Network of Embedded Systems for Motor Rehabilitation Post-Stroke of Upper Limbs using ESP8266 and ESPNOW protocol

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Abstract: Robot-assisted upper limb rehabilitation techniques have advanced rapidly in recent decades. Its diverse interactive strategies allow the personalization of the treatment, through a specialist, for each patient. Thus, the use of assistive robotics provides the individual with rehabilitation and restoration of motor functions, if not totally, at least in part, which directly impacts their quality of life.
This work presents a brief bibliographic review on works related to the area of motor rehabilitation with the use of wearable and / or wireless systems, as well as pathologies that compromise motor skills. It is proposed the development of a wireless system using Wemos D1 Mini and MPU-92/65 inertial sensors using the ESPNOW communication protocol. The preliminary results of data acquisition, topology and wireless communication network are exposed.

Resumo: As técnicas de reabilitação de membros superiores assistidas por robôs avançaram rapidamente nas últimas décadas. Suas diversas estratégias interativas permitem a personalização do tratamento, por meio de um especialista, para cada paciente. Assim, o uso da robótica assistiva proporciona ao indivíduo a reabilitação e restauração das funções motoras, senão totalmente, pelo menos em parte, o que impacta diretamente em sua qualidade de vida.
Este trabalho apresenta uma breve revisão bibliográfica sobre trabalhos relacionados à área de reabilitação motora com o uso de sistemas wearable e / ou wireless, bem como patologias que comprometem as habilidades motoras. É proposto o desenvolvimento de um sistema wireless utilizando sensores inerciais Wemos D1 Mini e MPU-92/65 utilizando o protocolo de comunicação ESPNOW. Os resultados preliminares de aquisição de dados, topologia e rede de comunicação sem fio são expostos.

Keywords: motor rehabilitation, wireless rehabilitation system
Palavras-chaves: reabilitação motora; sistema de reabilitação sem fio.

1. INTRODUCTION

Stroke is considered to be one of the main causes of disability in the world Burton et al. (2018) and about 80 % of stroke patients have upper limb motor dysfunction Ma et al. (2019). That is why it is so important to find ways to assist in the rehabilitation process of these patients.

Robot-assisted upper limb rehabilitation techniques are advanced rapidly in recent decades. Its diverse interactive strategies allow the personalization of the treatment, through a specialist, for each patient. Thus, the use of assistive robotics provides the individual with rehabilitation and restoration of motor functions, if not totally, at least in part, which directly impacts their quality of life.

Projects and research groups at universities have been doing significant work in the development of tools for assistance in the medical field Dos Santos (2019). Several techniques for robot-assisted upper limb rehabilitation have advanced rapidly in recent decades, making the importance of research in this medical field evident Van Delden et al. (2012); Brackenridge et al. (2016); Lo and Xie (2012); Proietti et al. (2016).

Difficulties in limb movement resulting from pathologies of the nervous system, usually lead to difficulties in manual skills, such as reaching, grasping, manipulating objects and letting go. These mobility restrictions can be reduced and treated through specific interventions, such as repetitive training specific to a specific task, the use of Biofeedback; Electrical stimulation, among others Boddice et al. (2010).

Some systems developed for use in motor rehabilitation of upper limbs use a wired sensor distribution that connect the sensors to a central brain (microcontroller) that processes the information for each sensor. An example of this system is the work developed Xsens MVN BIOMECH suit based on inertial sensors and footprint papers Guo and Xiong (2017), which can be seen in Figure 1.

