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Development and Evaluation of Hardware for Point-of-Care Assessment of Upper-limb Motor Performance

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Abstract— **This paper presents prototypes of a hardware interface that is directed towards possible integration with a Point-of-Care Testing Environment for Neurological Assessment (POCTENA). While the complete system is intended to assist with diagnosis of mild Traumatic Brain Injury (TBI), the focus of this paper is to present designs of necessary hardware that can be used to assess upper-limb motor performance in a point-of-care setting. The hardware interface is expected to facilitate execution of several visuomotor tasks in an attempt to reliably quantify motor deficits. System usability results are shown to corroborate future directions of the POCTENA system.**

I. INTRODUCTION

The sensorimotor system in humans involves several levels of complexity that comprises sensory input, limb mechanics, motor behavior and neural control [1]. Injuries to the brain specifically, mild Traumatic Brain Injury (TBI), may result in motor deficits that often lead to misconceptions regarding symptoms and complaints following the injury [2-3]. Motor deficits may include decreased performance in visuomotor control, upper limb coordination, proprioception, response speed and balance. There are very few studies that have evaluated spatial orientation disorder and proprioception loss as a consequence of mild TBI [4].

A broad objective of this work is to develop a Point-Of-Care Testing Environment for Neurological Assessment (POCTENA) to assist with diagnosis and rehabilitation of mild Traumatic Brain Injury (TBI). There are two distinct components in developing this platform: (1) A set of neurological tests or tasks that integrates sensory, cognitive and motor (specifically, upper-limb) assessment, (2) A hardware system that allows reliable quantification of motor performance in a point-of-care setting.

Several tasks are incrementally added to the POCTENA system. Tasks include simple and complex reaction time tests, visuospatial and visuomotor tasks. In the current iteration of development, a position sense task [5-6] is being added to the existing battery of tests. Position sense is a component of proprioception that arises in joints, ligaments, tendons, and muscles to provide a perception of relative position of body parts [7-8]. In the position sense task, one of the subject's arms is passively moved by a Device Under Study (DUS) to a certain spatial position and the subject is expected to move the other arm in an attempt to mirror match the same position. The focus of this paper is to present research prototypes of devices that can be used to perform a number of visuomotor tasks specifically, the position sense task, in a point-of-care locale.

II. HARDWARE DESIGN

Five different hardware devices are being explored as a part of POCTENA's design process: (1) Force-feedback Joystick, (2) Vertical Mouse, (3) Haptic Interface, (4) Omni-wheel-based Robotic Interface, and (5) Customized mechatronic system. The first two devices were extensively tested for usability during the early phases of development. Both the devices are not considered for further study because they failed to meet certain usability requirements [9]. Out of the remaining three devices, the omni-wheel-based device and the mechatronic system are in-house research prototypes. The haptic interface and the two research prototypes are evaluated to examine their efficacy in implementing sensorimotor tasks.

A. *Haptic Interface*

Three commercially-available haptic devices were initially considered:

a) delta.3 (Force Dimension) is a high performance haptic device with 3 degrees of freedom. Due to high cost of the device, it was not evaluated further.

b) PHANTOM Omni® (Sensable Technologies Inc.) is a compact and cost-effective haptic device with a stylus input and 6 degrees of freedom. The stylus input results in hand movement pivoting at the wrist that may not be desirable for upper-limb assessment. This device may be considered in the future for further studies.

c) Novint Falcon® 3D Touch Controller (Novint Technologies Inc.) is a low-cost haptic device with 3 degrees of freedom and a removable end-effector that comes in different shapes. This device, along with a removable pistol-like grip was selected for initial testing purposes.

A comparison of specifications of the three haptic interfaces is shown in Table I.

B. *Omni-wheel-based Robotic Device*

The idea behind this design is to build a joystick-like device with a movable base. Fig. 1 shows a basic sketch of the prototype. Omni-wheels have rollers along the periphery

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that allow them to slide sideways [10]. To enable movement in all directions, four 40-mm omni-directional wheels are mounted as shown in Fig. 1. For prototyping purposes, off-the-shelf motors and encoders are used to drive the omni-wheels. By changing the rotational directions and speeds of the motors using a microcontroller, the device can vector in any direction.

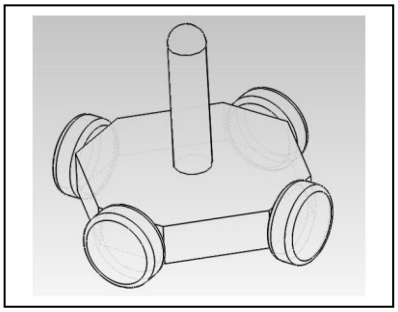

Figure 1. Sketch of Omni-wheel-based[§] Robotic Device ([§] Wheels in the sketch are not representative of the actual design of omni-wheels)

TABLE I. COMPARISON OF HAPTIC INTERFACES

Specification	*delta.3*	*Omni*	*Falcon*
Workspace W x H x D mm	~ 15 x 10	~ 6.4 x 4.8 x 2.8	4 x 4 x 4
Maximum Exertable Forces (N)	20	~ 4	~ 9
Degrees of Freedom	3	6	3
Cost*	~ $ 20,000	~ $ 2,000	~ $200
Interface	USB 2.0	IEEE 1394 Firewire®	USB 2.0

* Costs are relative and are provided for comparison purposes only; the values may not reflect actual cost of the devices.

