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EMG Controled Powered Exoskeleton For Upper Extermity Argumentation

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Abstract: ***This work presents a control system for exoskeletons that utilizes electrical signals from the muscles as the main means of information between the human operator and the exoskeleton. Those signals are picked up from the skin on top of selected muscles and reflect the activation of the observed muscle. They are evaluated by an algorithm to drive the control system of the exoskeleton. A calibration algorithm for those parameters is presented which relies on the same algorithm which measures the muscle parameters every time before the machine is used. The calibration is done to eradicate many erratic signal variations.The model fuses the results from different biomechanical and biomedical research groups and performs a sensible simplification considering the intended application. An exoskeleton for the upper extremity was designed and constructed to verify the model and investigate the interaction between the human operator and the machine in experiments with force support during everyday movements.***

Keywords—Powered Suit; exoskeleton; powered; extermity argumentation

I. INTRODUCTION

The human body consists of more than six hundred muscles, producing movements, which are inseparably connected to its life. That does not necessarily refer to the vital functions of the body, like breathing or the heartbeat. It refers to movement in general, which is very important for all living creatures. Aside from the immediate needs to eat, or the desire to communicate, be it with words, gestures or the whole body posture, mobility is one of the most important things in life. It does not only mean to travel around by car to a neighboring city or by airplane around the world. Already the common daily activities are very important for the quality of life: Getting up from bed in the morning and walking to the bathroom, the breakfast table, or the refrigerator. Alternatively, during work, whether inside an office or while carrying heavy parts in a factory. Furthermore, lack of mobility often results in lack of participation in social life, which in turn leads to an undesired reduction of communication. It is also important for the body health to move around to activate the circulation system of the body, the muscles, and to breathe fresh air. In this, work a device and control system are presented which support a human operator with extra force in the elbow joint. The device is worn around the upper body and should increase his or her mobility by supporting the biceps. Such devices are called exoskeletons. Exoskeletons in general, are structures of rigid links, mounted on the body of some living vertebrae and following the main directions and having the main joints of the living organism's endoskeleton. While the exoskeleton that is presented here - with one actuated degree of freedom in the elbow joint - already offers some support, an extended exoskeleton covering more limbs and using the same interface has a variety of potential applications:

For healthy people they can give support while carrying heavy loads, for example in a factory environment, on a construction site, or at home, transferring the major part of the load to the exoskeleton to protect the body. Depending on the size, weight, and handling of such devices, they could even be beneficial in everyday life at home, especially for elderly people, to improve mobility. But not only healthy people can take advantage of the support: Exoskeletons can offer assistance to patients during rehabilitation of the locomotor system by guiding motions on correct trajectories to teach motion patterns, or give force support to be able to perform certain motions at all. This could intensify the training leading to better results and reduce the cost of the whole rehabilitation process

A. Existing Methods

Exoskeletons that support a human operator in different tasks are not a new topic of interest for researchers around the world. Important scientific research started in the 1970's, where the group around Vukobratovic played a pioneer role: They had a clear goal in mind to help patients with defects in their locomotor system to regain walking capabilities. At this time, lack of computer processor power, heavy actuators (both pneumatic and electrical), and heavy power supplies limited the realization of interesting theoretical results. Nevertheless, researchers have been far from discouraged, and continued their work that led to interesting results. A large number of scientists have stuck to upper limb devices with a focus on hand prosthesis, because the required forces are rather low and helpful devices can be constructed with a reduced degree of freedom. In recent years, many exoskeleton projects emerged due to increased performance of computers, actuators, and power supplies. Potential applications that have occupied the minds of scientists and engineers for a long time seemed to become realizable.

1) Institute Mihailo Pupin, Yugoslavia: Exoskeleton Walking Aid: The primary goal of this research of Vukobratovic and colleagues was to develop exoskeletal devices that can be worn by patients with deficits in their locomotor system. Those devices were actively powered in the first versions by pneumatic actuators (around 1970), and in later versions by electrical actuators. The first version had four actuated degrees of freedom (hip and knee joints, both legs). The ankle joint was initially passive and actuated in a later revision. The air supply for the actuators and the computer were both separated from the exoskeleton because of their heavy weight and large size. Due to the low computational power of computers at that time, the joint angle trajectories have been computed off-line and were replayed during the experimental trials. No feedback from the patient or environment was incorporated. A full paraplegic patient unfortunately could not walk alone with this device. He needed two people for support or a rolling aid to maintain balance. To allow incorporation of overall stability control, the exoskeleton was extended in 1971 with a torso frame, adding two degrees of freedom to the system (in the frontal and sagittal plane). Software controllers were now responsible for moving the limbs along the desired trajectories, and overall stability was maintained by computing simplified correction terms with the zero moment point (ZMP). Those correction terms have been tailored to the task of walking on level ground. Actuation of the trunk was mainly used to maintain stability. Equipping the soles of the exoskeleton with force sensors allowed the incorporation of feedback from ground reaction forces to improve stability and safety. It allowed the patient to walk alone, only with the aid of crutches. After performing many experiments it turned out that the main drawback of the system was its heavy weight of 17kg (excluding air supply and computer hardware). This could be reduced in a new version to 12kg by using state-of-the-art actuators. But limitations still remained because of the air supply and large computer hardware: The system was confined to indoor use in a clinical environment.[1]

