REVIEW ON DESIGN AND DEVELOPMENT OF PROSTHETIC LEG FOR ABOVE KNEE AMPUTEES

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Abstract- ***In recent years, there has been a worldwide interest in the improvement of mobility of people with amputations. In spite of significant development of new technologies during the last decade, there exists deficits in motor control because of reduced sensory perception in the amputated leg, asymmetry in leg kinematics in consequence of different leg mass and inertia, energy loss during power transmission from the stump to the prosthesis, prostheses are still energetically passive devices.***

This paper presents the use of Flex sensor which accomplishes the above tasks with a great degree of accuracy. Flex sensor is a device which measures the amount of deflection or bending. The surface signals picked up from the calf muscles of a healthy leg during the muscle activity are interfaced with a Microcontroller. These signals are processed, analyzed and used to actuate the knee joint of the prosthetic leg. Microcontroller is linked with the DC Servo motor to drive its knee joints, sets up non-linear dynamics and adopts control algorithm to improve the robustness, speed of response and accuracy. During the course of the present work, it is possible to control the rotation of motor of prosthetic knee joint using the sensor signals received from the healthy leg. Hardware and software design of the robotic limb is controlled using flex sensor and arduino controller. The completely designed prosthesis will allow users to walk with a better gait. Microcontroller programming can be done with an ease to suit the requirements.

Keywords- *Robotic-Prosthetic, Flex sensor, Microcontroller programming, Control algorithm*

1 INTRODUCTION

1.1 Amputation

Amputation is the removal of a body extremity by trauma, prolonged constriction or surgery. As a surgical measure, it is used to control pain or a disease process in the affected limb, such as malignancy or gangrene. In some cases, it is carried out on individuals as a preventive surgery for such problems. In other words, amputation is the surgical removal of all or a part of limb or extremity such as arm, leg, foot, hand, toe or finger. The most common among these are the leg amputations- either above (transfemoral) or below the knee.

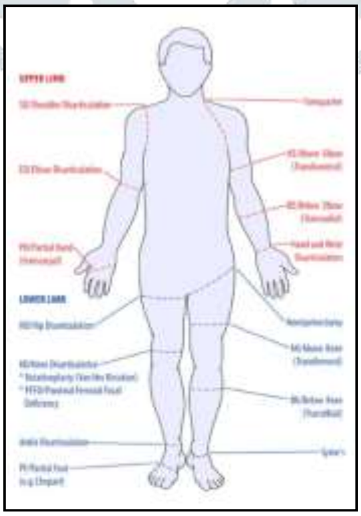

FIG1.1 Various amputations

FIG 1.2 Amputation for above knee

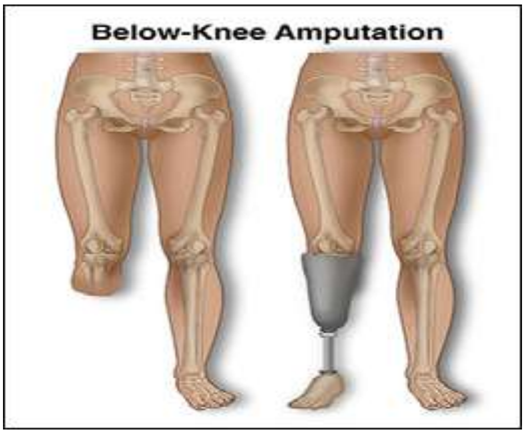

FIG1.3 Amputation for below knee

There are many reasons as to why an amputation may be necessary. The most common one is poor blood circulation because of damage or narrowing of the arteries, called peripheral arterial disease. Without adequate blood flow, the body's cells cannot get oxygen and nutrients they need from the bloodstream . As a result, the affected tissue begins to die and infection may set in.

Other causes for amputation may include:

- Severe injury(For example, a vehicle accident or serious burn).
- Cancerous tumor in the bone or muscle of the limb.
- Serious infection that does not get better with antibiotics or other treatment.
- Thickening of nerve tissues, called Neuroma.

1.2 Procedure of amputation

An amputation usually requires a hospital stay of 5 to 14 days or more, depending on the surgery and complications. The procedure itself may vary, depending on the limb or extremity being amputated and the patient's general health.

Recovery from amputation depends on the type of procedure and anesthesia used. Physical therapy, beginning with gentle stretching exercises , often begins soon after surgery. Practice with the artificial limb may begin as soon as 10 to 14 days after surgery.

