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Development of a Full Body Balance Model Using an Artificial Neural Network Approach

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Abstract— **The purpose of this paper is to identify body balance using an artificial neural network approach. This research entails the study of dynamic stability within a normal person. This study is inspired because persons suffering from lower extremity loss suffer a variety of complications including numbness on the residual limb and sores caused from the prosthetic. Because this occurs, they have a slightly abnormal gait pattern, possibly to keep balance while in motion. This study analyzes the gait motion of a normal healthy subject. We take the data and manipulate it to delete or alter the function of the right leg. Data was taken using an 8 camera VICON motion capture system at the Andrew Gitter GAIT Laboratory located in the Audie L. Murphy Veterans hospital. The markers placed at joints of the body were captured to give a 3-D position at a sampling rate of 120 MHz. A Neural Network was used for the modeling of normal walking gait using the given data.**

***Keywords*—Neural Networks, biomechanical modeling, bio-medical engineering**

I. Introduction

Amputees can suffer from difficulties in the residual as well as in their healthy limb. As many amputees can be prone to sores on the residual limb, they tend to lean on the healthy limb for compensation of the pain they are subject to in the amputated leg. Therefore, the gait changes are due to more pressure on one side. Above all, amputees in general struggle to maintain a desired walking speed as well as balance. This can cause difficulties in maintaining a healthy active lifestyle as well as difficulty with the prosthetic device.

This research targets the motion of the legs and whole body center-of-mass (COM). The COM is critical in balance and maintaining a steady gait. In maintaining a steady COM and the proper center-of-pressure (COP) involves the movement and placement or displacement of the legs. The primary determinants for fast or slow gait are the COM and COP. Reducing errors in their measurements enhances the understanding of postural stability.

Because amputees are subject to a prosthetic for the remainder of their life, they must also adjust their gait comfortably. This may not always be easy to due to the prosthetic and reliability on the device as well. Also, it may take years of adjusting to the use of the prosthetic because of the distribution of weight of the body that a person does while using the prosthetic and how the residual limb adjusts to the prosthetic.

In this study we research the body COM and the displacement and motion of the legs, more specifically, the use of the right leg that are needed to maintain full body balance while walking. Using a neural network to create a model we are able to see the actions of the right leg, which in this case is the 'amputated' leg or hurt, which will help maintain the COM. Then an inverse neural network controller is used to input what data is outputted from the model to analyze the full body COM while walking. We focus on adjusting to a changed COM to model the subject trying to optimize their gait. For instance if you have an active person that feels limited in walking due their prosthetic, they can learn to adjust their COM at certain position so that they can get the best motion and a faster motion from their prosthetic leg. This is what we want to analyze with this model; the motion of the body using this ANN model.

Many human static balance tests have been conducted among many different populations and are supposed to determine dynamic stability. And many have adopted the inverted pendulum model [2], which may not suffice for dynamic motion. Keeping balance while in motion may be easier to establish rather than balance in a static position simply because the pressure is not always focused on both limbs at the same time. Many studies have analyzed static balance among normal subjects and other populations, however due to the complexity of the material, there lacks any dynamic balance analysis among any groups of subjects. And these studies have shown that while a subject is not able to sustain good balance statically they are able to do so

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dynamically. However, in this study, the analysis of dynamic balance implies that the theory that static balance helps predict dynamic balance does not fully correlate.

Furthermore this research helps to identify the gait pattern among patients who have suffered strokes, succumbed to neuropathy due to diabetes and patients who are subject to KAFO's (Knee Ankle Foot Orthotics). Most of the KAFO subjects are veterans who have suffered from injures due to war. A thorough analysis of their center of mass is vital to their adjusted walking. These patients have to get accustomed to a device that puts on significant weight on the limb and adjusts their gait. The subject may become fatigued after some time and may not function as desired. This research can reach into this area and analyze their gait, thus making for a possible enhanced device that may improve their gait or conditions during gait. For example if a KAFO subject optimized their COM, then they may get better heel-to-toe off of every step they take which implies that they are using their limbs to full capacity rather than always leaning on one side.

