# A Feasible Action copying Exoskeleton upper limb for Partially paralysed polio patients in Sri Lanka

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***Abstract***— *although the WHO declared Sri Lanka as a country that is free from polio, many people who had previously been attacked by poliomyelitis are still left out in our society. Most of these patients belonging to flaccid paralysis category are dependent over others due to their bodily weakness. In the history of orthotic applications over polio patients, the weight of the brace has been a painful fact. These patients have to move their artificial limbs themselves, without backup, which craves excessive energy for mobile and other activities compared to a normal person. The main objective of this thesis is to augment the degree of self-reliance of partially paralysed polio patients by suggesting and evolving an action copying exoskeleton upper limb based on analogue electronics along with motion sensing which is light in weight, very low in cost with a label "MADE IN SRI-LANKA". In order to reduce the initial cost the exoskeleton was evolved via discarded items in our surroundings such as CD-ROM, VHS Players, aluminium bars etc. Also expensive sensors used for motion sensing were replaced with analogue motors. The final product was a three piece device. An exoskeleton frame worn around the weakened arm of the patient to sense the motions, an artificial robotic arm to copy the patient's exact motions and a junction box to electrically merge them. The total cost of the device was limited to two hundred rupees. What's more, the weights of each device ware limited to less than one kilogram. Moreover, the response of the device to rapid changes in motions were superior to what was expected.*

***Keywords***— Flaccid paralysed polio patients, Exoskeleton upper limb

## I. INTRODUCTION

The thirst for man's finding has been insatiable. Whereas this specifically made the field of science and technology grow rapidly and immensely. The growth of science and technology has made a huge impact over the field of bionic applications since the mid of 20$^{th}$ century. "Robotics" is the immerging field that dominates many areas. For instance, in military, robotic arms are used to dispose bombs (O'Brien, 2009), which is controlled by the controller's motions in an efficient and safer manner (Narayanan, 2015). Industries use computer controlled robotic arms in assembly lines. In medical applications "remote surgery" plays a stunning role. The surgery is conducted under the inspection of the surgeon via his or her desired movements of hands and fingers using auxiliary surgical supports, while there's no physical presence of the surgeon (Wall, 2008). Bionic limbs are used on patients who have lost their limbs due to war, hereditary diseases, amputation and especially poliomyelitis. The special needs of polio patients in our country imposes a unique challenge in catering to them. Most of the polio patients are sympathized by our society. This holds them back from being a normal human being. Also most of these patients are dependent over others due to their bodily weakness and poverty. Facts like these morally weakens them. Paralysed patients couldn't be cured due to continuous deterioration of their muscles (Halstead, 1985). Many of these patients are medically supported by "Bracing". In the history of orthotic applications over polio patients, the weight of the brace was a painful factor and a drawback. What's more the subsequent gait with the brace was abnormal (Young, c2008). Traditional bracing is an obsolete and the only method adapted in Sri Lanka to assist polio patients when compared with the methods used in developed countries, such as the Stance control braces, light weight brace, and electronic braces and Thought controlling method via brain sensing (McCann, 2012). These methods can be implemented over paralysed polio patient in our country to change the state of their paralysis conditions. However, the cost factor makes this implementation impossible, since most of the patients in our country can't afford such expensive equipment and undergo risky brain surgeries.

## II. METHODOLOGY AND EXPERIMENTAL DESIGNE

### A. *Methodology*

Design an effective exoskeleton action copying upper limb based on analogue electronics along with motion sensing, can be used to overcome the previously mentioned problems of a paralysed polio patients. Since the intended invention is to be an exoskeleton upper limb, here emerges a constraint where the patient who uses it should have an upper limb. What's more the patient's limb should at least function partially to provide input to the device via the limb motions of the patient. So it's clear that the device that is to be invented serves only the flaccid paralysed polio patients (Partially Paralysed patients). Luckily most of the polio patients found in Sir Lanka belong to flaccid paralysis category (Perera, 2012), (Robb, c2013-2016). Despite the superiority of robotic applications, there are certain draw backs which makes robotic applications specific only for the relevant fields and limit the efficiency and utilization, thereby causing major disadvantages due to the following reasons

- One of the key factor that holds back the integrity of a motion sensing equipment is the time delay. It's simply known as the time difference between the motion generated by the operator and the response showed by the machine.
- The shape, structure and the degree of freedom implanted in the grabber of a prosthetic limb specifies the geometrical shape of the object that can be grabbed and sustained by that particular grabber. Which means that objects with different shapes, that can be grabbed and sustained depends on the structure of the grabber. Besides the softness or the hardness of the grasp of a grabber can't be predicted due to delay in response.
- A conventional bionic equipment is not affordable for any ordinary person who would really need them for his/her backup. The main reason is the high cost of those machines, since they are encompassed of high performance sensors and specially fabricated materials.