2) EΞO – A Brain-Controlled Lower Limb Exoskeleton for Rhesus Macaques: a lower limb exoskeleton designed to allow an intact rhesus macaque to direct her leg movements using her cortical activity. To accomplish this goal, the monkey is trained to control a 2D cursor on a computer screen under operant conditioning. Cursor movements are then mapped onto the ankle position of the exoskeleton. This way, the monkey can control the position of her legs by modulating her cortical activity. In fact, the monkey is trained to keep her muscles relaxed during the experiment. Currently, the experimental setup controls airwalking; that is, EΞO is suspended so that there is no interaction with the ground. Cursor movements can therefore be directly mapped to exoskeleton ankle position without adjustment for issues related to ground interaction.[2]

II. BIOMECHANICS OF THE HUMAN BODY

The use of EMG signals has been motivated as the main way of information transportation between the human operator and the exoskeleton in section 1.1. This chapter describes the processes in the human body from the thought in the brain to the resulting muscle activations and reflex actions during which EMG signals are generated. The body functions described in the following sections are valid only for healthy persons, and only aspects, which are directly related to this work.

A. *From the Brain to the muscles:*

The motor system of the human body is responsible for transferring neural signals to physical energy: A thought initiates a motion. But not only conscious brain activity, but also input from the sensor system of the human body can initiate movements. During reflexes physical energy is converted into neural signals which in turn stimulate muscles without going through the brain. Movements can be divided into three categories depending on the influence of voluntary control:

1) Reflex responses: These are the simplest form of motor behavior. Examples are the withdrawal of the hand from a hot object, the knee jerk or swallowing. Reflexes are rapid, stereotyped responses and can be performed without any voluntary control, although they can be modified with conscious effort.

2) Rhythmic motor: These patterns are typically initiated and terminated voluntarily, but in-between no conscious effort to maintain the repetitive movement is necessary, although it can be adapted to certain circumstances. Examples for this type of movement are walking, running, or swimming.

3) Voluntary movements: These are the most complex movements, like playing an instrument and driving a car. Those movements are goal directed and can be improved with practice. The better those movements have been learned, the less conscious effort they require.

The implementation of this project depends highly upon the voluntary movements and the EMG signals acquired from the biceps.

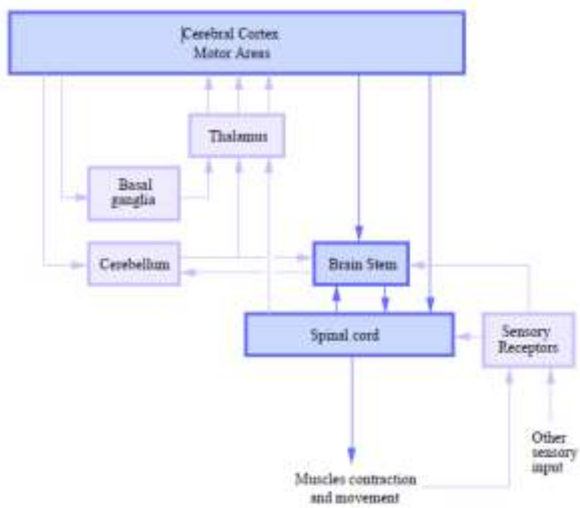

Fig. 1. Human Motor System

III. EXO-SUIT DESIGN

The design of the Exoskeleton works be the feedback provided be the user's EMG. The suit has two dominant parts, which include the EMG detection, acquisition and control system and the pneumatic system. The EMG detection, acquisition and control system is responsible to acquire the accurate EMG signal from the user and produce a control mechanism to control the pneumatics. This part includes the electronic circuits and the Arduino, which does the required processing. The pneumatic system of the suit includes the pneumatic actuators, the control valves that are required to control the activators and the air compressor.

