Real-Time Control of an Assistive Robotic Arm using a Wireless Finger Motion Sensor

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***Abstract*—A wireless, real-time control system composed of a motion sensor node worn like a ring to record motion and a base station is presented to help people with disabilities by enabling them to control an assistive robotic arm. The system uses data from a 3D gyroscope and a 3D accelerometer from a MEMS inertial measurement unit to control the robotic arm's axis speed using a complimentary filter. Empirical experience shows it to be on par time-wise with the manufacturer's joystick.**

***Index Terms*—wireless body sensor network, human-machine interface, internal measurement unit, robotic arm, ring**

I. Introduction

Adaptive human-machine interfaces (HMI) aim at providing the severely disabled with alternative control schemes [1]. Their residual functional capacities (e.g. motion, myoelectric signals, brain activity) [2] are sensed using dedicated electronic systems and translated into appropriate outputs to accurately operate external devices. So-called wireless body sensor networks (WBSN) are increasingly used in the fields of medicine [3], sports [4] and man-machine interface [5]. This paper presents a wireless, finger motion-based HMI designed to control a wheelchair-mounted robotic arm [6]. As shown in Fig. 2, it uses a custom inertial measurement unit (IMU)-based sensor that is worn like a ring and a control algorithm running on a Raspberry Pi (RPi) in the base station.

II. Existing Technology

Differents types of sensors and placements of IMU-based sensor nodes have already been presented in previous papers. A finger-mounted IMU ring addresses some of the drawbacks that these technologies present. First, Hochberg et al. [7] developed a robotic arm control system based on a 96-microelectrode chips recording the neuronal activity of a population of motor cortex neurons. This technology, although enabling for peoples with severe loss of mobility, is both very intrusive and expensive. It is thus only fitting for a limited selection of willing users with access to proper resources. Another technology, electromyography (EMG) enables the control of a robotic arm by recording the electrochemical potential difference between two points on a muscle at the time of contraction. This technology is often more intrusive than IMU-based sensor nodes because of the need for direct skin contact with either dry or wet electrodes and may require too much muscle contraction in order to obtain a satisfactory signal. Indeed, users may lack the required strength but may still retain enough finger freedom-of-movement to use an IMU-based sensor node. Moreover, a EMG-based robotic arm control system requires more complex algorithms and is less intuitive than alternatives. IMU-based sensor nodes placed on different parts of the body may not be compatible with certain user cases. For example, a head-mounted IMU sensor [8] is not usable in cases where the user feels intense pain when moving his head, which is the case of 62% of car accident victims [9]. Therefore, the proposed finger-mounted, ring-shaped IMU control sensor solves many of the drawbacks of existing systems.

III. System Overview

The HMI presented in this paper consists of three main parts: a wireless motion sensor, worn as a finger ring, which is used to sense the fingers pitch and roll angles, a base station receiver, included inside a USB dongle, which transmits the data packets to the RPi, which are control inputs to the algorithm and the robotic arm. The robotic arm, manufactured by *Kinova Robotics*, is controlled through a dedicated API by the RPi. Fig. 1 provides a functional overview of the system.

IV. Ring Motion Sensor Node Design

The sensor node is designed using components off the shelf and lies on a 7.77cm^2, 75μm thick, flexible printed circuit board (PCB) designed to be wrapped around a finger (Fig. 1). A MSP430F5528 (*Texas Instruments*) microcontroller unit receives IMU data from a LSM9DS0 (*STMicroelectronics*) through a SPI bus. A nRF24L01 (*Nordic Semiconductor*) transceiver is used to connect the sensor node to the base

