



Robotic arm inertial control for recreational child physiotherapy application

Robotic arm control to assist in the process of children's physiotherapy, making it fun and reducing the dropout rate of children/patients

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Abstract: According to expert reports, physiotherapy is not only a painful process but also uninteresting to children. The lack of dynamism and entertainment in the physiotherapeutic process makes it unappealing, hindering their development or even causing them to avoid it. In 2021, the "Robotic System for Pediatric Physiotherapy with Recreational Activities" project was developed, consisting of a robotic arm to assist in the physiotherapy process for children with Cerebral Palsy. According to the conclusions of the initial project, the developed control was effective in the proposed idea but not sufficient for implementing the project in rehabilitation environments. Therefore, this work presents a new control that is safer and allows for its application in assisting the rehabilitation of these children. This new control, applied with three MPU-6050 inertial sensors in conjunction with three Arduino Nano microcontrollers, enables the robotic arm to reproduce the movements of the human arm, allowing independent replication of forearm, arm, and hand movements. Through three NRF2401 radio-frequency transmitters allocated to the circuits with inertial sensor and Arduino Nano, and adjusted to the user's arm, the movements are reproduced simultaneously and in real time. As a result, the prototype control functions reliably and robustly, successfully achieving its objective of providing a safer and more efficient physiotherapeutic process for the users.

Keywords: Robotic Arm. Inertial Control. Recreational Physiotherapy. Inertial Measurement Unit.

Introduction

Cerebral palsy is a neurological disorder of a non-progressive character that affects neuromuscular functions and occurs in the prenatal, perinatal and postnatal periods. This disorder can cause intellectual deficit and has as consequences motor and/or psychic alterations, epilepsy, paralysis, among others^[1]. It has as one of its main causes hypoxias, a situation in which for some reason related to childbirth occurs the lack of oxygenation of the brain. In addition to this, they are also causes of it, traumas that occurred during childbirth, infections, diabetes, abnormalities of the placenta or umbilical cord, malnutrition, drug use, alcohol in pregnancy, hypoglycemia of the fetus, bleeding, genetic problems, and prematurity^[2]. Treatment for this condition aims to improve existing skills and functions, develop new ones; and promote patient independence. In view of this and the diversity of signs and symptoms in patients, we have as some forms of treatment physiotherapy, occupational therapy and orthopedic surgery. As it has no cure, the forms of treatment aim to minimize symptoms to try to make life easier for patients; but with regard to physiotherapy as a treatment, its importance is the motor and cognitive development of the child, improving the patient's techniques and abilities; in the social sphere of the patient, it promotes the independence of the child, facilitating the performance of daily activities and communication^[3]. Specific training, such as

walking, sitting, picking up objects and exercises aimed at increasing muscle strength and/or better movement control are part of child rehabilitation, since physiotherapy prepares the child for a function so that it maintains or improves existing ones, always aiming at reducing muscle spasticity^[4]. Rehabilitation is essential for children to perform adequately the daily activities, however, constantly treatment requires a long period of time and can become monotonous, tiring and demotivating. Knowing this, in 2015, the analysis on the influence of virtual reality (VR) with Nintendo Wii (NW), on the balance and gait of a child with cerebral palsy, showed that the use of this method provided improvement in static and dynamic balance, physical and cognitive performance of the child, also providing greater motivation and fun^[5]. The conventional treatments employed by physiotherapists, which involve the use of simple equipment or subjective observations, have evident disadvantages due to their subjective nature and lack of certainty. Studies demonstrate that robot-assisted rehabilitation can contribute to the reorganization and recovery of the central nervous system, as well as the restoration of the patient's arm motor function. This is achieved through the application of precise, repetitive, and task-specific therapies. Additionally, rehabilitation robots can stimulate patient engagement through resources such as virtual reality and other methods^[6].

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Received 10 January 2022; Accepted 16 February 2022; Available online 20 February 2022.

 <https://doi.org/10.52466/ijamb.v5i1.111>

The application of ludic activities in the physiotherapeutic process makes the treatment more acceptable and pleasant for the children and consequently favors the child's development [7].