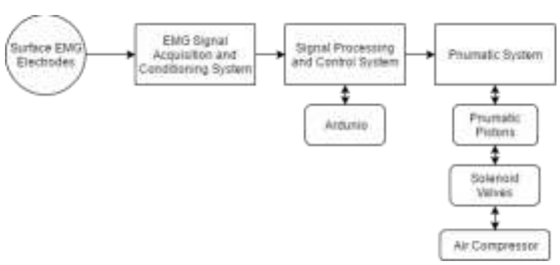

Fig. 2. General Block Diagram

A. Detection Of EMG

Electromyography (EMG) is an electro diagnostic medicine technique for evaluating and recording the electrical activity produced by skeletal muscles. EMG is performed using an instrument called an electromyogram to produce a record called an electromyogram. An electromyograph detects the electric potential generated by muscle cells when these cells are electrically or neurologically activated. The signals can be analyzed to detect medical abnormalities, activation level, or recruitment order, or to analyze the biomechanics of human or animal movement.

1) General Concerns:

When detecting and recording the EMG signal, there are two main issues. The first is the noise to signal ratio. That is, the ratio of the energy in the EMG signal to the energy of the noise signal. In general, noise is defined as electrical signals that are not part of any wanted EMG signal. The other is the distortion of the signal, meaning that the relative contributions of any frequency component in the EMG signal should not be altered.

2) Characteristics of The EMG Signal:

It is well established that the amplitude of the EMG signal is stochastic (random) in nature and can be reasonably represented by a Gausian distribution function. The amplitude of the signal can range from 0 to 10mV (peak-to- peak) or 0 to 1.5 mV (rms). The usable energy of the signal is limited to the 0 to 500 Hz frequency range, with the dominant energy being in the 50-150 Hz range. Usable signals are those with energy above the electrical noise level. An example of the frequency spectrum of the EMG signal is presented in Fig 2.

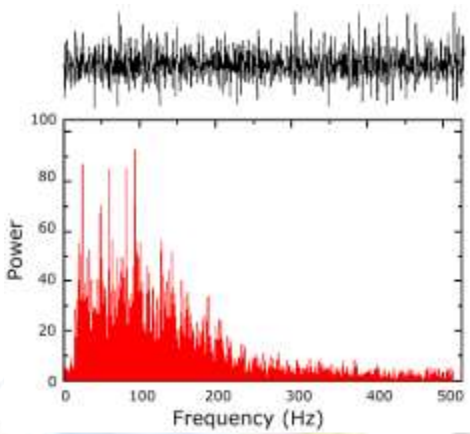

Fig. 3. Frequency spectrum of the EMG signal detected from the Tibialis Anterior muscle during a constant force isometric contraction at 50% of voluntary maximum.

It is desirable to obtain an EMG signal that contains the maximum amount of information from the EMG signal and the minimum amount of contamination from electrical noise. Thus, the maximization of the signal-to-noise ratio should be done with minimal distortion to the EMG signal. Therefore, it is important that any detecting and recording device process the signal linearly. In particular, the signal should not be clipped, that is, the peaks should not be distorted and no unnecessary filtering should be performed. Because the power line radiation (50 or 60 Hz) is a dominant source of electrical noise, it is tempting to design devices that have a notch-filter at this frequency. Theoretically, this type of filter would only remove the unwanted power line frequency; however, practical implementations also remove portions of the adjacent frequency components. Because the dominant energy of the EMG signal is located in the 50-100 Hz range, the use of notch filters is not advisable when there are alternative methods of dealing with the power line radiation. Such alternatives include designing a conditioning circuit in such a way that the majority of the power from an EMG signal is extracted. This is be done by designing a band pass filter coupled with amplifiers that work in 2Hz to 100Hz. This ensures that most of the power is attained.

B. Design of EMG Acquisition and Conditioning Circuit:

Using the Characteristics of the EMG signal and the pervious set frequency range the following module has been designed to work in 2Hz to 100Hz.

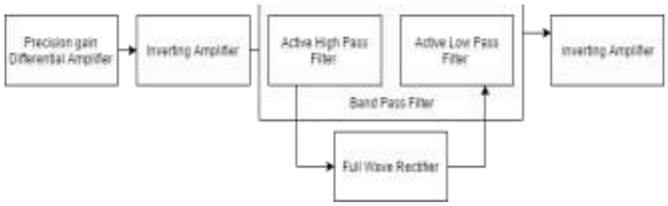

Fig. 4. Block Diagram of RMG Acquisition and Conditioning Circuit.

This circuit also takes into account the gain required to interface properly with the Arduino.

