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Faculty of Mechanical Engineering

DEVELOPMENT OF CONTROLLER FOR PROSTHETIC LEG USING PID METHOD

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DECLARATION

I declare that this report entitled " Development Of Controller For Prosthetic Leg Using PID Method" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : Asrul Bin Abd Rahman

Date : 24th August 2016

DEDICATION

To my beloved wife, Nurzahrawani Bt. Nawa and my childrens Arfan and Aisyah.

ABSTRACT

This report presents the modeling and control of an actuated prosthetic knee mechanism for trans femoral amputees. The mechanism consists of a linear actuation system that feeds the mechanism with the required moment and power at every different movements. Physical simulation that takes weight data that is used to simulate and identify the physical parameters of the prosthetic leg. Information from other research were collected and used as references for this study. Movements such as standing, climbing slope, and stair ascent were tested at different time intervals. The results of which can be summarized based on the weight difference is restricted to the shank and foot with a single angular position which does not exceed 20˚. PID control parameters were tuned and resulting the angle of the prosthetic leg could achieve the desired angle at time period of 1 s. Amplitude this point starts at 0 unit at the time of 0.42 seconds. At point 0 units - 20 units the movement takes longer than the 20-point and above. It was found that the effect towards the foot is more significant compared to the shank in terms of both studied variables; angle of movement and exerted pressure. Further analysis must be carried out for the development stage of the knee mechanism. Also, more experiments must be conducted with the trans femoral amputees to improve the overall performance of the knee mechanism.

ABSTRAK

Tesis ini melaporkan permodelan dan pengkawalan mekanisma sebuah prostetik lutut bergerak untuk pesakit kudung transfemoral. Mekanisma tersebut adalah sebuah sistem pergerakan linear yang menyediakan momen dan daya pada setiap pergerakan yang berbeza. Simulasi fizikal yang mengambilkira maklumat berat digunakan untuk menyimulasi dan menentukan parameter fizikal kaki prostetik. Maklumat daripada penyelidikan lain juga dikumpul dan digunakan sebagai rujukan untuk penyelidikan ini. Keputusan yang didapati menunjukkan bahawa perbezaan berat akan mengehadkan kedudukan sudut lutut dan kaki tidak melebihi 20˚. Pengkontrolan PID ditala dan menghasilkan sudut kaki prostetik boleh mencapai sudut yang dikehendaki pda masa 1 saat. Amplitud bermula pada unit 1 pada 0.42 saat. Pada unit 0, -20 unit mengambil masa lebih lama berbanding dengan 20 unit dan lebih. Ianya didapati bahawa kesan terhadap kaki adalah lebih banyak berbanding kesan terhadap lutut dari segi kedua-dua pembolehubah yang diselidik; sudut pergerakan dan tekanan. Analysis terhadap pembangunan mekanisma lutut mesti dilakukan pada masa depan. Lebih banyak eksperimen juga perlu djalankan terhadap pesakit kudng transfemoral untuk menambahbaik prestasi keseluruhan mekanisma lutut yang telah diselidik.

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APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality as a partial fulfillment of Master of Mechanical Engineering (Energy Engineering).

Signature	:______________________________
Supervisor Name	: Dr. Mohd Khairi bin Mohamed Nor
Date	:______________________________

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CHAPTER 1

INTRODUCTION

1.1 Historical Background

The mobility of the lower furthest point amputees depends entirely on the prostheses. Human lower limbs have an exceedingly verbalized and extremely complex structure having the capacity to produce sophisticated and flexible practical ankle, knee and hip joint developments. The above knee amputation is a sort of surgical impedance that disjoins the thigh fragment between the knee and hip joints. It is for the most part appropriate when a few mishaps, sicknesses and traumatic occasions happened. After amputation, the foot and the shank portions are lost totally while the thigh section is lost incompletely. After restoration period, an amputee can move his/her stump, which is the rest of the part of the thigh fragment, correspondingly with a typical leg. This implies an amputee can control a simulated leg utilizing the attachment giving appropriate association between the stump and the prosthetic leg.

Consistence (the reverse of stiffness) is available in all physical actuator frameworks as the mechanical parts in the drive train avoid under the connected burdens. The redirection might be altogether portrayed as a relationship amongst burden and uprooting or the circumstance might be more intricate including, for instance, stacks that rely on upon rates of removal. An actuator might be viewed as agreeable or "hardened" in a given application if its diversion under burden from its harmony position can be ignored or if its progression (as described, for instance, by its common frequencies) are a long way from being energized by the scope of frequencies required for its operation.

