Development of a Self Modifying Algorithm for Walking Gait Assistance Using Lower Limb Exoskeleton

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IndexTerm: Exoskeleton, Algorithm, Arduino, Gait assistance.

Abstract : This paper provides brief information about work that has been done in the previous decades in Designing and Developing of Powered Exoskeleton. Various research papers have been referred and thorough insight has been taken and most of the aspects are covered. 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 construction, working and control related to power exoskeleton. 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.

IndexTerms: Exoskeleton, Algorithm, Arduino, Gait Assistance.

I. INTRODUCTION

Figure 1: Grasshopper abandoning its exoskeleton(***image courtesy wikipedia*****)**

‗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 anddurability.

1.1 history

The first conceptualization of an actual exoskeleton was created by **Nistrog Dimitr** in 1896 was able to lift 50 kgs heavy objects with just a metal frame. But it had no feedback system it was unable to relay data back about the load that is being acted upon. The reaction time was very huge as it takes much time in processing the data. There were no advancements in developing this system until late 1900s. But by the end of World War 1 such a system started coming in horizons. Americans were first one to develop a complete functional exoskeleton known as ‗life-suits'. It was able to act upon weight up to 60 kgs and the real time response to the input was the most outstanding feature. Up until recently 15 version of life-suit have been introduced and is still under research to be able to commercialization. Similarly many other exoskeleton as per the need base were went under development [1]. These weren‘t a generalized research area until 2002. When Japan took the initiative to provide platform and encouragement for such kind of research by organizing ―International summit for Robotics and mechatronics‖. It was very successful and has been held continuously since then. Many private sector company provided there concept as well as design for various purpose exoskeleton. Then it came into realization that exoskeleton can be implicated in any type of industries where human are not able to perform due to their natural limitations. As well as it was able to provide support to those who were handicapped or suffered severe bone surgery.

1.2 types ofexoskeleton

The exoskeleton can be classified based on various aspects involved in its development. With almost each one is unique than 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 the 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 skeletonlinkage:

- Mechanical linkages i.e. rigid links andoperators
- Fabric and resin basedlinkages
- Pseudo-elasticmaterial

2) Based on their operationaltask

- Pre-defined task with boundarycondition
- Environment stimulatedcondition
- Emergency involuntaryresponses

3) Based on their mode ofactuated

- Pneumaticslider
- Hydraulicplunger
- Electricmotor

4) Based on their controllingUnit

- Activeresponse
- Passiveresponse
- Reactiveresponse

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.

1.3 Need ofexoskeleton

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 prototype 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 owndisability.***

II. LITERATUREREVIEW

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'.

2.1 PastAttempts

Following are the some past models that has been develop and are reviewed for gathering overall idea about various aspects of differentconditions

2.1.1 Exoskeleton Walking Aid: Institute MihailoPupin

Figure 2: First electrical actuated exoskeleton[4]

It was the first ever exoskeleton that used Electrical actuators. It weighed 16 kgs and was able to perform walking, climbing and descending. Using predefined motions and tracing. The entire mechanism is operated using switches that were pre-calibrated [4].

2.1.2 Bleex: University of BerkleyUSA

Figure 3: Bleex exoskeleton wth Engine[4]

It is built for soldier, firefighter and construction worker and it is now officially an undertaking of military development project. It was based on concept of minimum Human-Machine Interface and was powered using a small fuel engine. It worked on inversion dynamics model which works on Zero Motion Point [4].

2.1.3 Powered lower assist limb: University ofMichigan

It is built for prosthesis patients that have inactive neural chords and cannot move on their own. The design implemented of spring for storing the energy for half of gait cycles and utilizing for the second half cycle [4].

2.1.4 Cyberdyne:H.A.L.

Figure 4: H.A.L. carrying 90kgs of weight[4]

This is by far the most suitable assist limb compared to any other in the category. Built keeping in mind health issue of Japanese people. It can assist human in almost all the domestic conditions. It is operated based on EMG signal harvesting. These signals are measured and overall profile is created to generate a profile for torque predictions and electronic motors are actuated byfeedingthesedata.Itcanliftupto90kgs.Itisoperatedon–phasesequencealgorithm‖.Entiregaitprocessesisdividedinto five phases and then a sensor feed data about gravity beneath both the feet[4].

2.2 Components andSub-systems

2.2.1 ControlStrategies

All the exoskeletons are having a 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 then it is fed 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 are interpreted and motors are operated based on their will. This method is widely adopted as it provides a real time control over exoskeleton.

2.2.2 Mode ofActuations

Most basic capability of an exoskeleton is to 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 evolved as a compact, light weight and low power consuming actuator. This led 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* [8].

2.2.3 Structure

The frame is the base of skeleton part in the word _exoskeleton'. The frame will carry all the components alongside the weight of the wearer. The frame must be very tough but it should be light weight as well ideally being 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 contour of human body cannot be obtained for perfect fit to wearer plus such qualities vary with individuals using the wearer.

2.3 Electromyography

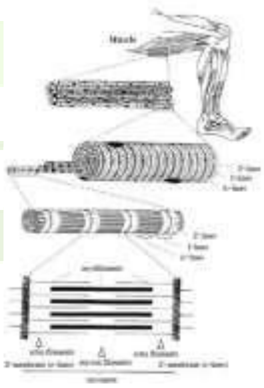


Figure 5: Human muscle anatomy[4]

During the depolarization of the postsynaptic membrane, ion movement causes an electromagnetic field in the vicinity of the muscle fibers that overlays with fields 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 figure6.

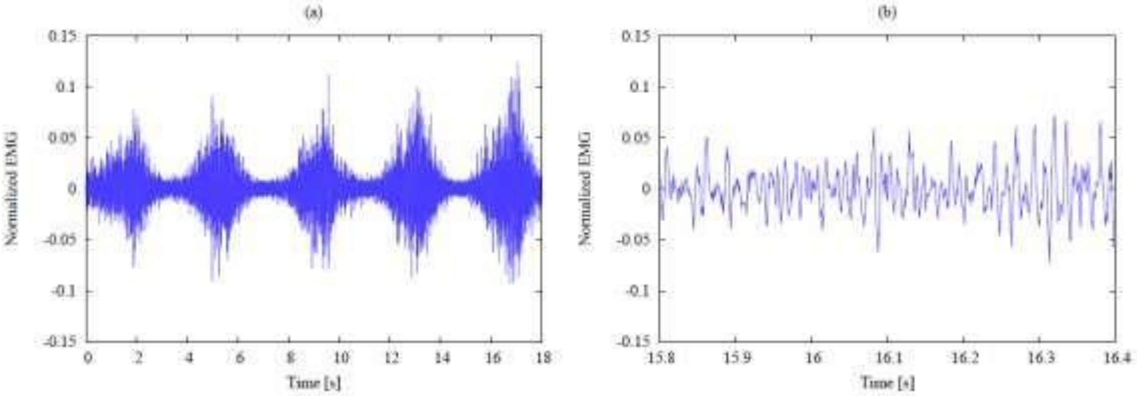


Figure 6: Muscle genreated EMG singal over time[4]

