Abstract

Upper limb loss is very critical for us as we perform innumerous precise manipulations with it in our various activities of daily lives (ADL). Upper limb prosthesis can be used to replenish the loss both physically and functionally. However, even in the state-of-the-art prostheses, the myoelectric control offered is significantly different from the intuitive and smooth control we possess over our natural limb. The existing myoelectric prosthesis for transradial amputee subjects only provides control of very few (two to three) Degrees of Freedom (DoF) while the upper limb has 22 DoFs. Further, the sequential, cumbersome, and discrete way of maneuvering the prosthesis increases the cognitive load of the users while carrying out activities of daily living; hence, leading to the high rate of abandonment of prosthesis. On the other hand, for transhumeral amputee subjects, due to absence of most of the muscles in the arm, only few functions namely hand open and close activities are being provided for the prosthesis.

Measures can be taken by incorporating functionally related physiological signals for the particular upper limb movement and extracting control out of it to provide an intuitive upper limb prosthesis. Motion estimation is the main building block in prosthesis controller. Several research works were reported in the literature since the last two decades in upper limb motion estimation. Few groups developed pattern recognition-based (PR) approach to classify multiple DoFs' activity simultaneously from relevant muscle groups with high accuracy. Then, a proportional control was added at the output side to provide smooth control of the DoFs. Other researchers tried the development of simultaneous and independent proportional control (SPC) for individual DoF using nonlinear regression-based techniques using relevant muscle signals (surface Electromyogram; sEMG). The inherent advantage of these regression-based approaches is that it extracts both the onset and intensity information from

sEMG concurrently for multiple DoFs. The algorithms were validated using transradial amputee subjects' data as well. However, the DoFs considered were inadequate for providing a prosthesis control. This motivated in developing an intuitive wrist prosthesis involving all its DoFs for transradial amputee subjects using better approaches. Instead of discrete wrist motions, as in previous reported works, here, complex and constraint-free wrist motion profiles were considered as it resembles real-life motion scenarios where different wrist DoFs get engaged dynamically with time. Further, real-time iterative implementation issues have been addressed here. EEG signal-based detection of upper arm kinematics were reported by various groups; but the poor resolution of EEG hinders in deciphering much of the DoFs activity required for providing a forearm prosthesis control by using EEG alone. Hybrid EEG-EMG approach as demonstrated by a very few groups can be taken up and extended by including other upper arm motion related Brain Computer Interface (BCI) modalities to develop an intuitive forearm prosthesis control for transhumeral amputee subjects.
First, functionally related muscles in forearm were identified, and two complex dynamic wrist motion profiles were designed along with basic wrist motions and data were collected from normal and transradial amputee subjects during those motions in different trials. A Kernel Ridge regression (KRR) based nonlinear regression approach was considered to estimate the motion profiles in 3 dimensions considering all the wrist DoFs. Though it demonstrated good result in validation stages, the performance dropped while employing it in a pseudo online situation. Coefficient of determination (R^2) was used mainly as the performance metric.

The nonstationary nature of sEMG causes it to change its characteristics over time. Hence, a nonlinear adaptive algorithm, Kernel Recursive Least Square Tracker (KRLS-T), was utilized next to estimate the wrist motions in 3 dimensions. KRLS-T includes the advantages of nonlinear kernel-based data transformation and adaptive tracking by using a sparse dictionary updation and forgetting method. This novel application, when employed in the same pseudo online scenario, it showed improvement in its performance with time and also provided a good overall accuracy of around 0.90 (R^2) for healthy subjects. To further reduce the computation complexity for online implementation, instead of using various features from sEMG, only Mean Absolute Value (MAV) from corresponding sEMG channels were included in the estimation. The nonlinear Hammerstein-Wiener (H-W) model was utilized as it has been showed earlier to represent the complex neuromuscular system efficiently and estimate limb torque/force from sEMG. Here, sEMG was employed in the H-W model to predict wrist position iteratively using an Extended Kalman Filter (EKF) based iterative implementation. The EKF estimated model parameters and wrist position in 3 dimensions simultaneously. In a pseudo online scenario, this novel application demonstrated high performance for healthy 0.95 R^2 and transradial amputee subject 0.89 R^2. For transhumeral amputee subjects, BCI modalities like Movement Related Cortical Potential (MRCP), Event Related synchronization/ Desynchronization (ERD/ERS) were employed for wrist and finger motion detection, and sEMG from upper arm were used for elbow motion estimation. KRLS-T used sEMG to estimate elbow motion with more than 0.90 R^2 accuracy for healthy and around 0.89 R^2 for the transhumeral amputee. EEG signal was classified using Least Square Support Vector Machine (LSSVM) based two stage classifier. It was able to discern among wrist, grip (hand open/close) and finger motions with $65\% - 75\%$ accuracy. Finally, EEG error feedback signal, called Error Related Potential (ErrP) was incorporated in the hybrid EEG-EMG scheme to cancel erroneous output of the hybrid EEG-EMG scheme, which improved the accuracy by another $5\% - 10\%$.