Table 1.1: Usability comparison of prosthetic leg product on ergonomic design

Core Indexes of Usability			Ordinary Prosthetic Leg (PL)	General Intelligent Prosthetic Leg (IPL)	Gait-following Intelligent Prosthetic Leg (GF-IPL)
Comfort C	Gait Symmetry C_1	Swing-phase gait symmetry C_{11}	5.0 (symmetry control for a single speed)	8.0 (symmetry control for few average speeds)	9.5 (symmetry control for full-time speeds)
	Environmental self-adaptation C_2	Identification of Level walking C_{21}, descending ramp C_{22}, sitting down C_{23}, stumbling C_{24}	0.0 (without this function)	10.0 (with this function)	10.0 (with this function)
Efficiency E	Fabrication and adjustment time E_1	Fabrication time E_{11}	5.0 (long time for adjustments)	5.0 (long time for adjustments)	9.5 (no need for adjustments, with auto-adaptation)
	Convenience for use E_2	Operation convenience E_{21}	7.0 (easy operation)	6.0 (difficult operation)	9.0 (easiest operation)
Safety	Anti-stumble function S_1	Anti-stumble function S_{11}	0.0 (without this function)	10.0 (with this function)	10.0 (with this function)
	Stability of support phase S_2	Stability of support phase S_{21}	8.0 (mechanical control)	9.0 (mechanical or automatic control)	9.0 (mechanical or automatic control)
Note: Values in the table are the results of investigation by interviewing the experts from prostheses fabrication centers based on the product performance (the ideal value is 10.0)					

A given actuator framework might be agreeable or not consistent contingent upon its utilization and the undertakings allocated to it. There are two principle wellsprings of consistence, or when all is said in done impedance, in an actuator framework. Dynamic input control can adjust the dynamics of a framework to give it the presence of being consistent.

1.2 Problem statement

How to control the angle of the ankle during walking. Assume that how do horizontal displacement.

1.3 Objectives

- To design the controller for prosthetic leg using the modelling MATLAB software.
- To study the effect of human weight on the shank and foot pressure.

1.4 Scope of work

- To design the suitable controller for the system.
- The analysis will be done to understand the performance of the MATLAB software when applied mathematical method.
- Involved the simulation study of the system by using any simulation software.

CHAPTER 2

LITERATURE REVIEW

2.1 Magnetorheological Actuator (MR Actuator)

A magnetorheological fluid (MRF) comprises of a suspension of infinitesimal magnetizable particles in a non-attractive bearer medium, for the most part a manufactured oil or water. Without an attractive field, the fluid carries on in a generally Newtonian way. At the point when an attractive field is connected, the infinitesimal particles suspended in the fluid structure chains along the attractive flux lines, changing the fluids's rheology. The ability of MRF to respond significantly fast within milliseconds is one of the key reason that the MRF is well known as smart fluid. It is fully functioanable in irregular condition of streets and tracks. One of the functional application of MRF is to control the damping attributes in suspension damper of ground vehicle. The special characteristic of MRF, which its quick response when it is subjected to magnetic field is a crucial component for the damping attributes control. As magnetic field is subjected to the MRF, the minuscule particles will response and the subsequent arbitrary particles will be gradually adjusted and arranged according to the direction of magnetic flux. (Mohd Hanif Harun et al. n.d.). MR actuator is normally made of a dynamic part which is motor and MR clutch.M actuator features is commonly consider has a safety aspect benefits because the features is compliance due to the exisistence of MR fluid if compared with regular actuator. (Li 2014). The simulations were done for a few common human movements such as walking, standing and sitting. As expected, the outcomes demonstrated that the exoskeleton structure is capable of doing its job to help in human movement. The actuator can produce adequate assistive torque. The estimation of torque has certain distinction when contrasted with the deliberate torque produced by the knee joint. Be that as it may, a coefficient can be applied to reduce the distinction while assessing torque. Furthermore, since the structure of human body is versatile, it can remunerate a few blunders. Is is expected that the new actuator with MRF brake will have better lifetime because the MRF is capable of delivering extensive torque at minimum power usage. The ranges and porousness of the materials have solid impact in the execution of the actuator. In recreation and examination works done by Harun et al. (n.d) demonstrated that the potential utilization of the MR liquid damper to be utilized as a part of semi-dynamic suspension framework.

