Smart Portable Fuzzy Logic Control Systems for Active Ankle Foot

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ABSTRACT
Without our foot, which God gave us as a gift to assist us in walking, running, and dancing, our daily activities would be negatively impacted. But occasionally, because of neurological conditions or strokes, the muscles or joints that control our gait pattern are also affected, which results in a gait pattern that is disrupted. This abnormality makes it difficult to maintain a correct foot landing and foot clearance throughout the foot striking and swing phases, respectively. Ankle Foot Orthosis (AFO), an orthotic device used to modify gait patterns, is created to get around this restriction. As a result, this paper enters the picture, and the controller is created and implemented onto the c-RIO to control the actuation mechanism for the device utilizing fuzzy logic.The controller is created using fuzzy logic and installed on the c-RIO according to the design of the paper. Analog gyroscope data is used to gather the gait patterns of both feet and feed them to the controller. In order to analyze the gait patterns, only two parameters—angle and angular velocity—are taken into account. Fuzzification, fuzzy if-then rules, and defuzzification are the three steps in the controller design process. The output that will operate the actuator is the defuzzified output. Extension or flexion With a regular walking speed, motion aid is given during various parts of the gait cycle. Designing an intelligent control system to initiate the necessary motion to generate flexion or extension by examining inputs from the sensors constitutes the bulk of the work. Additionally, the sensor data induces a torque through an actuator. By continuously observing the gait patterns, the control system gives real-time control of the damaged foot. The sensor system with a gyroscope produces the input signals for the control system. Plantar-flexion and dorsiflexion movements of the ankle during walking are provided by the FLC created in Laboratory Virtual Instruments Engineering Workbench (LabVIEW).

Keywords**:** *fuzzy logic, defuzzification, ankle*

I. INTRODUCTION

This paper includes a brief discussion of intelligent control techniques, why fuzzy logic is preferred over other conventional techniques while designing a controller. A brief insight into what Ankle foot orthosis is, why it is implemented is also discussed. Moreover we also give an in-detail description of why some people have abnormal gait patterns. Henceforth the main motivation leading to this objective is also discussed. Intelligent control techniques that emulate characteristics of biological systems offer opportunities for creating control products with new capabilities. Intelligence is a mental quality that consists of the abilities to learn from experience, adapt to new situations, understand and handle abstract concepts, and uses knowledge to manipulate one's environment. Fuzzy logic systems are based on the experience of a human operator, expressed in a linguistic form (normally IF-THEN rules). Fuzzy logic has the advantage that the solution to the problem can be cast in terms that human operators can understand, so that their experience can be used in the design of the controller. The input variables in a fuzzy control system are in general mapped by sets of membership functions similar to this, known as "fuzzy sets".[1] Fuzzy logic systems, emulate human decision making more closely, thereby increasing efficiency. The main advantages are that no mathematical modelling is required as in PID since the controller rules are based on the knowledge of system behavior and experience of the control engineer.

II. METHODOLOGY

The paper was started with literature survey of past work. Taking inspiration from work done by Dr. Kanthi on the fuzzy controller based AFO, membership functions were created in LabVIEW.

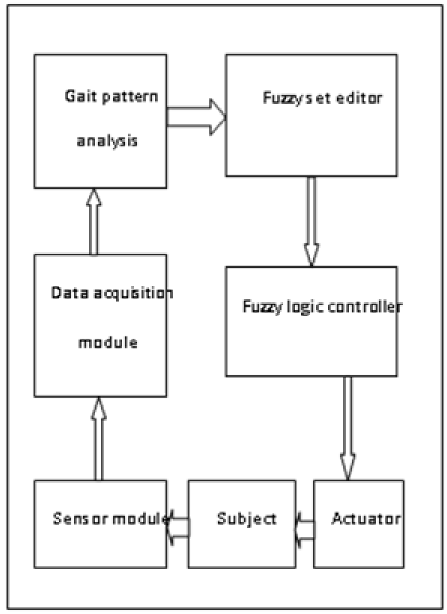

Figure 2.1: Functional Block Diagram

The gyroscope sensor LPY530AL is attached to the subject's working leg. The sensor is attached to the middle part of the foot so that both the dorsiflexion and plantar-flexion phases are determined completely for accurate data acquisition. The placement of sensor for gait data analysis is shown

