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Review Article

Gait Adaptive Robotic Leg

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Abstract

The paper is in the field of Bio Medical Engineering. It is focused on rehabilitation of above knee amputees through the implementation of a design that is simple enough to facilitate them carry out their daily routine tasks (walk, sit and stand) with ease. A working model of the gait adaptive robotic leg was developed using the various techniques of bio medical and mechatronics engineering. Amongst the phases of human gait the swing phase posture was modeled for working out the kinematics of robotic leg.

Keywords: Above knee amputees; Phases of human gait; Kinematics

Introduction

The technology now-a-days has sufficiently benefited the developed countries as they made it so as to fill the mould of their lifestyle, quiet fair for them as they worked hard for achieving that. On the other hand, this boom of technology has not only comforted the researchers of the developed countries but has also provided the developing countries with readymade products. This is showing an alarming situation and therefore, needs a wakeup call for the researchers of the developing countries to come up with at least what they can by utilizing the available resources, otherwise the technology gap will continue to rise. This research deals with active and passive prosthetic limb designs. Though both the approaches address the operating characteristics of a particular structure under study but the difference lies in the way they replicate the structure. The structure designed in active prosthetic limb design is quiet close to real structure as compared to the passive prosthetic limb design and this fact makes the implementation of former type expensive whereas the later approach stands inexpensive instead [1]. This paper reflects a mixture of both the limb design approaches and tends to motivate the researchers of the developing countries to unveil the creative ideas of their mind and try to design a product within the resources available to them.

Objective

The objectives of this paper is to modify the design of a robotic leg, implement the normal human gait using the designed knee joint and maintain stability using sensor data to eliminate the need of crutches.

Mathematical Modeling

The paper focuses onto facilitating the people of developing countries with an advanced solution against prosthesis. In developing countries the need of prosthetic leg came up from the same source that forced the researchers in the developed countries to come up with a suitable solution. In particular, the idea ascended due to the wars held at those times. They needed to have substitutes to their legs, arms, or hands, for which they started the work on artificial limbs at their own land because it was not economical to get delivered from overseas. Artificial limb centers have been developed since 1911 but none have come up with making the amputation replacement adaptive to human gait [2]. Now though the idea was there but it was further required to confine the area of research since leg amputations can be of six different types and to go through all of them was not at all a wise decision [3]. For the purpose of best utilization of the research the most frequently occurring leg amputation was taken into consideration, which even if addressed alone can cover the major parts of leg amputations [4]. Thus we started working on trans-femoral amputation (in which people suffer from Above knee disability) [5,6] as we found from our survey that it is the most frequently found amputation in people. Moreover, this type of amputation covers the knee joint and the ankle joint both being the sensitive and focal joints of leg where knee joint is responsible for the movement of leg during walk and hence it was figured out that it's the knee joint which is the basic joint that needs to be designed to adequately address the Above Knee amputation [7,8]. To start with we first enlisted the important parameters that are required to design a knee joint. Amongst these, phases of human gait were of utmost importance and are shown below (Figure 1) [9].

From the figure above it can be clearly seen that knee joint alone does not complete the walk parameters it takes help from the push of the foot for which ankle joint comes into action but it was further concluded from the figure shown above that it's the knee joint which plays the major role and if knee joint in designed as per requirement, design of the ankle joint would not be involving any major calculations and a spring supported mechanism may also fulfill the demand [10]. It can be taken as an obvious fact that the major weight of the human body is onto the knee joints and the most critical phase on the phase of human gait is the swing phase as weight is that

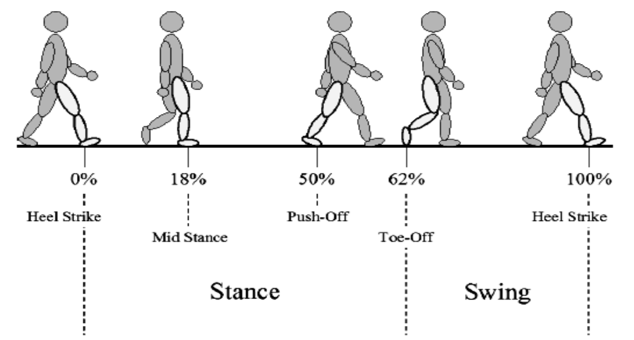

Figure 1: Phases of Human Gait.