The manufacturing of MR dampers are is not expensive since the fluid is insensitive to impurities and foreign matter. MR dampers has low requirement of power, reliability, and stability. Ranging from 20W to 50W of power, this devices is able to operate with a battery. Since the device is able to operate using battery, is does not require major source of power. Mechanical valves are not required in the device because different magnitude of magnetic field is able to adjust the forces. Therefore, it is a very reliable device. (Jansen & Dyke 2000). In a passive viscous dampers, there is a fluid that helps to distribute the force with minimum vibration effect. Specifically, the fluid that is filled in a MR damper that contains distributed micron-sized magnetic polarisable particles makes the device easily controllable by the user. The property of control is attainable because the existing particles change their position and pattern as magnetic is applied to it. The behavior of the fluid transform from linear viscous to semi-solid in less than a second. The applied current can be adjusted within the allowable range to ascend and descend the amount of energy induced by MR dampers. The damper's resistance to movement can be adjusted by varying the magnitude of current and patterns. (Mohamad Hafiz Harun et al. n.d.). The damping force induced by Newtonian flow represents the minimum backdrivable force that can be supplied by the actuator. At low speed, the force is below 20 N and it steadily increases with speed and stay steadily below 100N. Meanwhile the force observed at 5A is the maximum allowed force that ensures the integrity of the cores. Higher currents is be possible only for short periods of times, therefore they were not included in this study. The maximum force that the device can achieve is 0.8 kN. The forces at different current setting do not increase linearly with the current. This is expected since the yield stress curve of the MRF has a logarithmic behaviour which saturates around 0.8T at the gap. (Dominguez et al. 2015).