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

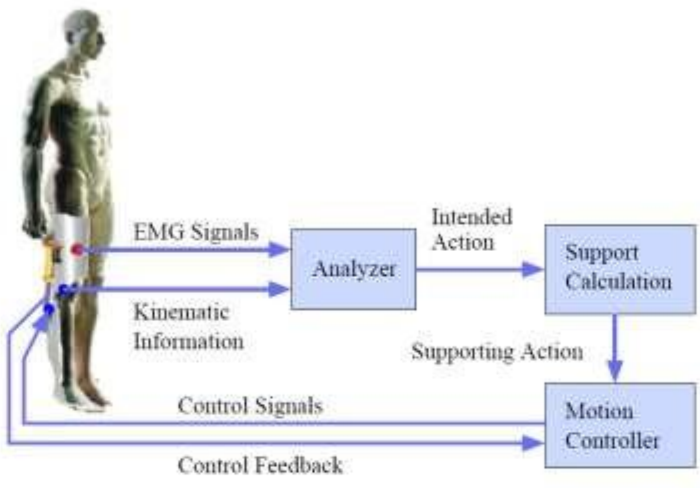


Figure 7: Circuit loop for the exoskeleton[4]

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 the electrode. Those details will not be addressed here.

The time between the emission and detection of the 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

2.4 Research gap andObjectives:

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 ofactuation.
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 – outputmethod.
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 pastdata.
4. Even lesser systems have looked into the idea using MACHINE LEARNING concepts for making smarter controllers[9].

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 therecompany.

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 generatedpreviously.
- 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 ofuser.

III. PRINCIPLE ANDOPERATION

3.1 Principle

The principle of exoskeleton is based on the human motor nerve adaption property of human being i.e. if subjected to variant external condition the human mind will adapt to it because of survival instincts.

3.2 Classification ofExoskeleton

Each of powered exoskeletons is classified into these three categories:

1. Gait RehabilitationAssessment
2. Human LocomotionAssistance
3. Human StrengthAugmentation

Our design is developed upon _Human Locomotion Assistance‘. We have directed over design in the first step of human motion that is _walking‘. Walking is most basic of human motion which has a repetitive pattern and can be run using a micro-controller.

3.3 Concept andDesign

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

3.3.1 walkinggait

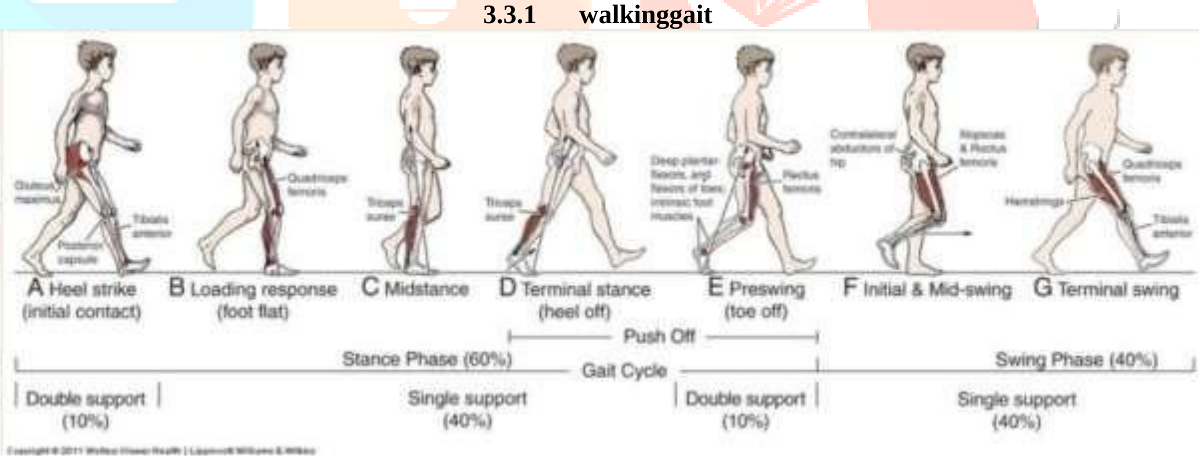


Figure 8: Muscle actutation pattern in Waking gait[4]

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

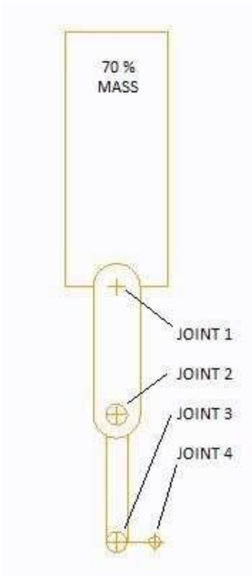


Figure 9: Simple body diagram of a human mass distribution

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.

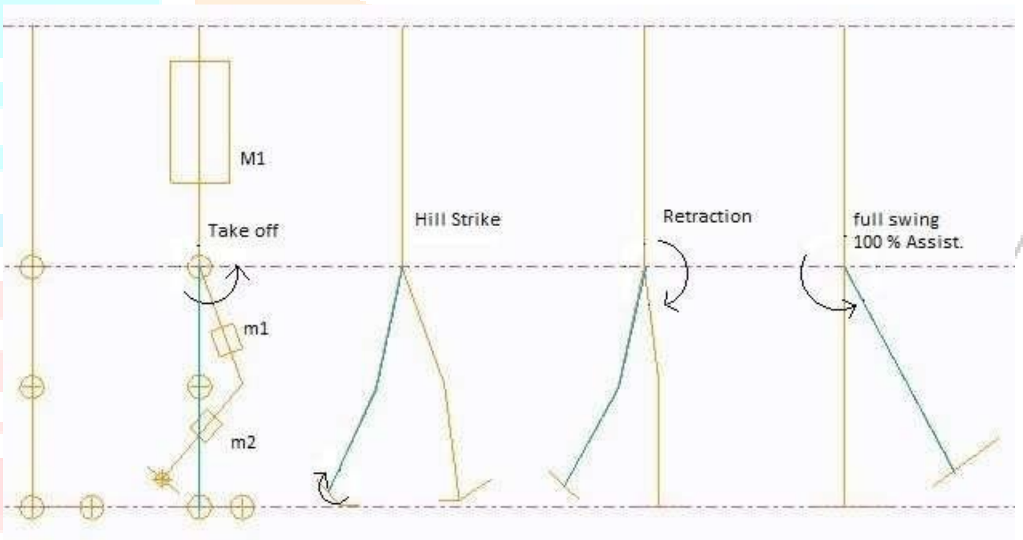


Figure 10: Free body diagram of a waking gait

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. TakeOff
   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. HillStrike
   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. Fullswing
   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.

