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Development of Mind Control System for Humanoid Robot through a Brain Computer Interface

Wei Li[1], Christian Jaramillo[1], Yunyi Li[2]

[1]Department of Computer Engineering and Science
California State University, Bakersfield, CA 93311, USA
wli@csub.edu
[2]Department of Psychology and Neuroscience, Duke University
417 Chapel Drive, Durham, NC 27708-0086, USA
yunyi.li@duke.edu

***Abstract*—We develop a mind control system for humanoid robot through a brain-computer-interface (BCI), consisting of a 32 channel electroencephalograph (EEG), a humanoid robot, and a CCD camera. We present two types of humanoid robots in the BCI control system: KT-X PC robot with 20 degrees of freedom (DOFs) or NAO H25 robot with 25 DOFs. The CCD camera takes video clips of a subject or an instructor hand postures to identify mental activities when the subject is thinking "turning right," "turning left," or "walking forward." As an initial test, we implement three types of robot walking behaviors: turning right, turning left and walking forward, and report the neural signals correlated to these three mental activities.**

Keywords-BCI system; humanoid robot; neural signal processing; mind control; robot walking behavior

I. INTRODUCTION

Brain Computer Interface (BCI) sets up a new communication channel which can be used to identify subjects' mental activities by analyzing brainwaves [1][2]. BCI systems are classified into invasive and non-invasive: An invasive BCI system uses electrodes implanted over the brain cortex (requiring surgery) to record signals, and a non-invasive BCI system uses an EEG electrode cup to acquire brainwaves from skin surface on a scalp. These BCI systems extract specific features of mental activities and convert them into device control commands.

Recently, there has been an increasing interest in BCI applications to control robots through neural signals. The works [3]-[5] propose and review directly employing cortical neurons to control a robotic manipulator. The research groups [6]-[8] report the navigation of mobile robots using BCI, including the control of a wheelchair [9]-[11]. The article [12] presents an example of humanoid robot control through a BCI system.

Comparing with manipulators and mobile robots, humanoid robots are more advanced as they are created to imitate some of the same physical and mental tasks that humans undergo daily [13], but control of humanoid robots is much more complex due their high DOFs. Humanoid robots are being developed to perform some complicated tasks like personal assistance, where they should be able to assist the sick and elderly, and dirty or dangerous jobs. However, for people with severe motor disabilities it is important to establish augmentative communication with humanoid robots for personal assistance [14].

Figure 1. BCI-based humanoid robot control system

This paper develops a brain-computer-interface (BCI) based humanoid robot control system, integrating an electroencephalograph (EEG), a humanoid robot, and a CCD camera, as shown in Figure 1. This system can serve as a platform to investigate relationships between complex humanoid robot behaviors and human mental activities, and to validate algorithms performance of controlling humanoid behaviors through brainwaves.

As an example, in this paper we implement three types of robot walking behaviors: turning right, turning left, and walking forward based on the robot kinematics. Control of the three types of behaviors is provided through three mental activities: turning right, turning left, and walking forward, which are correlated with their robot walking behavior counterparts. We conduct two sets of experiments on recording brain signals during mental activities. The first set of experiments records the subject's mental activities when the subject is thinking "turning right," "turning left" and "walking forward." The subject simultaneously moves the right hand, the left hand, and both hands when thinking "turning right," "turning left" and "walking forward." The recorded brainwaves in this experiment may include the

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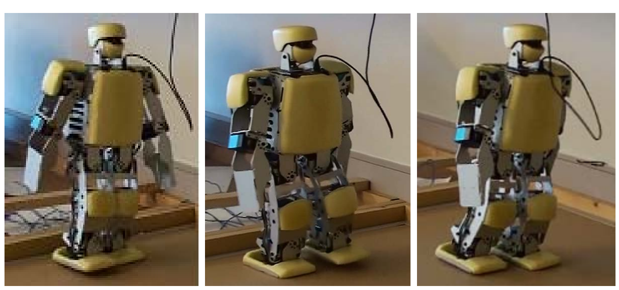
muscular signals caused by the subject's hand movements. The second set of experiments records the subject's mental activities which are triggered by an instructor's voice commands. In this set of experiments, the instructor moves the right hand, the left hand, and both hands. We analyze the neural signals correlated to the mental activities and use phase features of delta-band brainwaves to activate the humanoid robot walking behaviors.

