Platform for the study of virtual task-oriented motion and its evaluation by EEG and EMG biopotentials

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Abstract— **This paper presents a platform to study the relationship between upper limb kinematic and biopotential measurements. The platform comprises of a haptic joystick, biopotential acquisition systems and 3D rendered virtual tasks that require user interaction. The haptic joystick, named Tee-R, reproduces the pronation-supination and flexion-extension movements of the human arm, which are directly mapped to a 2D graphic display. The biopotential acquisition system is able to record electroencephalography (EEG) and electromyography (EMG) signals and synchronize them with kinematic data obtained from the Tee-R. The 3D virtual tasks are designed to obtain performance measurements from the user interaction. We include an example that depicts the possibilities of application for the study of event-related (de)synchronization (ERD/ERS) based on EEG during motor tasks.**

I. INTRODUCTION

Task-oriented repetitive movements designed to improve physical rehabilitation and skill training protocols can be programmed into a robotic platform capable of repeatable simulations [1]–[4]. The standardization of movement performance metrics in visuo-haptic systems is an important and active research area due to the need for quantitative evaluations of motion. Prior research has demonstrated that significant correlation exists between kinematic and clinical measures [5]. The comparison of these signals for defining performance measurements will find application in the following areas: medical training, motor skill training, physical rehabilitation and brain-machine interfaces [6]. El Saddik et al. [7] presented some reference kinematic metrics for healthy subjects, against which the performance of a patient was compared, thus facilitating the assessment of patient's progress. Their metrics are Time to Complete a Task, avatar's position and speed measurements against an "ideal" path (e.g. minimum jerk) and hand grasping angles. As concluded by Celik et al., kinematic measurements such as trajectory error and smoothness of movement have the potential to serve as important robotic measures, measures that when correlated with clinical measures, provide a quantitative approach for evaluating movement quality [8].

Nevertheless, motion measurement in humans is not only limited to mechanical variables but can also include electric biopotentials signals. Biopotential measurements provide direct measurable variables from the user that have information about the movement during the task. In this sense, there are two biopotentials that closely relate to movement: Electromyography (EMG) which is the electrical activity in muscles; and Electroencephalography (EEG) which refers to the electrical activity at the cortex in the brain. Since movement is fully related to mechanical and biopotential signals, a complete movement performance study ought to measure both, thereby providing information regarding the behavior and correlation between both types of metrics. In addition to existing metrics, the correlations between kinematic and biopotential measurements can be used as performance measurements for a determined virtual task. A technological platform designed toward this end must, therefore, measure and synchronize both kinds of variables.

In order to study these performance measurements, we designed and implemented a platform from which kinematic and biopotential measurements can be obtained. This platform is intended to study the relationship between kinematic and biopotential measurements within a virtual dynamic task through a haptic joystick for upper limb motion. This paper presents the design and implementation of the platform comprising a haptic joystick, the synchronized biopotential and kinematic data acquisition during a virtual dynamic task, and the software for the interaction with a virtual environment. We include an example that depicts the possibilities of application for the study of event-related (de)synchronization (ERD/ERS) based on EEG during motor tasks.

II. METHODOLOGY

A. The Tee-R haptic joystick

The Tee-R is a 2 DOF haptic interface for arm movement studies. This interface is a joystick-like device capable of allowing, restricting and aiding pronation/supination ($\pm 90^\circ$), as well as combined elbow-shoulder flexion/extension movements (0.15 m). The mechanical design process of our Tee-R joystick is described in detail in [9]. The objective of the Tee-R is to provide the user with both haptic feedback and direct mapping from arm movements to a computer screen during the completion of a virtual task. The Tee-R is interfaced to a virtual environment (VE) in which the user performs a predefined task. A picture of the device can be seen in the lower right corner in Fig. 1. The motors and motor drives of the Tee-R are connected to the computer via a data acquisition card ($Quanser^{TM}$ Q8-usb). The Q8 board is interfaced by the software of the virtual task described in section II-D.

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B. Biopotential acquisition

The biopotential measurements are obtained via a $BIOPAC^{TM}$ MP150 Data Acquisition System. EEG signals are measured by electrodes on a cap (Electro-Cap, International, standard 10-20 system). The output of each EEG electrode is fed to a $BIOPAC^{TM}$ EEG100C amplifier. Bipolar disposable Ag/AgCl surface electrodes with a gel skin contact area of 1 cm are used for EMG signals. Each electrode is connected to an EMG100C amplifier. The MP150 board is setup to sample all inputs at 1 kHz. The MP150 has 16 analog inputs and 16 configurable digital channels, this capacity is used to communicate the kinematic data synchronized with EEG and EMG.

