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Development of Motion Control Algorithm For Lower Limb Exoskeleton With Simulated EMG Signal

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Abstract— This is presents a control system for exoskeletons that utilizes the simulated electrical signals from the muscles, EMG signals, as the main means of information transportation between the human and the exoskeleton. A support action is computed in accordance to the patient's intention and is executed by the exoskeleton. The present work introduces a process of sensing Electromyography signals for wrist motion. A low-cost device is presented which involves active bidirectional (hyperextension/flexion) movement of the wrist joint, controlled by specific EMG signals triggered by forearm muscles. The design undertakes all procedures and techniques for extraction of EMG signal, sensatory circuit, signal acquisition, amplification and filtering, ADC, and interfacing of simple model hand controlled by a controller (Arduino) via DC motor for bidirectional wrist movement. The instrument assists its user in moving and strengthening respective muscles. The concept is well-suited for rehabilitation robotics and prosthetic devices for handicap individuals. An exoskeleton robot is a kind of a man-machine system which mostly uses combination of human intelligence and machine power. The structure of an exoskeleton robot consists of joints and links which correspond to the human body. This is provides brief information about work that has been done in the previous decades in Designing and Developing of Powered Exoskeleton. With Electromayography Signal Various research papers have been referred and thorough insight has been taken and most of the aspects are covered. Objective of lower limb exoskeletone with simulated EMG signal because of additional strength, protection, benefits of disabilities people with dangerous jobs or mobility issues. lower limb exoskeleton system already available but it is very costly, hence design of simple low cost exoskeleton system required, The prototype proposed here utilizes an economical structure with lightweight design for minimum mechanical loss.This field itself being under research we focused only on specific objective to be taken in account to be achieved by the end of this project. A brief description is provided on the working and control related to exoskeleton.with simulated electromyography signal. The intellectual model proposed here is developed upon predictive analysis using deep machine learning by use of algorithm. Sensory inputs are computed on intention and historical data. The prototype proposed here utilizes an economical structure with lightweight design for minimum mechanical loss. The model improves (learns) with minimizing error from recorded data and current data and interrupts the output in seemingly manner. This Approach is currently constraint to lateral gait walking. Further work in multi dimensional motion as well as multi-model learning is possible.

Keywords-Exoskeleton, Algorithm, Arduino, Gait Assistance, Emg signal.

1. INTRODUCTION

'Exoskeleton' can be interpreted into two different terms Exo- meaning the external and 'skeleton'- meaning rigid structure for any living organisms. Exoskeletons are used to perform task which are usually beyond the boundaries of human in their comfort environment. The exoskeletons can either be autonomous or operator depended on the task to be fulfilled. Usually an ideal exoskeleton should be able to perform any tasks which are done by human but with greater capacity and durability. As our topic being one of the most fancy and fiction like equipment it has been able to draw much wider attention than any other in the field of Robotics. But such a topic composes two very different fields of Applied Sciences – Robotics and Biology. In order to fully utilize these fields in development of Exoskeleton one must possess a keen knowledge of all aspects of these both separate fields. So a new Branch of Applied sciences has been introduced called 'Bionics'

- An exoskeleton, is word which has root from Greek language means outer skeleton ("exo"=outer & "skeletos"=skeleton) ,is an external structure that supports and protects a human body.
- In contrast to the internal skeleton, i.e., a human skeleton, Powered exoskeleton (later it is referred as 'robotic exoskeleton' or just 'exoskeleton') is wearable robot attached to subject's body, in order to replace or enhance its movements. It should be compliant with the user's movements and deliver at least part of the power necessary to accomplish the movements.
- Today human is in constant need of giving more work output than ever before, this type of device can be constructed to accomplish multiple purposes. (like enhancing work efficiency, rectify disabilities, protect human body from uncertain damages by environmental factors or risky jobs)
- The India, being the second largest populated country in the world, holds the biggest strength of man power still we are unable to use full potential in industry, defense, exploration of new landscape.
- Though it is being such a tremendous field there had rarely been any research & development in private sector for improvement of soldier's performance and safety criteria.
- This kind of devices takes the first step in **'Human-Machine Augmentation'**. Other several countries have already taken these

steps and are moving forward. This will act as the pivoting point for future models so because the device doesn't just read the input and acts but also remembers it and learns it. Human being the weakest species considering the mass to strength ratio is in many ways limited to perform tasks.