3.3.4 Loading Condition and torque requirement

Load acting on all the parts of the exoskeleton would only because of the human weight

$F = m \times a$;

F = Force generated (N)
m = Distributed Body Mass (kgs)
a = Acceleration generated (*g* = gravitational acceleration)

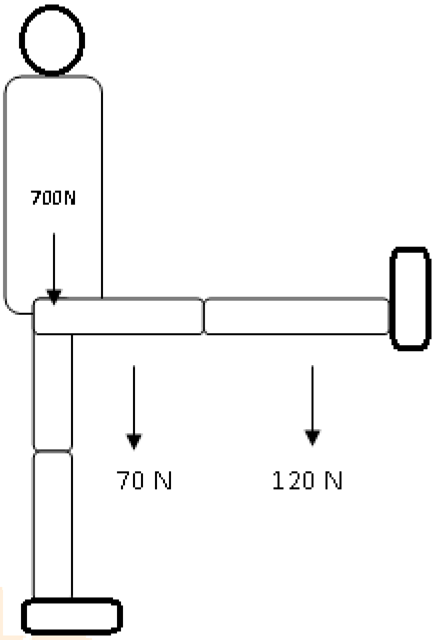


Figure 11: Mass distribution of 100 kg weigh human being

Here, we have two conditions for loading: 1) Motor moving the lower half
2) Motor moving the upper half

Now,

1) Motor moving the lower half:
$\text{Torque} = \text{Force} \times \text{Distance}$
$T = 70 \times 0.15 + 120 \times 0.45$
$= 65\ Nm$
Power required for the motion;
$\text{Power} = \frac{2\pi NT}{60}$
Here, N= RPM for human normal walking speed which isconsideratehere as 5 Kmph.
N= 8 rpm.
$P = \frac{2\times\pi\times 8\times 65}{60}$
$P = 55\ \text{watts}$

2) Motor moving the upper half for phase 3Retraction
$\text{Torqueat joint 2} = 700 \times 0.30\ T$
$= 210\text{Nm}$

Now the power required;

$P = \frac{2\pi NT}{60}$

$P = \frac{2\times\pi\times 8\times 210}{60}$

$P = 176\ \text{watts}$

From above Calculation it is clear that the power required moving upper half is 5 times that of the lower half.

As the power required for half is more as well as the torque so motor which required has to be more powerful which will ***Increase the cost as well as the weight of the entire system which is of utmost importance*.**

3.4 Kinematics ofFrame

For making a proper walking gait replica three joints per legs were considered as there are four joints present per leg anatomically. But third and fourth one being considered as inactive as providing power to this component is quite difficult.

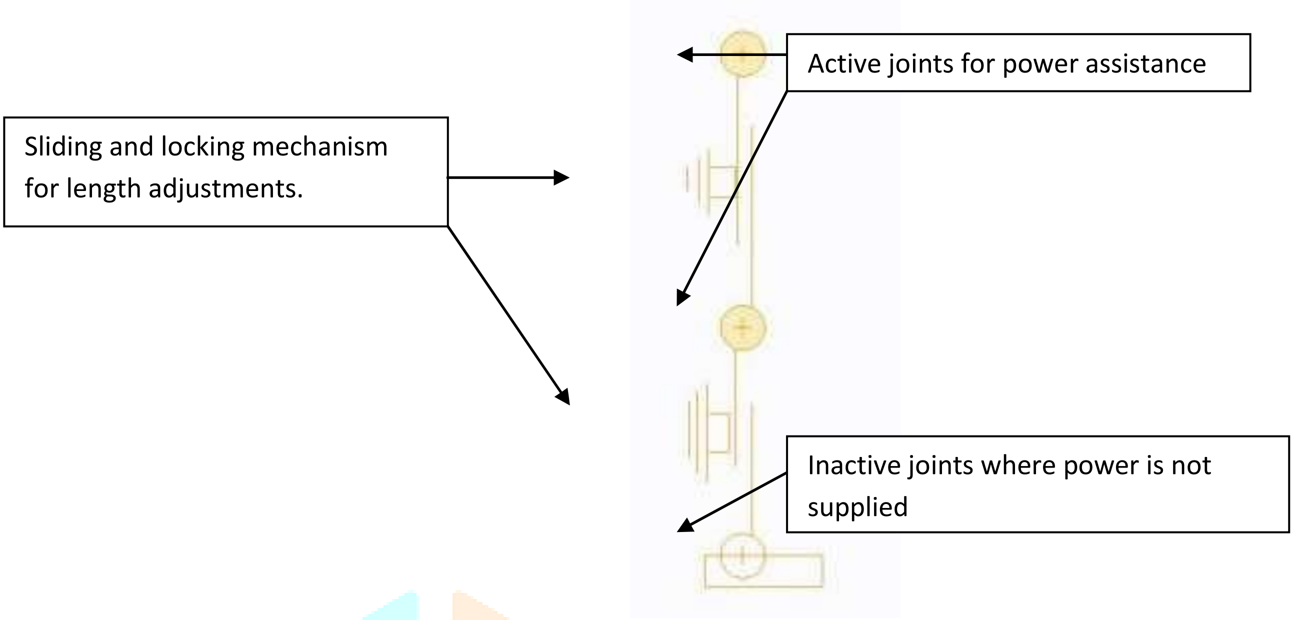


Figure 12: Kinematic representation of moving parts.

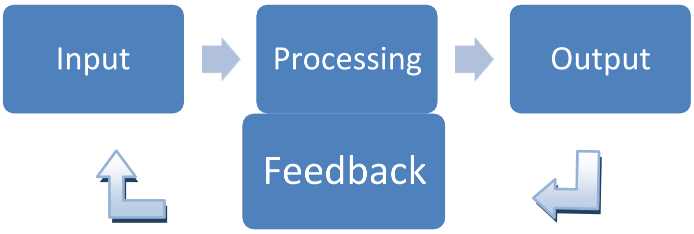
As we are designing a universally wearable exoskeleton we need to make it flexible as per wearer‘s requirements.