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Table 1: Characteristics taken as reference for this research [1].

Age group	20 to 32 years
Average human height	1.65 to 1.78 cm
Average length from human ankle to knee center	150 cm
Average human weight	67 to 83 kg

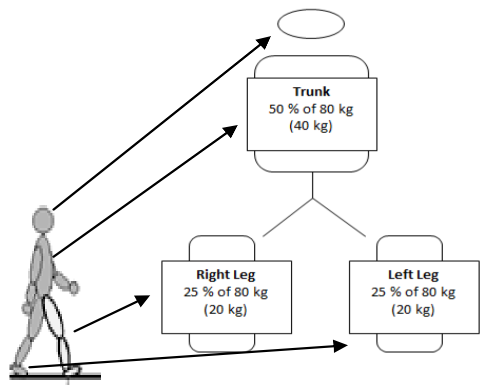

Figure 2: Weight distribution of a normal human body during stancephase.

factor which would define the torque required for lifting the leg and taking it from the toe-off swing phase to heel strike swing phase [9]. For the calculation purpose, characteristics tabulated below were taken into account (Table 1).

The reason behind focusing on the data above is because it is considered to fulfil the requirements of all age groups in general since life period from 20 to 32 is considered to be the most active period of a person's life.

Considering a person with a weight of 80 kg, as long this person is standing the weight distribution would be as follows (Figure 2):

According to the above flow chart, an 80 kg person while standing will have 40 kg trunk weight and each leg of such person will weigh 20 kg. Now since the phase under study is the swing phase, so during swing phase trunk weight remains the same whereas the weight of the leg in the swing phase further reduces by 50% and transfers that weight to the leg in stance phase. Thus in swing phase the weight distribution becomes (Figure 3):

Thus, the average weight of the normal human leg for a person of 80 kg weight comes out to be 10 kg. As an already available leg was being modified the rods connecting the thigh to the designed knee

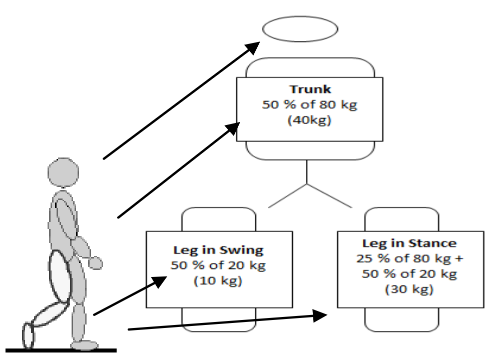

Figure 3: Weight distribution of a normal human body during swing phase.

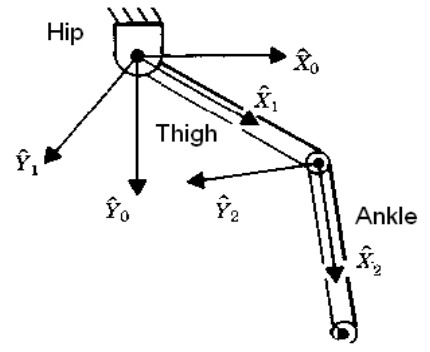

Figure 4: Leg Model.

joint and the accessories connecting the Knee joint to foot remained under consideration so as to make sure that the design of the knee joint is compatible to their fixtures [11]. Some components are:

- Artificial Foot
- Foot Adapter
- Tube Rod (Length: 40 cm, Diameter: 30 mm, Thickness: 4mm, can be cut down to length required)
- Suction Socket

The material of the above mentioned components is pylon (an alloy of Aluminium)

Kinematics of Prosthetic leg

Kinematics is required to estimate the amount of swing in the leg. In this research we have consider as a two link structure (Figure 4) [12].

The hip joint is taken as reference where initial world co-ordinates are (X_0, Y_0). The local co-ordinates of thigh are (X_1, Y_1) and similarly for ankle they are (X_2, Y_2). The design of leg does not involves the design of foot but in order to get an exact idea about the total swing of leg the foot is also assigned local co-ordinates (X_3, Y_3).

L_1 is the length between Hip and Knee Joint

L_2 is the length between Knee and Foot

θ_1 is the angle between hip and thigh

θ_2 is the angle between thigh and ankle

θ_3 is the angle between ankle and foot

We have taken the hip and knee joint as a pin joint. The hip is taken as reference and is taken as ground. The next step was to calculate the kinematics of the leg.

