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Development of a Humanly Supported Hybrid System Using PIC Microcontrollers for Prosthethic Limb Applications

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Abstract

Walking is one of the principal and complex movements of the human body. The human locomotion is a periodic physical activity occurring by driving of the bones by muscles, which are stimulated by electrical signals transferred by neurons from the brain. In the present living conditions people with muscle weakness and partial paralysis of limb are increasing day by day and to perform daily activities for such people an assistive device is necessary with which they can do their daily activities like ordinary people. Prosthetic limbs are incredibly valuable to amputees because it can help restore some of the capabilities lost with the amputated limb. This paper focuses on developing a driving circuit to actuate the motorized assistive device. The driving circuit for the supervisory control of DC motors to lock and unlock knee for a limb during locomotion is designed. Here PIC microcontroller is used to control the DC series motors for the desired position.

Keywords: DC Motors; Locomotion; Prosthetic Limbs.

1. Introduction

The human body is a remarkable piece of biological machinery, and our limbs are no exception. When someone loses a limb due to injury or disease, the functionality once offered by that limb is lost as well. Therefore prosthetic limbs are incredibly valuable to amputees because the replacement by an artificial body part can help restore some of the lost capabilities. Human leg provides numerous complex functions and multiple degrees of freedom. These wide varieties of functions of human leg cannot be imitated immaculately by any artificial means. However, incredible advancements have been achieved for active prosthetic legs in the recent years. The best known present day artificial leg is the C-Leg produced by Otto Block. The C-Leg supports up to 10 programmable modes for cycling, running, natural driving and other programmable activities that require different leg actions to normal walking and stair climbing. An inbuilt microprocessor interprets the user's movements and anticipates the actions allowing motion changes in real time. The C-leg keeps knee stability, free swinging and support whenever we need it.

The human walking pattern is a periodic function of the movement of the upper and the lower limb. Human locomotion involves the dynamics of two legs which includes the locking of first leg knee joint called stance phase, unlocking of the knee of the second leg called swing phase and dynamics of both legs during their unlock condition. During the stance phase the heel of the foot strikes the ground and the knee flexes and the whole weight of the body is shifted on the leg and the lower limb moves. During the swing phase the foot leaves the ground and the knee swings till the heel of the foot is ready to strike the ground. Stance phase accounts for approximately 60% and swing phase for approximately 40 % of a single gait cycle (Tong,1999). Specifically, a good artificial limb knee joint can guarantee the stability in the stance phase and the flexibility of the swing phase so the amputee gait could close to natural gait. At the same time, the artificial limb knee joint is also the determining factor of the entire artificial limb's performance and life (Kaufman,1996). The maximum energy is consumed during walking in swing phase. The requirement of above knee (AK) prosthesis is to provide support to the knee during the stance phase and provide damping to the knee during its swing phase. The conventional AK prosthesis designs consist of different spring mass damper mechanisms but they only provide support to the leg and did not fully anticipate in the movement of the leg (Yakimovich,2009). Attempts have been made to design a new orthosis that would improve gait over conventional locked-knee KAFOs. However, several difficult design challenges hindered efforts to solve this problem. Recently, a new type of KAFO has emerged on the orthotics market that allows wearers to flex their knee when swinging the leg forward while preventing knee flexion during weight-bearing. These new designs have been commonly labelled stance-control knee-ankle-foot orthoses (SCKAFOs) in the orthotics community. SCKAFO designs must ensure proper functioning during stance and swing, as well as appropriate switching between weight-bearing and nonweight-bearing modes (Kim,2001).

A SmartLeg model was developed (Dedic,2011) to prove a real possibility that a person with an above or below knee amputation can perform different types of motions which require power in knee and ankle joints, like climbing stairs, with hydraulic units whose weight and overall dimensions would not interfere with the comfort of the prosthesis user. An upper limb below elbow prosthetic was designed which can be used by both amputees and paralyzed patients to bring simple hand movements to the fingers like flexion, extension and grabbing of objects (Khanra,2011). Electrodes were attached between the patient limb and the microprocessor, which analyses nerve signals to be processed and a 360 degree rotational arm was developed by appropriately selecting the motor and impulse sequence (Aravinthan,2010). An on/off switch is provided on the waist harness to control the start and stop of the hand movement and is connected to the 8051 micro-controller to control the motor movement. The micro-controller is programmed to control the 12V DC motor movement. The control system extracts the mechanical or electrical signals from the amputee to perform signal processing and then combine them to take decisions and supervise the system function.