2 WHY USED ELECTRO-MYOGRAPHY[EMG] SIGNAL

- Use Algorithm with EMG[Electro-myography] signal because.
- ECG[Electro-cardiogram]test:used to test irregularities in the heart.
- EEG[Electro-encephalogram] test: Used to test abnormalities in the brain.
- EOG[Electrooculography] test:Used to Eye movement Recording system.

EMG[Electro-myography] test: Used to test skeletal muscles.

3 TYPES OF EXOSKELETON

The exoskeleton can be classified based on various aspects involved in its development. With almost each one is unique then other intended to solve any specific problem definitions. But still they can be generalized on the following basis.

The main three types are based on their human prosthesis condition:

- To assist disable or partially able limb(medical)
- To decrease the human fatigue for desired task(Assistance)
- To increase the human strength and capabilities(Augmentation)

Other are basically sub types depending upon their properties:-

(1) Based on their skeleton linkage:

- Mechanical linkages i.e. rigid links and operators
- Fabric and resin based linkages
- Pseudo-elastic material

(2) Based on their operational task

- Pre-defined task with boundary condition
- Environment stimulated condition
- Emergency involuntary responses

(3) Based on their mode of actuated

- Pneumatic slider
- Hydraulic plunger
- Electric motor

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(4) Based on their controlling Unit

- Active response
- Passive response
- Reactive response

From above we can remarkably say that each of these can be utilized for different problem definitions. Hence one needs to focus on developing the environment for the exoskeleton in which it is going to be operated.

4 NEED OF EXOSKELETON

This type of device can be constructed for multiple purpose fulfillments. Today human is in constant need of giving more work output than ever before. Our country being the largest democracy in the world holds the third biggest army as well. Though being such a tremendous field there had rarely been any research & development in private sector for improvement of soldier's performance and safety criteria. This kind of devices takes the first step in **'Human-Machine Augmentation'**. Other several countries have already taken these steps and are moving forward. This will act as the pivoting point for future models so because the device doesn't just read the input and acts but also remembers it and learns it. Human being the weakest species considering the mass to strength ratio is in many ways limited to perform tasks.

This machine can help humans to lift heavy loads, perform longer and most importantly overcome his or hers own disability.

5 COMPONENTS AND SUB-SYSTEM

5.1 CONTROL STRATEGIES

All the exoskeletons are having control strategy for the operation of exoskeleton for given task. For human locomotion assistance-*'Trajectory tracking control'*is widely used in which first the human motion trajectory are analyzed the it is feed in to the human-machine interface and this data is end to electric stepper motor. For human strength augmentation-*'ElectroMyoGraphy'*signals are read from surface of the wearer and it's interpreted and motors are operated based on their will. this method is widely adopted as it provides a real time control over exoskeleton.

5.2 MODE OF ACTUATIONS

Most basic capabilitiy of an exoskeleton is generate at least minimum or more torque equivalent to human muscle.plus this load is to be applied such that maximum movements are allowed unhindered.in earlier period pneumatic mode of actuation was preferred. But it had many draw backs firstly huge power required to start and run the system plus extra components were required such as a pump and reservoir. This decreases the scope of mobility for exoskeleton as well as increase the weight of entire unit. then motor envolved as a compact, light weight and low power consuming actuator. this lead to most widely implementation of motors as actuator.
The most ideal actuator must have following
PROPERTIES: ***Light weight, compact, high torque, sensible, low power consumption***

5.3 STRUCTURE

The frame is the base of skeleton part in the word' exoskeleton' the frame will carry all the components along side the weight of the wearer. the frame must be very tough but it should be light weight as well ideally beign zero. Frame is a dead weight with no sensitivity towards the input. Being so stiff it becomes impossible to copy and execute each and every movement of human body. plus strength requirements give rise to problems like inductility so the counter of human body cannot be obtained for perfect fit to wearer plus such qualities with individuals using the wear.

6 ELECTROMYOGRAPHY

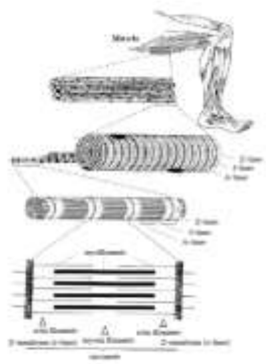

Figure 1: Human muscle anatomy

During the depolarization of the postsynaptic membrain, ion movement causes an electromagnetic field in the vicinity of the muscle fibers that overlays with firlds of fibers from other motor units which are intermingled within the muscle. the resulting sum of all fields is called the electromyographic signal of the motor units and can be directly measured invasively with needle electrodes or on top of the skin with surface electrodes. Example data is shown in figure.

