Abstract—We propose planning behavior selection network (PBSN) based brain-computer interface (BCI) for controlling a humanoid robot. BCI provides commands to external devices or computer applications only using user’s brain signals. However, few commands from BCI cause user fatigue. PBSN is a hybrid method between reactive system and goal-oriented planning system. PBSN has two beneficial points. One is robustness of reactive system and the other is long-term goal planning of planning system. This only requires high-level commands from the user and frees from make low level command to operate the robot. Finally, it makes possible to reduce user's fatigue. Online accuracy test gives reasonable accuracy rate, and PBSN based online simulation shows possibility as an assistant humanoid robot.

Keywords—Planning based Behavior Selection Network; Brain computer interface;

I. INTRODUCTION

BCI controls computer applications or external devices only using brain activity. The early works for BCI have limited application such as controlling a robot arm or a wheel chair. However, the BCI applications are getting wider by the advancement of EEG measurement techniques and signal processing techniques. TABLE I shows the robot based BCI works. The typical methods to implement BCI environment are P300 [1], SSVEP (Steady-State Visually Evoked Potentials) [2], and SMR (Sensory Motor Rhythm) [3]. However, the most of the methods provides limited command numbers because the above methods used limited feature in the part of the brain. It causes the user fatigue and time-consuming.

There are two general ways of control humanoids. One is plan based control. Another is reactive control that reacts to environment robustly. Plan based control makes sequence to achieve long term goal. It makes optimized action sequence in predefined environment [4]. However, when environment is changed, humanoid is unable to cope with the situation. Whereas the reactive control method cope with various environments. Reactive control makes fast response since it does not have information about environment [5]. Thus, it is difficult to applicable to task, which has long term goal. In this point, a hybrid control is suggested [6]. Hybrid control can react to change of environment and solve long term goal by its planning capability. Thus the system operates in two characteristics those are dynamic by reactive control and efficient by plan based control. In addition, the systems explicit structure makes available to simplicity in design.

In this paper, PBSN (Planning based Behavior Selection Network) and P300 based BCI (Brain Computer Interface) are used for humanoid robot control. By this method, only simple commands needed for creation of complex behaviors. The PBSN has two ways of control humanoid. Those are reactive control and plan based control. Plan based control makes robust behavior in uncertain environment. By hybrid two methods, PBSN executes user’s command by make long term plans and reactive actions.

II. PROPOSED METHOD

A. System Architecture

The entire system architecture of the proposed method consists of signal acquisition, user interface, BCI signal processing, planning based hierarchical BSN, and robot simulation. Figure 1 shows the detail system architecture. First, brain signal acquired from EEG with wireless and we use BCI2000 for the signal processing module. BCI 2000 is a general-purposed BCI system to provide the frameworks for BCI environment. UDP socket transmits the high level commands (SEARCH, MESSAGE, SWITCH, FREE) to the planning based BSN modules. The selected goal of planning based BSN determines robot behaviors and user can confirm it in real-time.

TABLE I. ROBOT BASED BCI RELATED WORKS

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Type</th>
<th>Number of commands</th>
<th>Robot</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. Escolano et al. [7]</td>
<td>2012</td>
<td>P300</td>
<td>7</td>
<td>Pioneer3-DX</td>
</tr>
<tr>
<td>Y. Chae et al. [8]</td>
<td>2012</td>
<td>SMR</td>
<td>3</td>
<td>NAO</td>
</tr>
<tr>
<td>G. Yang et al. [9]</td>
<td>2011</td>
<td>SSVEP</td>
<td>7</td>
<td>Pioneer3-DX</td>
</tr>
<tr>
<td>A. Lenhardt et al. [10]</td>
<td>2010</td>
<td>P300</td>
<td>20</td>
<td>Kuka</td>
</tr>
<tr>
<td>D. Valbuena et al. [12]</td>
<td>2007</td>
<td>SSVEP</td>
<td>4</td>
<td>Friend</td>
</tr>
</tbody>
</table>
B. BCI signal processing

Since raw EEG data contains various noises and difficult to distinguish, a signal processing procedure is needed to generate the high level commands. The signal processing method is organized as preprocessing, offline analysis, and classification. In the preprocessing step, raw brain signal high pass filtered as 0.1Hz and spatial filtering computes a linear transformation. Although P300 feature is usually detected in most people, we should consider the individual difference. The offline analysis for each subject is computed to extracts the P300 feature and to generate the specific feature weight. The r-squared value is calculated using coefficient of determination and provide a measure for the amount to which a particular EEG feature. Stepwise linear discriminant analysis (SWLDA) [14] is finally trained to generate feature weight. The generated feature weights are then passed to a linear classifier.

