

Prosthetic impact calculations through pressure analysis using force-sensitive resistors

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Abstract -Our project is designed to calculate the impact of the prosthetic leg on the amputated limb. There are many problems that a prosthetic user faces daily while using the prosthetic for example, sweating, cramps in the limb, Swelling, change in the residual limb, etc. Apart from that smart adjustable prosthetics are very expensive and they are also not easily available. Change in the fitness of the prosthetic socket is a very big issue as it is the main reason behind maximum residual limb problems. Our solution is to deal with these problems by providing a smart analytical solution that tracks the fitness of the socket along with its impact on the residual limb. We are calculating the impact of prosthetics on the amputated leg by doing a pressure analysis on multiple points on the amputated leg using FSR (Force Sensitive Resistors). It consists of two main parts, first is pressure analysis on 5 main points on the amputated limb by inserting FSR Sensors inside the socket. These sensors provide us with the pressure data and using that data we are doing the pressure analysis

1. Introduction:

A lower limb prosthesis refers to a prosthesis that replaces any part of the lower limb to restore the functional and/or cosmetic purpose of the lower limb. This may include artificial components that replace the hip, thigh, knee, ankle, and foot.

and generating a report. On the other hand, we have a motor mechanism that adjusts the fitness of the socket using the pressure values on various points on the amputated limb.

Our solution provides us with a report that doctors can use to monitor and check the issue in the prosthetic that is creating the problem. and on the other hand, it provides an auto adjustment feature that keeps the socket properly fit and leaves very less room for the problem and avoids many issues. It also makes it versatile as it changes the shape of the socket according to the thickness of the leg

This solution can be a complete solution to solve the major adjustment issues of the prosthetic legs along with providing the important analysis to improve the performance of the prosthetic

Keywords- Prosthetic fitness, Impact on amputated limbs, Pressure mapping, Infographic report, Auto Adjustment of the prosthetic.



Prosthetic Evaluation

Initial evaluation to determine if a patient is a candidate for a lower limb prosthesis should include the following assessment of the patient's history:

1. The patient's prior level of function and activity level, including the level of independence in ADLs, and any assistive devices previously utilized for ambulation
2. The patient's geographical location and proximity to medical care and prosthetic lab
3. Etiology of and time since amputation
4. General medical conditions, including comorbidities such as heart and lung disease, diabetes, vascular disease, and polyneuropathy
5. Employment
6. Recreational pursuits and sports participation
7. Goals of patient and family
8. Family and caregiver support

The patient must also be physically and mentally evaluated to determine the appropriate prosthetic prescription, complete assessment includes:

1. Assessment of cognitive function necessary to care for and don/doff the prosthesis, as well as the ability to learn techniques and strategies in therapy.
2. Function of the upper limbs
3. The function of the opposite lower limb
4. Residual limb strength, shape, length, and condition. This assessment should include skin condition, sensation, and circulation of the amputation site.
5. Stability of joints and ligaments of the residual limb
6. Presence or absence of any joint contractures in any of the limbs
7. Weight of the patient (as some prosthetic components have weight limits)

Based on the above-gathered information, physical examination, and potential for progress, the amputee patient is classified to a particular functional level. The K levels were adopted by the

federal government to clarify which lower limb prosthetic components (knee, foot, and ankle) should be used for patients depending on their functional levels. The higher the K level the more potential for prosthetic ambulation.

The initial prosthetic fitting

When preparing a patient's residual limb for a prosthesis the process includes healing, shrinking, and shaping the residual limb appropriately with the use of ace wraps and eventually an elastic shrinker. During this period often the patient's residual limbs are protected in a rigid protective device.

The goal of the shrinking and shaping process varies depending on the type of amputation. When there is a plateau in the day-to-day change in the shape of the residual limb the patient with a lower-limb amputation is prescribed and measured for their initial prosthesis.