C. Synchronization and processing

In order to synchronize all kinematic, biopotential data, virtual task the analog and digital outputs of the Quanser Q8 data acquisition card are connected to corresponding inputs of the $BIOPAC^{TM}$ MP150. The software (AcqKnowledge 4.2) records the EEG and EMG signals connected to the modules of amplification of the MP150, as well as the analog and digital inputs that carry data from the Quanser Q8 outputs. This connection is shown in Fig. 1.

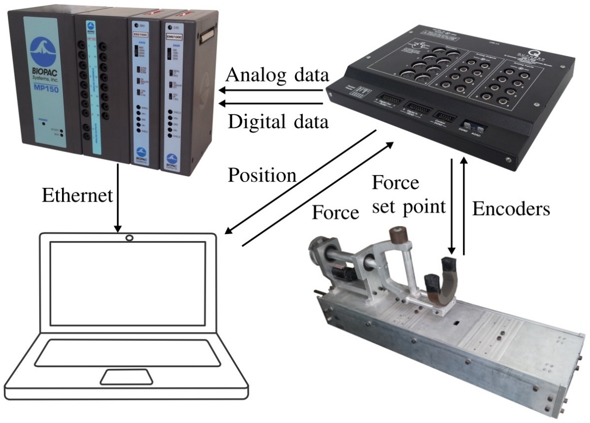


Fig. 1: Diagram of the hardware connections of the platform.

D. Software Architecture

The user interacts with a virtual environment (VE) through the joystick to perform a predefined virtual task. In order to develop the VE we used the Computer Haptics & Active Interfaces (CHAI) 3D framework. CHAI 3D is an open source object-oriented framework developed by Conti et al. in order to ease the haptic feedback integration into 3D visual simulations [10]. The VE is rendered such that it enables position acquisition in the virtual world and sends force feedback signals to the motor drives for proper haptic rendering. In this platform, CHAI 3D is interfaced with the Quanser's HIL (Hardware-In-The-Loop) API to perform the communication with the Tee-R. By running separate threads, the haptic control loop runs at a 1 kHz refresh rate and a the graphics loop at a 30Hz refresh rate. The haptic thread sets analog and digital outputs that provide information about the current task. These outputs are task-dependent and can refer to the position of the avatar and other objects of interest in the VE, as well as scores and time among others.

E. Virtual tasks

Two virtual environments with different virtual tasks are programmed for user interaction with the VE using the Tee-R. The first, a) uses 1 DOF in a **ball catching task**, and the second, b) involves 2 DOFs in a **target hitting task**. For a), the user has a virtual avatar rendered as a torus on the screen, as depicted in Fig. 2. The objective of the task is to catch balls, balls that fall from the top of the VE, by moving the avatar along the x-axis (horizontal axis on the screen). This movement is mapped from the angle of rotation of the pronation/supination movement in the joystick. For b), the objective is to hit as many targets as possible in a preset period of time. The VE displays a 2D screen as shown in Fig. 3. Targets appear in random order from the center of the screen in one of eight equally spaced positions. When the user acquires the target, it disappears and the user must return to the center. For these tasks, the positions of both the avatar and the drops are sent via the Q8 board to the MP150 as analog outputs. An additional analog output provides a pulse if the ball was caught ($+5V$) or missed ($-5V$).

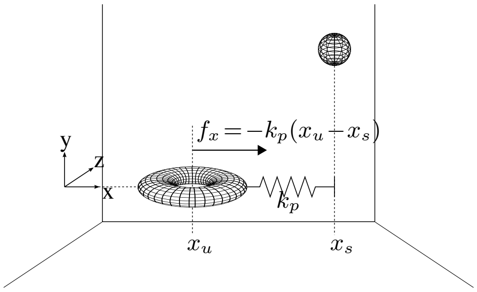


Fig. 2: Description of ball-catching task when a spring is rendered between the ball and the avatar.

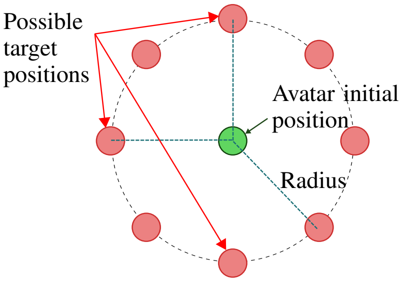


Fig. 3: Sketch representing the virtual environment for the target hitting task. The circle in the middle represents the avatar while the rest represent the possible target locations.

