A bicycle like exoskeleton pedal position monitoring device proposal

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***Abstract*—The ExoBike is a bicycle like structure, that takes over a human exoskeleton function for medical rehabilitation purposes. The proposed system enables lower limb movement control, based on the sensor data as well as the patient intentions. An adapted seat as well as a specific pedal structure and a number of other mechanical interface areas have been built. A number of sensors such as load cells, strain gauges and Inertial Measurement Units (IMU) have been implemented to monitor the user position and movements. Data is collected from the sensors and transferred to a central unit through a wireless communications protocol. In this paper a pedal position monitoring device for the Exobike is proposed. The device aims at determining the pedal position during the user lower limb movements. The pedal monitoring device has been implemented with an Inertial Measurement Unit (IMU) and a Texas Instruments CC2640R2F wireless MCU with a Bluetooth interface. The IMU is a BNO055 Bosch sensor with an I2C interface. The wireless interface enables a wire free sensor that is able to follow the pedal movements. The CC2640R2F runs a TI-RT Operating System that controls system operation. Data is transferred to a PC running a Graphical User Interface implemented with Processing. The proposed system architecture is described and the Operating System structure, namely the implemented tasks within the Texas Instruments SimpleLink framework, is presented.**

***Index Terms*—Exobike, Bluetooth Low Energy, Time Constraints.**

I. Introduction

THE technological developments associated with data sensing and wireless communications provide relevant contributions to a number of human activities and industries. Within this context, real-time motion tracking with electronic devices have a wide range of applications. Device for health and sports monitoring, navigation systems, robotics and machine interaction [1] [2] are nowadays available in the market. A number of medical solutions and developments are based on wireless communications of sensor data [3]. The identified projects contribute to the best practices of life quality, health, well-being and rehabilitation promotion. Industrial or scientific these projects may be usually described as employing inertial sensors to analyze movement either for sport monitoring activities or health care application. Within the context of movement analysis, the use of wireless communication is mandatory to avoid cumbersome wiring.

In this paper, the wireless communication framework of the Exobike project is proposed and tested. The Exobike [4] is an exoskeleton like a bicycle to be used for early diagnosis of health, integrated health data platforms, remote monitoring, predictive environments, personalised medicine and evaluation of predisposition to the disease. Moreover, this project aims to contribute to the development of health monitoring technologies, as well as to the rehabilitation of individual that suffered lower limb injuries or are otherwise impaired in their mobility.

A Bluetooth Low Energy (BLE) based wireless communication framework has been developed so that data from inertial sensors placed in the lower limbs and the upper trunk may be transferred to a processing unit. Furthermore, load cells have been placed in both pedals as well as in the handlebar. A central processing unit is responsible for the computation of the limb and trunk positions using recursive filters such as Extended Kalman Filter [5].

The proposed communications framework has been implemented so that data may be transferred to a central unit for processing. The correct operation of the framework includes the pedal monitoring system.

This paper is organized as follows. Section II presents a brief description of the Exobike project. A state of the art is presented in Section III. In Section V, the pedal struture is decribed. The described system has been implemented to access inertial sensors data, data from the strain sensors and a small position switch are available for processing. Conclusions and future work are described Section VI.

II. The Exobike project

The ExoBike is a bicycle like structure, that takes over a human exoskeleton function for medical rehabilitation purposes. The proposed system enables lower limb movement control, based on the sensor data as well as the patient intentions. An adapted seat and a number of mechanical interface areas with actuator and sensing capabilities have been built. The designed actuators allow therapeutics to implement an active/passive system that reacts dynamically to the needs of the user/patient under evaluation. The type and intensity of the training may be programmed by the medical staff in accordance with the received feedback. Data is collected from the sensors placed in the structures and transferred to a central unit through a wireless communications protocol. Adapted therapies may, therefore, be practiced by adjusting the patients' efforts to the medical prescriptions and the therapeutical requirements. The patients movements are monitored using a wireless sensors network, implementing a personal virtual reality solution where the patient play in a strongly reality connected environment. Figure1, illustrates the proposed system architecture.