Ideally, the wound should fully heal in about four to eight weeks. but the physical and emotional adjustment to losing a limb can be a long process. Long term recovery and rehabilitation will include:

- Exercises to improve muscle strength and control.
- Activities to restore the ability to carry out daily activities and promote independence.
- Use of artificial limbs and assistive devices.

1.3 Prosthesis

Prosthesis (plural: prostheses; from ancient Greek prosthesis- addition, application, attachment) is an artificial device that replaces a missing body part, which may be lost through trauma, disease or congenital conditions. Prosthetics are intended to restore the normal functions of the missing body part. Prosthetic amputee rehabilitation is primarily coordinated by a prosthetist and an inter disciplinary team of health care professionals including psychiatrists, surgeons, physical therapists and occupational therapists.

Prosthetics are commonly created with CAD(computer-aided design), a software interface that helps creators visualize the creation in a 3D form. But they can also be designed by hand.

1.4 History

Prosthetics have been mentioned throughout history. The earliest recorded mention is the warrior queen vishpala in the Rigveda. The Egyptians were early pioneers of the idea, as shown by the wooden toe found on a body from the new kingdom. The first confirmed use of a prosthetic device, however is from 950-710 BC.

An Italian surgeon recorded the existence of an amputee who had an arm that allowed him to remove his hat, open his purse, and sign his name. Improvement in amputation surgery and prosthetic design came at the hands of Ambroise Pare. Among his inventions was an Above-knee device that was a kneeling peg leg and foot prosthesis with a fixed position, adjustable harness, and knee lock control. the functionality of his advancements showed how future prosthesis could develop.


FIG1.4 Prosthetic Toe FIG1.5 Artificial Iron Hand

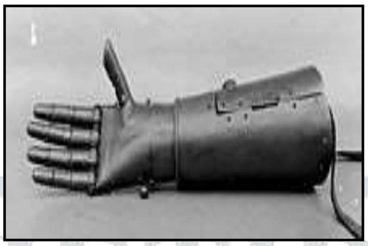

FIG1.6 Iron Prosthetic Hand

FIG1.7 Artificial Limb Factory In 1941

Other major improvements before the modern era:-

- **Pieter Verduyn**:-First non-locking below knee (BK) prosthesis.
- **James Potts**:- Prosthesis made of a wooden shank and socket, a steel knee joint and an articulated foot that was controlled by catgut tendons from the knee to the ankle, came to be known as "Anglency Leg" or "Selpho leg ".
- **James syme**:- A new method of ankle amputation that did not involve amputating at the thigh.
- **Benjamin Palmer**:- Improved upon the selpho leg, added an anterior spring and concealed tendons to stimulate natural locking system.
- **DubotsParmlee**:- Created prosthetic with a suction socket, polycentric knee, and multi articulated foot.
- **Marcel Desontter** and **Charles Desoutter**:-First aluminium prosthesis.
- **Henry Heather Bigg** and his son **Robert Heather Bigg**, won the Queens command to provide "surgical appliances " to wounded soldiers after Crimea war. They developed arms that allowed a double arm amputee to crochet, and a hand that felt natural to others based on ivory, felt and leather.

2 Types of prosthetic legs

2.1 Spring Type

This version, uses an actuator to store energy in springs, which is released when needed. By using a smaller, low-power actuator, the device is lighter and its batteries last longer, even though the actuator is essentially always busy. It is also one of the first prostheses to gather and store energy when the foot naturally bends upwards (towards the shin) during each step. A pair of force sensors (one in the heel and one at the toes) detect the leg's stance, so the locking device knows when to store and when to release its power. The role of mechanical system not only is to provide with the desired motion on rotation of the motor, but also to support the whole body of the amputee. The fitting frame of a commercially available passive prosthetic leg is used. The lower leg has to be light enough since this part has to be in constant motion when an amputee would walk. The centre of gravity of the lower leg is shifted closer to the knee joint so that the maximum toque required to lift it will be less. For driving the prosthesis, a servo motor is chosen over a stepper motor because of the former having higher speed, lighter weight and providing with smooth rotation at uniform angular speed.

