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BCI-based Semi-Autonomous Wheelchair Control using a Human-in-the-loop Cyber Physical System Approach

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Introduction: BCI-controlled wheelchairs have been the focus of innovative research over the past years [2-4]. We propose a HiLCPS design framework that focuses not only on rapid prototype design, but also on the seamless deployment of augmentative and assistive technologies [1]. This framework has three sub-systems: (1) human interaction through physiological signal extraction, user interface, and stimulation, (2) fusion of physiological and non-physiological evidence for intent inference, and (3) interaction of the system with the physical environment. Sub-systems and modules transfer information with each other via a unified communication scheme. The framework's modular design simplifies both upgrading as well as building new extensions; furthermore, forward compatibility has been a guiding design principle in order to support future use-cases. The ultimate goal of this work is to enable developers to build systems that empower locked-in users to move, communicate, and/or control their physical environment. To demonstrate that this framework can benefit researchers, we built a demo that tackles the use-case of semi-autonomous wheelchair control.

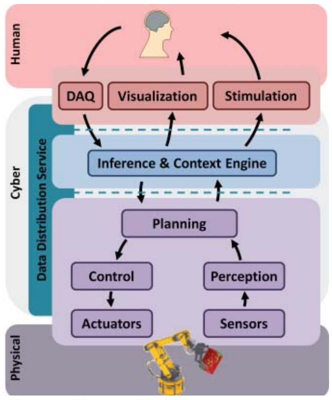

Fig 1: HilCPS diagram.

Materials and Methods: The HiLCPS framework is summarized in Fig 1. The main contribution of this design is its distributed nature. All system modules communicate with each other through OpenDDS, an open source real-time publisher-subscriber networking model. This gives developers the flexibility to add and build new features for BCIs. The inference engine is able to estimate the desired action (intent) using physiological information from the user, as well as non-physiological evidence collected from context. The framework allows the incorporation of sources of information, such as robot sensors that can output position, orientation, and velocity, history from the user, among others. Once a high level option has been selected by the user through the BCI, the intelligent robotics module converts the action into one or several physical commands to control the physical device (semi-autonomous control). This abstraction allows the users to define an action alphabet, leaving the lower level control to the robotics engine. In the wheelchair application, we implemented obstacle and cliff avoidance using a combination of LIDAR, infrared, and ultrasonic range sensors. The BCI driving this application was based on the SSVEP paradigm, using flickering LED arrays positioned around a tablet display. EEG acquisition was performed at 250Hz sampling rate with EEGu, our portable in-house DAQ running on a Beaglebone Black platform. The wheelchair system allowed 4 actions (forward, backwards, left, and right) for step-wise navigation.


Fig 2: Wheelchair trajectories for 5 users from odometry, displayed in a 3D model (top) of the physical home environment testbed (bottom). The odometry data for the other 5 users were corrupted and cannot be displayed .

Results and Discussion: Fig. 2 shows the wheelchair trajectories for 5 users overlaid on a 3D model of the home environment. Healthy users were asked to navigate from the bed to the living room area and point the wheelchair towards the TV to execute a realistic task. Each subject executed this test 3 times. The results are shown in Table 1. The optimum wheelchair command sequence length for fastest successful task execution was 11 (33sec total with 3sec/action).

Significance: We have demonstrated that the proposed HiLCPS design framework can be successfully applied to BCI-controlled semiautonomous wheelchair navigation. Current system required instantaneous maneuver commands from the BCI. Future work on the wheelchair includes extending the application to navigate via waypoints to a precise destination coordinate in complex indoor environments. With the publisher/subscriber design, it is straightforward to use HiLCPS for environment control or communication.

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	Runtime				Number of decisions			Training accuracy	Avg trials per decision
	Run 1 (in sec)	Run 2 (in sec)	Run 3 (in sec)	Avg (in sec)	Run 1	Run 2	Run 3		
U1	104.00	175.00	89.00	122.67	13	22	11	0.97	1.3
U2	97.00	127.00	104.00	109.33	12	16	13	0.91	1.2
U3	192.00	129.00	115.00	145.33	24	16	14	1.00	1.61
U4	216.00	120.00	222.00	186.00	27	15	28	0.79	2.1
U5	117.00	106.00	98.00	107.00	15	13	12	0.97	1.21
U6	99.00	105.00	111.00	105.00	12	13	14	1.00	1.18
U7	385.00	148.00	222.00	251.67	48	19	28	0.70	2.87
U8	141.00	109.00	114.00	121.33	18	14	14	0.87	1.39
U9	114.00	122.00	145.00	127.00	14	15	18	0.85	1.42
U10	88.00	114.00	163.00	121.67	11	14	20	0.91	1.36

Table 1: result of wheelchair application in home environment