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Deep Learning and Particle Swarm Optimization for the Intelligent Rehabilitation Robot Control

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Abstract

Particle Swarm Optimization (PSO) for Intelligent Control of agent autonomous rehabilitation robot is a very complex problem, especially for stroke patients' treatments and dealing with real-time EMG sensors readings of muscles activity states and transfer between real-time Human motions to interface with rehabilitation robot agent or assisted-device. The field of Artificial Intelligence and neural networks plays a critical role in modern intelligent control interfaces for robot devices. This paper presents a novel hybrid intelligent robot control that acts as human-robot interaction, where it depends on real-time EMG sensor patients data and extracted features along with estimated knee joint angles from Extended Kalman Filter method are used for training the intelligent controller using support vector machines trained with Adatron Learning algorithm for handling huge data values of sensors readings. Moreover, the proposed platform for rehabilitation robot agent is tested in the framework of the NAO Humanoid Robot agent along with Neurosolutions Toolkit and matlab code. The average overall accuracy of the proposed intelligent motion SVM-EKF controller shows average high performance that approaches average 96% of knee motions classifications and also good performance for comparing Extended Kalman filter knee joint angles estimations and real EMG human knee joint angles in the framework of Human Walk Gait cycle. Also, the basic enhancement of proposing PSO optimization technique for robot knee motion is discussed for future improvements. The overall algorithm, methodology and experiments are presented in this paper along with future work.

Keywords: Intelligent rehabilitation robot • Humanoid roboti • Extended kalman fillter • Support Vector Machine

Introduction

Stroke diseases have a high incidence in many countries. Beside the early detection of high-risk persons, their monitoring and the detection critical, deathtrap events, their effective emergency management the rehabilitation process is difficult and cost intensive.

Many stroke patients experience pain in legs and hands. Therefore, patients' rehabilitation treatment is very important. The rehabilitation points towards the intense and repetitive movement assisted therapy that has shown significant beneficial impact on a large segment of the patients. The availability of such training techniques, however, are limited by:

- The amount of costly therapist's time they involve,
- The ability of the therapist to provide controlled,
- Quantifiable and repeatable assistance.

These limitations are quite important. Rehabilitation robotics systems are a very important problem, especially in the therapeutic domain of stroke patients.

The complexities of patient's treatments procedures such as physiotherapy. Since Electromyography (EMG) detects muscle response during different actions, it gives useful identification of the symptoms' causes. The dealing with Electromyography (EMG) signals provides significant source of information for identification of neuromuscular disorders [1].

Literature Review

A robot-assisted rehabilitation can provide quantifiable and repeatable assistance that ensure consistency during the rehabilitation and the main goal of this paper is to extend our previous development of an Intelligent Tele-medical Robotic rehabilitation platform and enhance the intelligent control engine with real-time EMG signal feedback and artificial intelligence technologies.

Many researches were made in the field of EMG signal classification using different techniques. In one against all method multi-class SVM with Gaussian kernel function was implemented to identify six degree of freedom. The overall rate of correct class testing was 97%.

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In Support Vector Machines (SVM) was employed to extract classes of different force intensity from the EMG signals. The average accuracy reached about 96%.

In four electromyography (EMG) sensors were used. They placed at the thigh and two force sensing resistors (FSR) placed below the heel and the toe. Support vector machine was used to detect muscular activity changes. This system has reached accuracies of roughly 67% for an amputee and of 75% for a non-amputee individual.

Research has shown that the kernel function parameters affects the SVM affect its classification ability. When the values of the Kernel function parameters factor are appropriate, the classification of SVM will enhance significantly.

In proposes a two-Step SVM classification method based on one-versus-One SVM muti-class classification method in order to improve the time efficiency of upper limb motion classification by sEMG.

In SVM is used in upper limb motion classification using myoelectric signals. Also more experiments are done on SVM for motion classification.

Kalman Filter (KF) is widely used in studies of dynamic systems, analysis, estimation, prediction, processing and control. Kalman filter is an optimal solution for the discrete data linear filtering problem. KF is a set of mathematical equations which provide an efficient computational solution to sequential systems.

The filter is very powerful in several aspects: It supports estimation of past, present, and future states (prediction EKF have been extensively used in many applications where non-linear dynamics are prevalent. There are many instances where EKFs have been used in different Robot controls [2].

