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SmartStim: A Recurrent Neural Network Assisted Adaptive Functional Electrical Stimulation for Walking

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Abstract: According to the Neuro Patience report of the Neurological Alliance, 1 in 6 people in the UK has a neurological condition. With the growth in technology, rehabilitation for neurological problems is one of the fast-growing fields. Functional Electrical Stimulation (FES) is one of those neuro-rehabilitation methods that uses electrical nerve stimulation to restore functional muscle movements that are lost due to neurological problems such as stroke and multiple sclerosis. This neuroprosthetic device is frequently used to assist walking by treating a condition called Drop Foot, a result of paralysis of the pretibial muscles. This study proposes a two-channel FES device called the SmartStim, which has the ability to modulate its stimulation levels according to various obstacles such as stairs and ramps. This system employs a sensor-based module with a Recurrent Neural Network to classify these different walking scenarios. The module is built with Inertial Measurement sensors embedded in a pair of shoes, and the Recurrent Neural Network uses data from these sensors to predict various obstacles as the user is walking. These predictions are then used by a Fuzzy Logic Controller to control and regulate the stimulation current in two channels of the SmartStim system.
In the two channels of the system, one channel will help aid with drop foot, while the other will be used to stimulate another muscle group to help access stairs and ramps by the user. The Recurrent Neural Network module in this system has been trained and tested using the k-fold cross-validation. The evaluation of this trained model shows that it can predict obstacles from sensor data at 97 percent accuracy. Currently, further testing is being performed to assess the workings of the fuzzy logic controller in combination with the Recurrent Neural Network in healthy individuals. It is expected that the SmartStim system may aid users in accessing various walking scenarios more efficiently.

Keywords: Functional Electrical Stimulation, Drop Foot, Machine Learning, Recurrent Neural Network, Fuzzy Logic Controller

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1 Introduction

Functional Electrical Stimulation (FES) is a neuro-rehabilitation technique used to aid muscle movement in people with neurological disorders such as stroke, multiple sclerosis, or incomplete spinal cord injury. Most individuals affected by a neurological condition suffer from limited ability to control their ankle dorsiflexion through voluntary muscle activation. This condition is commonly known as Drop Foot (DF) and leads the individual to drag or scuff their foot while walking. DF mainly arises due to the weakness or paralysis of the dorsiflexor muscle. FES devices such as the Odstock Drop Foot Stimulator (ODFS) [1], Walkaide stimulators [2], or the Actigait system [3] treat DF by stimulating the common peroneal nerve or the tibialis anterior muscle to enable ankle dorsiflexion. All the commercially available Drop Foot Stimulators (DFS) have assisted walking in people with DF for many years. Yet literature reviews show that further developments can improve the working of these present devices [4].
A questionnaire was administered to the patients at the National Clinical FES centre, UK, which helped us identify some of the concerns each individual has while using the DFS in their routine life. Mainly, results [5] of the questionnaire showed that despite using the DFS, many participants required great effort to access different obstacles such as stairs and ramps. Some participants reported they followed special gait patterns to do so, such as descending the stairs by coming down backward or sideways, initially progressing with the unaffected leg, circumduction of the hip, dragging their foot, and other abnormal ground clearing methods.
A literature review taking into account past studies based on FES and terrains [1], [6], [7] showed that terrains played a vital role in DFS users. As a result, the goal of this study was

to design a new FES system that uses machine learning to detect terrains and regulate the stimulation parameters in the device.

2 SmartStim System

In this study, we present the SmartStim system, a two-channel terrain-adaptive FES device that can modify stimulation intensity in response to obstacles such as steps and ramps. Primarily, this system uses two 6-axes MetaMotionC (Mbientlab Inc., San Francisco) Inertial Measurement Units (IMUs) embedded in a pair of shoes to collect data points on the terrain the user is walking. Each of the IMUs consists of 3-axis accelerometers (BMI160) and 3-axis gyroscopes (BMI160).

Walking data was collected from the accelerometers at ±8 g and gyroscopes at ±500 °/s with a sampling frequency of 100 Hz. The data collected from the IMUs were analysed and further noise filtering was done using the Savitzky-Golay filter at 10 Hz. This processed data was then fed into a machine learning algorithm to predict the various obstacles. Three obstacles have been chosen for classification in this study namely ascending steps/ramp, descending steps/ ramps, and level ground. A Recurrent Neural Network (RNN) was programmed using the PyTorch framework and was used for this application. Due to its ability to maintain internal memory and execute classifications based on previous computations, a bidirectional Long-Short Term Memory (LSTM) RNN model was chosen for this project. The RNN model was trained and tested with the IMU data using k-fold cross-validation method, in which the dataset is randomly divided into k subsets and k-1 subsets are used for training and one subset is used to evaluate the model. As shown in the figure, a panel of LEDs with three colours shows the detected obstacles from the output of the RNN model in this system.