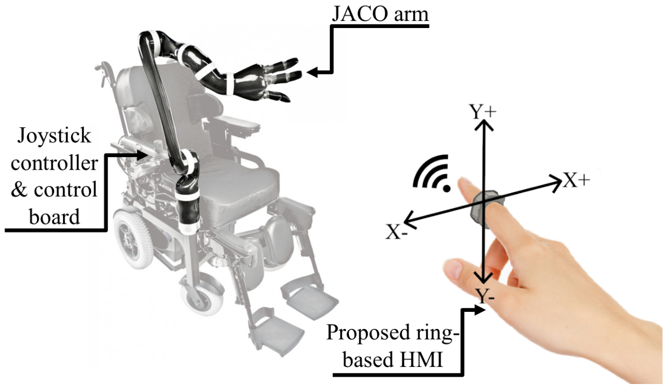

Fig. 1. Overview of the concept

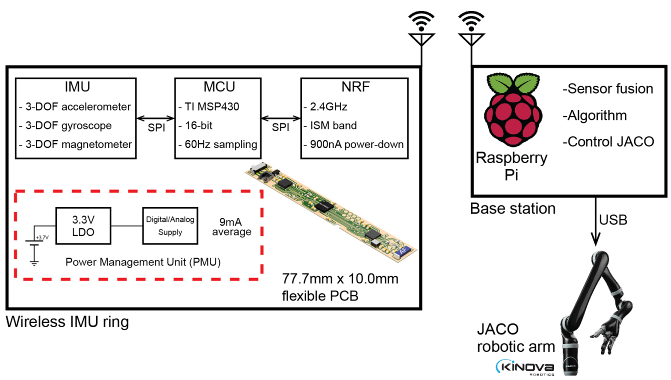

Fig. 2. Block diagram of the system

station. The finger pitch and roll angles are derived from the IMU data. The base station, which runs a custom C++ program, uses a nRF24L01 to connect with the sensor node. The data is transmitted to the base station in a 8-byte data packet, which is composed of 1 start byte, 4 angle data bytes, 1 byte about acquisition frequency, 1 byte about the selected operation mode and 1 end byte.

V. Data Fusion

The RPi runs a complimentary filter data fusion algorithm to obtain the pitch and roll angles from the linear accelerations and angular velocities. This data is obtained from the 3D linear acceleration and angular velocities given by the LSM9DS0 MEMS IMU. 1 shows that the acceleration value α on the axis *i* at time *t* is the mean value of the last few samples.

$$\alpha_{[i]}(n) = [\bar{\alpha_x}, \bar{\alpha_y}, \bar{\alpha_z}] \quad (1)$$

Similarly, 2 shows that the angular velocity ω obtained from the gyroscope on the axis *i* at time *t* is also the mean of past values.

$$\omega_{[i]}(n) = [\bar{\omega_x}, \bar{\omega_y}, \bar{\omega_z}] \quad (2)$$

The pitch/roll angles are given by 3, where α is the complementary filter design parameter and ω_i and α_i are the angular velocity and measured linear acceleration, respectively.

$$\theta_n = \alpha\left(\theta_(n-1) - \int_0^T \omega_z\right) + (1-\alpha)\left(\tan^{-1}\left(\frac{\alpha_z}{\alpha_y}\right)\right) \quad (3)$$

The user must calibrate the system by setting his motion range values on both axes, and his neutral position. Then, a non-orthographic polar coordinate system is created using these calibration values. The pitch and roll angle axis projections are used to control the linear velocities of the robotic arm. A so-called "dead-zone" is also defined as 15° around the neutral point in both axes, where the linear velocity is set to be zero. The control scheme provides a robust, flexible and intuitive way to control the robotic arm that adapts to each user.

VI. Results

When compared to the OEM joystick controller, the ring-based HMI system performs similarly, while providing a more intuitive experience for the user.

VII. Future Work

The system proposed in this paper could increase in user-friendliness by implementing a few improvements. First, combining the three ICs into one would significantly reduce the board area needed and promises to reduce the volume of the system. In addition, designing a custom, ring-shaped Lithium-ion battery and reducing the current consumption would reduce the bulk of the sensor node further. Finally, implementing wireless re-programming of the MCU should decrease utilization complexity, thus increasing user satisfaction, and enable improvement of the system over time.

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