II. Procedure

A. Subjects

A healthy subject with a range in age of 18 years to 35 years participated in this pilot study. The participant is a young healthy male with no history of medical problems. All subjects that we want to compare this data to have similar characteristics in their gait pattern; leaning forward, short stride length, and short heel-to-toe off on each step.

B. Equipment

The VICON camera system used in this study samples at a 120 [Hz] and optically captures the X, Y, and Z coordinates of each of the reflective marker spheres on the human subjects. Data collection at the GAIT laboratory is performed by having 14 [mm] retro-reflective marker spheres placed on the human subject and having the displacement of the spheres recorded.

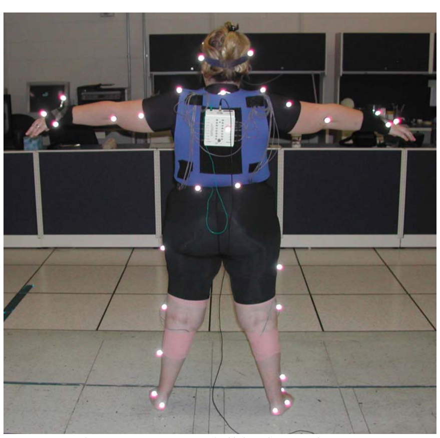

Figure1. VICON full body marker set

Both translational and rotational states are being collected under various standing and walking conditions.

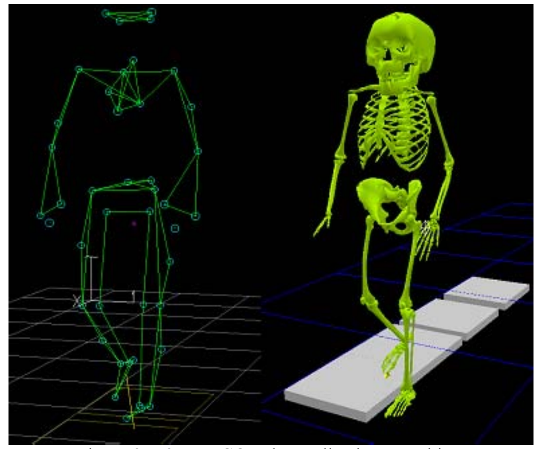

Figure 2. 3-D VICON data collection on subject

C. Test procedure

The data used for the system identification was collected at the University of Texas Health Science Center (UTHSCSA) Gait Analysis and Innovative Technologies (GAIT) GAIT Laboratory. The GAIT Laboratory operates an eight camera VICON optical motion measurement system that emits an infrared pulse which reflects off a series of reflective markers. Markers were placed at different joints and parts of the body and measurements of leg length, shoulder offset, hand thickness, elbow width, and ankle width were taken to construct a model to scale. Four ATMI force plates are also incorporated into the VICON system, which was used to analyze the subjects, enabling force measurements to be applied and measured synchronously with the 3D motion capture. Figure 1 shows data collection of a subject, portraying the compiled model with the reflective marker points and then displaying it as a meshed 3-D model. Force can also be collected in the VICON system as explained before via four ground force plates which are also displayed in figure 1. The subject was instructed to look straight ahead as they walked across the room, coming in contact with the four force plates. Data was taken at a self-selected speed and at a fast speed.

III. COM

The total body center of mass was calculated using the VICON marker data and anthropometric data using the formula:

$$X_{cg} = X_{proximal} + R_{proximal}(X_{distal} - X_{proximal}) \qquad (1)$$

Where $X_{proximal}$ is the position of the proximal end of the segment (i.e. leg, arm), and X_{distal} is the distal end of the segment. X_{cg} is the center of gravity or also known as the center of mass (COM). $R_{proximal}$ is the R value for the particular segment selected from a table of proportions known formally as an anthropometric data table.