1) Differential Amplifier:

A differential amplifier is the combination of inverting and non-inverting amplifier. A differential amplifier is a type of electronic amplifier that amplifies the difference between two input voltages but suppresses any voltage common to the two inputs. [3] It is an analog circuit with two inputs and one output in which the output is ideally proportional to the difference between the two voltages

$V_{out} = A(V_{in1} - V_{in2})$ (1) Where A is the gain of the amplifier.

The Differential amplifier used here is the INA106KP. The INA106 is a monolithic Gain = 10 differential amplifier consisting of a precision op amp and on-chip metal film resistors. The resistors are laser trimmed for accurate gain and high common-mode rejection. Excellent TCR tracking of the resistors maintains gain accuracy and common-mode rejection over temperature. [4]

$V_{out} = 10\,(V_{in1} - V_{in2})$ (2)

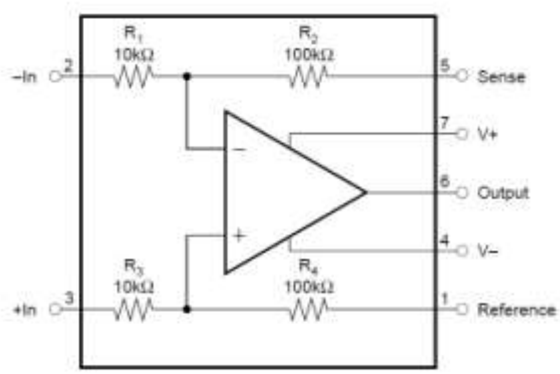

Fig. 5. The Internal Schematic of INA106KP Precision Gain Differential Amplifier.

2) Inverting Amplifier:

An inverting amplifier is a special case of the differential amplifier in which that circuit's non-inverting input V_2 is grounded and inverting input V_1 is identified with V_{in} above. The closed-loop gain is R_f / R_{in}, hence [5]

$$V_{out} = V_{in}\,(R_f / R_{in}) \quad (3)$$

3) Band Pass Filter:

This Filter as discussed earlier needs to allow the frequencies from 2Hz to 106Hz to have maximum signal to noise ratio.

F_H = 1/ (2*Pi*R*c) (4)

This is for the low pass filter which cutoff's at 106Hz.

F_L = 1/ (2*Pi*R*c) (5)

This is for the High pass filter which cutoff's at 2Hz.

4) Full Wave Rectifier:

A full-wave bridge rectifier converts the whole of the input waveform to one of constant polarity (positive or negative) at its output. Full-wave rectification converts both polarities of the input waveform to pulsating DC (direct current), and yields a higher average output voltage. Two diodes and a center tapped transformer, or four diodes in a bridge configuration and any AC source (including a transformer without center tap), are needed. [6]

A Full Wave Rectifier is used to rectify the ac voltage to dc for the Arduino to be able to read.

C. Signal Processing and Contol System:

The Arduino is used here for the signal purpose and as a control system

The output of the Signal acquisition circuit is from 0V to 5V and this in accordance with the Arduino MEGA used here and it has an onboard ADC, which can handle such voltages and convert it into an 8-bit value ranging from 0 to 1023.