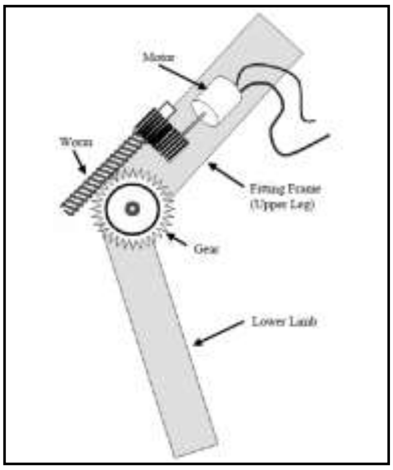

FIG2.1 Implemented Design of the Spring System

2.2 Hydraulic Type

A prosthetic leg has a pivotal knee joint and a hydraulic fluid control unit connected to provide variable forces which dampen flexion and extension of the knee and also bias the leg to its extended position. The unit includes an aluminum housing lined with an axially adjustable sleeve and control bushing defining a cylindrical chamber which receives a piston mounted on a tubular piston rod. The housing and chamber receive hydraulic fluid or oil which flows during movement of the piston through fluid control ports, channel and adjustable gaps defined by the sleeve and bushing for damping the movement of the rod. The piston rod encloses a gas filled flexible bladder which forms an oil accumulator during inward movement of the piston rod and also produces variable forces for moving the piston rod outwardly to its extended position. The housing confines a gap defining ring which compensates for changes in oil viscosity with heat.

An improved hydraulic control unit for use with a knee joint of a prosthetic leg for producing movement of the prosthetic leg simulating that of the natural leg over a wide range of walking speeds, said unit comprising an elongated tubular housing having an axis, said housing including a lower end portion defining a reservoir and continuing axially with an upper end portion defining a bore, a sleeve lining said bore and slidably supported by said upper end portion for axially adjustable movement, a control bushing disposed within said sleeve and defining a chamber for receiving a hydraulic fluid, said bushing and sleeve having means defining a series of flow control passages extending through said bushing from said chamber and axially between said bushing and said sleeve, a tubular piston rod having an inner portion extending into said chamber and an outer portion projecting from said housing, a piston on said inner portion of said piston rod and slidably engaging said bushing, a supply of hydraulic fluid within said reservoir and said chamber, said fluid flowing through said passages in response to axial movement of said piston and said piston rod within said chamber to effect damping of said piston rod.

FIG2.2 Hydraulic Type Prosthetic Leg

2.3 Pneumatic Type

A prosthetic component with a pneumatic device for knee articulation having an upper part, configured to support a socket element for a stump of a thigh, a lower part configured to receive a member comprised of an ankle and foot, an assembly of pivoted links forming a deformable prism for providing a connection between said upper and lower parts and a pneumatic cylinder having an upper chamber, a lower chamber, a piston separating said chambers and an adjustable flow, air duct providing communication between said chambers for controlling the movement of said two parts between two stable positions of complete extension and flexure, about a variable axis of rotation defined by said connections, and having the function of damping the end of a stroke and of propulsion by compressed air; the improvement comprising that, in each of said stable positions, the pressure of air in said chambers is greater than 1 bar, a first non-return valve for inflation via which said air duct is in communication with the ambient air, wherein a first arm of said air duct connecting said upper chamber to said first non-return valve comprises a second non-return valve and a first adjustable valve in parallel therewith and a second arm of said air duct connecting said lower chamber to said first non-return valve comprises a third non-return valve and a second adjustable valve in parallel therewith.

FIG2.3 Pneumatic Type Prosthetic Leg

2.4 Electrical Type

The design and control of an electrically powered knee and ankle prosthesis. The prosthesis design incorporates two motor-driven ball screw units to drive the knee and ankle joints. A spring in parallel with the ankle motor unit is employed to decrease the power consumption and increase the torque output for a given motor size. The device's sensor package includes a custom load cell to measure the sagittal socket interface moment above the knee joint, a custom sensorized foot to measure the ground reaction force at the heel and ball of the foot, and commercial potentiometers and load cells to measure joint positions and torques. A finite-state based impedance control approach, previously developed by the authors, is used and experimental results on level treadmill walking are presented that demonstrate the potential of the device to restore normal gait.