The same is done for the Y and Z coordinates of each segment. To get the total COM or center of gravity (cg) of an entire limb, we used:

$$X_{segment} = \frac{\sum_{s=1}^{L} P_s X_{cg}}{\sum_{s=1}^{L} P_s} \tag{2}$$

Where L is the number of segments in the limb and the P_i are each segments mass proportion [14]. The total body COM or cg is computed using:

$$X_{total} = \sum_{s=1}^{L} P_s X_{cg} \tag{3}$$

Where x_{total} is the entire body COM in the X coordinate. S is the number of body segments and each segment us weighted according to its mass proportions.

IV. Modeling

Three dimensional data was taken from the motion coordinates corresponding to the movement in the sagittal plane. The entire COM in the X coordinate was the target output for the system and the inputs were the subjects' weight in kg and height in cm. The data was also plotted to analyze the numerical 3 dimensional dynamics of the patients and analyze the motion of the COM.

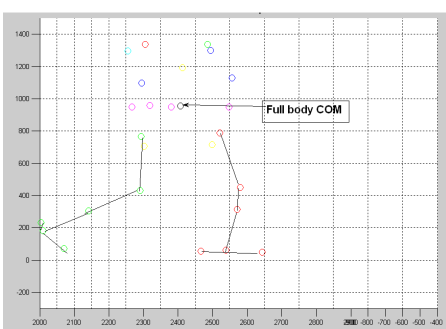

Figure 3. Full body marker data with COM

The segments that make up the calculation of the full body COM are the proximal and distal parts of each segment that makes up a limb. The X direction of motion is first taken into account due to the direction of the gait. Here we look at the COM motion in the arms, trunk and legs. The body's COM was calculated using the COM of the segments mentioned previously. We trained a neural network with the normal data, implementing a black-box model. The inputs were the left and right arm COM's, left leg COM and full body COM. The output to the network was the right leg COM.

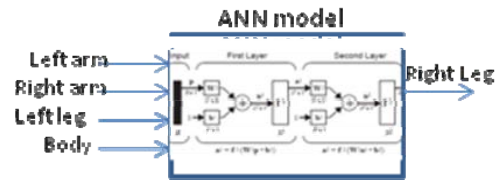

Figure 4. Neural Network Black box model

Then the model was tested with a different set of data taken from the same subject. The Neural Network is trained for one particular patient that has performed identical tasks as the other. Figure 5 shows the trained and tested data.