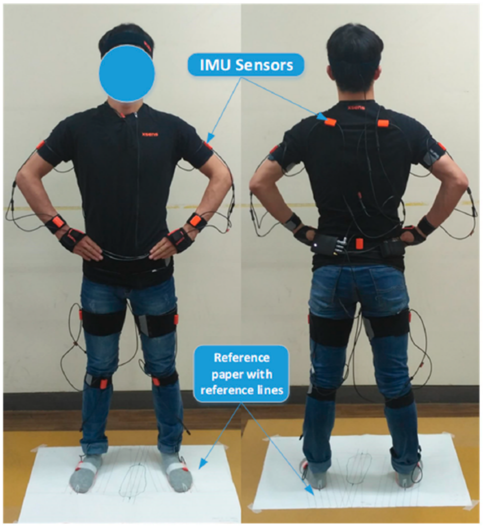

Figure 1. Xsens MVN BIOMECH suit based on inertial sensors and footprint papers Guo and Xiong (2017).

Systems using cables for connections between sensors and microcontrollers are not comfortable for the patient to perform their therapy. They also restrict the possibilities of therapies to be performed, by limiting the movement of the limbs by the length and arrangement of the cables, in addition to being able to tangle.

Rehabilitation systems with wireless components have the advantage of freedom of movement and allow easy adaptation for insertion of new devices in the sensor network. Some works and research in the medical field (mainly) use ESP8266, Zigbee Module, ESP32 or Bluetooth Modules for communication between devices. Among the possibilities of this communication, there are advantages and disadvantages, such as: cost, transmission speed, total data transmission and energy efficiency, since these systems will be shipped powered by battery. There are many works that use Wi-Fi technology for data transmission in the 802.11 (2.4GHz) standard.

Some wireless communication protocols, presented by Santos et al. (2016):

- Wi-Fi (IEEE 802.11)
- ZigBee (IEEE 802.15.4)
- Classic Bluetooth (v.2-)
- Bluetooth High Speed (HS) (v.3)
- Bluetooth Low Energy (BLE) (v.4 +)
- 3G / 4G
- LoRaWan
- Sigfox - Uses Ultra Narrow Band technology

The ESPNOW communication protocol developed by Espressif, allows multiple devices to communicate with each other without using wi-fi. The protocol is similar to the low-power 2.4 GHz wireless connectivity that is typically deployed in wireless mice. It enables easy and direct communication between devices that use the ESP8266 chip as a microcontroller.

The present work presents the process of research, design and construction of a wireless system to assist in the motor rehabilitation of patients, with monitoring the movement of the upper limbs using ESP8266 and ESPNOW Protocol, that is being developed by Assistive Robotics Research Group of Federal University of Rio Grande (FURG).

2. RELATED WORKS

In the work presented by Hoang et al. (2019), the problem investigated is wireless voice communication over short distances (cost of implementation and energy consumption). As a solution, a talk-bust system was developed for skyscrapers and factories that is solved around the low cost SoC ESP32 and its P2P ESPNOW protocol, in the developed system, all devices/nodes are independent of others, therefore, make the general network a decentralized system. An advantage is that, regardless of any inactive node, the network remains intact.

Devices based on the ESP family in order to create distributed control systems for complex mechatronic objects are the problem of Yukhimets et al. (2020) work, so the specified ACS (automatic control systems) contains a distributive node and executive nodes that exchange data with the ICS (information control system) of the mechatronic object, including the operator's PC with the necessary software to work with the control object. The main purpose of the distributive node is to provide an interface between IS and the executive nodes of the system. The interaction between the ICS and the distributive node is performed through a 2.4 GHz wireless WiFi network using the TCP / IP protocol, and the interaction between the distributive and executive nodes is performed using the ESP-NOW protocol. The purpose of executive nodes is to implement tracking systems that perform tasks from the distributive node. Any communication between executive nodes occurs through the distributive node.

The work Qiu et al. (2018) assesses gait movement in healthy adults and affected patients with gait disorders. A low cost, smart and lightweight wearable gait analysis platform was developed based on the emerging networks of body sensors, which can be used to assess the rehabilitation of patients with walking difficulties. A calibration method for accelerometer and magnetometer has been proposed to deal with ubiquitous orthoronal errors and magnetic disturbances. The complementary filter based on the proportional integral controller and the correction of errors of the travel parameters were defined with a multisensor data fusion algorithm. Figures 2 and 3 show the principle and structure of the proposed gait analysis system by Qiu et al. (2018).