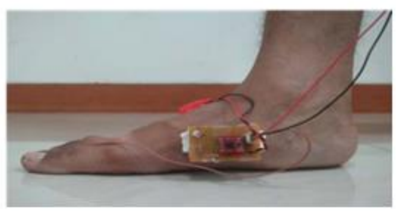

Figure 2.2: Gyro-sensor placement

The gait patterns of both the legs during one complete walking cycle are observed for a normal person and accordingly the controller is designed to replicate the same pattern for the defective leg. The fuzzy set editor is used to fuzzify the discrete data. The rules are made by analysing the input data. The fuzzy controller will defuzzify the output based upon the type of defuzzification method used and gives a discrete output which is used as a control signal for the actuation of the defective leg.

III. GAIT ANALYSIS

The gyroscope sensor LPY530AL is attached to the subject's working leg. The sensor is attached to the middle part of the foot so that both the dorsiflexion and planterflexion phases are determined completely for accurate data acquisition.[10] During the data acquisition phase the gyroscope is first attached to the left foot to observe the gait pattern during one complete cycle followed by the gyroscope being attached to the right foot. In both the cases a similar walking pattern is replicated so that the complete gait pattern followed by both the left and right foot could be detected almost synchronously. In the experimental set up the left foot is taken as the start of the walking cycle first. From the values collected it is observed that the left foot first makes a dorsiflexion motion followed by a plantar flexion whereas at the same time the right foot makes a plantarflexion movement first followed by a dorsiflexion. A similar pattern is observed for angular velocity values. The angular displacement of the foot from flat foot position can be determined by finding the area under the curve of the Angular velocity versus time plot. This is obtained by continuously integrating the angular velocity values with respect to time from zero to current time 't' [10]. The values of both angular velocity and angular displacement are plotted for an average gait cycle.

IV. FUZZY RULE BASE

Fuzzy rule base is based on the expert knowledge of the system to be controlled. The four main methods for finding control rules are:

- Expert experience and control engineering knowledge.
- Based on an experimental operators control actions.
- Based on a fuzzy model of the system.
- Based on adaptation or learning.

4.1 Creating Membership Values

The fuzzy rule base for the control system to be designed is developed using the gait patterns shown in Figure 3.3 which was obtained from previous work