At the same time this project translates the innovation and knowledge produced in the Academia (two higher education

institutions in the areas of technologies are involved) and used in medical community (two health institutions with experience in rehabilitation and support of the elderly fields of expertise are involved) to society, through the use of tools such as serious games, virtual reality or internet of things.

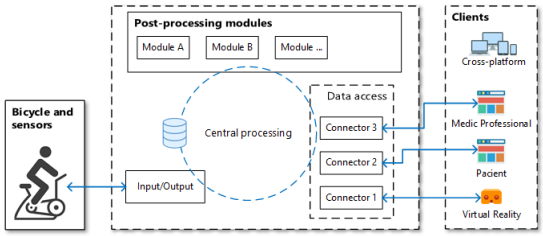

Fig. 1: Exobike Proposed System Architecture.

The presented project is to be used in rehabilitating of individuals who suffered bone injuries, as well as in recovery, training and early diagnosis of patients with neurodegenerative diseases. The ExoBike allows the therapeutic professionals to experiment practice adapted therapies with adjusted efforts for different patients, starting from zero to a certain maximum. The patients movements are monitored using a Bluetooth Low Energy wireless sensors network, implementing a personal virtual reality solution strongly correlated with reality. The system has the ability to collect, store and handle medical data from patients who can later be reviewed by qualified medical professionals.

III. Literature Identified Related Work

A study on a bicycle pedal push force performance with a Bluetooth Low Energy device is presented in [6]. The authors analyse the sensory device of measuring the pedal push force. Related parameters, such sensor device sizs and shape, the resistance and strain elements mounted position, where optimised.

The enterprise Xsens present a full body human measurement system which uses inertial sensors and a sensor fusion algorithm, the Xsens MVN BIOMECH [7]. This system provides real-time data output and 3D kinematic graphs from clinically relevant motion activities. The communication between sensors is made through wires. Combined data is transmitted via WiFi to a device which has a latency of 20 or 30 ms(depending on the system hardware).

In [8] an algorithm for detection of bicycles on the road from a sequence of images is presented. In this case, images are acquired by a stationary video camera. The leg movement may be studied and observed.

The X-IMU [9] from X-io its an IMU and AHRS which can communicate through USB, Bluetooth or UART that make this module a powerful one. The data output can be the sensor values, real-time measurement of orientation relative to the Earth by the AHRS algorithm, among others. With this module its possible select the data rates up to 512 Hz.

In [10] a BLE sensor system based on the Texas Instruments(TI) transceiver CC2640F is presented. biomedical parameters measurements are executed with the proposed device. In this work, a common communication platform for different medical sensors is presented. Data is then sent to an online server for monitoring. A prototype is presented to monitor body temperature and heart rate.

IV. Work in Progress

An evaluation system has been built and is presented in this section. The proposed system has been implemented with a Raspberry Pi 3.0 B+(RBPi) as the central processing unit. The RBPi has been chosen due to its ability to handle complex computations. This device is also able to receive Bluetooth Low Energy (BLE) incoming data, serving as a central node to the Exobike star network. The RBPi version 3.0 has an integrated BLE interface thus making it suitable for a project such as Exobike that implements a star network with several peripheral nodes.

The peripheral nodes have been implemented with Texas Instruments (TI) CC2640 BLE transceiver, each running TI BLE Stack with a proprietary profile.

The Inertial Measurement Units (IMU) have been implemented in the nodes placed at the patient lower limbs and trunk.

Peripheral nodes for the pedals and the handlebar have been considered and implemented. Figure 2 illustrates the sensor placement in the patient/user body.

