the creation of enriched practice environments which may lead to increased motivation and improved practice related to activities of daily living. Robots facilitate limb support and the control of motion dynamics. These technologies also support objective progress assessment since they enable monitoring motion.

Robots have also been used to administer upper limb treatment based on endpoint error augmentation (EA) (see [5, 6] for recent reviews), but for upper limb treatment results have been disappointing in terms of functional improvement. In an effort to improve the effectiveness of post-stroke upper-limb rehabilitation, we have developed a system for an innovative treatment, based on joint level error augmentation. The feedback presented is hypometric, and according to the referent control theory of motor control [7, 8], joint level error augmentation is expected to contribute to dynamic remapping of muscle-level control mechanisms, and thus to an extension of the articular range in which patients can control joint motion. This may lead to an increase in the patient's ability to perform isolated movement and consequently to an improved ability to perform voluntary motion. In the following, we present the developed system focusing on the virtual environment.

II. System

A. System overview

The system currently supports arm movement in the horizontal plane. It comprises three components: a passive manipulator for supporting horizontal motion against gravity, a motion tracking apparatus based on a Kinect camera, and an interactive VR game environment (Figure 1). The participant sits on a stable chair with Velcro straps limiting unwanted trunk motion. The wrist of the hemiparetic arm is strapped to the manipulator's arm support. A screen is positioned about one and a half meters in front of the participant and the screen is a bit higher than the plane of motion. A Kinect camera is placed on top of the screen so it is in front and above the motion of the arm. The system operates in regular room lighting.

B. Supporting manipulator

The supporting passive manipulator was modeled after an ergonomic computer desk armrest. Such devices support the arm while facilitating smooth horizontal motion. The manipulator has three rotating joints and three horizontal links. The wrist is placed on a padded wrist holder and connected to

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the manipulator using a Velcro strap. The hand is free, facilitating task relevant motion. The manipulator is connected to a stable base at an adjustable height [9].

Figure 1: System components: passive manipulator, motion tracking, and VR environment. The presented elbow angle is lower than the actual elbow angle (hypometric).

C. *Motion tracking*

Motion tracking is based on the Kinect skeleton. A Kalman filter is used for attaining required accuracy. The motion estimation model used for by filter is based on an expected low amount of trunk motion (due to the chair's Velcro straps), a rigid-body assumption regarding arm segment motion, and the limitation of the wrist motion to the horizontal plane (due to the supporting manipulator).

D. Virtual environment

Joint error augmentation requires accurate visualization of the entire arm, with the ability to include an error in the presented joint angle. The visualization should invoke a high degree of presence, so that the participant will accept the visualized arm position as representing his/her actual arm location, despite conflicting input from his/her proprioception. The game for training should encourage a functional gross arm motion task which is suitable for patients who have not yet re-gained fine motor skills. The game should be motivating but the visual scene should not be overwhelming, since the patient's perception capabilities may be reduced. The current environment is targeting the elbow for which the training range should be adapted to the zone in which each patient can control his or her arm motion. The task should be suitable for performance in the horizontal plane facilitated by the supporting manipulator.

The virtual environment was developed using TouchDesigner^{TM} software (Derivative, USA). A stationary reaching task was designed according to these specifications in which targets are presented within a horizontal plane (Figure 2). The virtual camera is placed to emulate a camera behind the subject at a tilt angle of 45°, emulating a first-person view. A full arm model is presented on the screen, based on the tracked motion with (or without) an inserted 10° error in elbow angle. The reaching task is time-limited, and the environment facilitates adaptation of the time allocated for reaching a target during any point in the training. A motivational icon is presented above the participant's hand upon each successful reach, and every 30 reaches an encouraging message is presented on the screen.

Prior to the training, a calibration procedure is performed for defining a patient-specific training zone. The participant is presented with an area-covering task, and 30 targets are later uniformly selected within this space. During training the system records the average success rate and the time to reach the targets. An interactive control panel facilitates entering session information and training parameter adjustment.

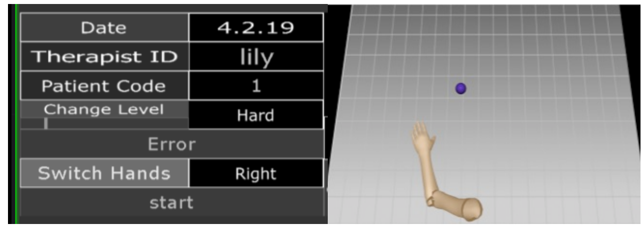

Figure 2: Left: Session information control screen. Right: Game environment.

III. Future Work

The system is currently deployed in the rehabilitation department at the Soroka University Hospital in Beer-Sheva, Israel and a pilot experiment is underway. A second system will be installed in Canada in the near future. Twenty-four sub- acute patients with sub-acute stroke (six weeks to three months post stroke) will undergo three thirty-minute training sessions on consecutive days. Half of the patients will receive visual feedback with error and half will receive visual feedback without error. The experiment in Israel has been approved by the Helsinki committee at the Soroka University Hospital.

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