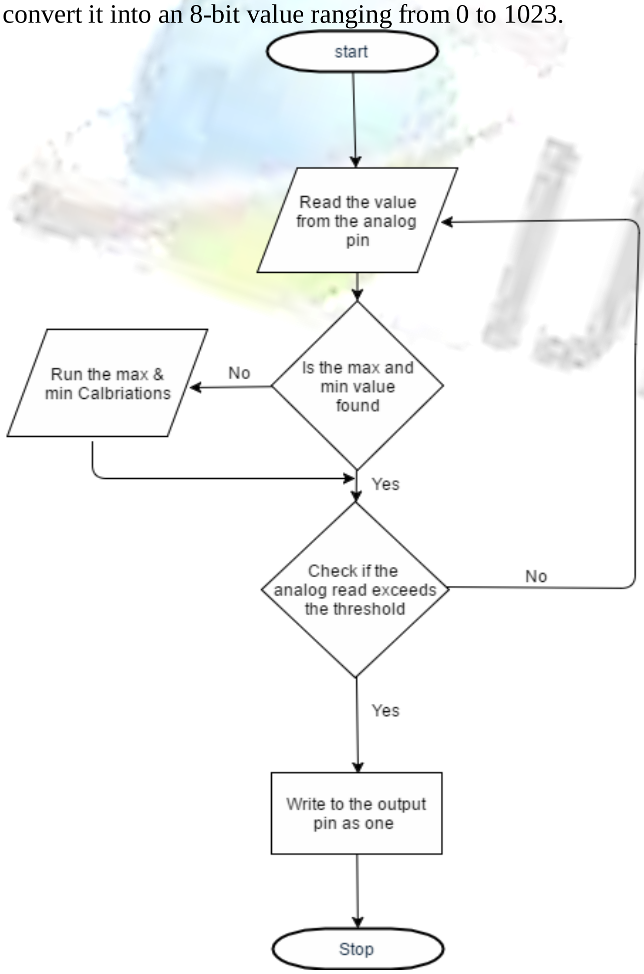

Fig. 6. Flow chart of the control system control algorithm

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The above given flow chart is a brief summary of how the overall algorithm works and the individual components have their own processes, for example the max-min algorithm has a generic method to find the maximum and minimum values from the stream of analog values received from the signal conditioning circuit.

D. Pnumatics:

The pneumatics are source of power in this exoskeleton and an air compressor of a maximum pressure of 115Psi powers the pneumatic cylinders here.

The Pneumatics used here are double acting cylinders, which are used when there is no need of an auto-retract function, which is usually done by a spring.

The force applied by the piston is directly proportional to the area of the piston and the pressure of the air.

$$F = P*A \quad (6)$$

Where the F is force, P is the pressure and A is the area. The area can be calculated be the diameter of the piston.

$$A = Pi*d*d/4 \quad (7)$$ Here the d is the diameter of the piston.

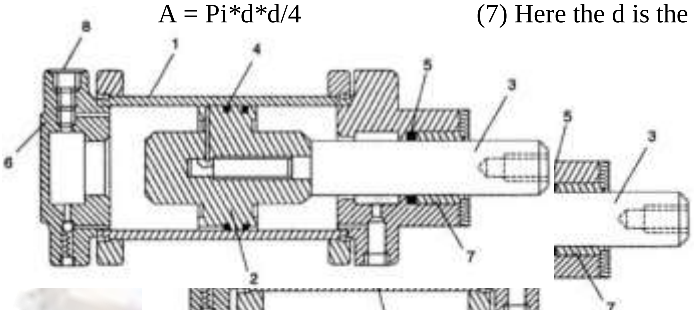

Fig. 7. Double acting Cylinder: 1. Tube 2. Piston 3. Piston rod 4. Double O-ring packing on the piston 5. O-ring for Piston rod 6. End Cover 7. Brush 8. Cushion assembly

TABLE I. THE AIR PRESSURE VS. THE FORCE OF A DOUBLE ACTING CYLINDER.

Air Pressure (Psi)	Piston Properties		
	Piston Diameter (mm)	*Force (N)*	*Piston Rod Diameter (mm)*
30	40	244	10
60	40	487	10
90	40	731	10
110	40	893	10

From the above table it can be noted that the pressure and the force relation is linear. However, there can be deviations from these general and theoretical values in practice. There is also a 15% to 20% loss in power from miscellaneous losses, which are unpredictable.

E. Exo-Skeleton Frame:

The frame of the exo-skeleton has three parts i.e. the back frame and the two arms. The entire system is wearable by the user and arguments his upper body.

The arms works as a lever where the elbow acts as the fulcrum and the effort is applied on one to lift the force on the other end.

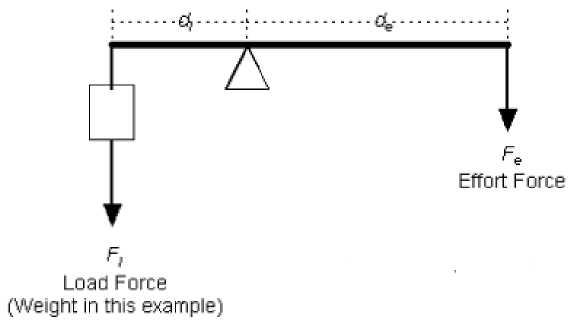

Fig. 8. The class 1 leaver ie. The arm of the exoskeleton

The Effort is calculated by

$$F_e = F_l \; d_l \; / \; d_e \qquad ()$$

The d_l / d_e ratio is kept at 2:1 that implies the effort required is simply 2 times the load. To counter this effort requirement we use two pneumatic pistons on each arm, which will effective result in providing the power of a single pneumatic cylinder.

IV. CONCLUDION AND DISCUSTION

This exo-skeleton design mainly focuses on the upper body and leaves the lower body unsupported. This is done to avoid complications and to minimize the cost of the project. The future research and development possibilities lie with the development of a lower body argumentation system.

The materials used in the structure were chosen because of their high tensile strength and toughness. The back of the frame was made using wrought iron and the arms was made using 302 stainless steel for its springy property.

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