Towards a neuromusculoskeletal platform to simulate healthy and deficient gait with assistive devices

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***Abstract*— The aim of the work presented here is to bring forward our neuromusculoskeletal gait simulation platform [1] and the robotic assistance system called UPS-PD [2]. The purpose of this project is to simulate patients with certain gait deficiencies to minimize their mobility problems. The project aims to simulate healthy and deficient human gait with the simulation platform and finally obtain an insight view of the motor system along with a plausible human neural system model.**

I. Introduction

Parkinson disease (PD) is a progressive neurodegenerative disorder commonly affecting middle-aged and elderly people causing different deficiency in their motor ability like slowness, stiffness of movements and tremors. One of the most common symptoms of PD is the Freezing of Gait (FoG) where the patient is locked in the Double Limb Support phase (DLS) during gait, without being able to continue walking. The goal of the proposed simulation platform is to 1) simulate different healthy and deficient digital gates generated by a neural control circuitry, 2) reproduce gaits recorded from experiments on humans 3) automatically classify the gates into different classes: Parkinson, healthy, other... 4) simulate gait with artificial devices aiming to improve or compensate for walking troubles 5) help better understand how the disease affects the other components of the motor system. The teams involved in this project as a collaboration are Team Neurorhythms - Loria, France and Pr. Shibata's Team Kyutech, Japan [2].

II. The simulation platform

A. Objectives

The first goal of this simulation platform is to generate various types of gaits by changing parameters of a neural controller based on Central Pattern Generators (CPGs) (Figure 1.). These gaits will help us feed a database for further analysis and research.

The second objective of the project is to replicate specific human gait based on visual analysis, wearable IMU and force sensors. This will help us understand how different diseases affect the gait from a muscular point of view.

The third objective is to build tools to analyze different types of gaits and highlight symptoms of certain diseases. These tools will allow to classify gaits based on specific indexes with the help of a customized classifier model for each purpose.

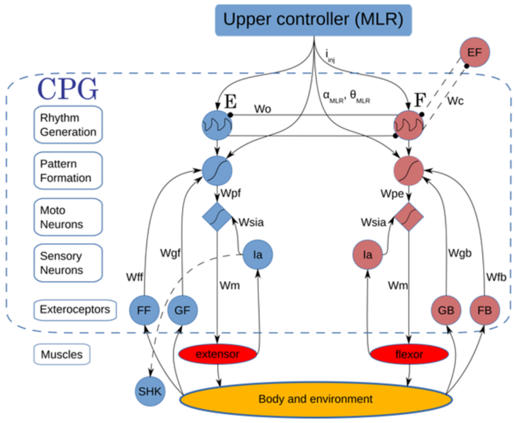

Figure 1. Central Pattern Generator architecture and parameters

B. Presentation and tools

1) CPG network architecture

To simulate the effects of PD on the human gait, we use a neuromusculoskeletal model of the human locomotion system. The simulation platform can be divided in several layers (Figure 2.). The goal of the first level is to model a part of the basal ganglia Mesencephalic Locomotor Region (MLR), which represents the brain region thought to initiate locomotion. This layer controls the second layer, which includes the Central Pattern Generator network (CPG), the reflex controller and the arm controller. The two later controllers help maintain balance in the stance phase and supplement balance control during gait, but it doesn't allow the removal of the support harness. Resulting information from this controller layer is sent to the third layer, the musculoskeletal model and simulator. This CPG control works in closed loop using the fourth layer which is the common sensory layer sending feedback at each time step of the simulation to the controller layer.

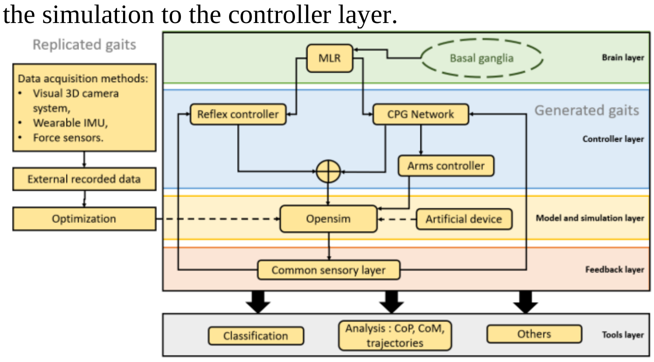

Figure 2. Project architecture and functionality

We use a four-layer CPG model (Figure 1.), including additionally the upper controller (MLR) and the sensory layer for feedback proprioceptive and exteroceptive informations. The MLR varies the frequency of the generated pattern by increasing excitability at both Rhythm Generation (RG) and Pattern Formation (PF) levels. The PF layer also gets inputs from the exteroceptors and the motoneuron layer (MN) gets inputs from the proprioceptors both belonging to the Sensory Neuron layer (SN). Refer to [3] for model details and equations of the CPGs.