In the past, this was referred to as preparatory or temporary prosthesis, although with the advancement of prosthetic technology this prosthesis is still custom-made and can be used for quite some time. It is designed to be strong and can be adjusted for alignment, fit, componentry, etc. With this prosthesis, the patient typically will work with physical and occupational therapists with the goal of achieving independence in ambulation and ADLs with the prosthesis. While the patient uses this initial prosthesis, the residual limb is expected to continue to shrink, but at a

slower pace, and sometimes the shape will change as well. The prosthetic socket often needs to be replaced as the residual limb shrinks, usually within the first 6 months to a year after amputation. When needed, a “definitive” prosthesis is prescribed. This term was often used in the past to describe when the socket, alignment, and componentry were no longer requiring change so that a cosmetic cover could be applied. Most patients currently choose not to cover their prostheses but to leave the componentry visible. The general public’s acceptance has grown, and this is much more practical for prosthetic management, as continued changes are often necessary. Currently, the semantics of “temporary” and “definitive” prostheses have fallen by the wayside, as most patients will use their initially prescribed prosthesis until a new one is needed.

Problems with Prosthetics:

Learning to get around with a prosthetic leg can be a challenge. Even after initial rehabilitation is over, you might experience some issues that your prosthetist and rehabilitation team can help you manage. Common obstacles include

- Excessive sweating (hyperhidrosis), which can affect the fit of the prosthesis and lead to skin issues.
- Changing residual limb shape. This usually occurs in the first year after an amputation as the tissue settles into its more permanent shape and may affect the fit of the socket.
- Weakness in the residual limb, which may make it difficult to use the prosthesis for long periods of time.
- Phantom limb pain could be intense enough to impact your ability to use the prosthesis.

At some point, you may notice that you aren’t as functional as you’d like to be with your current leg prosthesis. Maybe your residual limb has stabilized and you’re ready to transition from a temporary prosthesis that lasts a few months to one that can last three to five years. Or maybe you’ve “outwalked” your prosthesis by moving more or differently than the prosthesis is designed for. New pain, discomfort, and lack of stability are some of the signs that it may be time to check in with your

prosthetist to reevaluate your needs.

Your prosthetist might recommend adjusting your current equipment or replacing one of the components. Or you might get a prescription for a new prosthetic leg, which happens on average every three to five years. If you receive new components, it’s important to take the time to understand how they work. Physical therapy can help adjust to the new components of your new prosthetic leg.

Poor Balance, Instability, or a Fear of Falling

If you experience any of these issues, there is a good chance that it is not properly aligned. Over the months and years of use, your limb may have subtle changes that reduce your control of the prosthesis. If however your socket fits well and you are comfortable then there is the likelihood that the “alignment” of your prosthetic components are not optimized. If you are experiencing what feels like the rotation of a knee or foot, a sensation of walking on the edge of your foot or feel like you have a hitch in your step then adjustments are likely needed to your prosthesis to remedy the issue. MCOP’s skilled team works to optimize prosthetic performance and alignment and make adjustments before they begin causing problems.

Intact Limb Pain

Overuse syndrome is well documented in amputees, where additional and atypical amounts of time and pressure are borne down through the intact limb. Over time, this can and will cause early degeneration of the lower back, hip, knee, and ankle resulting in discomfort and other complications. This becomes even more important if there are injuries to the intact limb, which makes it even more critical that the prosthesis be designed to evenly bear the load and smooth out every step in your gait.

Irritation and Skin Issues

Research has shown that as many as 74% of amputees have skin issues associated with prosthetic wear. Sometimes these are minor and do not affect the use, but oftentimes if the cause is untreated, they progress to a new level.

We are specialists in understanding the skin/prosthetic interface and we are often asked to

work directly with manufacturers to understand the causes and prevent the occurrence of skin irritation and breakdown. If you feel rubbing in your prosthesis, that is the result of mechanical friction and pressure combined which can cause irritation and skin issues. Socket shape and fit along with stabilizing the soft tissue are all important to prevent this and preserve the long-term health of your skin. We utilize a variety of Gel and Silicone materials to match the skin's needs and dissipate friction or pressure to reduce irritation. If you experience liner or skin breakdown you should be even more concerned. A stable socket environment protects you and the liner both equally, and breakdown is the result of issues with the socket.

Our expert prosthetists are experienced in resolving skin issues and reducing and preventing skin breakdowns through the careful application of the latest socket, interface, and suspension technologies.

Socket Issues or Discomfort

Proper socket fitting requires a skilled clinician and a plan tailored to your unique needs. Without a sound clinical plan, socket fitting can take far too long, yet still, provide little in the way of improvement and comfort. Unfortunately, a one-size-fits-all approach is used in the prosthetic industry, which inevitably compromises comfort and your ability. Ask yourself, is your current socket:

1. Easy to put on and take off?
2. Wearable all day without causing irritation or discomfort?
3. Giving you full and complete control of the prosthesis?