Motor Used for over purpose is a stepper motor of NEMA make with 22kgcm torque.

Figure 13: Stepper motor

IV. ControlUnit

As described earlier _Human Machine Interaction (HMI)‘ is very important as it will interpret the human desire and operate the motors. As in any other controlling unit this entire system is divided into three parts as shown



4.1 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 14: High resolution noise filtered EMG sensor from ADVANCER TECHNOLOGY

4.2 Micro-controller

We are using the _Arduino Uno‘ Atmega processor having 0V - 5Vwith 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 15: An Arduino Uno chip from Ada fruits

4.3 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.

Figure 16: 4A 12V Lithium ion battery from Robokits India

4.4 Controlcircuit

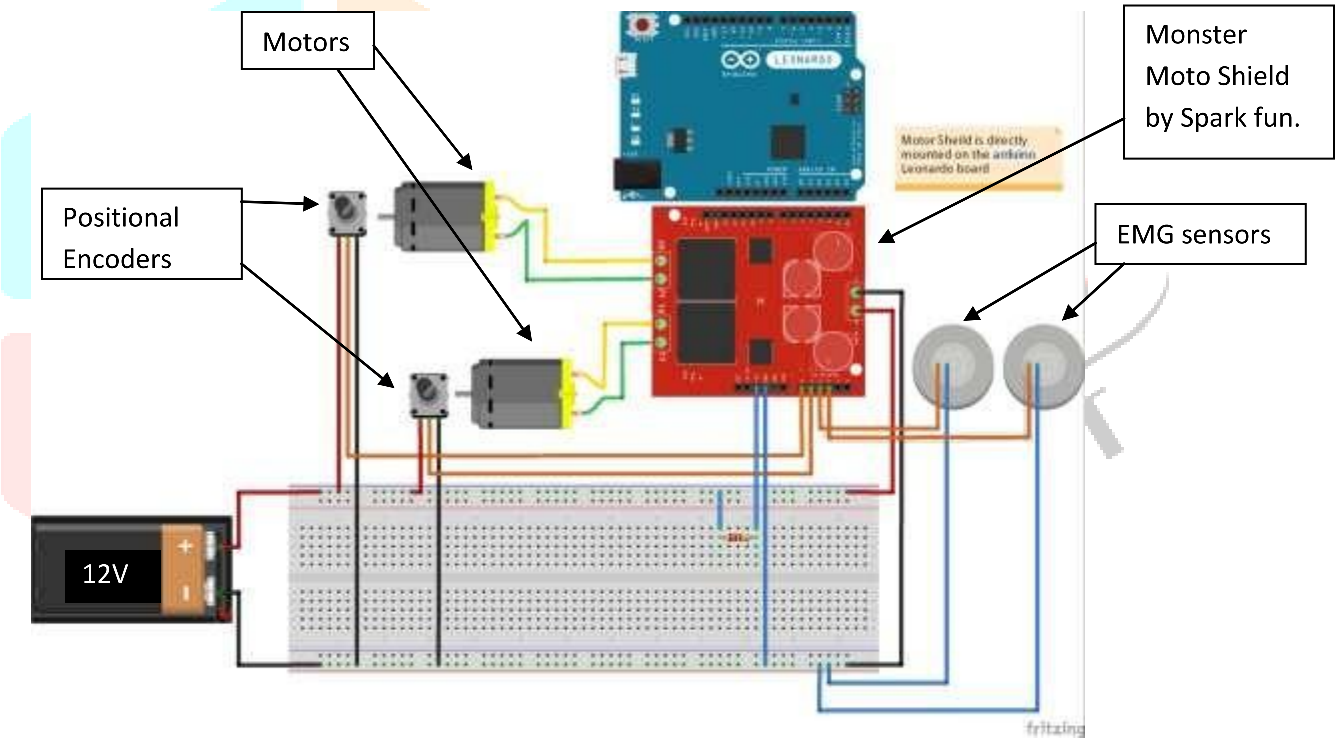


Figure 17: Primary circuit representation using Fritzing

The power required to move exoskeleton is around 55 watts and commercially motor available are around 100 watts which will be implemented so to power this system we are using 12 volt lithium batteries with maximum discharge being 4A. We will use two of these batteries in series to produce max current up to 8A (required 8.2A).

The coding is done such that the input from EMG sensors is read as analog inputs and simultaneously the encoder also provides the feed for the angle measurements. This is data is then Mapped on to each other and then fed to the servo motors.

4.5 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

Step 5: start interrupts

Step 6: Retrieve or start solver

Step 7: Feed values from Input to solver

Step 8: check interrupts

Step 9: get values from solver

Step 10: if interrupts true then feed value in history

Step 11: else feed values into output

Step 12: check interrupts

Step 13: if interrupts true then feed value in history

Step 14: else execute output

Step 15: check interrupts

Step 16: else read feedback and feed values from feedback into solver

Step 17: Execute solver

Step 18: if Error is true then perform correct and output the values

Step 19: check interrupts

Step 20: if interrupts true then stop output and feed value in history

Step 21: else feed corrected value into output

Step 22: check interrupts

Step 23: if interrupts true then stop output and feed value in history

Step 24: else execute output

Step 25: read feedback

Step 26: check interrupts

Step 27: if Error is true then perform correct and output the values

Step 28: 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 appendix A.

V. FRAMESTRUCTURE

5.1 The inceptivedesign

The frame which will support the human body and also provide torque to it needs to be Strong, light weight and fatigue free. These properties can be achieved by using aluminum. For skeleton limbs tubular frame structure is not suitable as it is prone to fatigue bending load. Loading criteria and analysis was done as per previous calculation [4,5,6]. For this configuration a ‗C' section membranes are used which can slide into each other as shown below

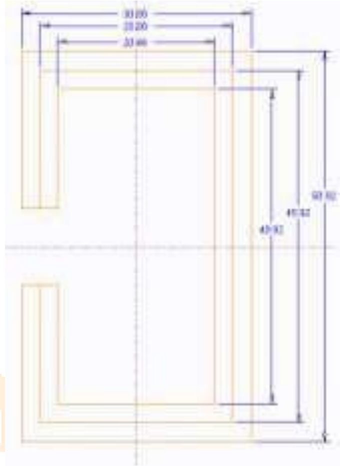


Figure 18: C - Shaped coinciding metal membrane

As the safety for the wearer is the priority here clamping is done away from the mating parts between human and machine. The Limbs are interconnected using circular bracing where motor will be mounted as well. The center of the ring coincides with human joint centre. This can be adjusted as per desire because the rectangular frame is extendable and can be clamped using bolts.