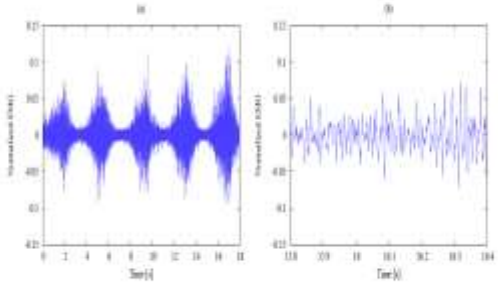

Figure 2: Muscle genreated EMG singal over time

Unfortunately,measured EMG signals arer not always exclusively from the muscle below the electrode. Due to the conductivity of tissue and skin, signal from neighboring muscles can interfear with the the muscle under observation.

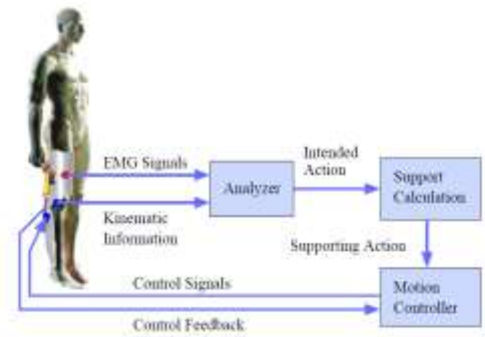

Figure 3: Circuit loop for the exoskeleton

On their way to the electrodes EMG signals are modified through filtering characteristics of the tissue it passes and,in case of surface electrodes,the characteristics of the connection between the skin and electrode.those details will not be addressed here.

The time between the emission and detection of EMG signal can be neglected in the context of this work.but there is also a time between emission and force production.this time called the *electromechanical delay*, is reported to be about 50-80ms

7 RESEARCH GAP AND OBJECTIVES

After thorough review of various researches materials following observations were made:

1. All the models develop focus either on reducing metabolic cost or Assist in rehabilitation, by changing controlling strategies, design or mode of actuation.
2. While all these methods are highly effective in research criteria's non of them involves the idea of evolving the control strategies. Because it seems more easy to have a system that only work on input – output method.
3. Very few effort were made in direction of making a program that will try to replicate human movement all the while LEARNING from the past data.
4. Even lesser systems have looked into the idea using MACHINE LEARNING concepts for making smarter controllers
5. While the models develop can be applicable on varied range of subjects, no true universal system or platform has been developed for commercial application.
6. Many of the models still developed based on a specific physical profile of masses applicable in there company.

Thus it is adamant that even new advances in field of robotics AI has been taking place, it is extremely unambiguous that none were implemented where the user is an in disposable part of the loop.

To utilize new methods and advantages of Machine learning following objectives are defined:

- The 'primary objective' is to remember from the data acquired and carry out machine learning using various Deep learning products such as Google Tensorflow generated previously.
- The 'secondary objective' is to able to develop an algorithm that can be modified based on historical date to fit the need of current user and reduce the effort required by human to do it.
- The 'tertiary objective' is to create a structure that can be fully customized as per the physical profile of user.

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8 CONCEPT

We will first understand the basics of human gait and then provide assistance in walking

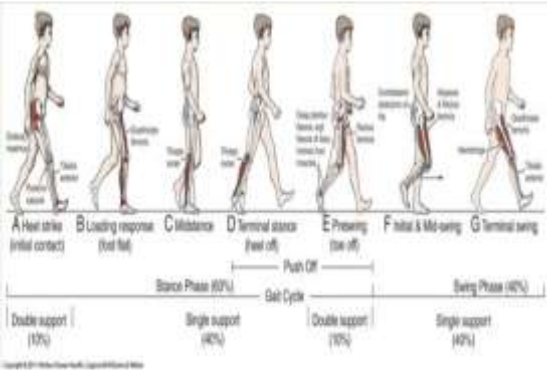

Figure 4: Muscle actutation pattern in Waking gait

Firstly, we can observe the order of the activation of muscle. We can use this pattern to start and stop the servo motors. As well as the acceleration can also be measured if needed. As mentioned earlier the muscle has one directional moment so it can only contract and not expand so each muscle is coupled with antagonist muscle which works against it. There are mainly four joints in each leg as can be observed below

