MINISTRY OF EDUCATION
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THESIS

SUMMARY

CONTRIBUTIONS REGARDING THE CONTROL OF AN EXOSKELETON TYPE SYSTEM

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Content

Introduction

In last years, more and more techniques and technologies have emerged that assist certain operations, which has led to the emergence of specially designed devices for the rehabilitation of people with different degrees of disability. Especially in the case of amputated arms or if the patient has mobility and limb control, several types of devices have been designed. At present, the prostheses used as extensions of any member bring both aesthetic and flexibility improvements.

Several research projects are centered on the idea of developing devices that support human movements, even if the results are promising, none of the proposed solutions offer an effective control or drive system for this type of device. This research is centered on creating an exoskeleton-type robotic device for people who have certain problems or limitations in upper limb basic movements. Although some movements may seem trivial, they are essential in the rehabilitation process, but also in everyday life because the patient will no longer be dependent on another person for certain operations.

The proposed device will be equipped with a EMG signal acquisition and analysis system that will be able to perceive the carrier's intentions of movement and the drive system will help and support the independent robotic exoskeleton movement.

We take this decision to focus our efforts on developing a device to facilitate arm movement because, after researching these types of devices, we noticed that most of them are focused on supporting or limiting arm movement in the recovery process, few of them also having a drive to reduce the effort of the arm to achieve the movement, despite the fact that most patients also need it.

From the beginning, it was necessary to determine the EMG signal from several perfectly healthy arms so that we can see the signal value according to the intention of the movement, then the same movement of a problem arm to see the differences that appear to be able to determine a pattern.

Then we will describe the structure of a biomechanical model of the human arm in order to recognize the intentions of the subject by making an analysis of the electromyographic activity. After determining the intention to move, it is necessary to execute the control of the actuation system for the movement of the exoskeleton in the same way as the arm. A complete model of the relationship between the EMG signal and associated movements will be useful in designing the robotic exoskeleton to support and assist the movement of the diseased arm. Additionally, IMU type sensors will be included to correct the exoskeleton movement based on information regarding the human arm segment orientation information.

From the general objective results specific objectives:

OB.1. Designing an exoskeleton to support the movements of a low-mobility arm
OB.2. Conducting motion prediction by using specific sensors.
OB.3. Operation of the exoskeleton on the basis of the intention of motion identified to support the arm.

The research is structured into three chapters of content, an introductory chapter, a chapter on research methodology, a chapter of conclusions, contributions and further developments and bibliographic references relevant to the subject.

Chapter I - Current state of research

This chapter presents a study of the literature in order to achieve the research objectives. A research has been carried out of the current state of the exoskeleton-type robotic devices used to support the upper limb movement or used in rehabilitation treatments by persons who have lost part of their mobility due to an accident because the muscles are no longer able to perform certain normal movements. At the same time, a research was carried out on the types of sensors and the signals acquired and processed to determine the intention of movement, and in order to determine the position to which the arm should reach in accordance with the intention of the movement, the order of the exoskeleton and the model of the movement .

1.1. Exoskeleton

First application of the active robot exoskeleton was to provide an external power to a soldier so that he could carry extra weight. Since then, this technology has focused on developing human power assisted and improved systems. Later, this technology has been used in other applications, such as limb rehabilitation and tele-surgery. Exoskeleton research is still a growing area and requires multidisciplinary approaches to solving complex technical problems.

1.2. Electromyography (EMG)

The development of electromyography (EMG) began with the documentation of Francesco Redi in 1666. The document informs that some groups of squirrel muscles generate electricity. In 1773, Walsh was able to show that the muscular tissue of the eagle could generate a spark of electricity. In 1792, a publication entitled "Viribus Electricitatis in Motu Muscles Commentarius", written by A. Galvani, appeared in which the author showed that electricity could trigger muscle contractions.

Electromyography (EMG) is the study of muscle function by analyzing the electrical potential produced by the muscles. EMG nowadays has become an important tool in biomedical and clinical applications. Thus, EMG detection, processing and analysis signal has become a major research element in the biomedical field, involving a wide range of physician, engineer, physicist, and computer scientist experts.

Electromyographic signals (EMG) can be used for clinical and biomedical applications. Currently, there are three common EMG signals. First of all, determining muscle activation time, that is, when the muscle starts and ends. Secondly, estimating the force produced by the muscle and third, obtaining an index of the moment when a muscle is tired by analyzing the signal frequency spectrum.