Forward kinematics

Forward kinematics is a geometrical method of computation of position and orientation of manipulator using its joint angles. The manipulator joint angles are known as the angles formed by the base and the input links. The unknown position is described by the reference co-ordinate in XYZ plane.

For this research we have calculated the transformations of the leg from hip joint to the foot.

Table 2: DH-Table of prosthetic leg.

i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	0	θ_1
2	0	L_1	0	θ_2
3	0	L_2	0	θ_3

In order to calculate the transformations, first we have calculated the DH table parameters (Table 2).

Where

a_i is the distance between z_i and z_{i+1} measured along x_i

α_i is the angle between z_i and z_{i+1} measured about x_i

d_i is the distance between x_{i-1} and x_i measured along z_i

θ_i is the angle between x_{i-1} and x_i measured about z_i

Using the above table the transformation matrix is calculated. The general form of transformation matrix is [12]:

$$ {}^{i-1}T_i = \begin{bmatrix} c\theta_i & -s\theta_i & 0 & a_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -s\alpha_{i-1} d_i \\ s\theta_i s\alpha_{i-1} & c\theta_i s\alpha_{i-1} & c\alpha_{i-1} & -c\alpha_{i-1} d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1) $$

The overall transformation is calculated as:

$$ {}^0_3T = \begin{bmatrix} r_{11} & r_{12} & r_{13} & p_x \\ r_{21} & r_{22} & r_{23} & p_y \\ r_{31} & r_{32} & r_{33} & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2) $$

Where

$r_{11}=(c_1c_2-s_1s_2)c_3 + (-c_1s_2-s_1c_2)s_3$

$r_{12}=-(c_1c_2-s_1s_2)c_3 + (-c_1s_2-s_1c_2)s_3$

$r_{21}=(s_1c_2+c_1s_2)c_3 + (-c_1c_2-s_1s_2)s_3$

$r_{22}=-(s_1c_2+c_1s_2)c_3 + (-c_1c_2-s_1s_2)s_3$

$r_{13}=r_{23}=r_{31}=r_{32}=p_z=0$

$r_{33}=1$

$p_x=(c_1c_2-s_1s_2)l_2+c_1l_1$

$p_y=(s_1c_2+c_1s_2)l_2+s_1l_1$

After this, parameters like angular velocity and torque required for lifting the leg were determined. On the basis of these results, an actuator with the following specifications was used as a knee joint (Table 3):

The system flow diagram can be understood from the following figure (Figure 5):

Accelerometer and gyroscopes were used to maintain the stability of the leg without using crutches.

Table 3: Specifications of linear actuator.

Operating Voltage	24 to 48 VDC
Weight	1.2 kg
Length Closed	10 cm

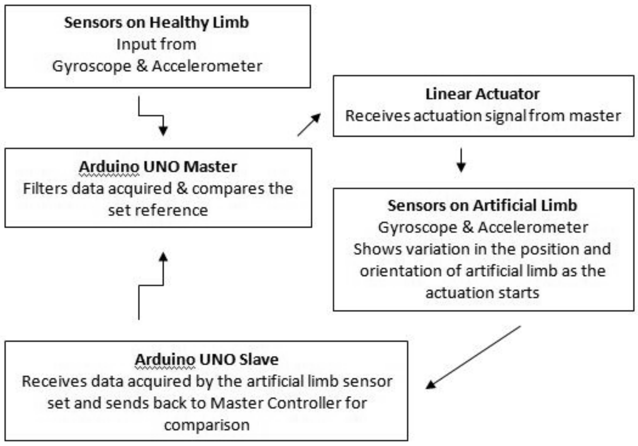

Figure 5: Control System Flow Diagram.

Figure 6 a & b: Two views of Robotic leg reference position.

Developed working model of robotic leg

Some pictures of the developed working model are given below (Figure 6 a, b).

Prior to application of the robotic leg on patients, cosmetics will be applied on the leg to cover the electronic circuits and design of the knee joint such that it depicts the shape as close to that of a normal human.

The operation of the robotic leg has been tested at 12 V, 24 V and 36 V, the results fairly fulfilled the desired criteria being set. However, the input voltage can be further increased from 36 V till 48 V. Batteries acquired by the user to operate the robotic leg will have to wear lithium polymer batteries on his/her belly in a utility waist pack.