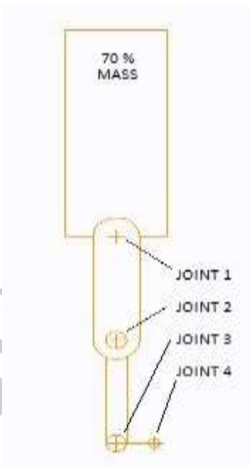

Figure 5:Simple body diagram of a human mass distribution

The upper body comprises of 70 % of body mass while each leg comprises of 15 % of body mass. So for our calculation we have consider a human of 1.80 m (6 feet) tall and weight of 100 kgs.

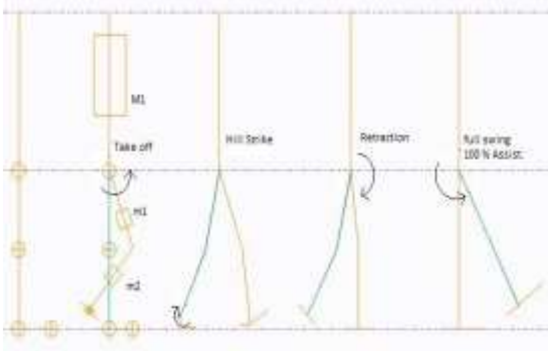

Figure 6: Free body diagram of a waking gait

As can be seen above the walking gait is divided in to 4 phases: 1 Take Off, 2 Hill Strike, 3 Retraction and 4 Full Swing. The Blue line represents the other leg.

1. Take Off
   Firstly from standing position joint 1 & 2 is rotated clockwise and primary leg rises as well as moves forward afterwards the joint 2 swings forward.
2. Hill Strike
   The primary leg strikes the floor and the secondary leg take off from joint 4 and push ahead with upper body moving forward
3. Retraction
   The primary leg holds firm with lower limb acting as stationary link and upper limb is pulled forward by rotating it counterclockwise so now both joints 1&2 moves in opposite direction while secondary leg is completely in air.
4. Full swing
   Now entire body weight is transferred on primary leg and the secondary leg swings forward these faze is the most appropriate one to provide assistance using motor.

9 INPUT

As the device is directly in contact with the human, the moving parts need to be constrained as well as properly coordinated with human desire so REAL TIME processing is required for the input. For these purpose we are implementing the 'Electromyography (EMG)'.

Human activity is noted using electrodes that are placed directly on the muscle and the data is acquired in analog form. This signal can directly be detected using the needle electrode and connected to the microcontroller. Whenever human mind wishes to move muscle the signals are generated and muscles moves after 20 - 80 milliseconds of generation of signal [5, 7]. So motor can be start or stop safely. We are using 'GROVE – EMG Sensor'

Figure 7: High resolution noise filtered EMG sensor from ADVANCER TECHNOLOGY

9.1 MICRO-CONTROLLER

We are using the 'Arduino Uno' Atmega processor having 0V - 5V with 14 analog pins and 10 digital pins. It has 10 bits operation channel. Entire circuit will be crafted on breadboard. 'Arduino' is an open source hardware that has its own human interface called I.D.E

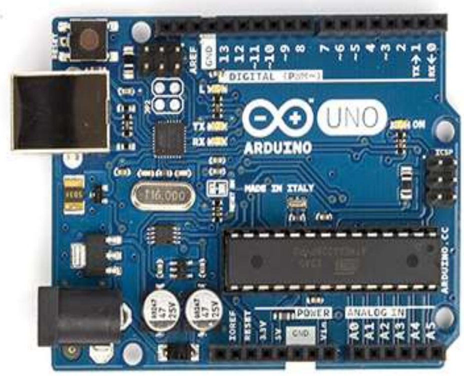

Figure 8: An Arduino Uno chip from Ada fruits

9.2 FEEDBACK

In order to have real time data acquisition and interpretation the motor should be able to keep track of its own position as well as verify it with some external source. For these purpose we are using inclinometer or tilt sensor which continuously provide the angle data to micro-controller and it will act as safety.

10 ALGORITHM

The Algorithm is the most important aspect from the perspective of achieving the goal of this thesis. Algorithm is set a set of steps /instruction that the program will execute to carry out a specific task using pre-parameterized aspects of the task. Hence, Objectives of the algorithm must be to the point and must be precisely thorough in performing its steps.

