HYBRID DATA FUSION CONCEPT IN EXOSKELETAL ROBOT MANIPULATORS

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ABSTRACT

Nowadays, exoskeletal robot manipulators are used in health, defense and industrial fields. However, development studies of the performance of these systems are being continued. There are many challenges in terms of control of the systems. For the high-performance control of these systems, it is extremely important that the feedback information is accurate, stable and noiseless. Hybrid data fusion approach has been trying to be used in these systems in recent years. In this approach, biological and biomechanical parameters are used together for the feedback. In this study, fundamentals, advantages, and disadvantages of the hybrid data fusion approach are presented. On the other hand, it is proposed the solution methods for existing problems.

Keywords: *Hybrid Data Fusion, exoskeletal robot manipulator, biomechanical parameters, EMG, EEG*

INTRODUCTION

Robotic systems for improving the quality of life of people are becoming more important. One of these systems is exoskeletal robots. Exoskeletal robots are used for the following purposes:

- Supporting or performing joint mobility functions for people with physical disabilities,
- Joint movement and power assist for workers to lift heavy loads or to work in different positions for a long time,
- Joint mobility and power assist for soldiers to carry heavy loads in the field.

The most important issue in exoskeletal robot manipulators is human-robot interaction. The following elements are critical in this interaction: accuracy, safety, sustainability and usability. Effective control of the system is indispensable to address these requirements. For good control performance, it is very important that the feedback information is accurate, reliable and available. For this purpose, many scientific studies have been carried out. In these studies, feedback is provided through biological and biomechanical feedbacks. Generally, biological parameters such as EEG (electroencephalography), EMG (electromyography) and biomechanical parameters such as torque, force and joint angle are used in exoskeletal robot systems.

EMG signals from biological feedback signals are used effectively in human-robot interactive systems [1], [2]. EMG signals are useful because they directly reflect the intention of limb motion. However, sometimes the weakness of muscle signals, changes in signal characteristics over time, the ability to perform the same movements with different muscles, and the absence of muscle contraction in some patient types (eg. partial or complete paralysis) are among the difficulties of EMG' usage.

EEG signals are obtained by measuring the electrical signals generated by brain activation. EEG signals do not require physical movement or muscle contraction, as they occur only through thought and its conversion into electrical signals. However, there are many challenges associated with EEG measurement. The characteristics of brain signals are different and varied and they are easily affected by disturbing effects, making it difficult to use. In addition, the use of EEG signals as feedback information alone is not sufficient. Additional feedback information is needed. These are classification, accuracy, user-specific adjustment, long-term reliability [3, 4, 5]. However, in many universities and research centers around the world, EEG signals are used in research studies called as **neuroscience**. In addition to exoskeletal systems [6, 7], EEG signals are involved in the control loop in wheelchairs [8, 9] and prosthesis [10, 11] applications.

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Due to the reasons set out above, the incorporation of biological feedbacks into the control loop with biomechanical feedbacks will bring about effective control. Considering an exoskeletal robot, EMG signals may not be available due to paralysis of some areas and tendon ruptures. EEG signals can be utilized in these regions. On the other hand, even if all the requirements for EMG have been met, EEG can be used in cases of fatigue or unwanted contraction (tremor). The use of biomechanical parameters in control will contribute to the efficient operation of the system in order to ensure safety despite the problems of classification in biological markers.

In this paper, the contributions of both biomechanical and biological feedbacks in the control loop are discussed. Additionally, the problems that may be encountered are put forward and a future prediction is tried to be made.

HYBRID EMG AND EEG BASED CONTROL APPROACH

Hybrid EMG / EEG-based control structure refers to the use of both signal types as feedback information by joining the control loop. These two types of signals can be combined and used depending on many different techniques and different factors (user capacity, intended use, etc.).

As discussed earlier, there are many ways to combine EMG and EEG signals to improve efficiency within a given control approach. In hybrid EMG-EEG-based control structures, these signals are fed back into the system either sequentially or simultaneously. Regardless of the hybrid use approach of EEG-EMG signals, it is necessary to produce more efficient results than the use of EMG or EEG signals alone. The researchers proposed a hybrid approach method for the solution of problems in EMG control [12, 13, 14, 15]. Two methods are used for the application of EMG and EEG signals under a single system. These are called sequential and simultaneous. In sequential approach, EMG and EEG signals are applied to the system in series at separate times. In the simultaneous approach, a parallel process is operated and EMG and EEG signals are given to the system together. Du at al. used sequential approaches to control a lower limb exoskeletal robot manipulator and Kiguchi et al. used simultaneous method [16] for controlling of an upper limb power assist robot [15]. In general meaning fusion approaches according to applications are given in Table 1.

Table 1. Mapping of fusion methods and applications

Fusion Method	Application Areas
Simultaneous (parallel)	Assistive devices
	Assistive exoskeletal robot manipulators
	Upper limb prosthesis
	Lower limb exoskeletal robot manipulators
	FES based exoskeletal robot manipulators
Sequential (serial)	FES based rehabilitation robots
	Lower limb exoskeletal robot manipulators

EEG Signals are used in the exoskeletal system in two different ways. Exogenous EEG signal and endogenous EEG signals. Exogenous EEG Signals are generated with external stimuli such as visual, audial or tactile. On the other hand, endogenous EEG signals are produced by the subject voluntarily.