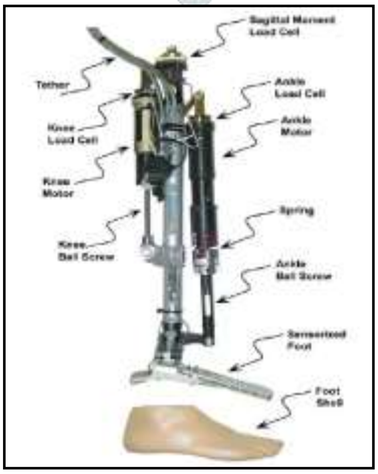

FIG2.4 The power tethered prototype

2.5 Sensor Type

The use of Flex sensor helps accomplish the tasks with a great degree of accuracy. Flex sensor is a device which measures the amount of deflection or bending. The surface signals picked up from the calf muscles of a healthy leg during the muscle activity are interfaced with a Microcontroller. These signals are processed, analyzed and used to actuate the knee joint of the prosthetic leg. Microcontroller is linked with the DC Servo motor to drive its knee joints, sets up non-linear dynamics and adopts control algorithm to improve the robustness, speed of response and accuracy. During the course of the present work, it is possible to control the rotation of motor of prosthetic knee joint using the sensor signals received from the healthy leg. Hardware and software design of the robotic limb is controlled using flex sensor and arduino controller. The completely designed prosthesis will allow users to walk with a better gait. Microcontroller programming can be done with an ease to suit the requirements.

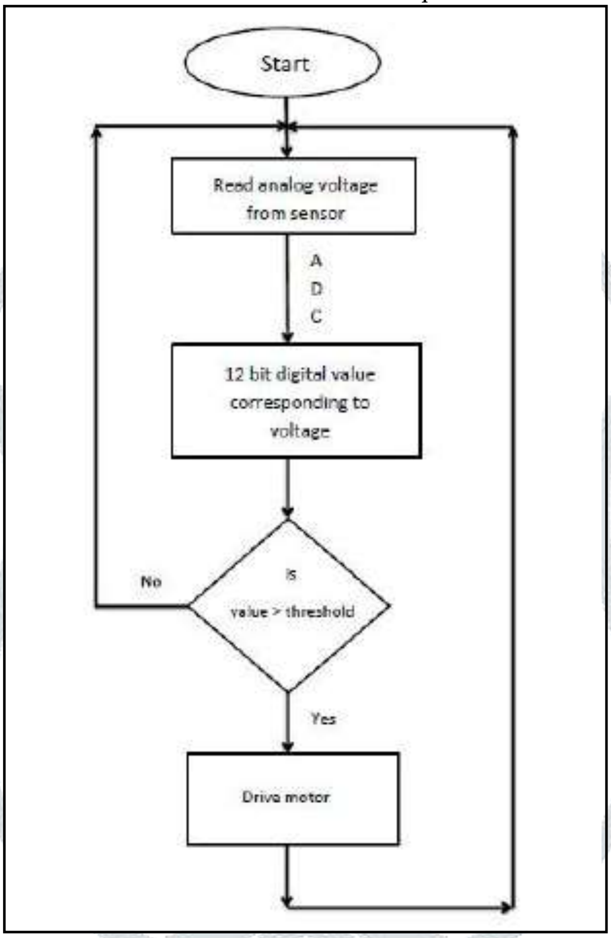

FIG2.5 Flowchart of Working for Sensor type

It was observed that those signals were following some kind of patterns. We found that apeak in the value of the signal is obtained at the point when70% of the weight is shifted to the foot of that leg. This is thepoint when the prosthetic knee joint is to be actuated. Based on the patterns recorded, we developed an algorithm. According toour algorithm, our microcontroller reads the value of signal in each loop. This value is checked and if this value exceeds the threshold value, a peak is said to be detected and at that point the routine corresponding to the actuation of the motor is serviced.

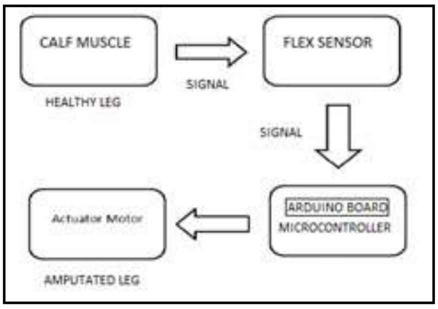

FIG2.6 Block Diagram of Working for Sensor type

3 Comparative Study

Table3.1 Comparative Study

No	Type	Cost	Pros and Cons	Main Parts	Materials	Market	Degrees of Freedom
1	Spring System	Low when compared to other existing types.	Cons: • Depends on spring stiffness. • Stiffer springs stores more and return less energy because they undergo less displacement for a given force. • Soft springs lead to increased metabolic cost due to abnormally high centre of mass. • Rusting of springs. Pros: • Spring cost is less (100-500 Rupees). • Light weight.	Spring Damper Flexural Component	Aluminium (as it is free from corrosion to a certain extent).	Market is not bad due to its affordability.	One (Forward)
2	Hydraulic	Very High	Cons: • Hydraulic cylinders are costly (3000-4000 Rupees). • Availability is major concern. • Weight is comparitively high. • Leakage problems of Hydraulic fluids can occur in case of rough usage. Pros: • Power to Weight and Power to Size ratios are efficient. • Have variable speed control, positioning benefits.	Hydraulic Cylinders Battery Actuators Valves	Carbon fiber or Aluminium or Mildsteel can be used.	Market is good. This system is mainly used by rich or aristrocrat people. If cost is a concern, then this is not advisable.	One (Forward)