Moreover, the leg has a manual bending feature which can be utilized to sit, stand or fold the robotic leg when the batteries are out of charge (Figure 6c) (Figure 6 d, e).

Results

The knee joint transformation with time was plotted on Matlab® showing the movement of leg during the swing phase (Figure 7).

Similarly the following graph displays the behaviour of the two sensors Gyroscope and Accelerometer when fused together to get a stable and understandable value (Figure 8).

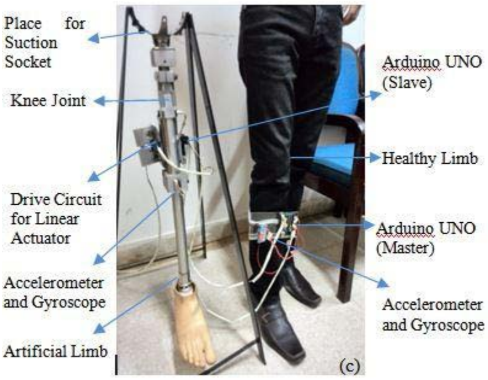

Figure 6c: Labeled view of developed working model of gait adaptive robotic leg.

Figure 6(d): Knee joint bent to demonstrate its position during the swing phase. **(e):** Showing the placement of linear actuator.

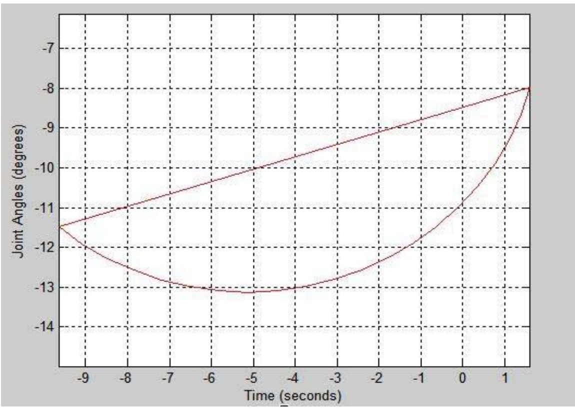

Figure 7: Knee Joint Transformation with time.

Where filtered angle (along the y-axis) is plotted against a number of samples (along the x-axis) taken at different intervals of times.

The graph developed above had the reason that whenever the sensors Gyroscopes and Accelerometers are used, there is a need of filtration in the acquired data according to requirement. In our case, the behaviour shown by the accelerometer showed acceptable variations as compared to that of the gyroscope. To bring the values of the gyroscope to some meaningful level we designed various filters. The data of the sensors acquired separately didn't come out to be

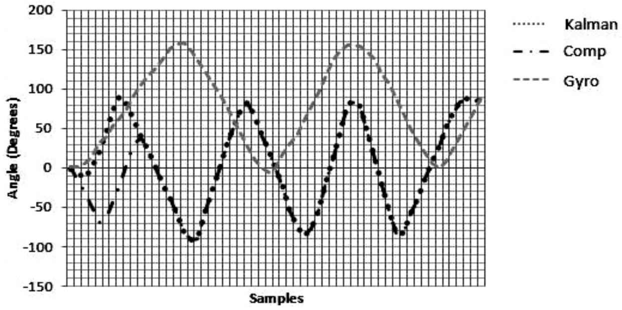

Figure 8: Filtered Output Data from Gyroscope and Accelerometer.

much helpful and hence using the fact that Accelerometer data can be used to achieve a certain level and gyroscope data can be used to filter accelerometer noise as well as quickly respond to any change in the orientation, their acquired data was fused together to not only read the current location of the leg but to also move the leg into the desired orientation.

Conclusion

The design of control systems, have always remained the most demanding subject in Mechatronics and to design an adaptive control demands much more than that. The implementation of control system using the synchronization of sensors needed proper installation and placement of sensors since the design of the algorithm was solely based on their output at various stages.

The controller we used was Arduino-R3 development board, the programming was simple (close to plain English) and the motor control became quite simple enough but the pins it had for Inter-Integrated circuit (I^2C), were sufficient for the interfacing of only one sensor due to which we had to use two Arduino-R3 development boards which increased the hardware to be attached to human body and increased the chances of lose of data through serial communication between the two control units (the master and the slave control).

Acknowledgement

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