Therefore, the proposed device for partially paralysed polio patients (flaccid paralysed patients) is evolved such that, it tackles the above mentioned problems via the following methods.

*1) Tackling the delay in response:* Latest motion sensing machines function coupled with computers. Though they function in a superior manner the utilization of those machines are limited due to delays such as….

a) Feedback delays in motion sensing.
b) Compiling delays due to the use of algorithms and programing devices.
c) Lack of superior algorithms, especially in EMG

The proposed system adapts an open loop system in spite of a closed loop system, because it inevitably avoids the feedback delays since there's no feedback mechanism. What's more, they are stable than closed loop system (Biswal, 2012). Since modern action copying devices are coupled to computers, the motion input is converted to a source that can be understood by the computers. Whereas, algorithms are compiled to achieve this task. As the superiority and complexity of the algorithm increases the compiling delay increases (Mikael, 2010). This causes the device to malfunction, by generating disproportionate outputs to the relevant motion inputs. This scenario is prominent in EMG sensing applications. It's so essential that EMG applications should have superior algorithms for their performance. What's more, EMG applications are very high in cost. In order to avoid complexity and undesired delays expensive programmable devices, micro controllers and high cost EMG sensors, video sensors were replace by simple and cheap analogue motors. These motors can be used to overcome the delays those were discussed above. In other words, analogue motors can be used to monitor the motions without any compiling process that may cause delays. What's more, the continuous and proportional inputs provided by analogue motors can be sent to a simple H-BRIDGE to generate precise and proportional outputs.

*2) Enabling the device to grab fragile materials and sustain objects which have unusual surface shape:* The grabber of the proposed device possesses the ability to grab and sustain any objects of unusual shapes. Moreover, the objects that can be grasped is regardless of the material that it's made of. Further the number of fingers used should neither less nor more, but adequate enough to grasp and sustain any objects of unusual shapes. Therefore, the grabber is evolve with three in-bent fingers to lock any objects from slipping off, since the minimum number of points needed to define a particular plane is three.

*3) Reduction of the weight of the device:* Indeed the exoskeleton should have a very low weight, since the partially paralysed patient will be wearing it around his/her weakened upper limb. Also the exoskeleton should possess high strength to weight ratio. This is achieved by evolving the device using lightweight materials such as Aluminium, Plastic, Polymers and Composites. What's more the maintenance can be reduced by using corrosion resistance materials mentioned above. Also machining these materials is really easy. Whereas, the cost can be reduced. Since the materials are of low density patients won't have to spend much energy on moving the light weight device.

*4) Reducing the initial cost of the device:* In order to reduce the initial cost of the device expensive sensors are replaced by cheap analogue motors. Materials mentioned above to build the device are scrounged from the surrounding. Whereas, aluminium parts are collected from discarded window frames, aluminium structures etc. plastic, polymers and composite are collected from household electronic equipment such as CD-ROM, VHS players etc.

B. *Experimental Design*

The action copying upper limb exoskeleton is of three degrees of freedom and consist of three main parts.

1. The frame
2. The junction box
3. The mechanical arm(Robotic arm)

Figure1. The mechanical-arm, Junction box and the frame

The frame worn by the patient is a three piece device that continuously monitors the motions of his/her weakened limb and convert these inputs as electrical outputs via analogue motions. Also the frame has three degrees of freedom. This device is designed to be completely worn around the weakened arm of a partially paralysed polio patient. The junction box is the device that electrically links the mechanical arm and the frame. The mechanical arm is a three piece device that assists the weakened arm of the patient according to the minute motions generated by the patient who will be wearing the frame. The device is to have three degrees of freedom.