Following equation was implemented to find out stress: $\frac{M}{y} = \frac{\sigma}{I}$

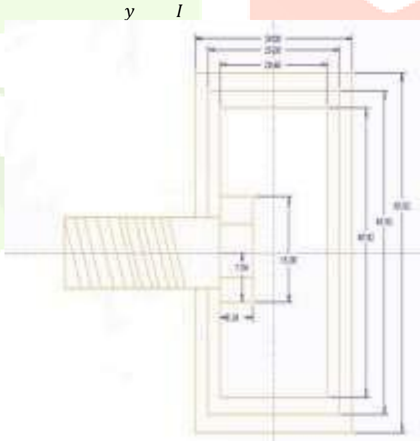


Figure 19 : Primary Dimensions of the C-shape membrane

The loading conditions were taken in to account for pure bending and buckling and the dimension were obtained using the material properties of the aluminum.

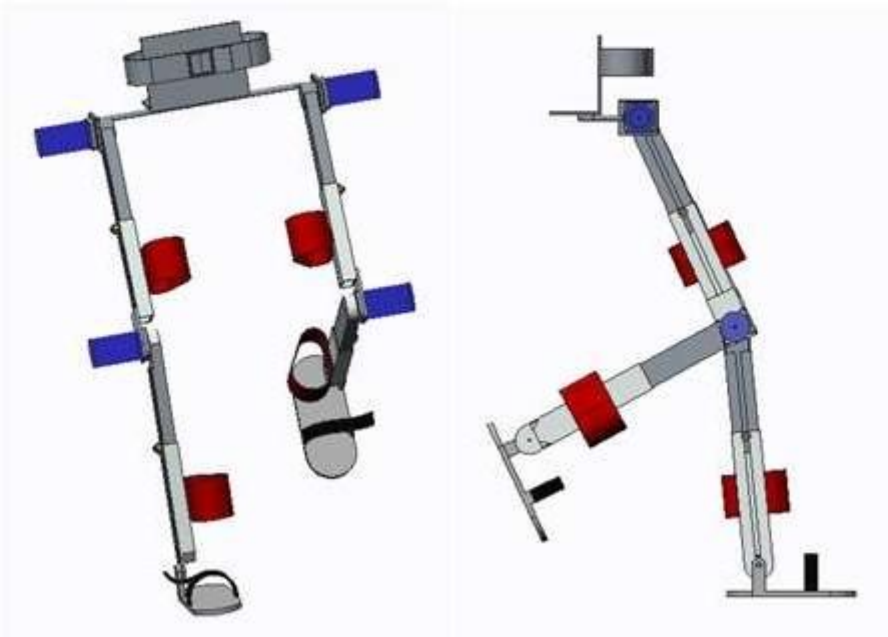


Figure 20: Final assembled frame for exoskeleton

Analysis is performed on the frame structure under loading conditions and then the Stress and Deformation was calculated. _Ansys workbench' was used for this purpose and sparse direct solver was used for the same. The load is applied in the inner face of _C'- section and the mounting points are consideredfixed.

5.2 Change indesign.

While trying to make the original C channel components it has been observed that, channel have open ended edges which needs to bent over because to enclosed the opposite edges so a slot is created for sliding and locking using nut and bolt, kept rupturing due to very small bend relief.

To overcome this difficulty the design needed to be modified in such a way that minimum metal forming or machining is required.

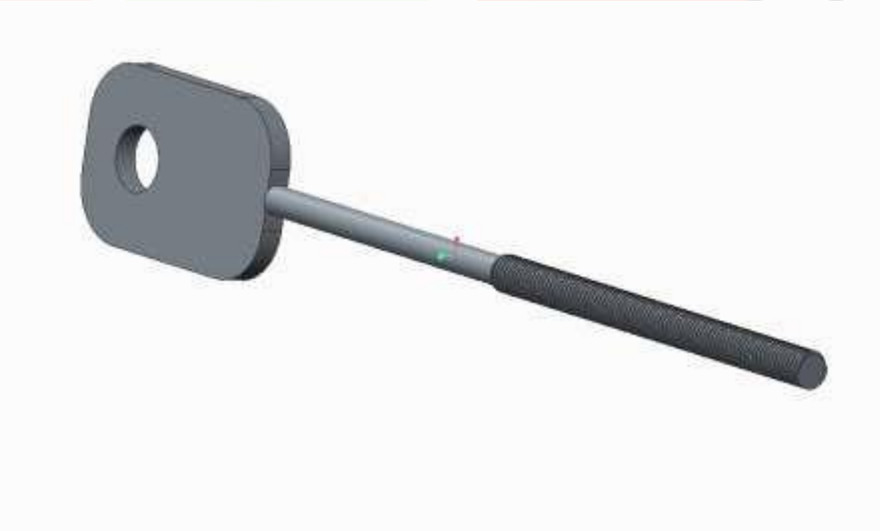


Figure 21: The shaft limb which provides assisting torque to the leg

Figure 22: The lower limb which provides length adjustment and motor mount

Threads and counter bore are utilized with Metric M8 x 1.25 threading used for Fastening purpose. Though these parts provide higher grip and stability with ease of manufacturing still the overall frame increases compare to previous design. The mounting supports are made directly on the parts which needs to be welded thus precise markings needs to be done

Figure 23: Final assembled frame

Figure 24: Only Frame with mountings

VI. COSTING GATHERING ANDMODIFICATION

After successful completion of algorithm with satisfactory results, coding must be carried out, this should be ready to implement, all the aspects of performing the process needs to be validated step by step. Thus first of all structured must be built to house all the system.

Also after the acquisition and assemble of the necessary components for inputs required, testing of these equipments shall be carried out. And primarily this model should be first operated without any actuator to authenticate the working proficiency. All the measures for safety should be taken care of and a Standard Operating Procedure - SOP must be created for safe execution of themachine.

Above all the project was applied for the scholarship grants programs from various private and government agencies which are listed below.

