IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.301
Volume 3, Issue 4, June 2023

A Multimodal Adaptive Wireless Control Interface for People with Upper-Body Disabilities

Kiran R. Borade[1], Deepika R. Thakare[2], Priyanka N. Mahale[3], Vijay J. Bodake[4]
[1,2]Department of Computer Engineering, Guru Gobind Singh Polytechnic Nashik, India
[3,4]Department of Computer Engineering, K. V. Naik P, Nashik, India

Abstract: *Assistive Technologies (ATs) also called extrinsic enablers are useful tools for people living with various disabilities. The key points when designing such useful devices not only concern their intended goal, but also the most suitable human-machine interface (HMI) that should be provided to users. This paper is based on a wearable wireless sensor network which presents several new modes of control interface for people with upper-body disabilities. This body machine control interface consists of modules and can be easily adapted to the residual functional capacities (RFCs) of different users. An algorithm has been developed for emulating a joystick control (JACKO arm-assistive technology) using head motion. In wearable sensor network up to six modular (modules) sensor nodes can be used simultaneously to read different RFCs including head gesture and muscular activity, and translate them into commands. Head motion is measured with a lightweight wireless inertial sensor enclosed in a headset and muscular, shoulder motion by patch sensor. Data collected from sensor are gathered (fused) in sensors itself to decrease power consumption by wireless link and the base station. Such an interface network is required for people using powered-wheelchairs and with weak or unexacting control of their arms, hands and fingers, but who have remaining abilities to control their head and shoulder motions, as well as residual muscular activity. This system is implemented and used to control a robotic arm for performing several tasks. At last comparison is made with joystick controller in which existing system works good over joystick controller.*

Keywords: Wireless Technology, IoT, Embedded, Human Machine Interface.

I. INTRODUCTION

The use of human machine interfaces (HMI) for general purpose applications has seen tremendous growth in popularity during the past years. Movement tracking tools such as the Kinect, the Xsens devices and the Leap Motion Controller are good examples of powerful devices that can be used in a wide range of applications such as gaming, monitoring, computer control, etc. They are usually provided with software development kits (SDK) with which developers can add or implement their own functionalities. Using wearable body sensor networks (WBSN) as a means of measuring and tracking the motions of our body also confers interesting possibilities in terms of human-technology interfaces. Compared to the former movement tracking tools, WBSNs provide a wider range of applications due to limitations of cameras and infra-red sensors used in devices like the Kinect [1].

The design of suitable human-technology interfaces for disabled people has often relied on mechanical tools such as head-mounted switches, dedicated keypads, trackballs, joysticks, sip-and-puff tools etc. Depending on the patient's disabilities, these devices could be sufficient and provide a good accuracy. For people suffering from more severe forms of disabilities, more ingenious and adequate controllers must be designed such as WWSN (Wearable Wireless sensor network) or WWBSN (Wearable Wireless body sensor network)[3].

The Canadian Survey on Disability conducted by Statistics Canada in 2012 revealed that the prevalence of disability has a tendency to grow with age, among the population aged 15 and older: flexibility, mobility and dexterity troubles were found by 7.6%, 7.2% and 3.5%, respectively. This study also shows that 80% of persons with disabilities use assistive devices of all kind [2]. These people need user and control interfaces that can adapt to their physical conditions to take full advantage of their residual functional capacities (RFCs). Research on Body-Machine Interaction (BoMI) aims at designing smart, unobtrusive tools easing interaction with assistive devices by exploiting users RFCs.

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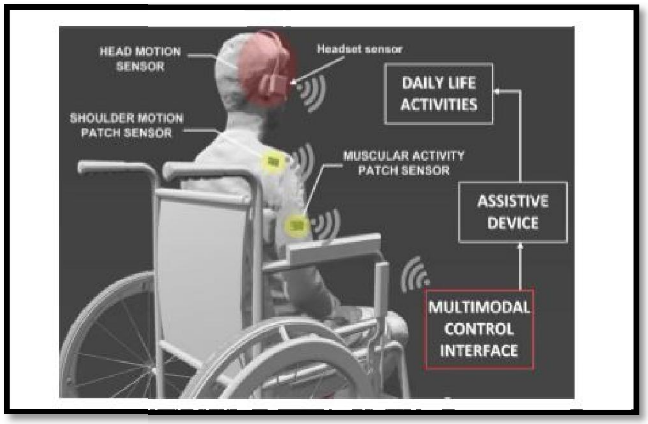

Fig. 1: Illustration of the existing multimodal interface strategy that reads the user's head and shoulders motion as well as his residual myoelectric activity, and translate them into control commands.