In both virtual tasks, two different force rendering modes are implemented. The first one is the **free motion rendering mode**, which involves the movement of the avatar without any haptic feedback. For the second mode, a spring is rendered between the position of the Tee-R's virtual avatar and the current target. An example of this haptic effect in the ball catching task is shown in Fig. 2. This mode is referred as **spring rendering mode**. Hence, as soon as a new ball or target appears, a force proportional to the distance along the x-axis for the ball catching task, and the x and y axes for the target hitting task is felt by the user. This force guides the movement of the user's hand to the desired position in order to catch the ball or target. Additional rendering modes can be implemented in this platform.

III. RESULTS

In order to test the functionality of the constructed platform, a ball catching task was carried out. It is worth mentioning that our intention is to show the possibilities for the potential users interested in the quantification of motor tasks, and not to present a complete series of experiments considering a group of study. Fig. 4 shows the setup of the experiment in which the test subject performs the ball catching task with the spring rendering mode while EEG signals and kinematic data are being recorded. This experiment was conducted for 20 trials. The EMG register can be included but it was not considered for this experiment. Both, the ball catching task and the target hitting task, are available to be executed by the subject depending the goals of the study. In this case and for brevity, only the results of the ball catching task are presented herein.

The EEG signals were recorded from electrodes C3 and C4 according to the 10-20 system, reported as the most important electrode locations for discrimination of different motor tasks [6]. Fig. 5 shows an example of the output of the software Acqknowledge which presents EEG readings at the C3 position. Two additional analog signals correspond to the avatar and falling ball positions along the x-axis as well as a signal that provides a positive or negative pulse if the ball was caught or missed. All of the signals were registered on line during the experiment by the MP150 and thus are synchronized. Additionally, the EEG signal at the C3 position was filtered offline and plotted on the same screen to show the beta-wave band (14-34 Hz). All data (including filtered data) were saved as comma-separated values file (CSV).

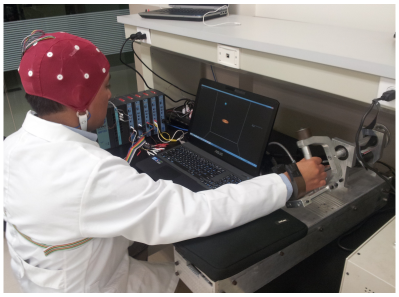


Fig. 4: An example of the setup of the experiment showing the platform and the test subject.

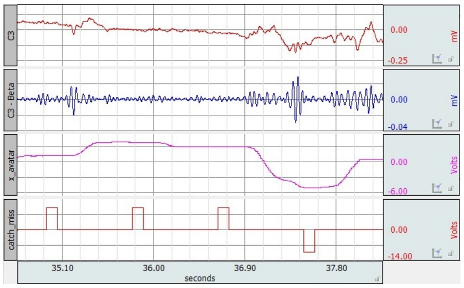


Fig. 5: Output of the software Acqknowledge plotting the EEG readings, the Beta band, and two analog signals representing the avatar position and a successful/failed task.

It is possible to use the acquired data to compare changes in EEG amplitudes elicited during the motor tasks. The standard event-related desynchronization (ERD) and the event-related synchronization (ERS) calculation process includes four basic steps [11]: i) band-pass filtering (2 Hz band interval from alpha (4-14 Hz) to beta (14 to 34) bands) of each trial, ii) squaring of the amplitude samples, iii) averaging over trials and over samples, and iv) averaging over time samples to smooth the data and reduce variability. The ERD/ERS is defined as percentage power decrease (ERD) or power increase (ERS) in relation to a 0.5 s reference interval before the appearance of the ball in the screen. Fig. 6 shows the spectrograms and ERD/ERS time-frequency maps calculated for the electrodes C3, C4 and C3-C4 bipolar configuration with horizontal lines representing the appearance of a ball. Initial time (0 s) corresponds to the appearance of the ball on the screen. For the C3 and C4 electrodes, the spectrograms show an increase in the spectral amplitude in the 20-35 Hz range (mid to high Beta) at the time the experiment starts. The ERD/ERS maps show synchronization on the same frequencies; however, the synchronization is higher on the 30-34 Hz bands. Moreover, some laterality is appreciated on the C3 electrode with respect to the C4 on the 20-24 Hz band. No noticeable change on the spectrogram can be seen when an event occurs in the bipolar configuration. The ERD/ERS map, however, shows synchronization on the 32-38 Hz range and desynchronization on alpha and lower beta bands. This type of analysis can be used for a complete performance study with patients [4], [6].