A wearable walking support device called wearable walking helper is proposed for supporting antigravity muscles on lower extremities and a model based control algorithm for the device without using biological signals (Nakamura,2003). The mechanical behaviour of leg muscles and tendons during human walking is analysed by (Endo,2009) and from the two-dimensional leg model the hypothesis was evaluated that a robotic leg can capture the dominant mechanical behaviour of the human knee during level-ground ambulation at self-selected speeds. Walking robots can achieve human-like leg mechanics and energetics without knee actuators. With the advanced technology biomechanics has made great strides in analyzing more complex body movements and because of the considerable interactions between adjacent muscles it is becoming necessary to identify motor synergies (David,1990).

2. System Description

The system envisaged can be represented by the block diagram shown in Figure 1. The input from the power supply unit is 5V which is provided to PIC18F microcontroller which in turn generates pulses and the driver circuit drives the DC motors accordingly and the corresponding angles and their direction of rotation will be displayed in LCD. Any angle desired by the user can be given as the input to the PIC16F microcontroller, by using keyboard interfacing technique.

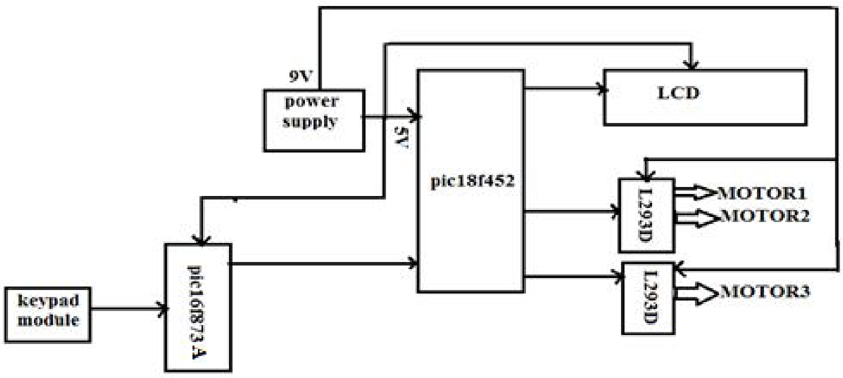

Figure 1: Block diagram of the Control Circuit.

In medical terminology the walking of a human leg is coordinated as follows:

1) When one leg moves forward, the knees of that leg rotate in clockwise direction whereas the hips rotate in the anti-clockwise direction.
2) When one leg is moving the other leg locks itself.

This movement can be achieved by using 6 DC motors mimicking the various movements of the knees, hips and the locking of the legs.

In this work mainly 2 microcontrollers PIC18F and PIC16F are used which is explained briefly. PIC microcontroller is used in this work to control and drive the 3 DC series motors for locking and unlocking the knees and hip for one leg involved in human locomotion. PIC18F452 Microcontroller is available in 40 pin DIP package and has program memory capacity of 32KB, RAM of 1.5 KB. They work in clock frequency range of 40MHz and an operating voltage of 2V to 5.5V and has 5 ports. PIC16F873 Microcontroller is available in 28 pin DIP package and has program memory capacity of 7KB, RAM of 192 bytes. They work in clock frequency range of 20MHz and has 3 ports and works with an operating voltage of 2V to 5.5V. It features 5 channels of 8-bit Analog-to-Digital (A/D) converter and can be configured as either 3-wire Serial Peripheral Interface (SPI) or a Universal Asynchronous Receiver Transmitter (USART).

Keypad is organized as a matrix of switches in rows and columns. In this work, an array of 10 buttons numbered from 0-9 which acts as a numeric keypad for entering the input angle for rotating the motor is used. Figure 2 shows the connection of keypad with PIC16F microcontroller. The concept of interfacing keypad with the MCU is simple. Every number is assigned two unique parameters, i.e., row and column number n(R, C) (Eg: 6 (2, 3)). Hence every time a key is pressed the number is identified by detecting the row and column number of the key pressed. Initially all the rows are set to zero by the controller and the columns are scanned to check if any key is pressed.