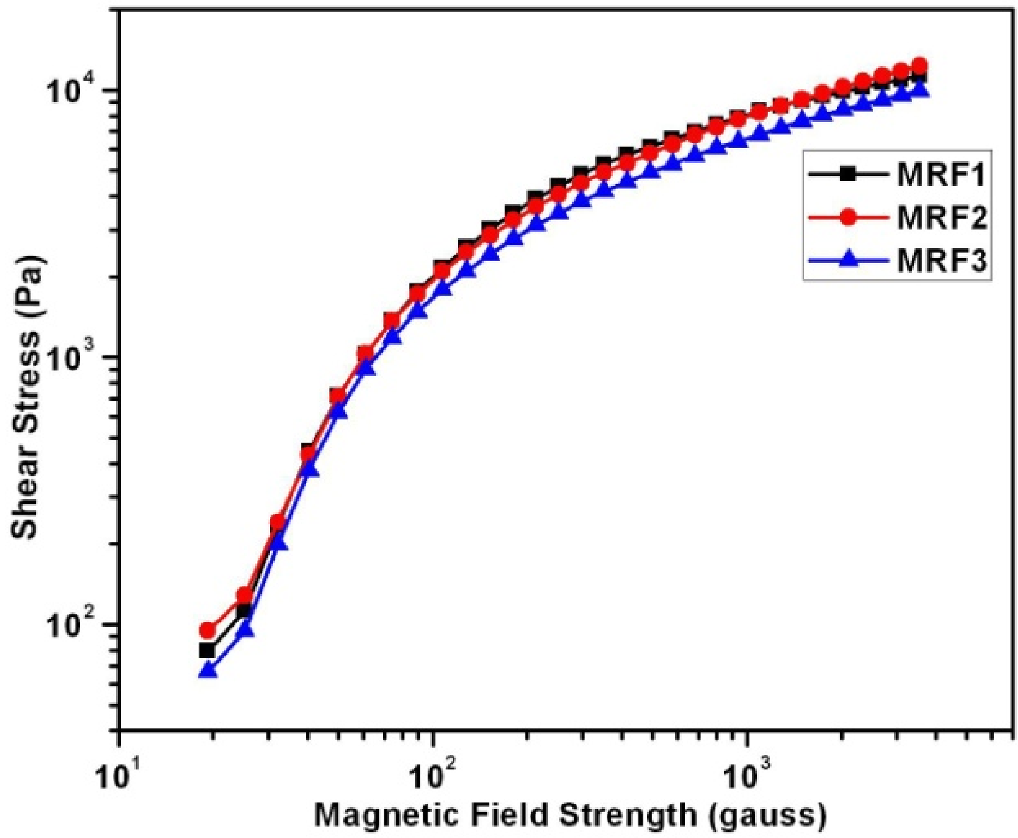

Figure 2.1: Magnetic Field vs Shear Stress for MRF1, MRF2, and MRF3

Magneto Rheological is a part of rheology that studies about flow and deformation of materials when magnetic field is objected to it. Rheological properties of the material will change if it is objected with magnetic field. It is able to change from liquid to solid in just a few seconds. One of the daily application of the high technology material is the MR damper. i.e. magneto rheological fluid. (Bajaj et al. 2014). One of the example of smart material is Magneto rheological materials (fluids) (MR). It has its own rheological properties (e.g. viscosity) that is able to changed in a short pace by introducing magnetic field. As magnetic field is subjected to the fluid, the particles will deform to construct a structure that is able to resist shear deformation or flow. As studied by Bajaj et al. (2014), Lord Corporation (Cary, NC), a company that deals with the technology of materials, transformed the magneto- rheological (MR) technology that is already exist in its truck-seat damper and applied it for a new application, the Smart Magnetic prosthetic leg. The Lord Corp. has also introduced an MR damper for a prosthetic knee in the world market. The damper, sensors, control unit, and battery are all placed within the knee itself. The device is able to operate much faster than prior state-of-the-art designs with the combination of MR, electronics, and software.The efficiency enable the device to achieve the precise neural human reaction time of movement. In short, the latest design more closely immitiate the natural thought and locomotion than previous designs. The new technology which is Magneto-rheological technology enable the prosthetic leg to closely mimics a natural stride.

According to Gudmundsson et al. (2008), Magneto-rheological (MR) fluids are one of the example of smart materials that is controllable by magnetic field. The fluid are used in wide area of application such as to make a certain structures or device adaptive and controllable according to users' requirement. As stated before, the rheological properties of the MR fluid is it can be controlled by introducing magnetic field. An MR fluid consists of liquid that act as a carrier immersed with ferromagnetic micron sized particles. MR fluids is used in numerous industrial applications. Since the MR fluid has various of rheological properties, the fluid are utilized in various actuators. The prosthetic knee is one of the main example of device. In order to adapt the variable stiffness condition of the knee, MRF rotary brake actuator is utilized. As stated by the researcher, a multiple objectives approach was used to conduct the design of the actuator. Firstly, the main objective is to increase the strength of field-induced and to reduce the off-state stiffness and the weight of the actuator itself. The rate of movement of the prosthetic knee joint, in load-free movements, is dependent on the off-state rotational stiffness of the MR actuator. The main factors that will influence the off-state rotational stiffness of the knee are: the radius of blades, the number of blades used, the distance between the blades, the friction in bearings and oils seals, and the MRF's off-state viscosity.

Gudmundsson et al. (2008) also studied that MR fluid is a type of fluid can interchange their rheological properties if magnetic field is applied on it. MR fluids consist of a carrier liquid which is immersed with solid particles. The paper inscribed the structure of the MR rotary brake actuator. The structure is proposed according to a few essential qualities. The three design qualities are; the actuator's highest acheivable field-induced braking torque, the lowest acheivable stiffness if magnetic field is introduced, and the MR actuator's weight. It is crucial to study the trade-offs between these qualities. High field-induced braking torque of the prosthetic knee is significantly necessary to ensure the capability of the knee to support high-weight user. Lowering the off-state stiffness of the knee is significantly influentil for quick mobility of the knee, in movements without additonal load. Besides, a light-weight of actuator is extensive to ensure users' comfort.