Lower limb rehabilitation robots can be classified as virtual reality, gait rehabilitation systems and assistive devices. Virtually reality systems provide control of the system using EEG signals in computer environment. This method is very useful especially in the training stage before starting to use real systems. Gait rehabilitation systems are used for walking training in spinal cord and similar cases with walking difficulties. Assistive exoskeleton robots

are systems that allow the mobilization of patients with partial or complete paralysis. Single joint exoskeletal systems with EEG control are also available. In these systems, rehabilitation of shoulder, elbow, knee or hip joints is performed according to the intention of movement.

EEG and EMG Signal Processing:



Figure 1. EEG and EMG Signal Processing Steps

EEG and EMG signal processing is a pattern recognition process that uses digital-analog signal processing and machine learning methods. The steps for this process are given in Figure 1. Primarily, raw biological data from the human body via DAQ cards are preprocessed. These raw data are rectified, amplified and filtered. In some methods, they are normalized additionally. Then, pre-processed signals are windowed using overlapping or adjacent methods. The windowed signals are sent to feature extraction unit to discriminate. This process can be performed in time domain or frequency domain. If it is necessary excess or unnecessary data is eliminated in feature degradation unit. After this whole process, classification process is executed using artificial intelligence (AI) classification methods.

PROBLEMS IN HYBRID DATA FUSION

Muscle fatigue:

One of the major problems in the use of EMG is the signal type disorder caused by muscle contraction or fatigue. This will affect the amplitude and frequency of the EMG signals. Therefore, the signals generated during the learning phase of the classification process will change and accordingly the system will not be able to perform motion classification correctly. Especially in elderly people, skeletal muscle fibers decrease in size and muscle strength decreases. This will bring muscle fatigue. Therefore, the use of EMG alone is problematic in this respect, and it should be supported by EEG.

As an exemplary procedure;

- Individual testing of EMG and EEG signals first,
- later used to control the system at equal weights,
- at the other stage, testing the system with Bayesian fusion approach.

Leeb et al. found only 87% accuracy of EMG activity and 73% accuracy for EEG activity alone. Then, they studied the hybrid approach. They achieved an increase of up to 91% with the hybrid EMG-EEG classifier. Therefore, experimental results have shown that the EMG-EEG combined classification accuracy is higher than when EEG and EMG inputs are used separately [12].

Tremor:

Another important problem in the use of EMG signals is tremor. This problem, especially in elderly people, makes it difficult to use EMG in exoskeletal robot manipulators. Therefore, it must be compensated. In the case of tremor, EMG signals cannot reflect the actual motion intent. Researchers have developed various algorithms to solve this problem. Racon et al. proposed a wearable active exoskeleton with quiver suppression [17]. Kiguchi et al.

developed a power-assist robot for the rehabilitation of upper limbs that prevent unwanted vibration or movement [18]. In recent years, multiple sensor approaches have been used for vibration suppression [19]. Rocon et al. developed a wearable robotic system in which the vibration of the FES-based upper limbs with brain computer interface was eliminated [19]. In addition to EMG, EEG, IMU sensors were used in their systems.

Loss of sensation:

In some elderly and patients, sensory loss may occur as well as loss of movement. Therefore, researchers have proposed assistive robot systems that are capable of perception support [20, 21]. Generally, EMG signals were used to evaluate or verify the sensing task and to teach the power-assisted exoskeleton robot to each task. However, there are some cases where such EMG signal variability is not sufficient for such inference operations. To overcome this problem, a combination of EEG and EMG signals has been proposed for Kiguchi and Liyanage upper limb power support control [15]. In this system, perceived data such as sound, image and touch perceived from the environment were evaluated. This information was supported by both EEG and EMG to control the exoskeletal robot. Accordingly, experimental results showed that 50% success with EMG and 80% success with both EMG and EEG.

EXISTING PROBLEMS IN THE USE OF HYBRID DATA FUSION

In parallel with the development of sensor technologies, more effective use of feedback information in control theory is increasing day by day. However, serious problems still need to be solved. With hybrid data fusion, a reliable, efficient and cost effective situation that could improve the efficiency of rehabilitation and the quality of life of individuals could not be achieved. Other pending major issues are:

- With the existing classification methods, there is a difference between the intention of movement determined by EEG and those coming from EMG.
- There are problems in the classification of the sitting, getting up and walking procedures, especially in patients with full or partial stroke, and the transmission of this to the mechanism in real time.
- The increase in the number of transactions to be classified affects network performance.
- EEG signals need more frequent calibration as there are more random processes compared to EMG.
- EEG sensors are used with caps. This presents certain difficulties with regard to use.
- Noise caused by motors and other electronic equipment in exoskeletal robot structures. These make it difficult to receive and process biological signals.

CONCLUSION

In this study, hybrid data fusion method which uses biological and biomechanical parameters together as feedback information in control of exoskeleton robots is explained. The difficulties encountered in the application of these methods are presented. Difficulties in control of exoskeletal robot with biological or solely biomechanical parameters have led to the use of hybrid methods. However, increasing the number of sensors at this point raises new problematic situations in terms of technology and cost.

In order to solve these problems, the following developments should be recorded:

1. Use of wireless sensor hardware,
2. Make the EEG and EMG sensors wearable, ergonomic and suitable for daily use,
3. Increasing CPU speed and hence sampling time, especially in mobile systems,
4. Effective software and hardware filter designs to prevent artifact and other electrical noise,
5. Invasive EMG and EEG electrode designs, use of neuro-prostheses in practical application,
6. Development of novel and effective classification methods,
7. Development of online learning algorithms and development of more adaptive software.

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