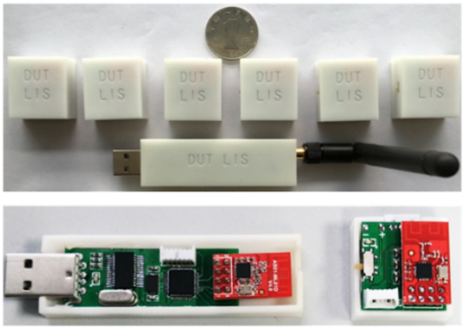

Figure 2. Self-made motion tracking sensor nodes proposed by Qiu et al. (2018)

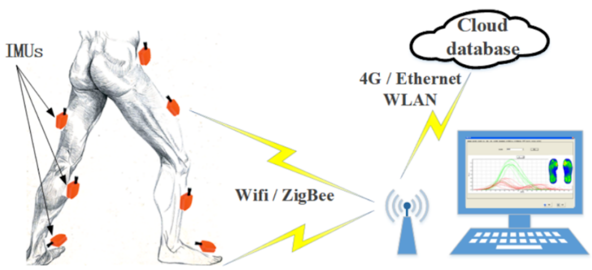

Figure 3. Gait analysis scenario Guo and Xiong (2017).

Rehabilitation after total knee reconstruction surgery using low cost and portability are studied in the work of Kontadakis et al. (2018), where an innovative gamified rehabilitation platform was developed, consisting of a mobile game and a custom sensor placed on the knee, aimed at patients who underwent total knee replacement surgery, in collaboration with the General Hospital of Chania. The app uses a single, lightweight, low-cost custom sensor that consists of an IMU attached to a lower limb to capture your orientation in space in real time, while the patient is performing a physiotherapy protocol (gametherapy), to increase engagement of the patient during physiotherapy, motivating the user to participate in a game. In 80% of the samples collected, the maximum ROM percentage measurements are increasing. This indicates that patients were constantly trying to improve their previous repetition performance, lifting the plane even higher and collecting more coins. At the end of some sessions, the ROM measurements decreased, in some cases, indicating that the patient was tired from the repetitions performed. This was mainly the case for patients who showed slower recovery due to other comorbidities. The slower recovery of these patients did not necessarily result in less involvement during the plane game. Patients were still trying to improve their previous repetition in 80% of the cases examined. A minority of patients did not improve their ROM. In these cases, according to the authors, patients did not understand the purpose of the game well and were not involved with it. Therefore, patients only performed the repetitions because they were instructed to do so.

3. METHODOLOGY

As a methodology to acquire the angles of the joints of the upper limbs of the human body, the distribution of IMUs from the work of Bora et al., presented in Bora et al. (2019), was used as a support. The Figure 4 shows the arrangement of IMUs along the upper part of the human body.

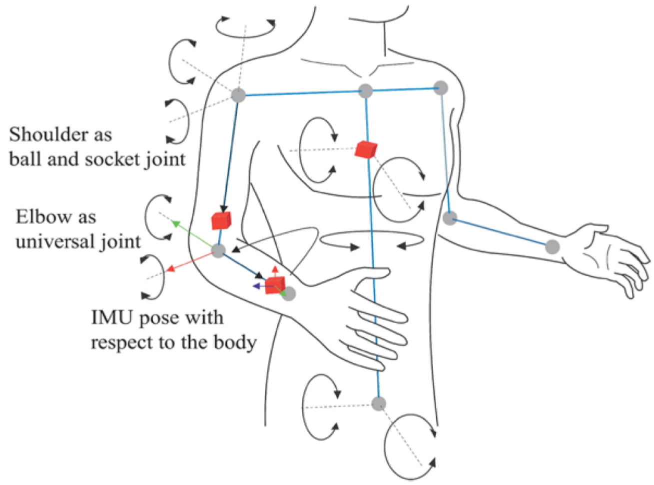

Figure 4. Functional model of the upper body with positioning of the indicated IMUs (red cubes) Bora et al. (2019)