Table3.2 Comparative Study

3	Pneumatic	High	Cons: • Air leakage can cause energy loss. • Pressurised air gets condensed easily. • Noisy at times. Pros: • Safe as it is not flamable. • Clean and is not harmful in case of leakage also. • Temperature is maintained. • Availability of source.	Pneumatic Cylinders Solenoid Valve Regulator Actuator	Carbon fiber or Mildsteel or Aluminium can be used.	Market is comparatively high than Hydraulic due to availability and safety. Cost is comparitively less.	One (Forward)
4	Electrical	Medium	Cons: • Short circuit problems are high. • Due to wires, system gets little complicated. Pros: • Higher efficiency • Weight is not a problem	Capacitor Wires Circuit	A non-conductive materials should be used.	Market is higher than spring type but less than pneumatic.	One (Forward)
5	Sensor	Optimum	Pros: • Better gait while walking. • Micro controller programming is easy and can be altered as per the requirements. • Using High capacity DC Gear Motor two degrees of freedom can also be achieved. • Response rate is higher than others. • Higher effeciency, and energy lost is minimal.	Flex Sensor DC Gear Motor Arduino Board Micro Controller Aluminium Rod	Aluminium Rod and Aluminium Sheets.	New to market. Expected to get high market in future.	Two (Forward And Backward)

4 Mechanical Design of the Leg

The role of mechanical system not only is to provide with the desired motion on rotation of the motor, but also to support the whole body of the amputee.

The fitting frame of the prosthetic leg is made of mild steel which is covered with soft rubber for safety and isolation. The lower leg has to be light enough since this part has to be in constant motion when an amputee would walk. Aluminum is used to make a lower leg weighing around 0.942 kilograms. For driving the prosthesis, a servo motor is chosen over a stepper motor because of the former having higher speed, lighter weight, more degrees of freedom and providing with smooth rotation at uniform angular speed. Moreover, the driving circuits for such motors are cost-effective. A 5V, 2W motor, with a rated rpm of 10 is used in the design.

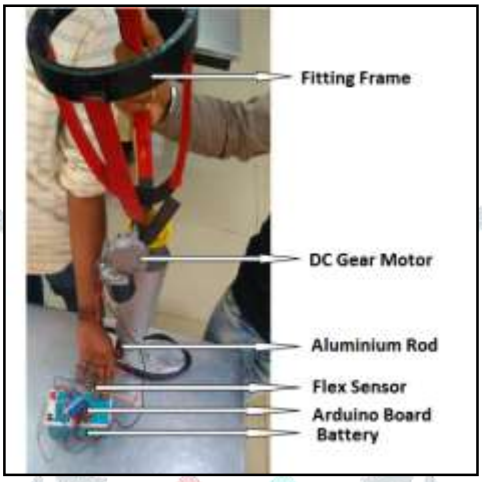

FIG4.2 Motor and Lower Leg attached to the Fitting Frame

5 Safety and Isolation

The whole system, which includes the circuits and associated equipments in the design, are all battery powered. Since the system is not connected to the mains, there is no necessity to consider the safety of the amputee from severe electrical shock.

6 Conclusion

Some developments have already been made in the field of prosthetic legs with no or little concern for Third World countries. The paper discussed a simple, but meaningful design of an above-knee prosthetic leg with a focus on cost effectiveness. At this point, the primary concern is on perfecting the design: both electronic and mechanical. This paper dealt mainly with the mechanical part leaving out the details of the electronic details and programming. Research is being done on the mechanical design in order to see the face of perfection. The lower leg, currently being used, are made of Aluminium and this makes the prosthesis light and very quick in performance. If the leg could have been made using a light-weight, but strong material and the with material lighter than Aluminium, the weight of the whole prosthesis would have significantly reduced and the performance might have improved.

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