To aquire the sEMG signal, the electrodes are placed on the skin in the area surrounding the muscle. Alternatively, wired or needle electrodes are used and they can be placed directly into the muscle. When the EMG signal is taken from electrodes mounted directly on the skin, it is a composite of all the potentials of muscle fibers that are very close to the skin

1.3. Controllers

The exoskeleton is an electromechanical structure worn by the user, which matches the shape and functions of the human body. It is capable of increasing the capacity of human limbs and / or treating muscles, joints or skeletal parts which are weak, ineffective or injured due to a disease or neurological disorder. Moreover, it combines machine power and human intelligence to enhance machine intelligence and user power. The exoskeleton operates mechanically in parallel with the human body and can be actuated passively and / or actively.

One of the types of exoskeleton control systems is the model-based control system. Generally, according to the model used, the control strategy for the exoskeleton can be divided into two types: control based on the dynamic model and control based on the muscle model. The dynamic model of the exoskeleton is derived by shaping the human body as rigid bundles joined by joints (bones). This model consists of the combination of inertial, gravitational, Coriolis and centrifugal effects. The dynamic model can be obtained in three ways: the mathematical model, the system identification, and the artificial intelligence method. The mathematical model is obtained by the theoretical modeling of the exoskeleton based on the physical characteristics of the system. The second way to get the dynamic model is to identify the system. This method is very useful because it is difficult to achieve a good dynamic model by using the theoretical mathematical model. The last method for obtaining the dynamic model is artificial intelligence. His popularity of solving many nonlinear problems has attracted some researchers to become involved in the dynamic identification of the model.

1.4. Applications

Nowadays, the usual wearable robots are mainly for military applications, health care rehabilitation and cargo lifting in industry and production. The Sensor and Control Concept for a Wearable Robot for Manual Load Handling Assistance presents a sensor and control concept for a robot that can be worn for manual handling of loads in the industry. Special requirements are addressed, such as reduced costs, direct human contact and cargo, and easy configuration. A stand mounted on the test wall of a hinged joint was built to evaluate proposed sensors and control algorithms. By using a torque sensor in the joint as a reference it is shown that low-cost force sensors can be used in the forearm to measure the interaction of the robot with the man. A torque and speed-based approach and an impedance control-based approach, which allows the user to move freely while not handling tasks, and which also allows the integration of a human control signal to adjust the force support, is compared.

Chapter II - Research methodology

The PhD thesis is part of applied scientific research.

Present research methodology responds to the overall objective and derived objectives.

Thus, the research in this thesis aims to provide solutions to the identified problem, namely the need for devices to complement the array of exoskeletons to support human arm movement while the number of people affected by neurological problems limiting upper limb movements is increasing.

From the study of the specialized literature, including the current stage of evolution of the theoretical and applicative approaches in the field of the subject, the following specific objectives were formulated for the realization of the research:

Objective 1: Design an exoskeleton to support the movements of a low-mobility arm.

First stage in designing the exoskeleton is the mathematical modeling of the human arm, namely the kinematical shoulder-elbow-wrist chain. For this, the kinematic models develop directly and inversely, as well as the dynamic model. All of these models are implemented in the MatLab-Simulink simulation modeling platform using the SimMechanics toolbox.

Objective 2: Achieve motion prediction by using specific sensors.

In order to use the directly determined DH model, it is necessary to know the angles of movement of each arm coupling. Angle sensors (EMG) are used to estimate the angle of movement of each arm of the human arm. This system is designed using system identification tools based on input data collected from EMG sensors and output data provided during the identification of angular position sensors (IMU).

The acquisition and processing of EMG signals is done in a non-invasive way, in accordance with already established models.

Objective 3: Operation of the exoskeleton on the basis of the intention of motion identified to support the arm.

At this stage the model and simulation of the human arm assembly - exoskeleton for the testing of their synchronous motion - are carried out. The direct kinematical model of the human arm and the invasive kinematic model of the exoskeleton are used at this stage. Movement of the human arm is done by actuating each coupling, based on the angles estimated using the EMG sensors, and determining the kinematical position of the wrist. The wrist, according to the exoskeleton prototype project, is used as a reference for movement of the final element of the exoskeleton. That is, the position of the wrist, resulting from the straight arm model, represents the position to which the final element of the exoskeleton must arrive, which is the input size for the inverse kinematic model of the exoskeleton. This model determines the translation and rotation movements of the exoskeleton's couplers, which bring the final element of it to the same position as the wrist.

Chapter III - Modeling and simulation of the human arm

This chapter presents the simplified approach of the human arm to develop mathematical models both cinematic and dynamic. For kinematic models, Denavit-Hartenberg formalism is used to determine the direct kinematic model and vice versa. For the kinematic model, all the rotation couplers of the three arm couplings are considered: shoulder (3 turns), elbow (2 turns) and wrist (2 turns). For the direct kinematical model and vice versa, only the coupling of the shoulder and the elbow is considered because in the case of this thesis we are interested in the position of the wrist. For dynamic models, the Jacobian method is used to determine the speeds both as a direct and vice versa. Before performing motion simulation, the types of motion trajectories that were useful in conducting any robot or system assimilated to a robot were analyzed.