The methodology consists of a chain of wireless devices based on the communication and synchronization reliability of the information obtained by the inertial sensors. Each set for measuring the angle of each joint, must acquire the information through the inertial sensor and forward to a device/system that integrates the information of all the joints. The proposed methodology uses the master-slave procedure, where the acquisition of data from the IMUs comes from the slaves that are monitored through local microcontrollers. The modules that enable the monitoring, include 1 Unit of Inertial Measurement of model MPU92/65, 1 microcontroller ESP8266 D1 Mini and 1 USB cable (in the final prototype, it is replaced by a lithium battery) to energize the system. The master coordinates the slaves in order to synchronize and control the data. The Raspberry Pi 3B + microprocessor integrates information from the master for viewing and use in software. This methodology can be viewed in Figure 5.

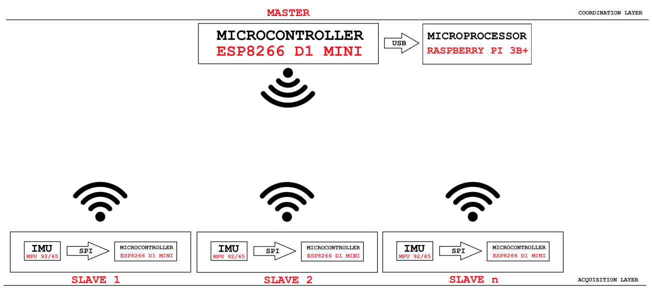

Figure 5. Methodology for wireless system development

For the connection between the MPU 92/65 and WEMOS D1 MINI, a shield was developed for ease of exchange in case of burning or malfunction of both systems. For the correct communication between sensor-microcontroller, the I2C communication protocol was used, which has up to 100 kbits / s speed, and has a structure where two microcontroller pins (SDA and SCL) send and receive data and the other synchronizes (through clock), respectively. These pins on WEMOS D1 are: D2 PIN - SDA and D1 PIN - SCL. Therefore, the shield facilitates the connection of the SCL port of the WEMOS D1 MINI, to the SCL port of the MPU 92/65, as well as the SDA port. The speed that the I2C protocol is sufficient for the project presented here.

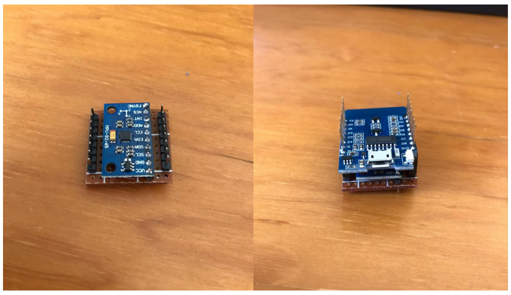

Figure 6. MPU 92/65 to WEMOS D1 MINI Shield

4. TESTS AND RESULTS

The topology defined to be implemented in this system was the star topology. Where the information obtained from each of the slaves (Wemos D1 Mini + MPU92 / 65), is sent to a central station, which has the Wemos D1 Mini hardware connected by USB on a PC.

The first test places all IMUs in the 90-degree X-axis orientation and maintains the 0-degree Y-axis orientation. The test result can be seen in Figure 7.

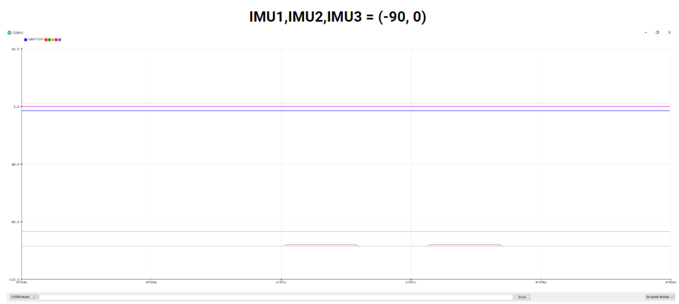

Figure 7. IMU1,IMU2,IMU3 X-axis test in evidence

The second test was carried out with the orientation of one axis of one of the IMUs in -90 degrees in relation to the others (which maintain the 0 degree orientation in both axes). The test result can be seen in Figure 8.