II. BCI-BASED CONTROL SYSTEM

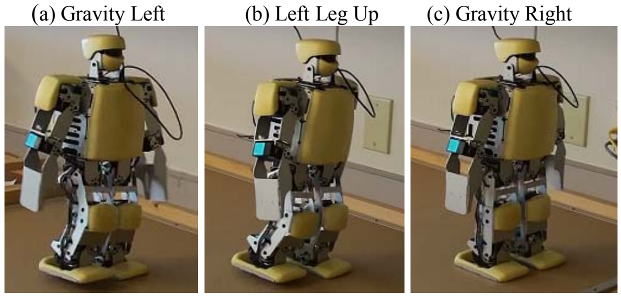
The investigation of relationships between complex humanoid robot behaviors and human mental activities could be interesting to scientists in interdisciplinary fields, such as neuroscience, psychology, robotics, and computer science. Figure 1 shows the BCI based humanoid robot control system which integrates the neural signal acquisition equipment connecting to an electrode cup, a humanoid robot, and a CCD camera.

A. Data Acquisition System

The most important part in our BCI interface is a Cerebus™ Data Acquisition System with a 32 microelectrodes cap. The Cerebus™ includes an amplifier, an amplifier power supply, and neural signal processor, as shown in the bottom window of Figure 1. This system is capable of recording from both surface and extracellular microelectrodes, and the system provides several on-line processing options for neural signals including noise cancellation, adjustable digital filters, simultaneous extraction of spike and field potential recordings from microelectrodes, and automatic/manual online spike classification. The BCI interface records the neural signals during mental activities.



(a) Gravity Left (b) Left Leg Up (c) Gravity Right



(d) Right Leg Up (e) Right Leg Forward (f) Right Leg Down

Figure 2. Configurations of the robot walking forward behavior

B. KT-X PC Robot

Our system uses a KT-X PC humanoid robot manufactured by Kumotek which has 20 degrees of freedom (DOFs), 12 DOFs located on hips, knees, and ankles, for humanoid robot walking, 6 DOFs on shoulders and arms for arms motion, and 2 DOFs for head yaw and pitch motion. The KT-X PC incorporates a 1.6GHz Atom Z530 processor, memory expansion slots, video input for vision, speakers, a 60Mhz motor controller, 3 axis gyro/accelerometer chip, a 1.3 megapixel CMOS camera, 6 high-torque/titanium gear motors in the legs and an external urethane foam casing to protect the robots internal PC and equipment from shock, as shown in Figure 2. The onboard PC computer provides a 16 gigabyte hard disk and two USB ports, which connect a wireless adaptor and an additional flash drive. For this study, we implement three robot walking behaviors: turning right, turning left and walking forward.

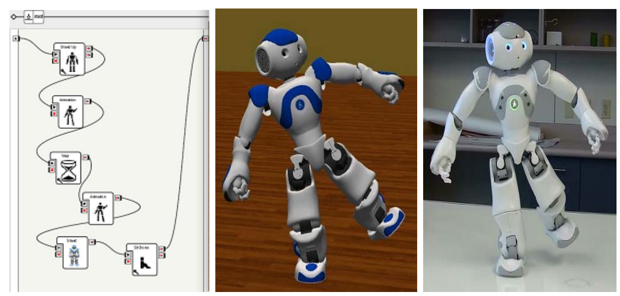


Figure 3. NAO humanoid robot

C. NAO H25 Robot

An alternative humanoid robot used in our mind control system is NAO H25 robot from Aldebaran Robotics, as shown in Figure 4. The NAO robot is equipped standard with an embedded computer and WIFI connection, The NAO is fully autonomous and can establish a secure connection to the Internet to download and broadcast content. With 25 degrees of freedom, the NAO is capable of executing a wide range of movements, including walking, sitting, standing up, dancing, avoiding obstacles, kicking, seizing objects, etc. The NAO humanoid robot has a vision system allowing him to capture and send photos, video streams, recognize colored objects, detect and recognize faces and communicate with the PC or the web for downloading files, behaviors, sending images in real time, etc.