In recent decades, human beings have increasingly appropriated technology, which is constantly evolving, being a major milestone of this the digital revolution, which enabled an acceleration in the expansions and improvements of computers [8]. The knowledge to control such technological advances safely is essential for human-machine interaction. According to Isaac Asimov's first law of robotics, robots cannot harm humans or allow them to suffer any harm [9]. An example of non-compliance with Asimov's proposed law is the case of the artificial intelligence known as "ChatGPT" manipulating a person to perform a task, a situation exposed by the AI's owner in a report [10]. Therefore, it is important that the creation and maintenance of robots that have direct relationships with humans receive special attention to ensure their safety and minimize the dangerous risks for people. Devices designed to assist in limb rehabilitation must significantly improve the quality of life of their patients, otherwise it can cause dissatisfaction, leading to the discontinuation of treatment in a short period [11].

In view of the risks in the event of failures resulting from the lack of improvement of systems and circuits, whether electrical or mechanical, is important that projects that work in the Human's company need constant evolution. Then, it is idealized to improve specific parts of the project "BRAÇO ROBÓTICO TELEOPERADO APLICADO PARA A REABILITAÇÃO INFANTIL ATRAVÉS DO LÚDICO" presented by Silva et. al. [12], which was based on childhood cerebral palsy, which has physiotherapy as one of the forms of treatment. In this project, the robot's movements were controlled by a system of inertial sensors located in a glove on the patient's hand. It was possible to conclude the need for improvements, for example, increase the reduced number of replicated movements presented and the possibility of sudden movements.

Faced with these problems, is present the development of a system that makes the movement of the hand, arm and forearm independently through the application of inertial controls using Inertial Measurement Unit sensors. It was expected that with the application of a new inertial control system applied in different parts of the upper limb, the prototype could operate safely with a robustness control and more precision, therefore being applied in child rehabilitation environment, allowing the use combined with ludic activities.

Experimental procedures

The technology used as principle for the new control is based on Inertial Measurement Units (IMU) or inertial controls. The inertial controls have an inertial principle of operation, that according to Newton's first law, refers to the state of the matter of staying at rest or uniform

rectilinear movement unless external forces are applied [13].

The inertial controls are aimed at monitoring acceleration, velocity, and position, in various directions and senses, of moving bodies, in addition to being portable and low cost. They are sensors that have associations of accelerometers and gyroscopes. The use of this technology enables several applications in controls and monitoring systems linked to human movement [14].

So, considering these functionalities, for the proper application of the technology, an inertial sensor was designed for each part of the patient's arm. Additionally, the methods used include the C++ programming language to develop the control logic and integration between the inertial sensors on the patient and the corresponding motors in the robotic arm. Literature review, mainly focused on cerebral palsy and therapies based on ludic methods to understand the needs and desires of the patients, specifically, children.

To achieve the independence of each control part in the child's arm, a transmitter circuit system was applied to the hand. Based on the development presented in the mentioned robotic arm system, it was replicated in identical circuits for the arm and forearm. The transmitter circuit system consists of 1 Arduino Nano®, 1 MPU6050 (orientation sensor), and 1 nRF24L01 (radio frequency module). This system can be observed in Figure 1.

The microcontroller Arduino Nano® is responsible for reading the values of the orientation sensor and make the communication between it and the radiofrequency sensor. The MPU6050 sensor is responsible to detect the position of the individual's upper limb links on three-dimensional coordinate system and send these positions values to the microcontroller. The radiofrequency module nRF24L01, in turn, sends the wireless signal transmitting the values of the axes to the robotic arm controller. Complete this circuit, two rechargeable 4V batteries connected in series as power supply, but it was represented on circuit software with two 9V batteries.

Only in the system embedded on the hand has a difference in comparison with the circuit represented in figure 1 (arm and forearm), this difference is an additional button to open and close the robotic gripper.

After completing the hardware of the transmitter circuits to the hand, arm and forearm, it was studied how to perform a wireless communication of these three transmitters respectively, for 2 receivers, that is, for actuating the robotic arm.

Each sensor applied here contain a library in the Arduino application. The library that enables the wireless communication between sensors is called RF24. But, in this application it was necessary to modify the library to be able to communicate the three transmitters with two receivers on the robotic arm system. This modification was necessary to avoid signal interferences.