*1) Mechanics of linkages:* The frame and the mechanical arm are designed with aluminium bars to form a structure that is very similar to the cranes found in sites. Whereas, in order to ensure the rigidity of the structure, cross links are used along with bolts, spring washers and conventional reverting. There are mainly two slider and crank linkages that are used in the frame and the mechanical arm in order to convert rotary motion into linear motion and vice versa. In the frame, one end of the slider and crank linkage is coupled to the tray of a CD-ROM, which is fixed on the rear side of the triceps of the exoskeleton. The other end is fixed to the perforated metal strip that's rigidly fixed on the fore arm of the exoskeleton. Whereas the centre of the crank is the centre of the elbow joint. Now the slider and crank linkage can change the rotary motions of the patient's elbow in to linear motion. Likewise, in the mechanical arm the slider and crank is used to perform the task of the bicep muscle of human. One end of the perforated metal strip is connected very close to the elbow joint in the fore arm. Whereas other end is connected to a slider fixed on the bicep section of the mechanical arm. A lace or a cable is fixed to the slider while the other end is connected to a gear box with an analogue motor in order to actuate the elbow.

*2) Force calculations:* The mechanical arm is the component of the overall product which undergoes considerable amount of mechanical forces compared to the frame. As it was mentioned earlier, the mechanical arm consists of three parts. The motor and the gear setups found in the grabber and the fore-arm parts will always work against a low torque compared to the motor and the gear setup found in the bicep. The reason behind this is the self-weight bearing by the motors of those individual parts. According to the design of the mechanical arm, the self-weight of the grabber and Fore-arm are directly transferred to the slider and crank at the elbow. Whereas, the corresponding motors of those parts are not affected by their weights. Nevertheless, the motor setup found in the bicep has to work against the individual weights of the grabber and the fore-arm. The maximum force and torque outputs of the worm and wheel setups those were scavenged from VHS players are as follows. Bicep motor setup = 15.68 N, Fore-arm motor setup = 3.65 N and Motor setup in the grabber = 5.08 N.

Consider the free body diagram of the mechanical arm once it's assembled to gather with all the individual parts.

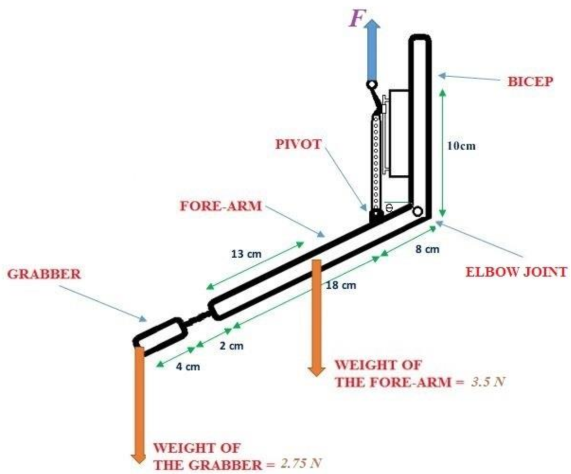


Figure2. The free body diagram of the fully assembled mechanical arm without the counter weight

Calculate the force "F" showed on the free body diagram of the mechanical arm. This is the force that should be exerted by the motor on the slider and crank linkage in order to lift the mechanical arm when it's free. This can be calculated by balancing the torque around the elbow joint

$$F * Cos\theta * 8 = 3.5 * Cos\theta * 13 + 2.75 * Cos\theta * 32$$
$$8 * F = 3.5 * 6 + 32 * (2.75)$$
$$F = (3.5 * 13 + 32 * 2.75)/8$$
$$F = 16.68\ N$$
$$F \approx 17\ N$$

By practical calculations it's clear that the motor and gear setup on the bicep should be at least able to lift 17 N to serve the purpose. Unfortunately the current motor used in the bicep with a worm and gear does not deliver more than 15.68 N Lifting force. Therefore, a counter torque is used to balances the self- weight of the lower elbow part of the mechanical arm. What's more this will increase the efficiency of the motor found on the bicep, since the motor has to work only against the torque created by the weight of the object that's grabbed by the grabber. To achieve this task a weight of "W" is fixed behind the Fore-arm, 8 cm away from the elbow joint. Now this torque will make the lower portion of the mechanical arm float. Besides the motor on the bicep can actuate the mechanical arm with higher efficiency.