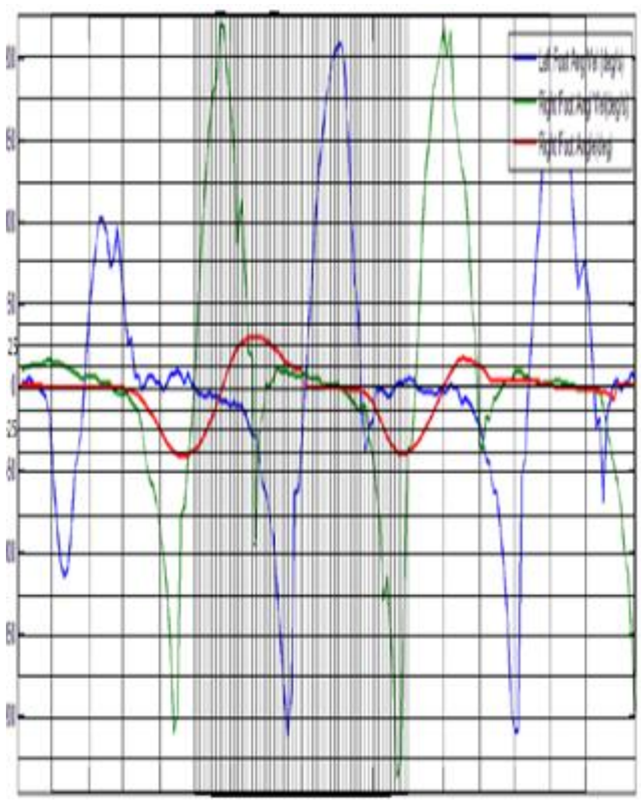

Figure 4.1: Gait pattern

Figure shows the plot of the input variables right foot angular velocity, right foot angle and left foot angle simultaneously with respect to number of samples. . From the graph we notice that it is periodic although not precisely (since the data is real time). Also we notice that the angular velocities for both the feet range approximately between -225 to +225 and the right foot angle ranges between -50 to +50.

We now write the membership values for the three linguistic variables by considering any one period of interval from the above gait plot. The graph is divided into many small grids and in each grid the range of the variables is noted and the membership values for each variable is defined.

The left foot of the test subject was assumed to be defective, while the right foot was considered normal. The sensor then read the angular velocity and the angle of the right foot of the test subject in degree/second (deg/s) degrees (deg). Using the right foot as a reference for a normal person, i.e. a person not suffering from foot drop, the actuation to the left foot was provided in deg/s. In the given figure, the green, red and blue curves represent the angular velocity of the right foot, the angle of the right foot and the actuation provided to the left foot respectively. The angular velocity and actuation ideally replicate a sinusoidal curve. Using this graph and the properties of sinusoidal curves, the membership functions were plotted considering the region of the graph with the dense grids, i.e. from sample number 50 to sample no 110.

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Table 4.1: Membership functions

Velocity	Angle	Actuation
V1 [-220,-180]	An1 [-50,-30]	Act1 [-200,-165]
V2 [-200,-150]	An2 [-40,-25]	Act2 [-180,-120]
V3 [-160,-120]	An3 [-30,-20]	Act3 [-150,-90]
V4 [-140,-110]	An4 [-25,-10]	Act4 [-120,-50]
V5 [-120,-90]	An5 [-15,0]	Act5 [-60,-30]
V6 [-100,-60]	An6 [0]	Act6 [-35,-20]
V7 [-70,-30]	An7 [0,15]	Act7 [-25,-10]
V8 [-35,-10]	An8 [10,25]	Act8 [-15,-5]
V9 [-15,0]	An9 [20,30]	Act9 [-10,0]
V10 [0]	An10 [25,40]	Act10 [0]
V11 [0,15]	An11 [30,50]	Act11 [0,10]
V12 [10,35]		Act12 [5,15]
V13 [30,70]		Act13 [10,25]
V14 [60,100]		Act14 [20,35]
V15 [90,120]		Act15 [30,60]
V16 [110,140]		Act16 [50,120]
V17 [120,160]		Act17 [90,150]
V18 [150,200]		Act18[120,180]
V19[180,220]		Act19[170,225]

The input right foot angle has been divided into eleven membership functions namely m1,m2,m3,m4,m5,m6,m7,m8,m9,m10,m11 as shown in Figure

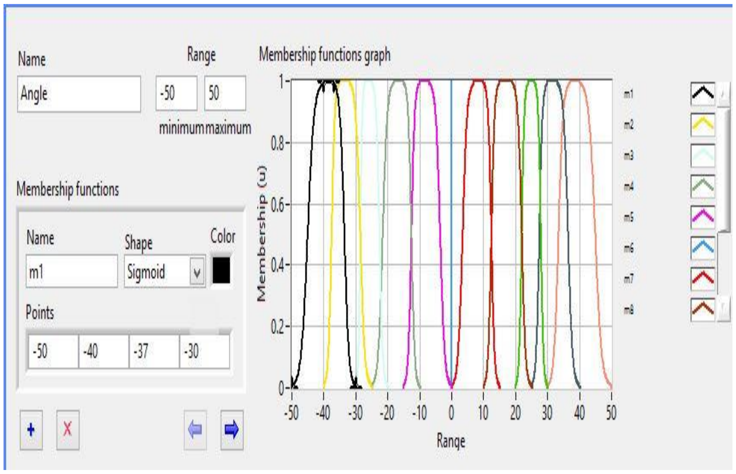

Figure 4.2: Membership function for angle (Right leg)