D. CCD Camera

The camera used in our system is a Cannon VC-C50i communication camera, as shown in the left window of Figure 1. This camera provides high-speed high-precision head movement and noise reduction circuitry for crystal clear images. It is capable of shooting at low light levels down to 1 lux. The built-in infrared light allows shooting even at 0 lux (night mode). The CCD camera takes video clips on the subject's or the instructor's hand postures to identify mental activities which are correlated to the robot walking behaviors.

III. Programming Environments

We use the program *Central* developed by Blackrock Microsystems to record neural signals. The neural signals can be processed off-line and on-line. The heart of the communication between the Cerebus™ and *Central* is a protocol program to listen for spike data or for continuous data.

The basic programming software for KT-X PC robot is RobovieMaker2 (RM2). Robot can be controlled by either a separate computer or the on-board PC using a USB cable or a wireless adapter. A real-time motion control program in C++ loads the motion files of the robot walking behaviors created by the RM2 software and sends them to a micro-controller to control robot walking by a serial communication port. For our initial test, we implement three walking behaviors: turning right, turning left, and walking forward. For example, one full step walking forward can be described by the following configurations:

Gravity Right → Left Leg Up → Left Leg Forward → Left Leg Down → Gravity Left → Right Leg Up → Right Leg Forward → Right Leg Down.

In order to implement the configurations, we develop the robot kinematics in terms of Denavten-Hartenberg notation. Figure 2 displays the scenario of robot forward walking.

The Nao robot can be controlled via Choregraphe wholly designed and developed by Aldebaran Robotics. Choregraphe is the programming software that lets NAO users create and edit movements and interactive behaviors with complete simplicity. The intuitive graphic interface, the library of behaviors delivered as a standard feature and the advanced programming functions satisfy the needs of novices and experts. Users can compose their own behaviors by a simple drag/copy from the library or else create their own boxes and save them in their personal library. Choregraphe accepts Urbi and Python language, so it can directly call C++ modules developed separately. The left window in Figure 3 shows the program of controlling a NAO robot standing with the right leg via Choregraphe. The middle and right windows in Figure 3 show a simulated and real NAO robot.

IV. Experiments

A. Motor Cortex

The primary motor cortex (also known as M1), a strip located on the precentral gyrus of the frontal lobe shown in Figure 4, is an important brain region for the control of movement in humans. M1 maps the body topographically, meaning that the ventral end of the strip controls the mouth and face and the other end the legs and feet, with the rest of the body represented in between. The amount of representation is not proportional to the size of the body part. For example, the trunk is represented by only a small region on the primary motor cortex, because humans do not generally use the trunk for fine, precise movements or a wide range of motion. On the other hand, the fingers are greatly represented on M1, because the fingers are sensitive appendages and are used for many different movements. The primary motor cortex is thought to control both muscles and movements [16].

The nonprimary motor cortex is located just adjacent to the primary cortex and is important in the sequencing of movements. The premotor cortex (PMA) has been implicated in movements that require external cues. This region also contains mirror neurons, which are activated both when one is performing a movement and when he or she is observing someone else do the same movement; in this case, the brain is utilizing visual cues [17]. In contrast, the supplementary motor area (SMA) is utilized for movements that are under internal control, such as doing some sort of action from memory [18].