In research done by Crivellaro (2008), Magneto-rheological (MR) devices are semi-active control actuators that utilize MRF. The MRF enable the device to have dampers, brakes or clutches that can be controlled and adjusted accordingly. These features makes the operation of the device to be reliable can be considered as fail-safe since the device will turn into a passive devices if there is malfunctioning of control hardware. A MRF, a fluid that is consists of micron sized, magnetically polarizable particles scattered in a carrier medium such as mineral or silicone oil. As magnetic field is introduced to the fluid, bond and chains between particles are constructed, and the fluid will turn into semi-solid, manifest or deliberately display the characteristic of plastic. Thus, these process will cause the transformation of the fluid's flow properties. Transitions to rheological equilibrium is acheivable in less than a second, enabling the device to have as maximum bandwidth as possible. It can be designed and structured using a conventional damper with additional magnetic valves which will able to cope the special characterisitc of MRF. Minimum power is required for the fluid control; smaller than 30 watts. The low power consumption enable a continuous operating time for more than one hour using a mobile power source which is a battery.

Crivellaro (2008) also studied that, to adapt with the rheological behavior of the fluid, the magnetic choke generate a magnetic field. The accumulator of the damper absorbs the volume variation that is caused by the introduction of the rod inside the fluid camera. Generally, the accumulator is composed of a bladder or an air camera with a flexible piston pressurized at 2×10^6 Pa. The dampers are able to generate forces in the opposite direction of the direction of the piston. The piston moves due to two different sources. The first one is similar with existing dampers, corresponding to a viscous friction, which the forces generated is proportional to the speed of the piston. The second one is the effect of the magneto-rheological fluid behavior within the piston under the controllable magnetic field. The force generated is influenced by the electric current or the electric tension applied to the magnetic choke indirectly instead of depending on the speed only. However, the speed is non-linearly dependent to the viscous friction in this case. The relationship of hysteric behavior between force and velocity. This hysteric behavior is enhanced by the elastic effect of bushings at the joints of damper.

According to Xie (2010), instead of only achieving more accurate position control, human joints is one of the biggest parameter to be considered. The human joints are divided into two category; active joint and semi-active joint. An example for active joint is the hip joint whereas the semi-active joints are knee and ankle joints. The MR damper is able to provide more damping force and a certain degree of elastic recovery force. Besides, the Mr damper has limited achievable flexibility. Hence, the MR damper is implemented in the design of knee joint that uses smart bionic leg. There are many benefits of active joint and passive joint of a partially-active controlled knee joint by an MR damper. The benefits are good agility, minimum power requirement, and many more. It mimics almost completely to real human leg and it is a perfect choice for intelligent prosthesis.

Xie (2010) also studied that human walking is a sophisticated movement of multi-freedom space mechanism. The control system of human walking is a very complex self-regulation system. These facts are stated based on the point of view of mechanism. Generally, the aim of the research of prosthesis is to simulate the deficient functioning of amputees' limb to be accurate and similar as before. The functional requirement of above-knee prosthesis is stated below:

1) Security

The most important criteria of the knee prosthetis is its security. It is a prerequisite requirement before the other functional charactieristic can be implimented on the prosthesis. To acheive natural movement of the lower limbs and ensure stable balancing of body, prosthesis must be able to provide enough stability during support phase. Besides, it must also have managable amount of flexibility and extension.

2) Light-duty and miniaturization

The invented knee prosthesis must be light-weight because of many reasons. The specific part of the users' body that will control the movement of prosthesis is the thigh nub. It is very weak and has low muscular strength yet it has to do a very difficult job. The energy from tigh nub of the amputees is contributing to the force that controls prosthesis motion. Hence, in order to make this easier for the user, the invented prosthesis should be designed to be light-weight. In addition, prosthesis design must be simplified and miniaturized in order to ensure a good-looking appearance with symmetrical shape of the amputee's actual legs.

3) Minimum power requirement

The inoperable amputess leg is not capable to supply torque to create flexion and extension for the prosthesis knee joint. The damper will control the implementation of the knee joint. Longevity of prosthesis is important, hence minimum power usage of the device is a general demand in prosthesis design.

4) Personification

A knee prosthesis must be able to mimics human natural gait as accurate as possible. For an instance, the shape of the prosthesis should seem natural and realistic shape during static state and ensure stability of support phase during dynamic state. It also should be able to control heel rise at initial phase, free swing at metaphase, and forward swing of crus at telophase during swing phase. Moreover, prosthesis should transform automatically with gait rhythm to maintain normal gait.

5) Functional compensation domain

Human does not only walk in our life. We run, jump, squat and many more. Since human can do various activities using our leg, knee prosthesis should also fullfil the need of standing up, sitting down, going up/down the stairs, riding a bicycle, doing athletics/sports, driving a car and even dance.