Our current network has four CPGs, two for each leg, meaning right and left hip-knee and knee-ankle. The muscles are grouped according to muscle activation patterns during walk and each muscle is controlled by only one CPG.

2) Analysis and data acquisition methods

To analyze and compare healthy and PD gaits, several complementary and analysis tools based on multiple articles related to gait and foot pathologies ([3], [4], [5]) will be built.

To acquire the necessary data for the optimization of parameters of our simulation platform (see section 3)), equipment such as force sensors and inertial measurement units (IMU) from the TEA Captiv products (https://www.teaergo.com) will be used along with visual motion capture. This allows to drive free walk experiments with subjects by recording synchronized CoP and joint trajectories. The placement of the force sensors is inspired by the placement of the contact spheres in the Opensim model as in Figure 3. A). The same experiment can be used to get experimental data on joint trajectories and center of mass (CoM) trajectories.

Some work has already been done to implement center of pressure (CoP) trajectory and density analysis in the simulation platform as shown respectively in Figure 3. B), Figure 3. C).

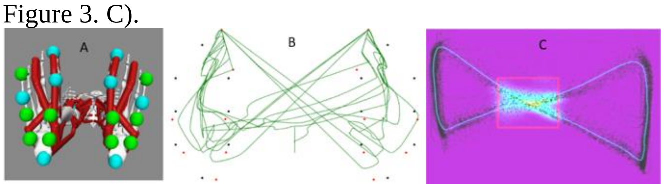

Figure 3. A) Contact sphere placement in Opensim model, B) CoP trajectory display, C) CoP graph density analysis

3) Parameter's optimization

To replicate or generate varied types of gaits, we need to change the CPG parameters shown in Figure 1. To find a correct set of parameters, we must go through an optimization process with the goal of either replicate the joint movement of a specific gait or generate a constant walking gait. We don't know if there exist any link between parameters or what is the correct range of search for each parameter, so we need to explore first from a large scale and then reduce the space of research. A genetic algorithm is used with a custom fitness function to evolve toward good or better solutions.

III. IMPLEMENTATION OF ASSISTIVE DEVICE

Threshold theory exists as a mechanism for the occurrence of FOG [6]. FOG occurs when the progression of gait asymmetry and the progressive deterioration of gait, represented by a decrease in stride length and an increase in cadence, exceeds a threshold value. Many PD patients can ride a bicycle despite being severely compromised by gait disturbances up to freezing of gait [7]. Therefore, Shibata's research group developed UPS-PD [2] to support the maintenance of self-induced bipedal coordinated movement, similar to that of a bicycle (Figure 4.). UPS-PD detects the ground contact using the threshold of the foot sensor and drives the artificial muscles by inputting CO2 gas between heel contact and heel release by switching the valve using Arduino and solenoid valve. Preliminary results show that UPS-PD improves the gait of PD patients and reduces the frequency of scooting in meandering pathways where scooting is more likely to occur in PD patients. The simulator platform will allow us to form hypotheses about how UPS-PD suppresses FOG and explore more ways to assist.

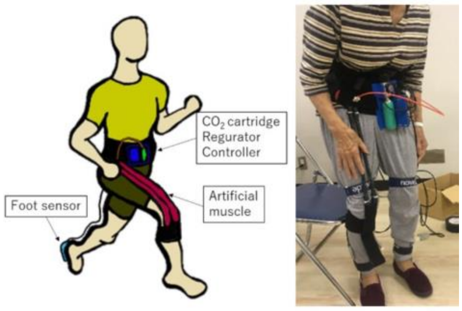

Figure 4. Schematic view of UPS-PD mounting.

IV. ACKNOWLEDGMENTS

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