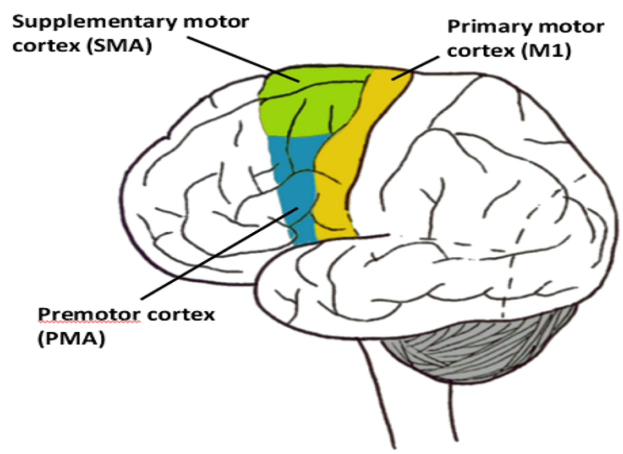


Figure 4. Motor cortex

B. Brain Signal Recording

We use a 32 channel EEG to record human brain activities of thinking “turning right,” “turning left” and “walking forward” for control of the humanoid robot walking behavior. We design two sets of experiments. The procedure for the first set of experiments is described as follows. When the subject starts thinking “turning right,” “turning left” or “walking forward” the subject moves the right hand, the left hand, or both hands, respectively. These hand postures are synchronously taken by the CCD camera. We use these hand postures to analyze the features of brainwaves by identifying mental activities of thinking “turning right,” “turning left” and “walking forward.”

The second set of the experiment is designed as follows. The subject starts thinking “turning right,” “turning left” or “walking forward” following an instructor’s voice commands “turning right,” “turning left” or “walking forward.” At the same time, the instructor moves the right hand, the left hand, or both hands, respectively. In this experiment, the CCD camera takes synchronously the instructor’s hand postures which are used to analyze the features of brainwaves correlated to the mental activities. Figure 5 plots the brain signals during mental activities of turning left (left half) and right (right half) from the second set of experiments. Figure 6 shows that control of robot to make left turn through the recorded brainwaves.

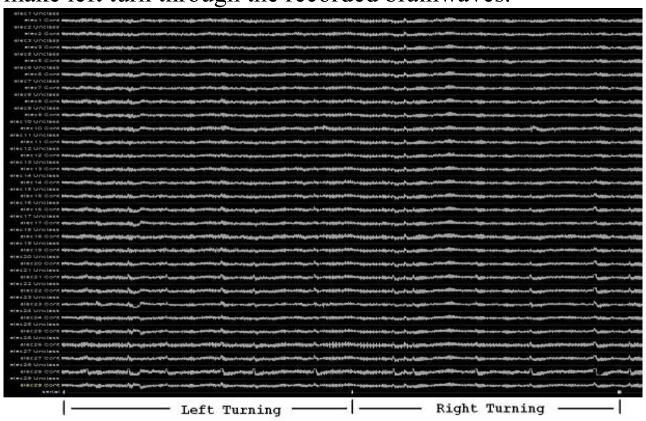
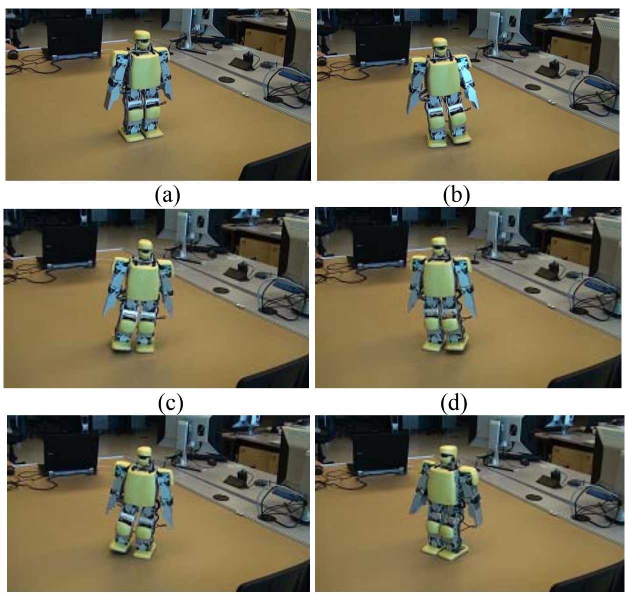


Figure 5. Brain signals during mental activities of turning left and right.



(a) (b) (c) (d) (e) (f)

Figure 6. Control of robot turning left through brainwaves

V. CONCLUSIONS

This paper develops a BCI based humanoid robot control system which can serve as a platform to investigate a relationship between complex humanoid robot behaviors and human mental activities.

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