The input variable right foot angular velocity is divided into nineteen membership functions namely M1 to M19 as shown in Figure

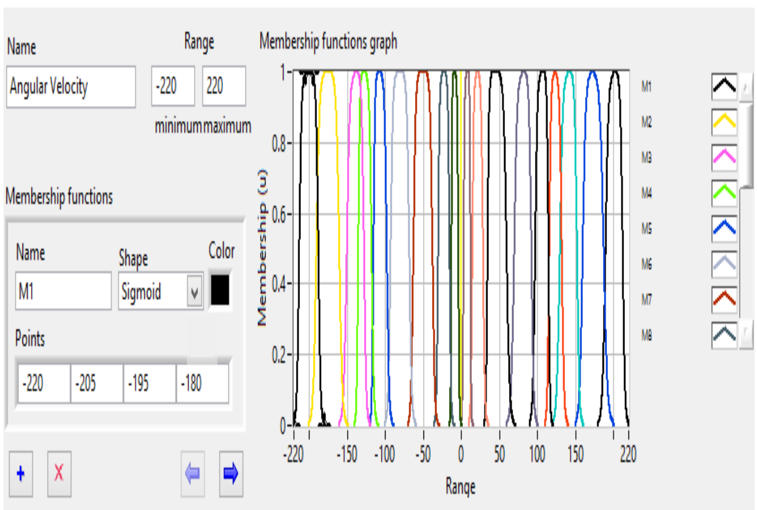

Figure 4.3: Membership functions for angular velocity (Right leg)

The output left foot angular velocity has been divided into nineteen membership functions namely a1 to a19 as shown in Figure

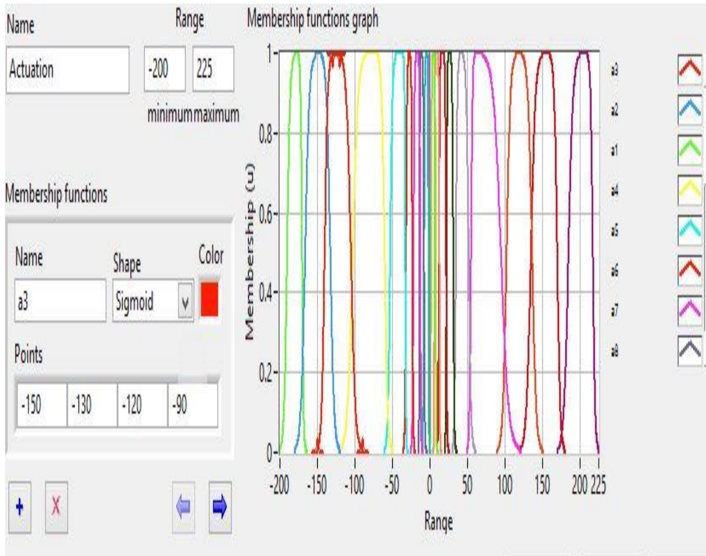

Figure 4.4*:* Membership functions for Angular Velocity (Left leg)

V. DESIGN OF FUZZY CONTROLLER IN VI

Fuzzy controller was made due to lack of possibility to use LabVIEW built in tools. FPGA mode make it impossible to use 'drag and drop' method that is why fuzzy controller in this project was made manually. The design of a fuzzy controller was divided into 3 parts: Fuzzification, Implementation of Fuzzy rules and De-fuzzification.