Proposed intelligent robot motion controller

For the robotic control, on each level of signal processing the system provides feedback and interaction. The first level (Plant) allows to react quite fast at lower level, where it will consist of hand sensory information, arm sensory information and microcontroller, then a more differentiated behavior pattern is possible by level two through interface and conversion of lower levels behaviors to intelligent patients

motions and trainings of tasks and finally at third level that form the final intelligent behavior control considers the specific context and previous knowledge for final decision making of patients therapy and suitable actions.

The main objective of this robot control is to develop intelligent control architecture for robot-assisted rehabilitation systems that can provide assistance to leg rehabilitation in a coordinated manner to allow stroke patients to undergo task-oriented active training therapy.

The EMG sensors are placed on eight muscles (left and right). M. biceps, M. femoris, M. vastus-lateralis and M. tibialis anterior (Figure 1) [3].

The sensor node data were collected by Multisync-software by shimmer with a sampling rate of 512 Hz.

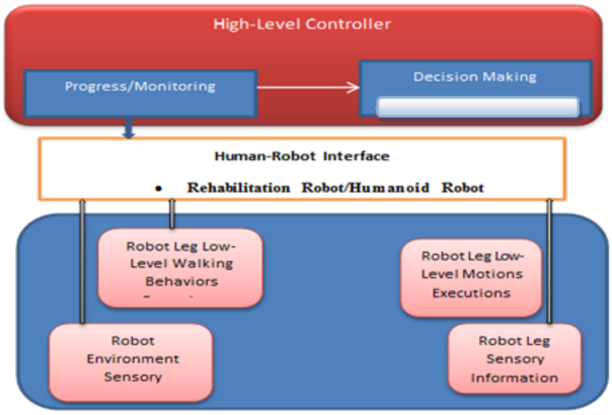

Figure 1. Robot Control Architecture (High-Level Control/ Low-Level Control).

We have extracted five main frequency and time features using wavelet method. The proposed intelligent mission signal processing model for the neural network engine for robot motion control. The medical domain is characterized by a high complexity due to two different aspects:

- Many different diagnosis and critical states are possible which influence the setting of sensors, collected data and their processing.
- Beside the personal diagnosis of each patient each person has an individual problem setting and specific aims of monitoring and rehabilitation.
- To handle this complexity a mission based model for sensoring signal will be provided by the platform for decision support as shown in Figure 2. The missions can be described as a quadruple of diagnosis, individual problem, personal aim/goal and sensor data.

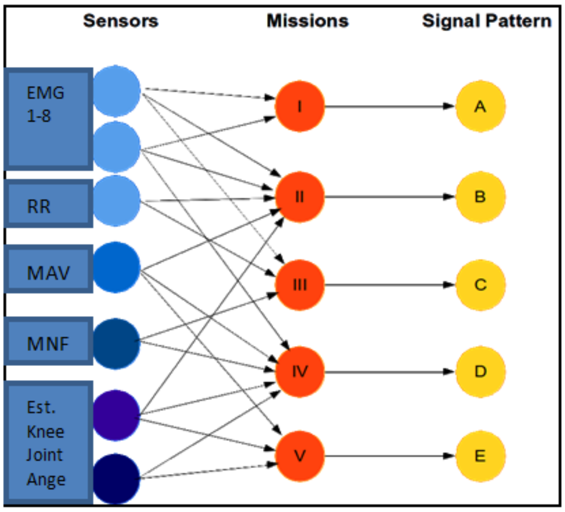

Figure 2. Intelligent sensor mission model.

The Support Vector Machine (SVM) is based on the concept of transforming data, especially biomedical real-time EMG data, into a high-dimensional space to transform complex problems into simpler problems. In this work, we implement SVM using Neurosolutions toolkit. One Against All Multi-Class SVM classifier is used in identification of EMG motions with Radial-Basis Functions. The learning algorithm is based on the Adatron algorithm extended to the RBF network as it is best suitable for Huge Dataset classification. The Adatron algorithm can be easily extended to the RBF network by substituting the inner product of patterns in the input space by the kernel function, leading to the following quadratic optimization problem:

Extended kalamn filter for estimation of knee joint angles

In this work, we use the standard EKF method for knee joint angle estimation and compared to joint angle of the humanoid robot to test human rehabilitation knee and walking motions without including robot full kinematics.