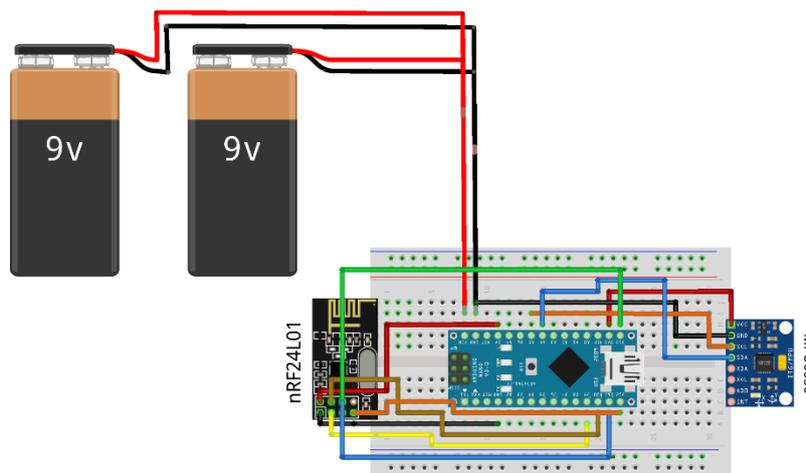
In the first tests each transmitter was given a different address that would later be identified by the receiver and the values of the axes are sent in a data package called “msg”. However, it was necessary to designate a specific identification for each transmitter because the values of the 3 transmitters when arriving at the receivers would be mixed causing possible problems in the future. Therefore, the solution adopted was to send together with the axis values of each transmitter circuit, a number chosen arbitrary for identification of different ones, so the values 99, 100 and 101 were assigned to the corresponding hand, forearm, and arm circuits, respectively.

Both the three transmitters would perform the main same function, which is to send the X, Y and Z axis values, but the values sent by the MPU6050 are not of integer type and the servomotors used to work with integer values, so it was necessary to convert these MPU6050 values into integers using specific functions on microcontroller program to a proper communication between the system on the human arm and the robot arm. The scheme of communication can be observed in figure 2.

In the receiver circuit, the structure used to simulate the human arm was a acrylic arm in a black color. The robotic arm was chosen due to its sufficient 5 Degrees of Freedom (DoF), its good flexibility, and its great resistance due to its material, it is approximately 50 centimeters tall and has good stability in movements.

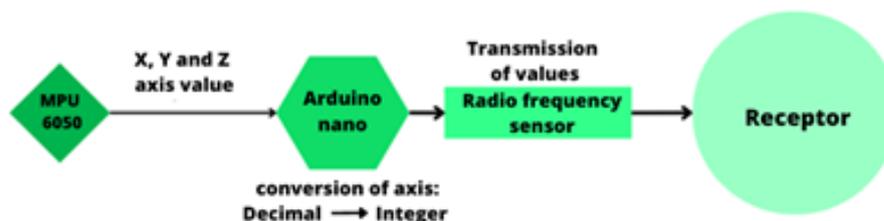
It is known that the human arm has seven Degrees of Freedom. The human arm has two spherical joints, each type of joints like this provides three DoFs to the arm, being the shoulder joint and the wrist joint, when combined with the simple revolute joint in the elbow in which there is one more DoF, is given the seven Degrees of Freedom. However, due the redundancy of this system in order to position the arm in the three-dimensional space is necessary just six DoFs. So, making some analyses was conclude that due to the most tasks in the rehabilitation environment being done in the plane reference, e.g., to move an object from one point to another on a table or to move an object from bottom to top, the five DoFs presents in the robotic arm are considered sufficient for the application of the project.

Figure 1 – System embedded in each link of the human arm.



Source: Own Authorship, 2023.

Figure 2 – Transmitter operation flowchart.



Source: Own Authorship, 2023.

The system of robotic arm consists of the following components: 1 protoboard, 2 Arduino UNO® microcontrollers, 5 MG996R servomotors, 2 9g micro servomotors, 1 nRF24L01 radio frequency module and a 400W ATX power supply. The acrylic robotic arm simulates a patient’s arm in a ludic environment, where the servomotors perform the movement of the joints of a human arm. The robotic arm aforementioned and chosen for this application can be seen in figure 3.

Figure 3 – Robotic Arm.



Source: Own Authorship, 2023.