6.1 Costing of equipments(Tentative)

Table 1.1: Costing

Sr No.	Component	Sub-component	Cost(Rs.) (per piece/set)	Quantity*	Total(Rs.)	Supplier
1	Motor	Motor	3500	2	7,000	Robokits India
2	Sensor	sEMG-Detector	3100	4	12,500	Groove
		Other	700	2	1,400	OEM
3	Battery	Battery	2800	1	2800	Robokits India
4	Control Unit	Microprocessor	1500	1	1500	Adafruit
		Motor driver	2800	2	5600	RMC
		Rotary encoder	2600	2	5200	OEM
		SMPS charger	2000	15	2000	OEM
5	Frame	Membranes	250 (including weld)	4	1000	Vaghela Engineering
Grand Total					43,300	

6.2 An attempt at cheaper alternativeoption

The sensors mentioned above which are being utilized for the of Electromyography (EMG) are very costly hence, an attempt was made to produce such a part by myself without any prior knowledge of field. A circuit diagram and instruction were obtained online an the circuit was developed using following equipments:

1. Instrumentation Amplifier(AD620)
2. Operational Amplifier (TL072)
3. Skin friendly ECGsticker

The cost of manufacturing a working prototype exceeds the affordability by us. Requiring _State-of-the-Art' equipments to accomplish a high degree of performance. It also required the same level of testing facilities to accurately validate the results. So in order to demonstrate the working and to present a fruitful idea of the working we decided to make a working model which will collect input from user and generate motion. These are the necessary.

Figure 25: 9V batteries and 5V adaptors

These power supplies are directed into the breadboard which houses the entire circuit for the microcontroller.

Figure 26: Skin ECG sticker with clamp

Figure 27: sticker with clamp

These electrodes are connected to the circuit using clamps for steady flow as well as it can be engaged and disengaged pretty easily. These are further connected to the following circuit components which Filters, Rectifies and amplifies the circuit.

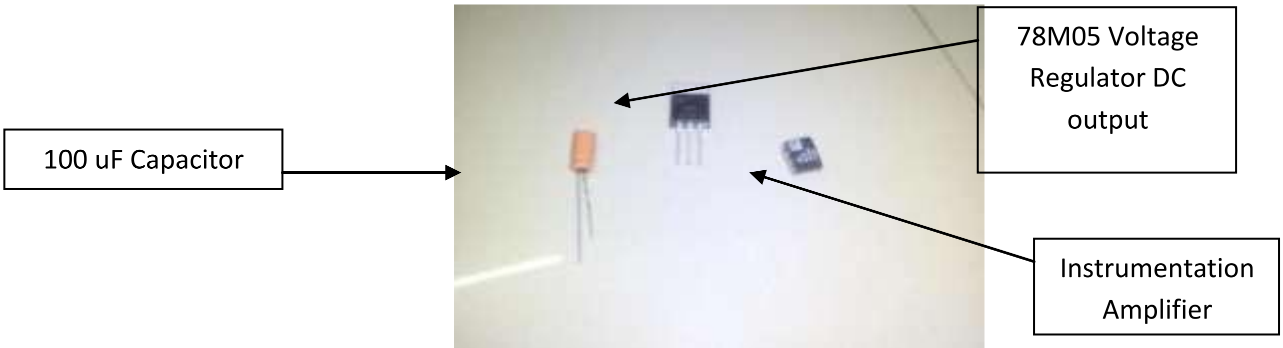


Figure 28: ICs required for sensor

The output servo motors required for motion generations as well as tracing the trajectory for the output.

Figure 29: Toy servo motor for testing purpose

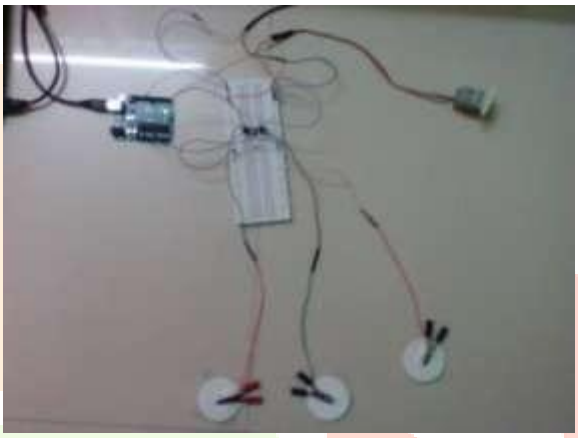


Figure 30: first test using just AD620

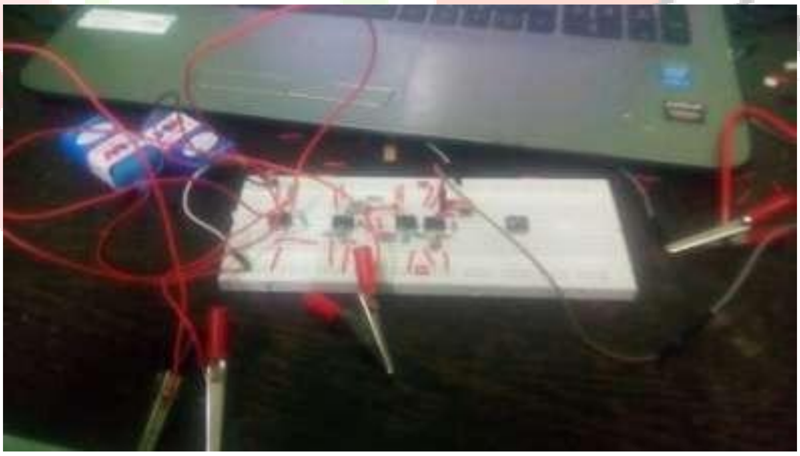


Figure 31: The final circuit with amplificaiton, rectification and stabilization

The above circuit failed to provide any valuable output which can supplied to motor without any pre processing. A lot of noise was still generating due to the nature of human muscle.

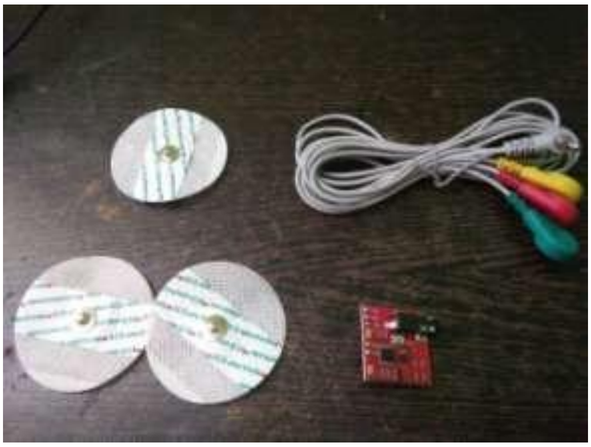


Figure 32: The sensor brough from Advancer Technology

Hence, respecting the time at hand a decision was made to purchase sensor from commercial outlet which needed to be shipped from overseas.

VII. MANUFACTURING AND TESTING

After correction in model the remaining equipments were ordered and acquired within expected time limit, which left only with the fabrication of skeletal structure. It was carried out under supervised environment under guidance of expert manufacturer.

The following images represent the individual part, sub-assembly and final assembly.