If your answer to any of the above questions is no, you important to remember that you're not alone in navigating the many different prosthetic leg options. Your care team will help you weigh the pros and cons of each and decide on the ideal prosthetic leg that matches your lifestyle. There are many solutions available to tackle the issue of prosthetic issues some of them are as follows:

RevoFit2:

should consider other options. If your current efforts are not solving the issues you are facing, contact us for a specialist opinion on the many available solutions which you may not have tried.

2. LITERATURE REVIEW

Prosthetic Leg Technology Is Always Evolving

There are always new developments in prosthetic limb technology, such as microprocessor-driven and activity-specific components.

- **Microprocessor joints** feature computer chips and sensors to provide a more natural gait. They may even have different modes of walking on flat surfaces or up and down stairs.
- There are also specialized **prosthetic legs for different activities**, such as running, showering, or swimming, which you can switch to as needed. In some cases, your everyday prosthetic leg can be modified by your prosthetist to serve different purposes.
- **Osseointegration surgery** is another option. This procedure involves the insertion of a metal implant directly into the bone, so there is no need for a socket. The prosthetic leg then attaches directly to that implant. While this procedure is not right for everyone and is still under study, it can provide an improved range of motion and sensory perception.

It's



RevoFit Prosthetic Solutions by Click Medical

deliver a micro-adjustable prosthetic limb that allows you to instantly control the fit of your socket without ever having to remove it. You can easily customize the fit, feel, and performance of your prosthesis by fine-tuning socket compression around your limb. Now, as you change throughout the days, months, and

Harmony vacuum pump:



The Harmony is a modern closure system. It ensures that the artificial limb is securely connected to the residual limb.

Active vacuum systems, such as the Harmony, pump out virtually all the air between the liner and socket, thereby regulating the vacuum in a defined range. The system is individually adapted to the needs and activity level of the respective user. In addition to a secure connection between the socket and the artificial limb, the system stabilizes the residual limb volume. High adhesion also improves control of the artificial limb.

The Harmony system is available as the mechanical Harmony P3 pump, which regulates the vacuum at every step according to the stride rate and load using a function ring. It is suitable for below-knee amputees.

Genium microprocessor-controlled knee joint:

The microprocessor-controlled Genium supports the natural movement pattern down to the details – without requiring the user to consciously control the joint.

years, you can have a socket that will change with you.

A new generation of technology is designed to provide a micro-adjustable prosthetic device based on Boa Technology® components that allows instant control of the socket fit.



Everything happens in real-time, regardless of the situation, and is even forward-looking. This is made possible by the latest computer, sensor, and control technology. The Genium responds intelligently to a wide variety of everyday situations. This is the closest an above-knee artificial limb system has come to recreating a natural, physiological gait pattern.

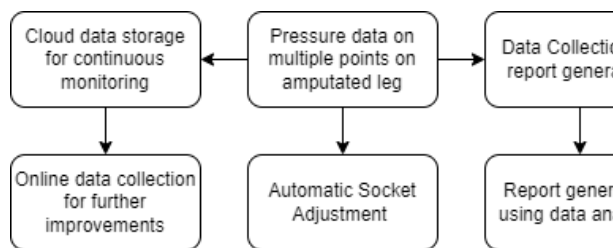
A motor-driven adjustable prosthetic socket operated using a mobile phone app:

Sockets that allow incremental size adjustment during ambulation may help prosthesis users improve the management of their changes in limb volume and the quality of their prosthetic fit. A platform system was developed that allowed people with trans-tibial limb loss to adjust the radial positions of socket panels during ambulation in small increments via a motor mounted beneath the socket. The motor altered the length of a cable running through the socket panels according to commands communicated from a mobile phone. A proportional-integral-derivative controller adjusted the voltage applied to the motor via pulse-width modulation to achieve target settings.

Bench test results showed that when the system was subjected to loads comparable to those expected during clinical use, a maximum absolute steady-state error was 0.036 mm. Treadmill testing on 16 people with trans-tibial limb amputation demonstrated that the range of cable lengths over which participants deemed fit clinically acceptable

varied between 24 mm and 114 mm depending on the user. In field testing 11 of 13 participants were comfortable making socket size adjustments while walking. The developed system achieves incremental socket size adjustments appropriate for the research and development of ambulatory adjustable sockets.