- *Fuzzification*

Fuzzification is a process to change the crisp input into fuzzy values. In this controller were used sigmoidal membership functions - for two inputs: angular velocity and angle.
A sigmoid MF is defined by eq ---------------1

$$sig(x,c) = \frac{1}{1+\exp(-a(x-c))} \quad (1)$$

Where *a* controls the slope at the crossover point *x*=*c*.

Depending on the sign of the parameter *a*, a sigmoid MF is inherently open right or left and thus is appropriate for representing concepts such as "very large" or "very negative".

The range of values for slope 'A' and angular velocity, Angle 'C' are considered and the crisp input is converted into fuzzy input and stored in an output array. The VI's in which fuzzification for angle and angular velocity are done is shown in Fig.

VI. C-RIO CONFIGURATION

After designing the VI's for fuzzification, fuzzy-rules and de-fuzzification, it has to be combined into a single VI so that the resulting controller can be implemented onto the c-RIO. Before this, it is necessary to configure the c-RIO.
The following steps should be followed while configuring the CompactRIO[9].

Step1: Click on Measurement & Automation Explorer (MAX) which is a part of LabVIEW software and which allows us to configure the NI hardware connected to PC.

Step2: Expand Remote Systems in MAX to verify CompactRIO is detected or not.

Step3: Select the CompactRIO device (pointed with arrow in Figure 3.12) and then go to the Network settings part of the panel and enter IPv4 address and subnet mask. In our thesis IPv4 address is assigned as 10.10.10.10 and subnet mask as 255.0.0.0 in Figure

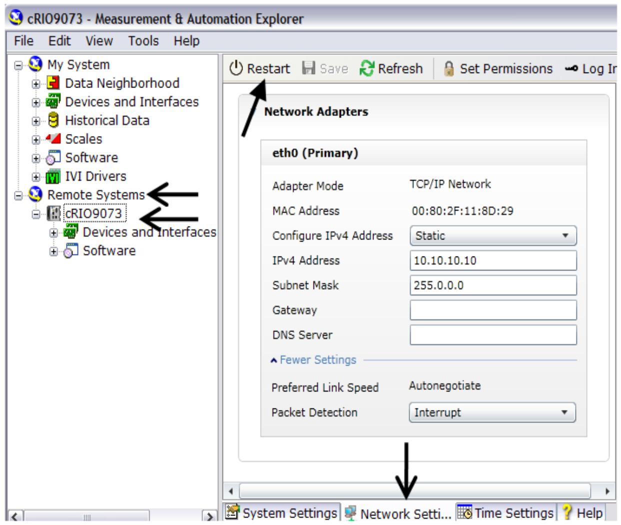

Figure 6.1: Screen shot of IPv4 configuration

Step4: Now click the Restart button in MAX (pointed with arrow in Figure 3.12). MAX will reboot the CompactRIO. (Note: It won't reboot the desktop computer).

Step5: The software required should be transferred to the CompactRIO by using MAX. Click on Software and Add/Remove software as pointed with arrow in Figure 3.13. It will pop up a Real- Time Software Wizard window which allows us to transfer the required software to the CompactRIO. As we are processing and filtering the signals, make sure that digital filter tool kit is transferred to CompactRIO.

Figure 6.2: Screen shot of select software

VII. CONCLUSION

There is extensive usage of fuzzy logic in machine control. When logic is described as "fuzzy," it means that it may deal with ideas that can only be described as "partially true" rather than as "true" or "false." Fuzzy logic offers the advantage of allowing the problem to be solved in terms that human operators can comprehend, allowing their expertise to be included into the controller design. These sets of membership functions, referred to as "fuzzy sets," typically map the input variables in a fuzzy control system. The usage of fuzzy control methods is required in numerous industrial applications. It is challenging to

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integrate fuzzy control methods on industry-standard hardware, nevertheless. In order to make project implementation and system control in foot orthoses easier, this project intends to develop a fuzzy controller.

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