In this work, we focus on designing an intuitive, reliable, robust, low-cost and wearable control interface for people who have a weak or unexisting control of their arms, hands and fingers, but who have remaining abilities to control their head and/or shoulder motions, as well as residual muscular activity (see Figure 1). The existing interface reads the head motion to replicate the behavior of a 2D joystick device. The user buttons can be emulated through EMG onset detection, depending on users' abilities, thanks to a multimodal sensor network designed to adapt to a wide range of disabilities. The JACO arm (assistive technology), developed by Kinova Robotics, Canada, is used as a test bed to prove its functionality.

Following are sensors, actuators and data:

System Quality: we focus on designing an intuitive, reliable, robust, low-cost and wearable control interface for people who can control their head and muscular/shoulder motions.

Body Machine Interface (BoMI): We focus on implementation of system that has accurate interfaces between body and sensor nodes, disabled people and JACO arm to perform operations like actual physical one using multiple sensors.

Connection establishment: We have existed a wireless communication between sensor and computer and then between computer and arm.

Sensor Data: Data collected from sensor are gathered (fused) in sensors itself to decrease power consumption by wireless link and the base station.

II. METHODOLOGY

People suffering from spinal cord injury have different degrees of autonomy depending on the damaged vertebrae. Patients with injuries around the C5-C8 cervical vertebrae may have a weak residual control or total paralysis of their wrists, hands and fingers, while retaining complete control of muscles above the damaged areas. The use of controller devices such as joysticks is then tiring or almost impossible due to lack of dexterity[7]. In such cases, WBSNs appear to be an adequate means of tracking and measuring. The residual gestures for further translation into adequate commands[6]. The controller presented in this article has been designed for disabled people with Residual Functional Capacities (RFCs) allowing them to control muscles of their shoulders. By simply moving their head in different directions and lifting their shoulders, patients are able to interact with assistive robotic devices using their natural gestures, and obtain the same results similar to those of a physical joystick controller.

The existing strategy includes the following aspects to provide them with a suitable control interface [4]. Their RFCs are mapped to joystick functions as depicted in Figure 2. The existing control strategy combines IMUs and EMG sensors measurement. In this work, IMU sensor is used to read the head orientation angle for proportional joystick command emulation, and to measure users shoulders elevation level (if the user has enough motion amplitude) to activate buttons B1 and B2 (Figure 2). If not, resort to any of these user buttons is done by means of EMG sensor activity onset detection from any available muscle zone.

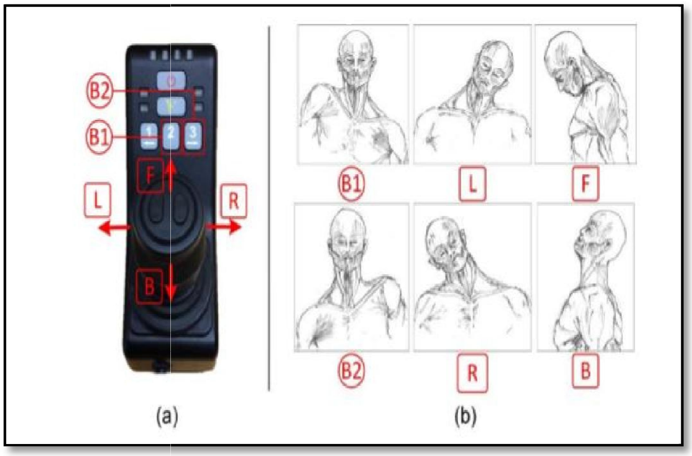

Fig. 2: (a) Upper-body motions to emulate the joystick control, (b) 2D conventional joystick tool with corresponding functionalities implemented by the exisiting interface. Forward (F), Backward (B), Right (R) and Left (L) represent the 2D translation commands on → y and → x respectively, B1 and B2 help switching between the arms predefined modes to access fingers control, joints rotations and translations on → z.

III. HARDWARE AND SOFTWARE ARCHITECTURE

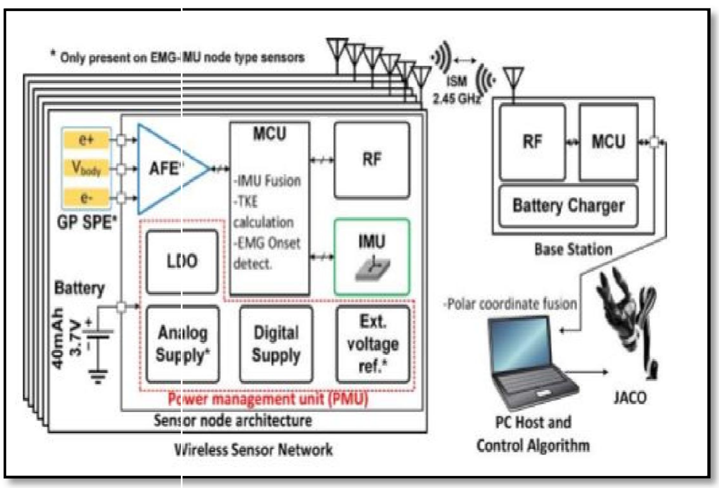

Fig. 3: Diagram of the controller that describes the sensor node and base station's architecture. Connections with the PCB Host and JACO arm, both through USB, are illustrated as well. Operations implemented in-situ (IMU Fusion, TKE calculation, EMG Onset detect) and ex-situ (Polar coordinate fusion) are reported. GP=Gold-Plated.