The Arduino UNO is fundamental for the development of the new control, since it is responsible for managing the entire logic of the new system. Initially, the use of one microcontroller was evaluated to perform the functions of the receiver circuit. However, after some tests performed, it was seen that only one unit of this microcontroller did not have sufficient processing capacity for the data flow. It was then noticed that the Arduino receiver was receiving 28,512 bytes and using another 11,132 bytes of its own programming, consuming 39,464 bytes and its limit is based on 32 Kb. It was necessary the use two microcontrollers to drive the robotic arm, but in the future, it will be changed by a new microcontroller model with better data processing

capacity. In Table 1 is possible to understand the processing costs.

There are two nRF24L01 radio frequency modules present in each Arduino and are designed to receive the data from the transmitters and communicate to control the servomotors. The robotic arm has five servomotors, being one servomotor applied to the movement of the base rotation that corresponding to the shoulder rotation movement, two servomotors associated with the same base but applied to carry out the elevation, so called, flexion and extension movement of the link corresponding to the human arm in the robotic arm, another one for the flexion / extension movement to the link that corresponds to the forearm and a last one for the flexion / extension movement of the wrist. There are two additional micro servomotors, the first responsible to rotation movement of the wrist and another one to open and close, or, flexion / extension movement of the gripper. All these motors are powered by a 400W power supply aforementioned. This circuit is shown in figure 4.

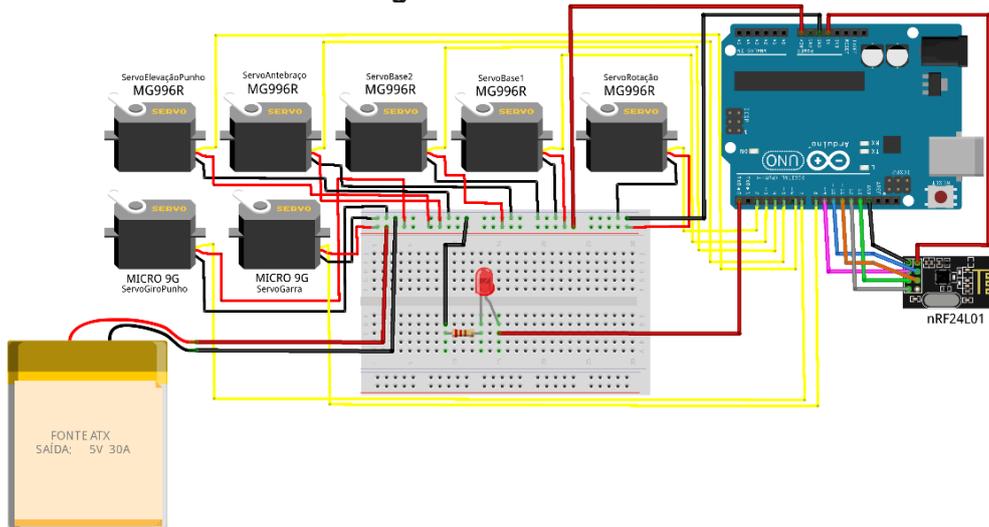
Completing to the logic operation idea of the new control, the radio frequency receiver modules were first indicated to which addresses it must communicate to receive the signals from the three transmitters. The transmitters were identified using an identification number corresponding with the motor that each one need control as already explained. After this, the data received, that is, the values of the cartesian coordinates, are converted into angles so that the motors can follow every small variation of motion values in real time. In figures 5 and 6 is shown the described system, it is possible to observe in detail how the communicators and microcontrollers are divided and what each one must control.

Table 1 – Consume of bytes.

Bytes spent on each part of the circuit	
Circuit	Byte consumption
Transmissor: Hand	11.270 Bytes
Transmissor: Forearm	10.710 Bytes
Transmissor: Arm	6.352 Bytes
Receptor:	11.132 Bytes
Total	39.464 Bytes

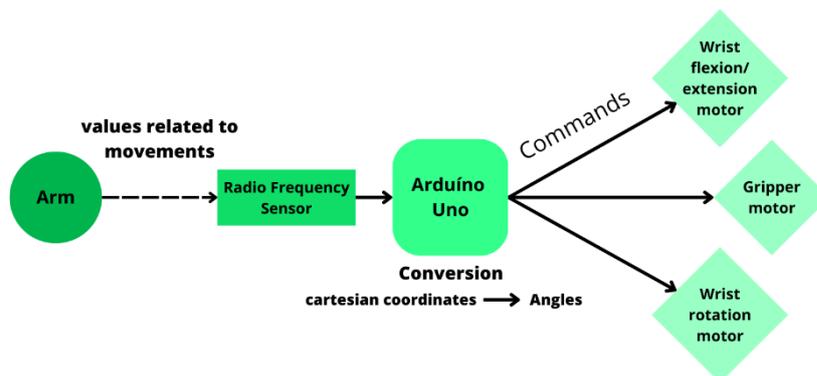
Source: Own Authorship, 2023.