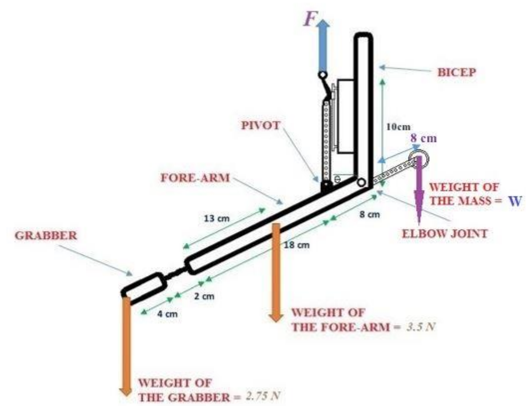


Figure3. The free body diagram of the fully assembled mechanical arm with the counter weight

$$F = \frac{3.5 * 13 + 2.75 * 32}{8} - W$$
$$F \approx 17 - W$$

Table 1. Values of force exerted by the motor for the relevant counter weights

| COUNTER WEIGHT "W" | FORCE "F" TO BE EXERTED BY THE MOTOR TO ACTUATE THE FREE MECHANICAL ARM |
|---|---|
| **17 N** | **NIL** |
| **12 N** | **5 N** |
| **7 N** | **10 N** |
| **3 N** | **14 N** |
| **1 N** | **16 N** |
| **0 N** | **17 N** |

*3) Specifications of components used:* The final product is made of scrap items found from the surrounding. Therefore, there is very less chance to obtain devices such as, micro controllers, programmable devices etc. despite this reason, items such as MOSFETs *(*Metal-Oxide Semiconductor Field-Effect Transistor*),* OP-amps can be easily obtained from discarded items. In the junction box, the main circuitry contains three identical sub circuitries. Each sub circuitry corresponds to each joints in the frame worn by the patient. A sub circuitry is to be built with

a) An LM324 OP amp
b) A 1K resistor.
c) A 100K resistor.
d) Two n-channel MOSFETs
e) Two p-channel MOSFETs

While the patient moves his/her arm, the analogue motors in the frame will generate a proportional voltage since a motor can perform the task of a generator. This voltages are the inputs for the junction box. This signal is sent to an OP amp in order to amplify the input signals. The amplified signal is then sent to an H-BRIDGE that is formed via the MOSFETs mentioned above. Then the output of the H-BRIDGE is sent to the relevant joints of the mechanical arm. MOSFETs are intended to be used in the junction box since they can draw huge current through them. And heating is very low at low voltage. In order to excite a MOSFET voltage is needed instead of current. So to excite the MOSFET an OP amp is used. Now the mechanical arm could be actuated according to the input generated by the partially paralysed polio patient without any delays that were discussed earlier.

*5) Developed product and how it works:* The device is evolved with three degrees of freedom. The elbow, the wrist and the fingers are the parts those could be moved independently. Now the task of the frame is to convert motions of above mentioned parts of the patient in to voltage. A single analogue motor can be used to provide three distinct outputs for the motions of a particular joint. When stretching output is a positive voltage. When bending the output is a negative voltage. At rest the output is zero volts. Since there are three analogue motors monitoring those parts, voltages will be generated in each motor that's proportional to the angular velocity of the respective joints.

$$e = N\frac{d\Phi}{dt}$$

*Where,*

$e$ = (Instantaneous) induced voltage in volts
$N$ = Number of turns in wire coil (straight wire = 1)
$\Phi$ = Magnetic flux in Webers
$t$ = Time in seconds

This proportional voltage will be sent to the junction box for further processing. The junction box is made of an old CD-ROM. In the junction box the output signals of the three analogue motors are to be amplified and sent through an H-BRIDGE as it was discussed earlier. There are three identical sub circuitries to form the main circuitry. The schematic diagram of a sub circuitry is given below.

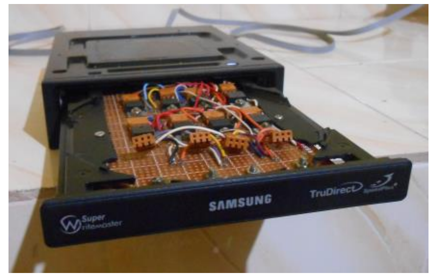


Figure4. Circuitry inside the junction box

An H-BRIDGE is used to change the direction of the terminals of a particular motor found in the mechanical arm. When the input to the junction box is +vie with respective to ground the motor in the mechanical arm rotates in a particular direction. When the input to the junction box is –vie with respect to ground the motor in the mechanical arm rotates in the other direction. When the patient rest his/her arm the motor won't rotate. What's more, the above circuitry will serve the expected task by reducing all the delays such as.

a) Feedback delays in motion sensing.
b) Compiling delays due to the use of algorithms and programing devices.
c) Lack of superior algorithms, especially in EMG (electromyography) motion sensing applications.