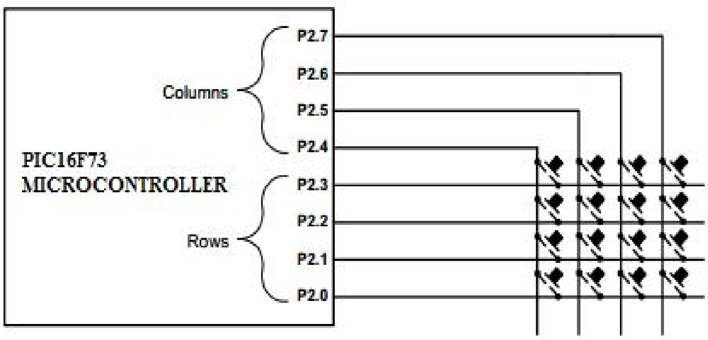

Figure 2: A simple keypad interfacing circuit.

LCD is Liquid Crystal Display which is a 16pin display unit. The PortD of the PIC18F microcontroller is used to send the data for displaying on the LCD. LCD has 3 control lines- RS(Register Select), R/W(Read/Write) and EN(Enable) pins respectively. Here separate LCD's are used for each motors to display the direction of rotation and the corresponding angle rotated. To control the direction of the DC motor L293D IC, which is an H bridge converter is used. A H bridge is an electronic circuit that enables a voltage to be applied across a load in either direction. These circuits are often used in robotics and other applications to allow DC motors to run forwards and backwards. The great ability of an H-bridge circuit is that the motor can be driven forward or backward at any speed, optionally using a completely independent power source. The L293D is designed to provide bidirectional drive currents of up to 600-mA at voltages from 4.5 V to 36 V. It is suitable for use in switching applications at frequencies up to 5 KHz.

DC motors are a good choice whenever controlled movement is required due to simplicity, low cost, high reliability, high torque at low speeds, and high accuracy of motion in applications where you need to control rotation angle, speed, position and synchronism. The speed of a DC motor can be controlled by changing the voltage applied to the armature or by changing the field current. Here 12V DC series motor with torque 10Nm is used. The DC motors employed are bidirectional and can be rotated in forward and backward directions. A photograph of entire setup of control system drive is shown in Figure 3.

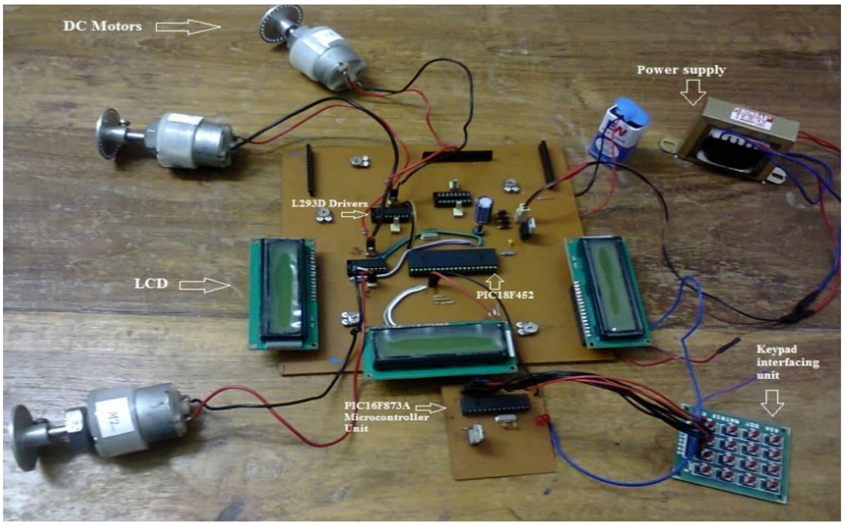

Figure 3: Entire control system drive setup.