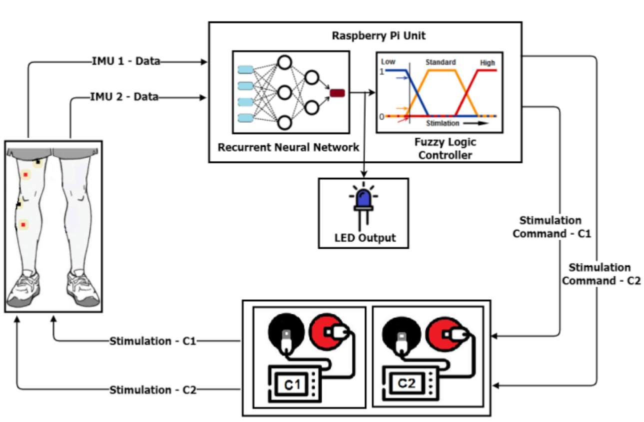

Figure: SmartStim System Layout

The classifications from the RNN were then fed into the Fuzzy Logic Controller (FLC) to control the stimulation current of the devices to provide sufficient stimulation, enabling the user to lift their leg as required to overcome each obstacle.

The main participant group involved in this project will be people with hemiplegia due to stroke and multiple sclerosis. This specific group of people were chosen for this study because the sensor on the unaffected leg helps detects the obstacles before the affected leg touches the ground. The working of the system is programmed as such that the sensors can detect the terrain with enough time to change the stimulation for the affected leg to clear the specific obstacle with more ease.

Three alternative settings are available on the stimulation controller, one for each obstacle. The stimulation controls for level ground in these settings will be equivalent to the participant's standard settings used regularly by them in their device. Similarly, the stimulation control for ramps and stairs will be tailored to the specific needs of each individual.

A questionnaire was administered to FES clinicians to get opinions about a two-channel stimulator to be used in different walking scenarios by people with unilateral drop foot. The two main results obtained from questionnaire was to introduce a second channel of stilmuation to a different muscle group and alter the stimualtion parameters to allow efficient walking in various obstacels. Hence, the SmartStim system design involves stimulation controls being delivered to two channels of the FES device. In order to control dorsiflexion, channel-1 (C1) will control the common peroneal nerve and the tibialis anterior muscle. While, channel-2 (C2) will be utilised to control a second muscle group, such as the quadriceps for knee extension or hip flexion or the hamstrings for knee flexion or decrease knee hyperextension, according to each users.

3 SmartStim System Testing

Initial testing of the SmartStim system has been planned and the study includes three sessions including five people affected by Multiple Sclerosis and five people with Stroke, with 10 participants in total. The study will take place in an outdoor area consisting of slopes, steps, and flat ground on a set course. In Session A participants will walk around the set area at their own pace with their normal FES device in its usual settings with required walking aids for support. The ODFS used by the participant everyday will be setup with a single channel for this session.

Then in Session B all the participants will walk with the SmartStim system with two stimulation channels setup as required for each participant. During both session A and B all the necessary data including walking distance, speed, heart rate, and videos for validation. Finally in session C, after finishing both the walking tests the researcher will administer a usability questionnaire to the participants.

4 Preliminary Results

In evaluating the initial data from the LSTM-RNN model, it shows that this model can classify all the various obstacles with 97 percent accuracy. Similarly, the Receiver Operating Characteristic Curve (ROC-AUC) score for this model was calculated to be 0.99. The ROC-AUC allows the model to create true prediction thresholds that are ideally between 0.5 and 1. Currently, the SmartStim model is being tested with ten healthy participants and further studies involving FES users are planned.

5 Conclusion

In conclusion, a basic design for an FES device that can adapt to various walking scenarios is presented in this article. The design proposes using IMU sensors with an RNN-LSTM model to detect terrains and an FLC control system to modify stimulation parameters in response to the terrain variations. The preliminary findings demonstrate that a terrain adaptive FES system can be constructed to help people with neurological disorders move more easily. The stimulation controls previously done manually by the patient as needed for each terrain, can now be automated with the help of the SmartStim system. This may allow users to access steps and ramps without requiring external adjustments to the FES device. This also serves to pave the way for future research including more terrains and changes to DFS stimulation parameters.

Author Statement

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