The reasons for this are…

a) The entire system is to be an open loop system. Therefore the system will me stable.
b) Since no programmable devices are used, there will be no delays in compiling algorithms.
c) Since conventional sensors are replaced with simple analogue motors, proportional outputs can be generated to the inputs without unnecessary delays.

The mechanical arm is coupled to the junction boxes' output. The mechanical arm too possess three degrees of freedom. When the patient tries to move his weakened arm, small voltages are sent to the junction box by the analogue motors in the frame. Whereas the mechanical arm will receive the proportional inputs. Now the mechanical arm will follow the exact actions of the patient who will be wearing the frame.

Figure5. The mechanical arm and the frame worn around the paralysed patient's weakened arm

## III. RESULTS

The weights of the evolved exoskeleton upper limb were as given follows. Fore-arm = 350 N, Bicep = 425 N and the Grabber = 2.75 N. The weight of the frame was around 170 g. which means the patient is not going to feel the weight of the device that is worn by him/her. Tests on the device proved that the maximum wattage required is always under 8.04 W. This reveals that the power craved by the device is very low. Besides, the cost for energy can be reduced. Moreover, the response showed by the device for rapid changes in motions of a normal person wearing the frame was extremely superior to the expected outputs. This reveals that the device would work successfully over partially paralysed polio patients. The cost to build the device was limited to 200 rupees.

## IV. DISCUSSION AND CONCLUSION

### A. *Discussion*

Consider a partially paralysed polio patient who is wearing a frame around his/her weakened arm. His/her motions can be used to carry heavy objects by the mechanical arm. In other words, the mechanical arm can lift anything but not the patient who is wearing the frame. So is it possible to say that the proposed device has made any impact on the self-reliance of the partially paralysed polio patients? In order to achieve the exact aim of our project some other work is needed to be done. The evolved action copying arm is the 1$^{st}$ phase. This is used to test and prove that the 2$^{nd}$ phase intended to be built will work in an expected manner. The 2$^{nd}$ phase is the final device that will serve the needs of partially paralysed polio patients. The second phase is the device that will be obtained by merging all three parts of the action copying robotic arm of the 1$^{st}$ phase. Whereas, the final product is a single piece. Now the weakened arm of a partially paralysed patient is covered by the frame. Besides the weakened arm and the frame is covered by the mechanical arm. Now the patient him/herself can carry heavy objects since there is continuous backup provided by the mechanical arm to the patient's limb according to the motions those are sensed by the frame. Since the frame is inside the mechanical arm, the mechanical arm will always follow the frame. And the mechanical arm will be actuated by the minute motions generated by the patient's limb via the frame. Therefore, the mechanical arm will always assist the patient by following his/her motion rather than over performing and controlling the patient's arm. And this is the remedy that can be use to ensure the stability and the accuracy of the device although it possess an open loop system. In order to enhance the safety of the system safety triggers may be implemented on the synchronized arm to ensure that a patients arm will not exceed the safety limits. That is if the elbow, wrist or the fingers reaches more than a limit, the power supply to the particular joint will be cut off. It's to make sure that not under any circumstances there will be an injury to a patient who will be wearing it. It could be hypothesized that this particular system will serve the needs of partially paralysed polio patients as expected in order to enhance their degree of self-reliance.

### B. *Conclusion*

Consider the polio patients in our country, the percentage of emerging polio victims is nil, since polio disease had been eradication since 1993. However, as time kept passing more and more paralysed polio patients found today in our country have entered the middle age category. What's more the majority of them belong to flaccid paralysis category. The special needs of paralysed polio patients imposes a unique challenge in catering to them. This thesis is based on the concept of building a feasible action copying robotic arm for partially paralysed polio patients in Sri Lanka to augment their self-reliance. This was achieved by analysing the past and present methods of how polio patients around the world were/are assisted, and the technical draw backs of robotic applications along with the economic environment of our country. What's more, the device is an environment friendly device. The entire device is evolved by using discarded items found in our environment. The device is successful since its outputs were superior to what was expected. Up to now it can be concluded that, the analysis are appropriate, and the project will continue.

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