3. Our Solution:



Our solution is to calculate the impact of prosthetics on the amputated leg by doing a pressure analysis on multiple points on the amputated leg using FSR (Force Sensitive Resistors).

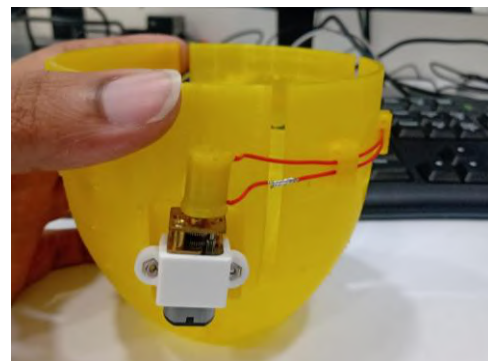
It has two parts:

1. **Impact Analysis:** As we know, there are main points on the leg which comes in contact with the prosthetic socket and hold maximum pressure on the tightness and weight of the prosthetic leg. There are 5 FSR sensors placed, one at the base and 4 on the sides. These sensors provide us with the pressure value applied on the leg because of the tightness of the socket. All the sensors are attached to a thin sheet of plastic that goes inside the socket of the prosthetic. All the data given by the sensors get collected in an excel sheet using python code. Then using data processing, we are generating a report for the doctors to analyze the impact.
2. **Autofitting:** We have designed an auto-adjusting mechanism in the prosthetic socket. It works using a small high torque DC motor and the FSR sensors to securely fit the prosthetic to the amputated leg. We have specified a threshold pressure value. When the user puts the socket on the amputated limb, the FRS continuously checks the pressure, and the motor keeps tightening

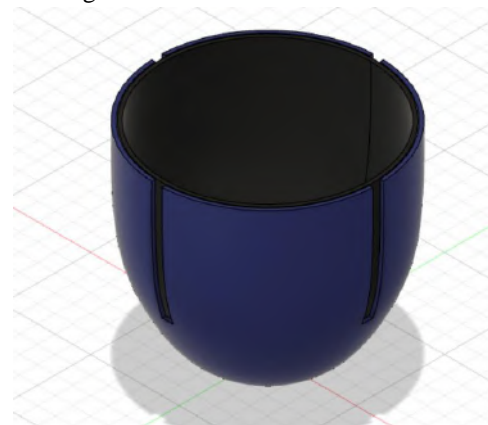
the socket grip. When the pressure on the limb reaches the threshold, the motor stops.

We have also made a program that keeps changing the tightness of the socket according to the need and the mode. It helps the user to always keep a secure fit and puts less impact on the amputated limb.

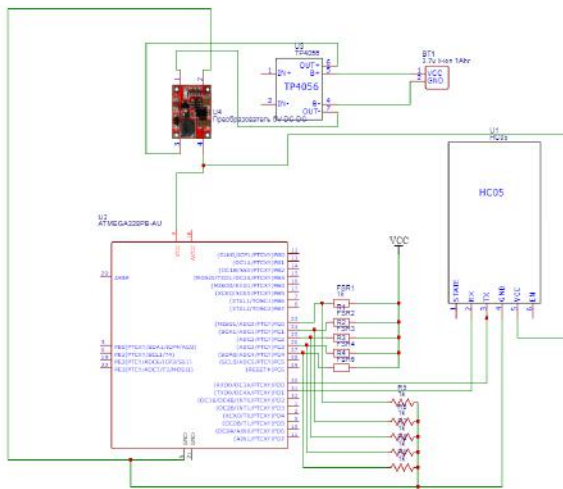
The Prototype:



We have designed a small proof of concept to check the working and accuracy of our solution. We designed a miniature 3D Model of the socket and then got it 3D Printed.



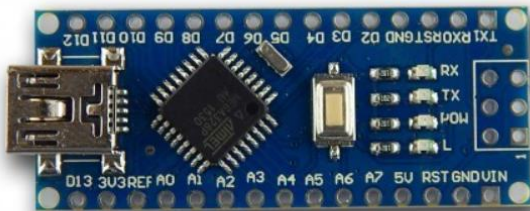
We have made a circuit using Arduino Uno and connected 5 FSR Sensors on a plastic sheet that goes inside the socket. As the circuit is small and has a wireless connection with the computer for data transfer, it fits easily on the outer side of the prosthetic socket.