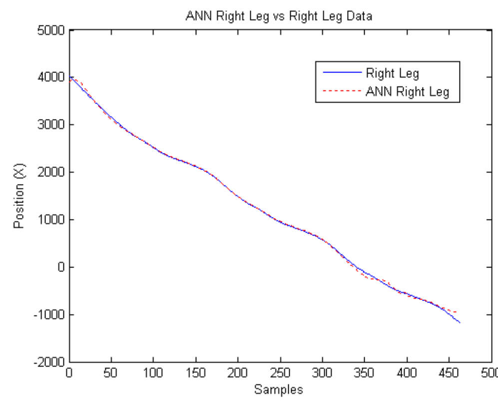

Figure 5. Tested ANN model

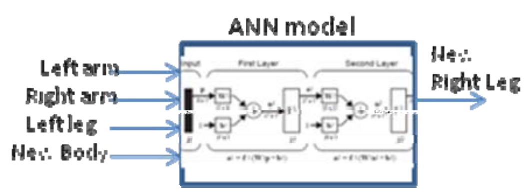

Figure 6. Model with new COM and new right leg output

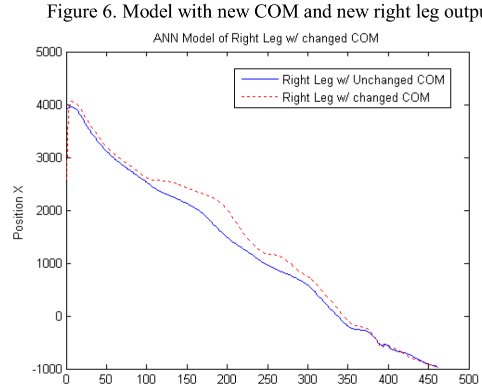

Figure 7. Model using changed COM and Right Leg output

Figure 7 displays the model with a changed COM. With this the right leg output (red) adjusts the needed position that corresponds to the desired COM. This optimizes the subject movement and gives a preferred walking speed. This model serves the purpose of viewing the changed or adjusted gait given a different COM. We are trying to view the model output and dynamics of the changed parameters and compare them to the original right leg motion with the corresponding COM of that leg. The figure displays the change in motion from the model. Overall this would mimic a situation in which a person with a device wants to move faster or adjust their motion; we can see what the motion would be of a limb given their whole body moves different. This is what is modeled here based of the corresponding limb in which we are analyzing. We are able to see and compare the motion.

This optimized output simulating the movement of the right leg is then inputted into the model with the other parameters, left leg, right arm, and left arm, and will give an output of COM. This is then compared to the optimized COM that was first inputted to see the validation of the model and analysis of the movement of gait. This is also to verify that the 'amputee' or person can or will maintain a good enough COM as a normal person to maintain steady gait.

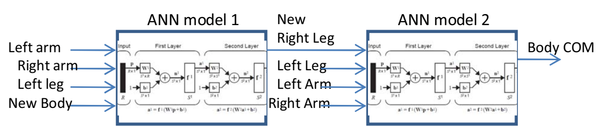

Figure 8. New Right leg output as input for new COM

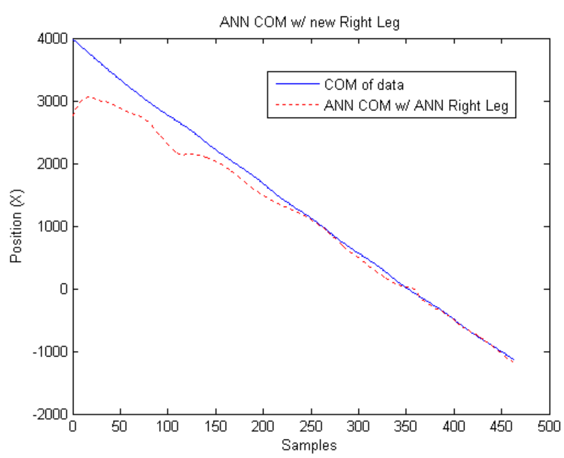

Figure 9 ANN COM output compared to data COM

Figure 9 shows the neural network output from the model of the entire body COM compared to the desired COM, using the neural network output of the right leg motion. This is to confirm that the ANN COM compares well with the actual COM using the ANN right leg output as an input.

V. CONCLUSION AND FUTURE WORKS

This research is particularly critical to the amputee population due to the growing number people losing limbs due to disease and war. The overall goal is to have a better understanding with the educational, clinical and research aspects of the effects of a lost limb on people and how to function. Not only for those effected but to provide a better understanding for the families and to provide adequate and proper care specific to the patient.

With the establishment of a larger amputee database data collected was able to be analyzed in many ways. Many studies involve in depth analysis of muscle actuation during walking as well as ground reaction force. This research focuses on the physical aspects of prosthetics and orthotic devices and how they may affect a person during gait movement. This is particularly important because this is new research involving the biomechanics for this particular population. This research helps defining problems in the gait pattern, justifying it and the problems in the gait dynamics that affect the person. (i.e. foot pressure, posture, joint fatigue).

The purpose of the research is to eventually develop a dynamic model of amputees while walking. This amputee model will eventually be used for the prediction of falls or imbalance in subjects.

Fuzzy logic is proposed to be used to first find the relationship between the 2-D COP and 3-D COM. However accurately determining ones COM has been a question among many researchers and many methods have been accounted for. A Particle Swarm Optimization (PSO) method is to be used as a controller and assists in the coefficient fittings by optimizing the curve fitting. The relationship between the COM and COP has been a major factor in addressing how this population maintains their balance statically and dynamically. Many static balances among these patients have determined that they maintain little balance, which is supposed to determine if they can balance dynamically. However, this study has shown that although statically they cannot balance well or long, while in motion they are able to balance and maintain it.

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