Figure 33: Motor with mountings

Figure 34: Motor mountings from side

Figure 35: Mountings for electronic system

Then electronics were mounted at their respective predetermined position places. The motor drivers wire directly behind the user alongside the motor controller which currently is plugged with a laptop for real time monitoring. The chip which is used for gathering data from muscle has been handled separately from preventing any damage.

The motor were directly concentric to the joints which were coincided by angle sensor with accuracy of ±0.5 mm. For purpose of safety the angle sensor

Due to nature of project and direct forces and moment acting upon the user a rigorous testing was needed to be done. Also a complete pre-requisite check of all the moving and electrical components needs to be done a standard to do list was create alongside for future purpose.

7.1 Limbs andmounts

The limbs are prepared from aluminum for keeping the weight as less as possible; the machining and welding work was carried out by expert manufacture alongside me. The Limbs are needed to be aligned carefully such so that the center of the both upper support and the lower extension does not misalign, moreover the limbs must lie in same plane for the successful implementation of 2D planer motion.

As shown above the limbs are assembled with the back frame, along with motor mounts and sensors, the motor needs to be mounted with reference such as it always comes down to pre-assigned zero which is referred in programming as well.

Figure 36: Rotory encoder side view.

The rotary encoder needs to be zeroed as well and also needs to be coinciding with the motor shaft, as shown above is preliminary mounting of encoder for testing and validating purpose.

7.2 Back supports andmounting

Figure 37: The final assembly

The back support carries most of the electrical components alongside the power supply module. The Arduino is mounted along with the driver shield for the motors which can be operated using 5V PWM generated from Arduino. The sensor chips are also mounted with their batteries for normal operations. The electrodes get extended to the surface area on the muscle.

As shown above the power supply is also presented in parallel with the drivers the Arduino is currently operated using laptop for two reasons: (1) Real time correction is needed for optimal use of algorithm as well the data needs to be analyzed in real time (2) The power supply from a standard battery cause surges into the signal acquisition due to high inductance when connected that resulted in noise for dataacquisition.

Everything is isolated using non conductive stripes and paper also a parallel earth grounding is also provided in case of leakage of any current.

An emergency stop switch is provided in case of user wish to stop the entire power supply such that motor will get instantly disconnected and system will stop.

7.3 Theprocedure

Figure 38: The Assembly mounted to user

The model created is not sufficiently strong enough to be able to completely synchronize with person wearing it. Considering the risk involve and high knowledge of system is required for choosing a particular course of action in case of adversary, I acknowledged myself to be best subject for purpose of testing rather than anyone else. Here two things needed to be considered before moving forward: (1) my skin comprises of very high hair density though it was removed for testing purpose the fact that the pore still remains embedded into the skin which leads to noise generation in reading the EMG signal (2) my weight is considerably high 90 kgs which leads to very high counter torque on motor that can stall motor at a times when full load is directly acting on the motorshaft.

7.3.1 Initial data acquisition and profile gathering

First step: appropriate muscle area is selected on the leg and it is treated accordingly to remove dirt and sweat, muscle sensors are placed in optimal position based on trial error method. Model is then fitted to the maximum comfortability and maximum accuracy. The pattern for purpose of data recording is taken in standard procedure of ‗stand-up and walk'