C. Processing command with Plan based Behavior Selection Network (PBSN)

The processed command from EEG flows into the PBSN. PBSN is consist of two parts. There are two parts in the designed PBSN. One is dubbed as, Deliberative part for make sequence of BSNs and another is BSN modules for generate humanoid actions. Based on user’s command and feedback from BSNs, deliberative part plans operation of BSNs. BSNs are designed for simple commands and can cope with environment. BSN is consists of relationships between actions, goals and environments. Among them, BSN selects the appropriate behavior for the current situation. The results of BSNs action is applied as feedbacks to Deliberative part. By using this feedback, Deliberative part determines sequence of BSNs operation. Designed PBSNs are follows as.

Figure 2 is PBSN for autonomous walk. Using sonar sensors, humanoid evades walls and obstacles by estimate their locations. If no obstacle on the way, then humanoid goes forward. Thus humanoid is able to explore over a long distances without any collision. Stand up behavior is inserted in case of fall down or pose of humanoid is not adequate for navigation.
Figure 3. PBSN for find and recognize user

Figure 3 is PBSN for find and recognize user. It contains navigation and find user BSNs. Humanoid is able to watch all directions by Find user BSN. Find user BSN makes humanoid shook its head or turn its position. It also detects location of sound Thus humanoid is able to watch sound source. If humanoid cannot find user’s face over a time, then Deliberative part use Navigation BSN for change humanoid’s location. This PBSN terminates when success to find user’s face

Figure 4. PBSN for message passing

Figure 4 is PBSN for passing message to certain user. It contains Message BSN and Find user BSN. Message BSN is for recording and playing message. Using this BSN, user is able to recording message. After record, the humanoid find designated user.

Figure 5. PBSN for find user

Figure 5 is PBSN for find object. It contains navigation and object scan BSN. Object scan BSN has ability for scan objects and interact with.

III. Experiments

A. Feature analysis and extraction

We conduct offline analysis to confirm the P300 feature and to extract the feature weight. The healthy 4 male subjects from 25 to 29 participate for the experiment and they had no previous experience with BCI experiment. Thirty sequence of stimulus are given. Inter stimulus interval is set to 125ms and stimulus is set to 31.25ms. The subjects are asked to gaze a word among search, message, switch, and free and to count the number of the stimulus. Figure 6 shows the feature plot calculated from r-squared value for all subjects. The vertical axis corresponds to the EEG channels while the horizontal axis corresponds to the time delay after the stimulus. As can be seen in the figures, all subjects shows the largest r-squared values between 300–400ms.

B. Online test with humanoid operation

In this experiment, online humanoid control conducted. Thus UDP protocol is used for connect humanoid with BCI.

For appropriate determination of the number of stimulus sequence and evaluation of the accuracy, we conduct an online test. The configuration of the experiment is same with offline analysis except the number of stimulus sequence. The subjects are asked to gaze the predefined sequence of the words. A sequence is consists of random 20 words. Figure 7 shows the result of the online accuracy test. Despite the period between the presented words is short, the average accuracy rate still above 80%.
Figure 7. Accuracy rate over sequences

Figure 8 shows Topography maps for all subjects using online experiment data. We confirm occipital lobe involves in a discriminative activity. This is consistent with other P300 study [15], where parietal lobe or occipital lobe have been found to contribute significantly to detect the p300 response.

Figure 8. Topography maps for all subjects

To find the goal, PBSN changes operation of BSN. And PBSN get information from environment and feedback of BSN. Total time spent for find the goal was 6 min 30sec. Since humanoid does not have map algorithm, most of time was spent for movement.

IV. CONCLUSION

In this paper, PBSN based on BCI is used for humanoid control. For in ordinary humanoid control, numerous and detailed commands are needed. However BCI environment makes limited commands since it does not use physical input but brain signals. To ease these strict, PBSN is used. PBSN makes stable plans for long period even though BCI sends simple commands. We verified that all users in the experiment could make commands successfully and humanoid execute the commands well. PBSN in this paper make ease the problem for command processing, but additional behavior network will make elaborate humanoid movement. Besides the number of commands, information transfer rate (ITR) and selection of classification algorithm are the crucial issues. ITR is an evaluation measurement in a BCI and the types of BCI affects ITR. Thus, new command paradigms or improvement of exist BCI command paradigms is needed for better ITR. The appropriate selection of classification algorithm such as Artificial Neural Network (ANN), SVM (Support Vector Machine) also has a potential for improving ITR. In near future, continued development of this system might be a good assistant for challenged person.

ACKNOWLEDGEMENT

This research was supported by the Original Technology Research Program for Brain Science through the National
REFERENCES