3. Simulation Circuit

The microcontroller programming was done in MPLAB and the system was simulated using Proteus software. The simulation model designed in Proteus software is shown in Figure 4. MPLAB Integrated Development Environment (IDE) is a software program that runs on a PC to develop applications for Microchip microcontrollers. It is called an Integrated Development Environment because it provides a single integrated environment to develop code for embedded microcontrollers. It provides an integrated toolset for the development of embedded applications employing Microchip's PIC and microcontrollers. Proteus is the software for microprocessor simulation, schematic capture, and printed circuit board (PCB) design.

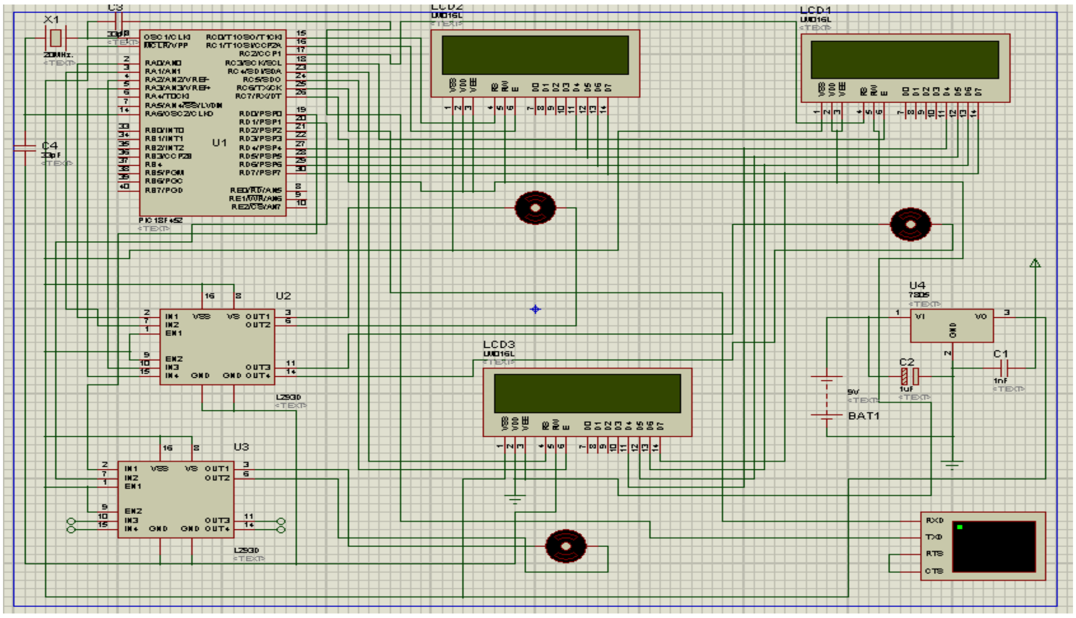

Figure 4: Simulation circuit of the proposed System.

4. Algorithm

1) Ports of PIC microcontroller is initialized and the appropriate mode of timer is chosen.
2) The PIC18F microcontroller is checked whether it is ready for accepting the data, if so then enter the angle through keypad which is connected to PIC16F microcontroller otherwise check continuously whether the microcontroller is ready or not.
3) PIC18F receives the data from PIC16F via serial communication.
4) PIC18F gives instructions to driver circuit (L293D) to drive M1(Knee) Clockwise, M2(Hip) Anticlockwise and M3(Knee) Clockwise and LCD Displays “LOCKED”.

5. Conclusion

The objective of this work is to develop a control system drive (software as well as hardware based) for the assistive limb by considering modification of existing control theory. The driving circuit for the supervisory control of 3 DC series motors to lock and unlock the knee and the hip of a leg during stance phase and swing phase of human locomotion is designed to conduct the motion and dynamic analysis for variable speeds. The human locomotion is concerned with the movement of 2 legs and this can be achieved by controlling 6 DC series motors for locking and unlocking. The control strategies for remaining 3 motors are in progress. These two drives need to be sequentialised and synchronized such that the locomotion of both the hip and the knee is executed. The microcontrollers used are PIC16F and PIC18F to control the DC series motors for the desired position. The proposed mechanism is an open loop control and checked with the hardware developed and results seems to be satisfactory. Future work involves making the control system drive closed loop with the help of feedback circuitry which includes optical encoders.

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