A. HARDWARE ARCHITECTURE:

The existing wireless wearable BoMI (Body Machine Interface) includes upto 6 independent low-cost sensors nodes using two different node architectures [3]:

-IMU sensor node

-EMG sensor node

1)IMU sensor node measures the head orientation.

2)EMG-IMU node which collects inertial data and measures EMG.

The nRF24L01 low-power wireless transceiver from Nordic Semiconductor, Norway, which allows up to 6 peripheral nodes, is used as a transceiver. Due to its high precision and its low power consumption, the 1 channel ADS1291

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integrated analog front end (AFE) circuit from Texas Instrument is used for EMG measurement. Both wireless sensor node architectures are described in Figure 3.

B. SOFTWARE ARCHITECTURE

1) The inertial measurement unit (IMU) sensors:

A large variety of sensors for physical activity measurement is commercially available. DOF IMUs have been used while a 9-DOF XSensMTUx IMU has been adopted nowadays. Such devices are essentially based on the use of accelerometers, gyroscopes and magnetometers[2]. The LSM9DS0 multi-sensors module from STMicroelectronics was chosen for this project based on key.

The IMU data fusion algorithm is implemented inside the sensor nodes and provides Pitch and Roll angles at a frequency of 50Hz. This fusion step is crucial as it merges the information into single parameters, the components of which are uncorrelated and provide different types of inputs. It provides the equivalent orientation angle from 0 to 360o. From a design point of view, this allows for a higher flexibility and robustness. For each direction D (Forward (F), Backward (B), Right (R) and Left (L)), only 4 parameters need to be calibrated: the head inclination angle in the unit circle, margin the desired angle margin on both sides, max and maximum and the threshold head inclination magnitude along direction D.

2) EMG Data Processing and Onset Detection:

In order to use EMG to emulate the buttons, electromyographic signals collected for the EMG IMU nodes placed over the target muscles with RFC and undergo robust onset detection. The overall operation is implemented on sensor nodes. This is done using the Teager-Kaiger Energy Operator (TKE) which is independent of signal to noise ratio (SNR). It is used in several studies for detection and has proven to be robust. Muscular activity is sampled at a frequency of 2kHz[1].

IV. MULTIMODAL CONTROL INTERFACE DESCRIPTION

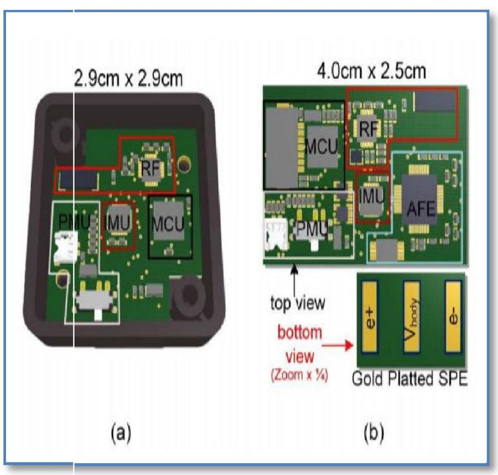

Fig. 4: Node architecture description and comparison test setup. a) Internal view of the IMU sensor node plastic housing, b) Top and bottom views of the EMG-IMU sensor node.

The existing controller described tracks the motion and orientation of the head using a head mounted inertial measurement unit (IMU) sensor, and surface electromyography (sEMG) to read the user's gesture and guide the JACO arm (See figure 4). The EMG signal is processed for onset detection with a robust algorithm to allow switching between the assistive robotic arm's operating modes. The head-mounted inertial sensor, laid on a 29 mm by 29 mm printed circuit board (PCB), is powered by a 3.7V Li-ion battery, and enclosed into a 10-g lightweight headset that is be worn on the head (Fig. 3c). The EMG patch sensor, laid on a 40 mm by 25 mm PCB, is made of components off-the-shelf and uses dry gold-plated surface printed electrodes (SPEs). Up to 6 wireless sensor nodes can connect to the base

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station board that receives the sensor data and sends it to the PC host through a USB connection[1]. Then, the control algorithm translates head orientation into commands to emulate conventional joystick control. People wear the headset and the EMG patch sensor to test the existing interface and use it to control JACO, along its 6 degrees of freedom and using its fingers made end-effectors to mode and grab objects. This wearable sensor used to measure body motions are lightweight, easy to calibrate and doesn't require any preparation.