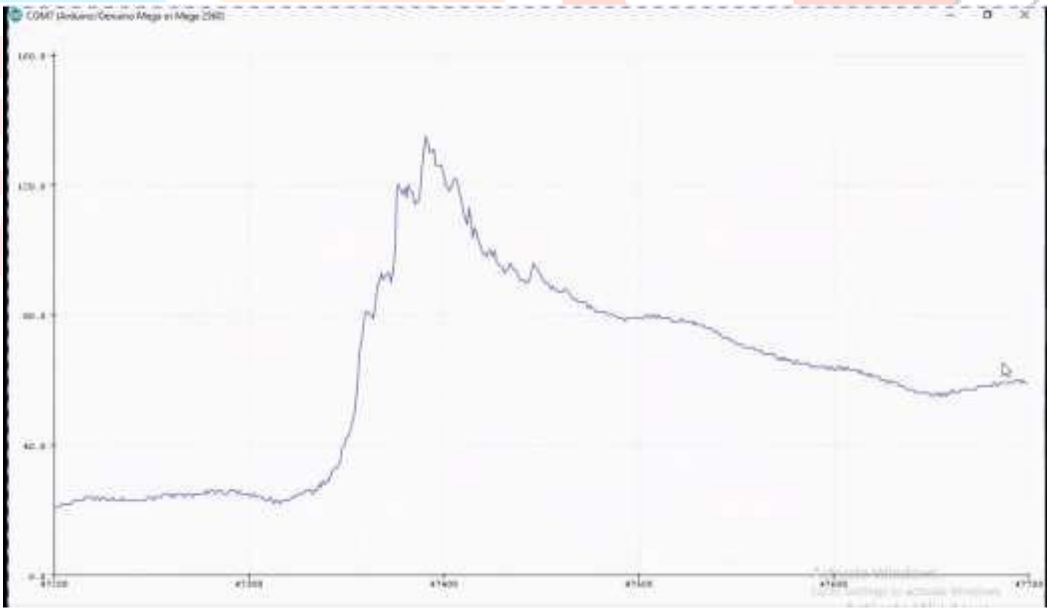


Figure 39: Raw Emg Data from frontal muscle

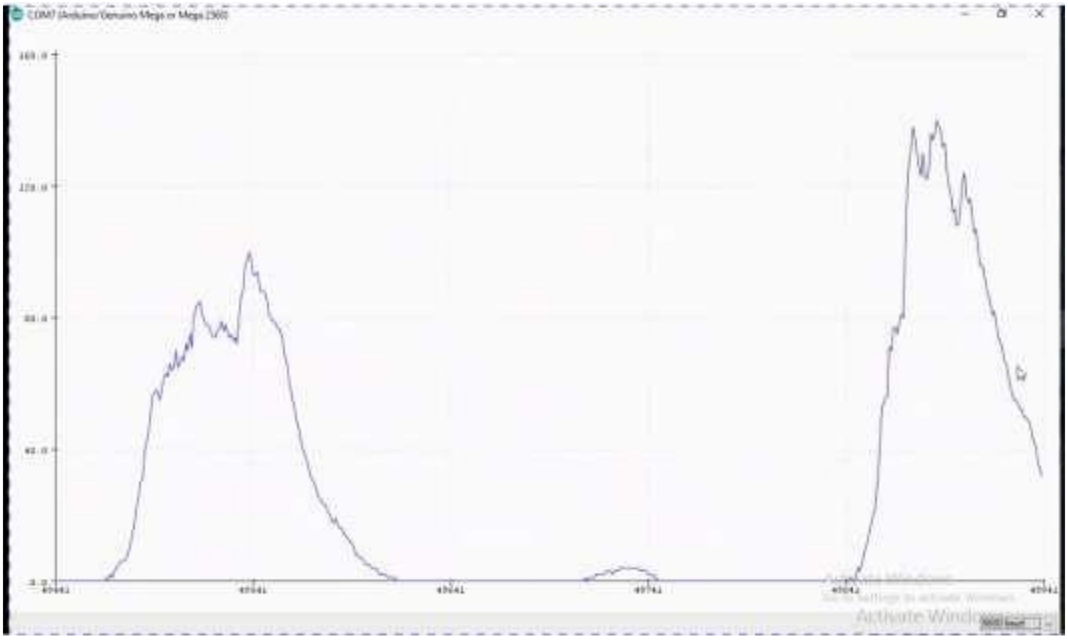


Figure 40: Raw Emg Data from rear muscle

The person, sitting at almost horizontally parallel to datum plane of earth surface, will stand from that position and walk forward towards a distance that is equivalent to 2 full cycles of gait motion. This will lead to twice data acquisition of the profile each time this test is conducted. Currently due to lack of financial support the operation is so created to be of least possible expense hence the user (i.e. me) will carry the laptop along for real time data acquisition.

Second step: The exoskeleton will be fitted with motors which will directly be commanded to move based on algorithm to desire angle by the sensor generated data at their highest speed which is controlled by pulses. The data collected is send to the excel spreadsheet for further plotting and modification. The data is shown in next segment

The data is inform of hexadecimal values which is generated by a 8-bit module of Arduino this data needs to be converted into voltage using simple mathematical conversion which adds to the fact that voltage gain isadjustable.

VIII. RESULTS

8.1 Conclusions

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

1. EMG signal profile of fourmuscle
2. The angle rotation profile for twojoints
3. The error generated between the idle and motorizedwalk

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.

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 secondphase.

The Error found in idle walk and powered walk was far on an average 78% which is quite higher than acceptable 50% ratio allowed for idle motion.

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

8.1 FutureWork

Many aspect of this project needs improving in various perspectives. For instance the design created is adjustable in length and width which allows for multiple users. However it certainly lacks the stability required for professional use or in case commercial use.

Currently the range of the machine is limited to only about 2.5 meter radius from the power source. Efforts should be made in direction show that machine can be operated on battery.

The data acquisition in respect of real time is gathered using USB connectivity with laptop. The wireless connection should be made for real time data gathering

Lastly the Algorithm must be tested and modify to correct error in real time.

REFFRENCES

1. Stand-Alone Wearable Power Assist Suit–Development and Availability–Mineo Ishii, Keijiro Yamamoto, and Kazuhito Hyodo Kanagawa Institute of Technology ,1030 Shimo-Ogino, Atsugi, Kanagawa 243-0292,Japan

2. Smart Suit® Lite: KEIROKA Technology : Takayuki Tanak, Hiroyuki Nara, Shunji Shimizu, Youmeko Imamura-Hokkaido University, Sapporo-city, Japan.

3. A Myosignal-Based Powered Exoskeleton System Jacob Rosen, Moshe Brand, Moshe B. Fuchs, and Mircea Arcan, IEEE TRANSACTION ON SYSTEMS, MAN, AND CYBERNETICS—PART A: SYSTEMS AND HUMANS, VOL. 31, NO. 3, MAY2001

4. ‗Controlling Exoskeleton using EMG signals' : Christian Fleischer , Von der Fakultät IV - Elektrotechnik und Informatik, University of Berlin,2007

5. Design of Walking Assistance lower limb Exoskeleton for paraplegic patients and hardware validation using CoP, Jung-Hoon Kim, Jeong Woo Han, Deog Young Kim and Yoon Su Baek, ‗INTECH' an international journal for advance robotics system, DOI: 10.5772/55336.

6. Chen B, et al., Recent developments and challenges of lower extremity exoskeletons, Journal of Orthopaedic Translation (2015),http://dx.doi.org/10.1016/j.jot.2015.09.007

7. EMG Analysis of Lower Limb Muscles for Developing Robotic Exoskeleton Orthotic Device by Ashish Kumar Mishraa* , Amit Srivastavaa , R. P. Tewaria, Rakesh Mathura, International Symposium on Robotics and Intelligent Sensors 2012 (IRIS2012).

8. Recent developments and challenges of lower extremity exoskeletons Bing Chen , Hao Ma, Lai-Yin Qin, Fei Gao, Kai-Ming Chan, Sheung-Wai Law, Ling Qin, Wei-HsinLiao.

9. Adaptive controller algorithm for 2-DOF humanoid robot arm. Adam Tan Mohd Amina, Abdul Hakim Ab Rahima, Cheng Yee Lowa. 2nd International Conference on System-Integrated Intelligence: Challenges for Product and Production Engineering. Procedia Technology 15 (2014) 765 –774

10. A muscle-driven approach to restore stepping with an exoskeleton for individuals with paraplegia. Sarah R. Chang, Mark J. Nandor, Lu Li, Rudi Kobetic, Kevin M. Foglyano, John R. Schnellenberger,Musa L. Audu, Gilles Pinault,Roger D. Quinn and Ronald J. Triolo. Journal of NeuroEngineering and Rehabilitation (2017)

11. Development of Real-Time Gait Phase Detection System for a Lower Extremity Exoskeleton Robot. Dong-Hwan Lim, Wan-Soo Kim, Ho-Jun Kim, and Chang-Soo Han. INTERNATIONAL JOURNAL OF PRECISION ENGINEERING AND MANUFACTURING Vol. 18, No. 5, pp. 681-687 MAY2017.

12. In vivo estimation of the shoulder joint center of rotation using magneto-inertial sensors: MRI-based accuracy and repeatability assessment. M. Crabolu, D. Pani, L. Raffo, M. Conti, P. Crivelli and A. Cereatti. BioMed Eng OnLine (2017).

13. Algorithm to demodulate an electromyogram signal modulated by essential tremor. Yuya Matsumoto, Masatoshi Seki, Yasutaka Nakashima, Takeshi Ando, Yo Kobayashi, Hiroshi Iijima, Masanori Nagaoka and Masakatsu G. Fujie. Matsumoto et al. Robomech J (2017).

APPENDIX A

```
// Establish the constant and variables required
// 4 variables are required for gathering muscledata
int Mus1 =A0;
int Mus2 = A1;
int Mus3 = A2;
int Mus4 =A3;
// Variables required for smoothing thedata
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 pulserequired.
   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);
    }

}
```