These two novel applications can be used in upper arm motion estimation to provide an intuitive prosthesis to transradial and transhumeral amputee subjects.

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Keywords: Upper Limb Prosthesis, Transradial Amputee, Transhumeral Amputee, Intuitive Prosthesis Control, Surface Electromyogram (sEMG), Electroencephalogram (EEG), Kernel Ridge Regression (KRR), Kernel Recursive Least Square Tracker (KRLS-T), Hammerstein-Wiener Model (H-W), Extended Kalman Filter (EKF), Hybrid EEG-EMG, Error Related Potential (ErrP).

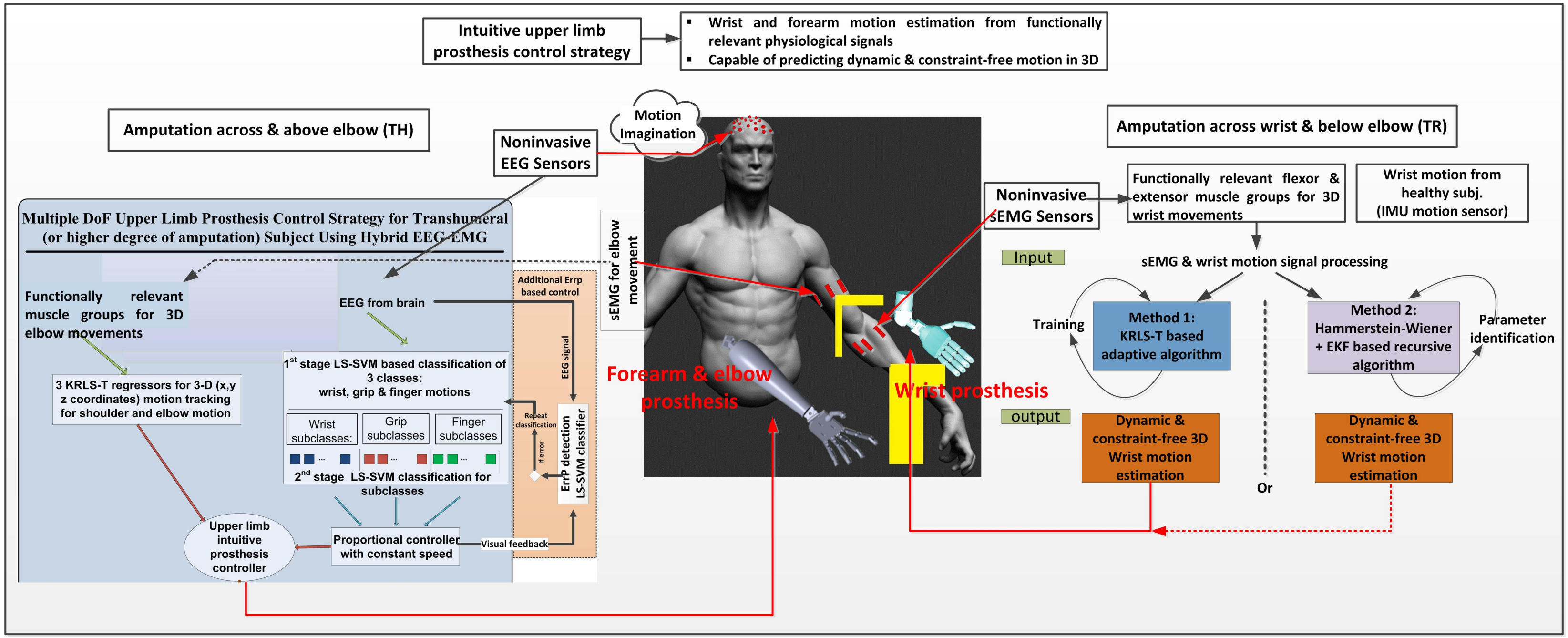

Figure 1: A graphical representation of the proposed schemes for developing intuitive motion estimator for transradial and transhumeral amputees.