The third test is carried out by applying different orientations in each of the IMUs, in order to measure possible influences of modification in the values obtained through the network slaves. It was not possible to notice any kind of this interference. The result can be seen in Figure 9.

Figure 10 shows the successful delivery of the 3 test slaves to the master. During the tests, all packages were successfully delivered.

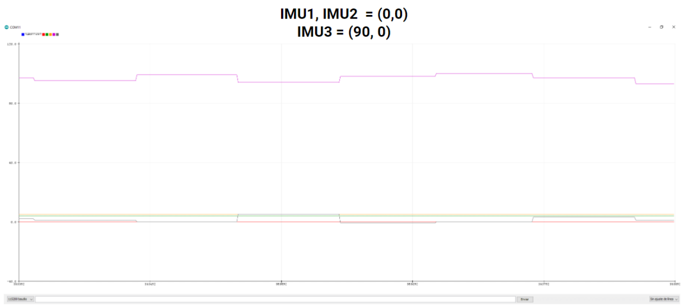

Figure 8. IMU3 X-axis in evidence

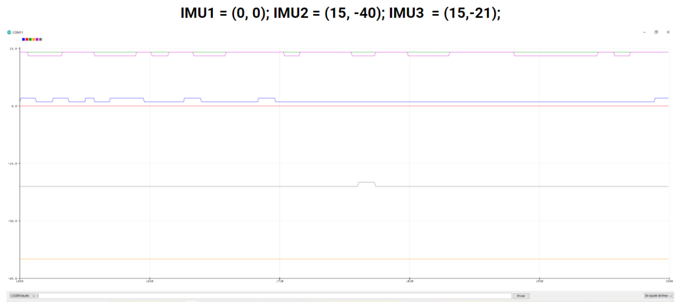

Figure 9. Test with different orientations on the X and Y axes on the 3 IMUs

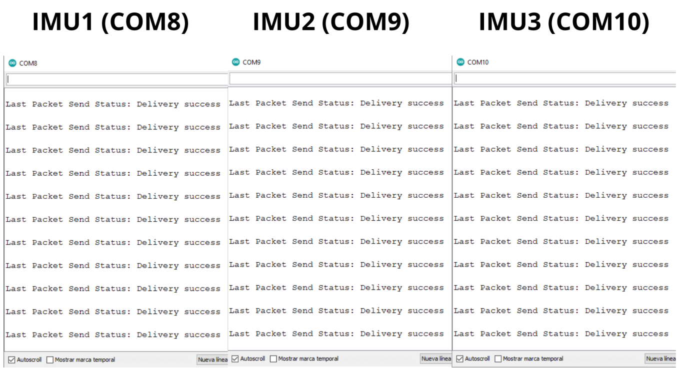

Figure 10. Data submission feedback successfully performed on IMUs 1,2 and 3

5. CONCLUSION

The Star Topology meets the needs of the project. the ESPNOW protocol did not fail to deliver packets. The communication speed between SENDER and RECEIVER is sufficient. In the tests (approximately 4 hours without interruption), the stability of the communication in the network proved to be stable and without interference that would alter the data integrity and/or failure/speed in the packet delivery. The use of the ESPNOW Communication Protocol is versatile and easy to implement. It has the advantage of the ease of adding new devices.

With the implementation presented in this work, it is possible to monitor the 2D movement (X and Y axes) of members/joints of the human body. The developed system does not have the objective of having the highest energy efficiency in the market/scientific field, but rather to have a lower hardware cost compared to other state-of-the-art methodologies, coupled with communication speed, complete data delivery and stability enough connection points for application in upper limb motor rehabilitation therapies.

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