Figure 4 – Receiver circuit



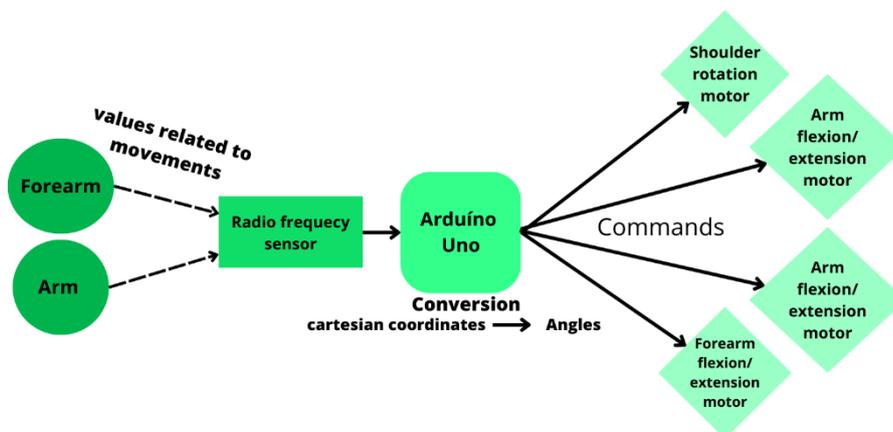
Source: Own Authorship, 2023.

Figure 5 – Receiver operation scheme.



Source: Own Authorship, 2023.

Figure 6 – Operation scheme of the second receiver.



Source: Own Authorship, 2023.

Results and discussion

After carrying out the communication tests between transmitters and receivers, applying independent control of each link of the robotic arm and finally integrating the whole system, that is, simultaneous operation of all sensors, motors, and systems an independent control of the links in real time can be observed.

It was verified that a stable communication was established at several points, but some interferences can be observed in specific situations. As with the nRF24L01 operation, as it operates at 2.4 GHz, when the system is close to some device that used to use the same frequency is possible occurs these not desirable noise signal making it difficult for the robotic arm to reproduce fluid movements in some situations. However, when communication did not suffer from these external interferences, it was observed that the prototype was able to fluidly replicate the movements made by the user, thus presenting the operation of the new control as expected in environments with a few numbers of equipment working at the frequency of 2,4 GHz, as in the case of physiotherapy environments.

Trying to adjust this communication problem, it is intended in the future to change the channels in which the module operates, defining channels that have as little external interference as possible. In addition, as previously described, due to the low processing capacity of the microcontroller used, it was decided to use two microcontrollers to reduce the processing data problem, but to reduce the volume occupied by the hardware, it is ideal to use only a microcontroller with a suitable processing data capacity, as the Arduino DUE microcontroller, for example.

Having fulfilled the proposed objectives for the safe operation of the robotic arm, we sought to improve the operator's experience with wearable sensors. With the use of adjustable Velcro, all members of the development team were able to use the transmitter circuits, unlike the previous project where such flexibility did not exist due to the size of the glove that housed the old transmission system. This alteration is also reflected in the final application of the project, as it enables its use by patients with different arm sizes.

Conclusion

Based on the arguments presented, it is concluded that the project has positive results, since the success in the operation of the new idealized control can be observed and this provided good stability in the movement in relation to the old control used. The improvements applied also provided a good fluidity during its movements and improved the precision of the movements operating in what is considered "real time", where as soon as the operator performs the movement, the robotic arm can reproduce it in a very short period of time.

This "real time" operation is defined by peer observation, that is, being observed by the human eye, no

delay can be noticed. However, in a future improvement this could be measured with an electronic system to prove this concept.

For the definitive use of the robotic arm developed in child physiotherapy it is necessary, first of all, the evaluation by a professional in the rehabilitation area.

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