We use EKF method that depends on real-time EMG sensors for estimation of Human Joint angels.

In our previous works, we have used neural network as separate engine for based only on features of EMG sensor.

The process model of walking (knee) motion of the robot follows approximately sinusoidal signal whilst corrections by EMG sensors readings. In our proposed method, the joint angle Robot-knee-Joint-Angle can be assumed to follow sinusoidal wave and we add MNF, mean frequency to remove low noisy signal frequencies and it is defined in equation 6 as follows:

Particle Swarm Optimization (PSO) is population based stochastic optimization method inspired by social behavior of bird flocking. PSO exploits a population of individuals to probe promising regions of the search space. In the context, the population is called a swarm and the individuals are called particles. Each particle moves with an adaptable velocity within the search space, and retains in its memory the best position it ever encountered. In the global variant of PSO the best position ever attained by all individuals of swarms is communicated to all the particles.

Many researchers have used PSO for optimization of Humanoid walk features such as torso stability or walk speed. We use a similar algorithm code that Humanoid Gait optimization by human data. Then the PSO main algorithm is applied and it is tested especially for robot knee joint angles trajectories. The inputs to PSO code are the robots and the human's joint angles trajectories which are calculated by applying the method of Seven Wehner and Maren Bennewitz where the PSO fitness function is computed in an iterative fashion, where the individual joint angle trajectories are calculated over the entire walking sequence. In each iteration, the relative change of an individual joint angle is the same for all time steps of the walking sequence. For each time step, the new angle of an individual joint is computed proportional to the difference between the robot's original joint angle but this paper calculates knee joint angle trajectories (Figure 3) [4].

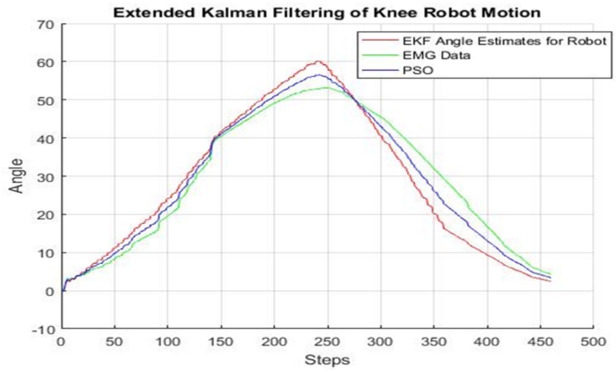

Figure 3. Knee Angle at initial Contact and Loading Response with PSO.

This section summarizes the main hybrid Pseudo-code of the proposed Artificial intelligence engine for rehabilitation motion control.

EMG data analysis allows the identification of activity and rest states, their properties (duration, amplitudes, area under the curve etc.) and their dynamical behavior. In the course of experiments with different tasks of kneeing motions the activity states have different durations and amplitudes indicating different knee poses. Especially the phase of knee flexion increased the frequency and duration of activity states and it can indicate an increase of knee poses. However integrating EKF for knee poses shows an increasing classification accuracy of SVM. Nevertheless, these observed changes still requires full robot kinematics equations to be included for complete gait analysis. However, the results of the proposed hybrid intelligent controllers increased significantly by PSO optimization. It seems that the synchronization of parameters enhances performance of robot controller [5].

The knee is in about 5 degrees of the flexion and knee flexion is already underway until it reaches to 16 degrees flexion.

Conclusions

This paper investigates a new applicable and ejective sitting/lying multi-joint lower limb rehabilitation robot. In order to improve patient's training initiative and accelerate the rehabilitation process, a new motion intention acquisition method based on biomechanics is proposed. The simulation experiment demonstrates the correctness of the mechanism leg dynamics equations, the calibration experiment of the joint torque sensors provides the hardware support for active rehabilitation training, and the consecutive variation of the torque sensors from just the mechanism leg weight and both Sensors 2019, 19, 3439 13 of 15 the mechanism leg and patient leg weights obtains the feasibility of lower limb motion intention acquisition. In the future, new active rehabilitation training for the LLR-Ro will be proposed on the basis of the motion intention acquisition method in this paper. Meanwhile, the patients' recovery e_ciency through the future active rehabilitation training method will be verified in clinical trials.

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