For the above mention objective the concepts from previous chapter are being used. The gait cycle is analyzed and distinctive parts are conferred onto inputs and Output

Following are the steps needs to be perform for this specific algorithm:

Step 1: Start

Step 2: Declare Variables

Step 3: Start reading values

Step 4: start recording values

Step5:selecting muscle{flexion/extension}

Step 6:calculate torque

Step 7: start interrupts

Step 8: Retrieve or start solver

Step 9: Feed values from Input to solver

Step 10: check interrupts

Step 11: get values from solver

Step 12: if interrupts true then feed value in history

Step 13: else feed values into output

Step 14: check interrupts

Step 15: if interrupts true then feed value in history

Step 16: else execute output

Step 17: check interrupts

Step 18: else read feedback and feed values from feedback into solver

Step 19: Execute solver

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Step 20: if Error is true then perform correct and output the values

Step 21: check interrupts

Step 22: if interrupts true then stop output and feed value in history

Step 23: else feed corrected value into output

Step 24: check interrupts

Step 25: if interrupts true then stop output and feed value in history

Step 26: else execute output

Step 27: read feedback

Step 28: check interrupts

Step 29: if Error is true then perform correct and output the values

Step 30: Else exit solver

The above mentioned steps need to be programmed into the controller and needs to be executed in similar manner. However the code must be tried and modified as per needed once working model is created.

The code based on the above algorithm is shown in. Below Appendix A

11 CONCLUSIONS

The data was gathered as per previously mentioned procedure the data was treated in excel for determining following properties during the cycle:

1. EMG signal profile of four muscle
2. The angle rotation profile for two joints
3. The error generated between the idle and motorized walk

The data gathered shows that the error encountered in idle walk and powered walk various in pattern over-time simply because the motor responses is quite different from initiation to execution along the walk.

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The algorithm was successful in first phase i.e. capturing, storing, post-processing the data, while it was successful in carrying the first phase it failed in execution in second phase.

Thus it can be concluded that while the algorithm is accurate in creating personal profile on any individual who is using the exoskeleton.

PART PROGRAM

```
// Establish the constant and variables required

// 4 variables are required for gathering muscle data

int Mus1 = A0;

int Mus2 = A1;

int Mus3 = A2;

int Mus4 = A3;

// Variables required for smoothing the data

int LastRead1 = 0;

int LastRead2 = 0;

int LastRead3 = 0;

int LastRead4 = 0;

int NewRead1 = 0;

int NewRead2 = 0;

int NewRead3 = 0;

int NewRead4 = 0;

// 2 variables are required for gathering angle data

int Ang1= A4;

int Ang2 = A5;

// Variable required for driving motor

int MotorPin1 = 12; // Pin number 12 on arduino Atmega250

int MotorPin2 = 11; // Pin number 11 on arduino Atmega250

int MotoDir1 = 10;

int MotoDir2 = 9;

void setup() {

  //Begin communicaiton with Arduino
```

```
  Serial.begin(9600);
  pinMode(MotoDir1,OUTPUT);
  pinMode(MotoDir2,OUTPUT);
}
void loop() {
   LastRead1 = analogRead(Mus1);
   LastRead2 = analogRead(Mus2);
   LastRead3 = analogRead(Mus3);
   LastRead4 = analogRead(Mus4);

   NewRead1 = map( LastRead1, 0,1023, 0,185); //Mapping the motor to the extreme pulse required.
   NewRead2 = map( LastRead1, 0,1023, 0,185);
   NewRead3 = map( LastRead1, 0,1023, 0,185);
   NewRead4 = map( LastRead1, 0,1023, 0,185);

   if(NewRead1>NewRead2 && NewRead1!= 0)
   {
    analogWrite(MotorPin1,NewRead1);
    digitalWrite(MotoDir1,HIGH);
   }
   else
   {
    analogWrite(MotorPin1,NewRead2);
    digitalWrite(MotoDir1, LOW);
   }

   if(NewRead1>NewRead2 && NewRead1!= 0)
   {
    analogWrite(MotorPin2,NewRead1);
    digitalWrite(MotoDir2,HIGH);
   }
   else
   {
    analogWrite(MotorPin2,NewRead2);
    digitalWrite(MotoDir2, LOW);
   }

}
 // put your setup code here, to run once:

 // put your main code here, to run repeatedly:
```

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