Component List

The parts used in the circuit are as follows:

Arduino nano: Arduino nano is a smaller more concise version of the Arduino Uno. To maximize space for other facilities while still maintaining a small box we decided to use the Arduino nano. Furthermore, the Arduino nano is breadboard friendly and provides a constant voltage. Arduino nano is also preferred in automation, circuits, and robotics due to its low cost and small size.

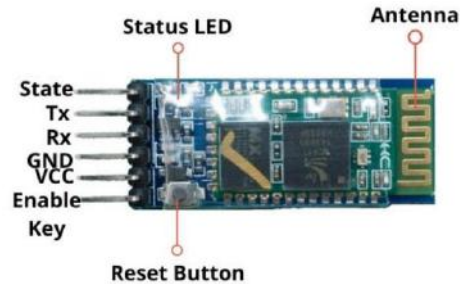


Battery - The battery powers the entire circuit.



Switch - The switch allows the user to toggle the band on and off.

Bluetooth Module (HC-05): The Bluetooth module is meant for short-range wireless data communication. It facilitates easy interfacing between the Arduino and the computer. It is connected to the Arduino via the Rx and Tx. The Arduino sends data to the Bluetooth module which is connected to the app.



DC to DC Micro-Booster (FC - 400): The function of a micro-booster is to translate the incoming voltage from one level to another. In his case, we were using a DC to DC Micro-Booster as we needed to increase our voltage up to 6 volts. We desoldered the USB port from the micro booster to allow connections from the 4 flat pins just underneath it.



FSR Sensors:



FSRs are basically a resistor that changes its resistive value (in ohms Ω) depending on how much it is pressed. These sensors are fairly low cost, and easy to use but they're rarely accurate. They also vary from sensor to sensor, perhaps 10%. So basically when you use FSRs you should only expect to get *ranges* of responses. While FSRs can detect weight, they're a

bad choice for detecting exactly how many pounds of weight are on them.

We have used 5 FSR Sensors in total.

Costing:

S.No	Component	Cost in Rs
1	Arduino Nano	400
2	FSR Sensor (5 NOS)	5000
3	Power Circuit	1500
4	Bluetooth Module	300
5	3D Printing	3000
	Total	10200

4. Algorithm:

Arduino Program:

Our Arduino program is collecting data from FSR Sensors and merging it using the comma separation method. then we are sending the data serially via Bluetooth.

Code:

```
#include <SoftwareSerial.h>
SoftwareSerial bt(12, 11); // RX, TX

void setup() {
  // initialize serial communication at 9600 bits per
  second:
  Serial.begin(9600);
  bt.begin(9600);
}

// the loop routine runs over and over again forever:
void loop() {
  int sensorValue0 = analogRead(A0);
  int sensorValue1 = analogRead(A1);
  int sensorValue2 = analogRead(A2);
  int sensorValue3 = analogRead(A3);
  float voltage0 = sensorValue0 * (5.0 / 1024.0);
  float voltage1 = sensorValue1 * (5.0 / 1024.0);
  float voltage2 = sensorValue2 * (5.0 / 1024.0);
  float voltage3 = sensorValue3 * (5.0 / 1024.0);
```

```
Serial.print(sensorValue0);
Serial.print(" ");
Serial.print(sensorValue1);
Serial.print(" ");
Serial.print(sensorValue2);
Serial.print(" ");
Serial.println(sensorValue3);

bt.print(sensorValue0);
bt.print(" ");
bt.print(sensorValue1);
bt.print(" ");
bt.print(sensorValue2);
bt.print(" ");
bt.println(sensorValue3);
delay(500);
}
```

Python Code:

Our python code is taking the data from the device via Bluetooth and then saving it in a CSV file using the pyserial library. Then after that, we are opening the same CSV file using the panda's library and sort the data into multiple variables using NumPy arrays. In the last, we are generating a report of the analysis using matplotlib.

```
import datetime as dt
import serial
import sys
import time
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
from fpdf import FPDF

pdf = FPDF('L','mm','A4')
pdf.add_page()

date = dt.datetime.now()
ser=serial.Serial("COM22",9600)#left
f=open('data.csv','w')

f.write('FSR1')
f.write(',')
f.write('FSR2')
f.write(',')
f.write('FSR3')
f.write(',')
f.write('FSR4')
```

```
f.write('\n')
read = ""

# time_s = time.time()
name = input('enter your name')
age = input('enter your age')
d_name = input('enter your doctor name')
while True:
    try:
        read=ser.readline().decode("utf-8") # left
    except UnicodeDecodeError:
        print('unicode error')
    else:
        x = read.strip('\n\r')
        y = x.split(',')

        break

input('press enter to start')
for i in range(20) :
    try:
        read=ser.readline().decode("utf-8") # left
    except UnicodeDecodeError:
        print('unicode error')
    else:
        x = read.strip('\n\r')
        f.write(x+'\n')

        print(x)
f.close()
x = pd.read_csv('data.csv')

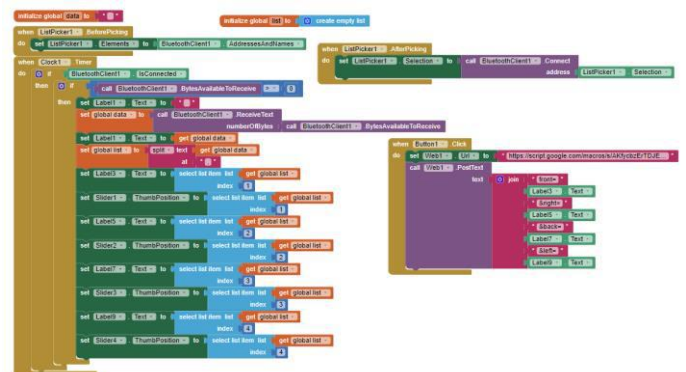
x = pd.read_csv('data.csv')

plt.subplot(411)
plt.title(name+', '+age+', '+Doctor-'+d_name)
#plt.title("front")
plt.plot(x.FSR1)
plt.subplot(412)
plt.title("left")
plt.plot(x.FSR2)
plt.subplot(413)
plt.title("back")
plt.plot(x.FSR3)
plt.subplot(414)
plt.title("RighBluetoothlot(x.FSR4)
plt.show()
```

Mobile Application:

We have made a which connects with the device via Bluetooth and displays the impact of the prosthetic

on the amputated limb in real-time. Along with that it also keeps uploading the data to the cloud for continuous monitoring and data recording. We have used an MIT App inventor to design the prototype app.



Testing of the solution:

We have done 2 types of testing to check the accuracy and wearability of the device.

1. Using the sensors on the real person using a strip to tightly attach the sensors on the leg while walking and taking the readings



In this way we have tested our hypothesis about the Solution and found that it is actually providing us promising results which can be used to examine the walk and the pressure applied on various muscles.

2. We have tested the fitness of our solution in the real prosthetic leg socket by 3D Printing a miniature model of the socket.



This 3D Printed model is a miniature model of a prosthetic socket and it has auto-tightening feature using FRS sensors

5. Future Scope:

There is a range of improvements that could be made in the future since this is just a prototype. We have made a small prototype as a proof of concept. so in future we will be implementing this solution in the real size prosthetic so that we can do the real testing on the subjects. There is a lot of work to do in the designing part as it is really important that it should be really very comfortable to wear so we need to design a proper aesthetic casing for the circuit along with the sensor placement in the socket. In future we will be doing the field testing once we are done with a life size model of the project. We will collect the data using the model and then that data can be used to improve the performance of the device using machine learning or even by data analysis. In future this solution can provide a full proof solution for better analysis of the amputated leg and prosthetic impact on it.

6. Conclusion:

The device and app have been tested for the accuracy and consistency of the results. We have tested it on the fellow members using a cloth belt and putting the FSR Sensors around the leg. We have found that it is providing us promising results which can be used to examine the walk and the pressure applied on various muscles. Then to check the fitness we used a miniature 3D Printed socket and that also worked very well as we can control the fitness according to our need using a mobile phone app. To conclude we can say that our solution can provide a full proof solution for better analysis of the amputated leg and prosthetic impact on it. This solution can be a complete solution to solve the major adjustment issues of the prosthetic legs along with providing the important analysis to improve the performance of the prosthetic

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