Chapter IV - Designing an exoskeleton for the right arm

This chapter presents the mechanical design of a right arm exoskeleton to track the movement of the human arm and be able to support the arm if the person using the exoskeleton is tired. In order to achieve the design of the mechanical part of the exoskeleton, a first research was made on existing devices and patents on this subject. After studying in detail several types of such devices, we propose an exoskeleton model used to support the movement of the upper right arm.

Mathematical models have developed both cinematic and dynamic. As in the previous chapter, for kinematic models, Denavit-Hartenberg formalism is used to determine the direct kinematic model and vice versa. For dynamic models, the Jacobian method is used to determine the speeds both as a direct and vice versa. For motion simulation, the motion trajectory types presented in the previous chapter were used.

As simulation modeling environment, MatLab-Simulink, along with the SimMechanics toolbox, allows the implementation of cinematic and dynamic mathematical models to simulate the movement of the exoskeleton.

In the last part of this chapter, in MatLab was implements the direct cinematic and dynamic arm model coupled with the inversely cinematic and dynamic model of the exoskeleton.

Chapter V - Control of the integrated arm-exoskeleton system

5.1. Basic concepts for system identification

Very often, engineering practice requires the dynamic mathematical model of the process, the execution element, the measuring element, etc. In the field of automated process management, mathematical models are required for system simulation and design, and later defect detection and process optimization. Mathematical models can be conceptual (phenomenological), physical (empirical) and mathematical (analytical). Determining experimental mathematical models is the object of system identification study. The experimental analysis of the system that is to be mathematically modeled involves the off-line or on-line purchase of the input and output variables of the system, and then their processing in order to determine the mathematical model.

5.2. System identification using neural networks

Neural networks characterize assemblies of simple, interconnected and parallel processing elements that aim to interact with the environment in a biological-like and learning-friendly way.

There is no generally accepted definition of these types of systems, but most researchers agree to define artificial networks as networks of simple elements strongly interconnected by means of links called interconnections through which numerical information is propagated.

Artificial neural networks are part of the so-called cognitive systems, which are a collection of computer technologies inspired by the mechanisms that are used by the human brain to process received signals, thinking, decision making, and the principles of natural evolution. Fuzzy systems, genetic algorithms and expert systems are included in the same category.

The origin of neural networks is in the study of brain-formed networks of neurons and their synapses. They have the ability to learn from examples in a connexons way and improve their performance using previous experience.

5.3. Identify the intention and position of the arm based on the EMG and IMU signals

Two types of sensors were used to achieve the experimental part. The Electromyography Sensor (EMG) was used to detect the intention to move for the abduction / arm adduction. An IMU sensor has been positioned along the EMG sensor to determine the angle of the arm.

The Electromyography Sensor (EMG) measures muscle activity by monitoring the electrical potential generated by muscle tissue. It picks up, amplifies and processes the complex electrical activity of a muscle group and turns it into a simple analog signal that can be read by any digital analogue converter (DAC) microcontroller. The relationship between muscle activity and output voltage can be adjusted with the potentiometer on the sensor board.

IMU

The BNO055 arm angle measuring sensor is the first in a new family of absolute directional sensors that includes all sensors in a single package.

BNO055 is a package system that integrates a 14-bit triaxial accelerometer, a 16-bit triaxial gyroscope with a range of ± 2000 degrees per second, a triaxial geomagnetic sensor, and a 32-bit microcontroller.

5.4. Modeling and simulation arm exoskeleton assembly

We have the direct kinematic model Denavit-Hartenberg, which calculates the position and orientation of the wrist based on the estimated movements from the signals received from the EMG and IMU sensors. The wrist position determined from the human arm's Denavit-Hartenberg model represents the input size in the inverse Denavit-Hartenberg model of the exoskeleton, which calculates the displacement d_1 for the translation coupler and the angles θ_1 and θ_2 for the rotation couplers.

Capitolul VI - Contributions and further enhancements

Contributions

3. We realized the direct and inverse kinematic model of the exoskeleton to determine the position to be reached and the speed with which to do so.

4. We designed, following the study of the exoskeleton, a model using only electric drives.

5. Making a new exoskeleton model that follows the user's arm to support the movement.

6. The use of a translational movement to support the shoulder movement of the arm, which means a lower wear of the motion transmission system than the use of a rotational movement.

7. Acquisition and processing of EMG signals by non-invasive method in accordance with already established models and improvement of prediction by use of sensors for the orientation of the arm.

8. Implementation of the exoskeleton actuation system based on the intended motion to support the arm.

Further enhancements

1. Use a lot of lighter materials, but at least as resistant to the construction of the exoskeleton.
2. Try to create an exoskeleton that can be worn by the user.
3. A universal device easy to adapt for the right or left arm

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