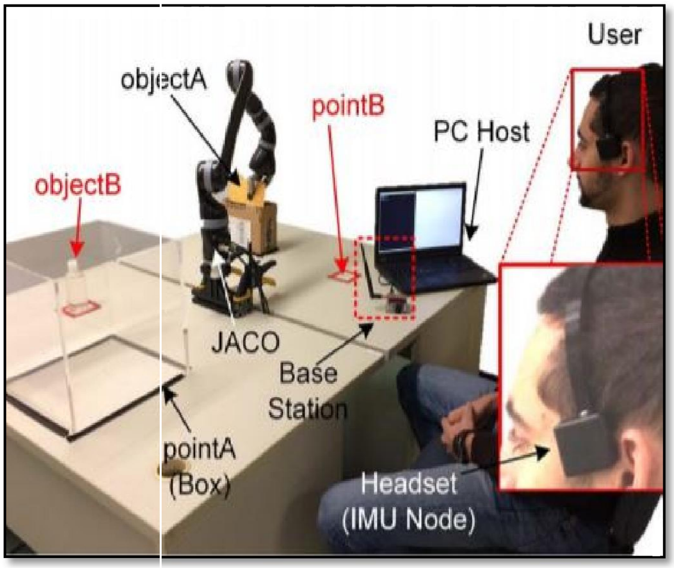

Fig. 4c: Test setup used to quantify the performance of the head orientation-based controller. The test first consists of picking up ObjectA and should dropping it into the box at PointA, then ObjectB must be grabbed and moved to PointB.

V. SETUP DESCRIPTION

The setup consists of the JACO arm fixed on a table, 2 meters away from any obstacle and a Laptop computer connected to the robotic arm. The PC host will run a MATLAB GUI program designed to illustrate the sensors measurement data. A separate C++ application, also running on the PC host, is in charge of translating measurement data into appropriate commands using a dedicated data fusion algorithm.

VI. EXPERIMENTAL RESULTS WITH THE JACO ARM

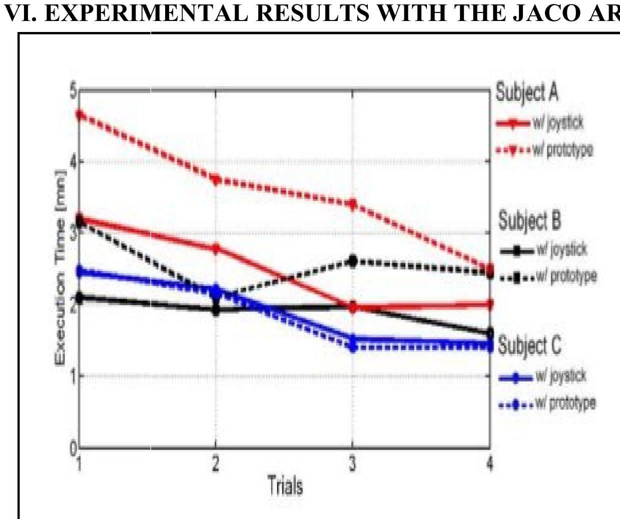

Fig. 5: Comparison test results.

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A test procedure has been implemented to compare the existing head orientation controller with the conventional joystick tool depicted in Figure2. Indeed, 3 disabled bodied subjects were asked to move ObjectA and ObjectB to PointA and PointB, respectively, first by using the joystick controller, and then by using the existing wireless body sensor interface. Tasks durations were measured for 4 trials and reported in Figure 5. Participants showed quick abilities to learn and the results show that the existing system can provide performance close to the conventional joystick device, while potentially reaching a wider range of users [1].

VII. CONCLUSIONS AND FUTURE WORK

A head-orientation based BoMI is existing, for people living with upper body disabilities, as an alternative to conventional control interfaces. The system uses a wireless wearable body sensor network to read users RFCs making it unobtrusive and flexible. Specific requirements have been considered, during the design process, to allow a comfortable utilization by people in powered wheelchairs. Finally, comparison tests results show that the existing prototype controller is a promising solution that can contribute to increase the adoption rate of assistive devices by severely impaired people.

In this paper's future work, clinical tests will help quantifying the added value of such an assistive interface into the community of disabled people. In future external sensors can be replaced my implanted sensors that are for permanent usage but the Assistive Technologies (ATs) must be smarter i.e., multitasking and act on real time environment.

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