C. *Customized Mechatronic System*

This hardware system is based on sliding structures on T-slotted extruded aluminum rails, as shown in the Fig. 2. There are two rails: (1) An X-rail that is mounted on a fixed base to provide motion in X-direction, and (2) A Y-rail that is mounted on the X-rail to provide motion in the Y-direction. A handle is attached on top of the Y-rail that can be used to move both or just one of the rails. A pulley-belt mechanism is used to drive the rails. The entire set-up (shown in Fig. 2.) allows movement of one of the subject's arms in any direction. Another set of X-Y rails can be easily added to accommodate movement of the other arm.

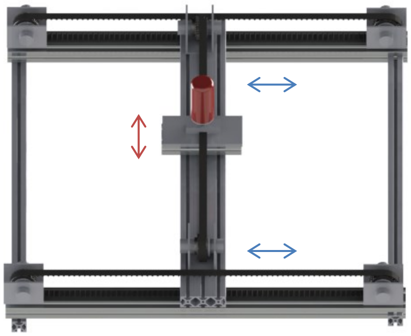

Figure 2. Prototype of custom mechatronic system

III. PRELIMINARY EVALUATION OF HARDWARE

All three hardware considerations, Haptic Interface (HI), Omni-Wheel-based Device (OWD), and the Customized Mechatronic System (CMS), were evaluated using a System Usability Scale (SUS). SUS is often referred to as a "quick-and-dirty" to conduct cheap usability evaluations [11]. The SUS tool comprises 10-statements that are scored on a 5-point Likert scale (1 being *strongly disagree* and 5 being *strongly agree*). The primary reasons for choosing SUS for this iteration of testing over other usability instruments are: (1) the alternating positive and negative statements require participants to understand and carefully rate each statement, and (2) It gives a single composite score that represents the overall usability of the system Also, the original 10 SUS statements were slightly modified to closely match the Device Under Study (DUS).

A simple application that displays (or flashes) a clearly visible circular object at a random position on a laptop screen was used to simulate a reaching task. The participant is required to move the pointer (or cursor) to the position of the object using the handle on the DUS and then click on it. The position of the object changes every time the object is clicked, and continues for 60 seconds. The number of clicks is recorded for each trial. It is important to mention that the number of clicks is not a measure of reaction time or performance of the participant but, only a measure of movability of the DUS. Hence, this number is referred to as maneuverability count.

Six male volunteers in the age group of 23 to 29 evaluated each DUS in an order determined by a 3 x 3 Latin square. A brief explanation of each DUS and each SUS statement was given at the beginning of the experiment. Also, participants were explicitly informed that the study was solely meant to evaluate the usability of the devices, and that no clinical assessment was involved. After using all the three devices, participants were asked to complete SUS surveys. They were also individually debriefed to provide feedback and their scoring rationale.

The ratings for each SUS statement do not have any meaning on its own and hence, a single composite score was calculated as per the original design of the SUS tool. Table II shows the SUS usability scores for each DUS based on ratings provided by every participant. It can be observed that the average usability scores clearly reflect the effectiveness of the three devices. Table III shows the maneuverability count that was recorded for each participant while performing the reaching task using the various devices.

IV. DISCUSSION

The SUS scores, maneuverability count and the comments from debriefing sessions, collectively brought forth several insights that were not very obvious before this study.

It can be seen from Table II that the omni-wheel-based device has the lowest average SUS score and the lowest maneuverability count. This can be attributed to the following reasons that were obtained through debriefing: (1) Most participants found that it required relatively more effort to physically move the device, (2) Also, there were comments on not very smooth movements in many directions and (3) Consequently, some participants often hefted the device during rough motions.

On the other hand, the haptic device incurred a reasonable SUS score and maneuverability count. This device required a 3-D Application Programming Interface (API) for developing the simple reaching task application. It was expected that the 3-D interface might enhance the interaction with the device but, it was inferred from participant remarks that 3-D objects had slight negative effects on the usability of the device. Nonetheless, the relative usability of the device was still substantial.

Finally, the mechatronic device based on sliding rails received the highest SUS score and maneuverability count. Although the device was in a primitive stage during this study, there were many positive comments: (1) The device was easy to use due to a larger physical space, (2) Navigation was smoother than the other two devices and (3) There was one mention of interaction with the device being intuitive and simple.