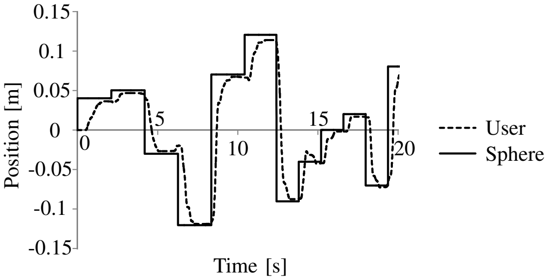
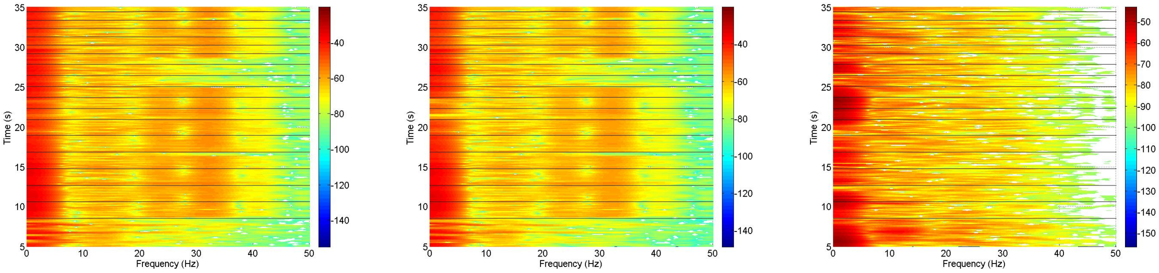
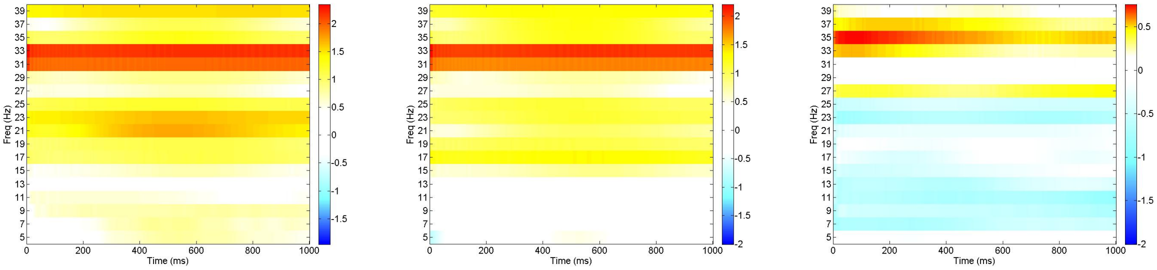


Fig. 7: Trajectory along the x-axis of the test subject for the first 20 seconds of a single trial, as well as the position of the current dropping ball.

A comparison between the user's trajectory and the ball position along the x-axis is depicted in Fig. 7. The sum of the squared error for all time steps for one trial of free rendering



(a) C3 electrode (b) C4 electrode (c) C3-C4 bipolar electrode



(d) C3 electrode (e) C4 electrode (f) C3-C4 bipolar electrode

Fig. 6: (a), (b) and (c) show the spectrogram for a single trial for the three configurations. Horizontal black lines represent the occurrence of an event. (d), (e) and (f) show the ERD/ERS maps for the corresponding electrodes and the same trial.

mode was $60.76\ \mathrm{m}^2$ while for a spring rendering mode $78.18\ \mathrm{m}^2$. A comparison against an optimal trajectory, such as minimum jerk, can be done to quiantify the performance.

IV. CONCLUSIONS

This work develops a visuo-haptic system that serves as a platform for the study of motion in virtual tasks via the evaluation of both kinematic and biopotential signals, including EEG and EMG signals. The platform comprises a 2-DOF haptic device capable of capturing position and providing force-feedback to the user, a biopotential acquisition system and software to develop virtual tasks. The problem of synchronization was solved by acquiring both the biopotentials and kinematic data using the same acquisition system, thereby eliminating the need of manually synchronizing the signals or a more complex synchronization scheme on the software side. Two representative virtual tasks were presented, although other environments could also be implemented. This open platform will be used to perform future studies of the synchronized kinematic and biopotential data and the effects of haptics on rehabilitation applications with patients that suffer malfunction of the motor skills caused by a cerebrovascular accident.

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