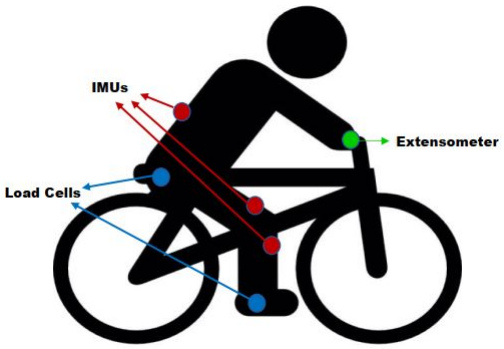

Fig. 2: Exobike Sensor Placement.

The peripheral nodes description is the following:

- Two knee nodes
  - 9 degrees-of-freedom device sensors: ± 2 to 16g accelerometer, ± 250 to 2000/s gyroscope, and $\pm 1200 \mu$ T all sensor have a three axis outputs (BNO055).
  - CC2640 BLE module from Texas Instruments.
- One trunk node
  - BNO055.
  - CC2640 BLE module from Texas Instruments.
- One handlebar node
  - Two extensometers
  - CC2640 BLE module from Texas Instruments.
- Two pedal nodes
  - BNO055.
  - One load cell
  - CC2640 BLE module from Texas Instruments.
  - One magnetic position sensor

V. The Pedal Structure

As described in Section III, a number of documents may be found relating to pedal bicycle monitoring with a BLE network. In order to implement such a network, it's important to design an architecture that is able to address all data required. Also the full Exobike structure has been described in Section IV

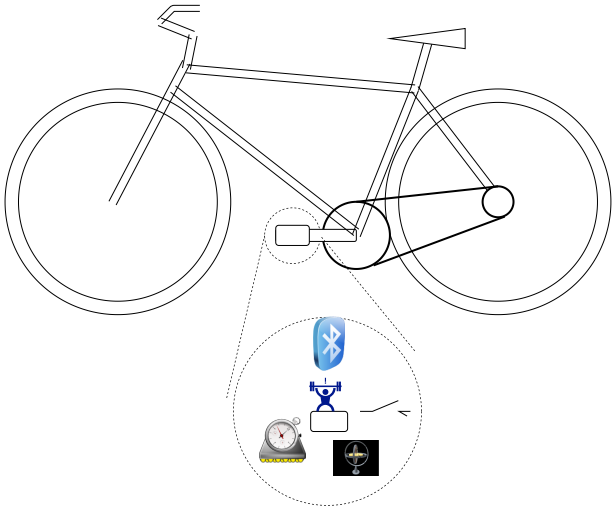

Fig. 3: Exobike pedal monitoring system description.

Figure 3 details the pedal monitoring components. The pedal monitoring device is BLE enable for wireless communications. A load cell sensor has been mounted on the top of the pedal so that the weight/force the user is exerting may be measured. Also an Inertial Measurement Unit (IMU) with an Accelerometer and a gyroscope has been mounted on the device. The proposed IMU is the Bosch BNO055 in this case used with a breakout board. A magnetic reed switch has been implemented so that the pedal pass on its crank may be measured. This sensor associated with a micro-controller internal timer may be used to time the pedal frequency, thus measuring the users pedalling velocity.

The micro-controller used is the CC2640R2F that runs a TI-RT Operating System. The proposed system has been implemented with processing tasks within the Texas Instruments SimpleLink framework.

VI. Conclusion

In this paper a pedal position monitoring device for the Exobike system is presented The device architecture is described and its component function addressed.

The pedal monitoring device has been implemented with an Inertial Measurement Unit (IMU) and a Texas Instruments CC2640R2F wireless MCU with a Bluetooth interface. The IMU is a BNO055 Bosch sensor with an I2C interface.

The wireless interface enables a wire free sensor that is able to follow the pedal movements. The CC2640R2F runs a TI-RT Operating System that controls system operation. Data is transferred to a PC running a Graphical User Interface implemented with Processing. The proposed system architecture is described and the Operating System structure, namely the implemented tasks within the Texas Instruments SimpleLink framework, is presented.

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