Typical acceptability ranges for the overall SUS scores are: 70 or above (acceptable), 50 – 70 (marginal) and < 50 (unacceptable) [12-13]. A caveat to this acceptability scale is that, it may not directly apply to studies that compare different interface technologies. Hence, SUS scores from this study may only be viewed on a relative acceptability scale. Also, these scores may not be used as baseline data for future iterations of usability studies.

TABLE II. SUS USABILITY SCORES (HI = HAPTIC INTERFACE, OWD = OMNI-WHEEL-BASED DEVICE, CMS = CUSTOMIZED MECHATRONIC SYSTEM)

Participant #	SUS Score		
	HI	*OWD*	*CMS*
1	50	22.5	85
2	30	12.5	80
3	47.5	10	70
4	40	22.5	82.5
5	42.5	15	77.5
6	32.5	25	62.5
Average	**40.42**	**17.92**	**76.25**

TABLE III. MANUEVERABILITY COUNT BY PARTICIPANT FOR THE THREE HARDWARE INTERFACES

Participant #	Number of clicks		
	HI	*OWD*	*CMS*
1	21	8	25
2	15	11	23
3	20	6	26
4	18	9	28
5	23	12	27
6	17	10	23
Average	**19**	**9**	**26**

V. CONCLUSION

It is evident from the study in Sec. III that the hardware based on sliding rails is a practicable interface for the POCTENA system. An immediate goal is to expand the hardware to add another set of rails so that both arms can operate on the device. Eventually, this set-up can be used to execute an upper-limb position sense task. The following are few system-level plans to pursue after completion of hardware development:

- Examine the effectiveness of Head-Mounted Displays (HMDs) as opposed to using a laptop screen for presenting tasks to subjects.
- Conduct a study to assess the capability of the hardware to accomplish visuomotor tasks beyond a simple reaching task.
- Investigate the possibility of quantifying the maneuverability of the device during an upper-limb motor task by collecting Electromyography (EMG) signals in subsequent usability studies.
- Evaluate the potential of POCTENA system to provide useful information to aid in diagnosis of sensorimotor impairments like proprioception loss.

REFERENCES

[1] S. H. Scott, “Optimal feedback control and the neural basis of volitional motor control,” *Nature Reviews Neuroscience*, vol. 5, no. 7, 2004, pp. 532-546.

[2] I. Gagnon, R. Forget, S. J. Sullivan, and D. Friedman, “Motor performance following a mild traumatic brain injury in children: an exploratory study,” *Brain Inj.,* vol. 12, no. 10, pp. 843-853.

[3] W. R. McCordie, “Twenty year follow-up of the prevailing opinion on post-traumatic or postconcussional syndrome,” *Clinical Neuropsychologist*, vol. 2, pp. 198-212, 1988.

[4] C. T. Debert, T.M. Herter, S. H. Scott, S. Dukelow, “Robotic assessment of sensorimotor deficits after traumatic brain injury,” *J. Neurol. Phys. Ther.*, vol. 36, no. 2, pp. 58-67, Jun. 2012.

[5] S.H. Scott, and S.P. Dukelow, “Potential of Robots as Next Generation Technology for Clinical Assessment of Neurological Disorders and Upper-limb Therapy,” *J Rehabil. Research and Development*, vol. 48, no. 4, pp. 335–354, 2011.

[6] S. P. Dukelow, T. M. Herter, S. D. Bagg, and S. H. Scott, “The independence of deficits in position sense and visually guided reaching following stroke,” *J. NeuroEngg. Rehabil.*, vol. 9, no. 1, 2012: 72.

[7] S. M. Lephart, D. M. Pincivero, J. L. Giraido, and F. H. Fu, “The role of proprioception in the management and rehabilitation of athletic injuries,” *The American J.Sports Medicine*, vol. 25, no. 1, pp. 130-137, 1997.

[8] D. L. Smith, A. J. Akhtar, W. M. Garraway, “Proprioception and spatial neglect after stroke,” *Age and ageing*, vol. 12, no. 1, pp. 63-69.

[9] V. Subbian, F. R. Beyette. Jr., and P. A. Wilsey, “Design and usability of a medical computing system for diagnosis of mild traumatic brain injury,” *34th Annual Int’l Conf. IEEE Engg. Med. Biol. Society*, San Diego, CA, Aug. 28 - Sept. 1, 2012.

[10] J. F. Blumrich, “Omnidirectional Wheel”, U.S. Patent, 244 519, 1974.

[11] J. Brooke, “SUS-A quick and dirty usability scale,” *Usability Evaluation in Industry*, pp. 189–194, 1996.

[12] A. Bangor, P. T. Kortum, and J. T. Miller, “An empirical evaluation of the system usability scale,” *Intl. J. Human–Comp. Interaction,* vol. 24, no. 6, 2008, pp. 574-594.

[13] A. Bangor, P. Kortum, and J. Miller, “Determining what individual SUS scores mean: Adding an adjective rating scale,” *J. usability studies*, vol. 4, no. 3, 2009, pp. 114-123.