HUMANOID ROBOT CONTROLLED BY REMOTE PRESENCE USING NON-INVASIVE BCI DEVICE

Dr. Bhavin C. Shah
Assistant Professor, Electronics & Telecommunications Department, Atharva College Of Engineering, Malad-Marve Road, Charkop Naka, Malad (West), Mumbai-400095, India

Abstract: This paper presents a platform for "Remote Presence" which enables a person to be present at a remote location through the embodiment of a humanoid robot. It specifically proposes the use of a humanoid robot since it will endow human like capabilities for manipulating the remote environment. The various sensors which are available on the humanoid robot like vision, microphones, etc...are essential to give feedback to the human controller about the remote environment. In addition to this, the humanoid has capabilities such as speech synthesis, obstacle avoidance, and ability to grasp objects which can be used to perform a wide array of tasks. To control the actions of the robot the paper proposes the use of non-invasive Brain Computer Interface. The BCI enables the user to conveniently control the robot in the remote environment. The human user receives audio and video feedback from the robot on a personal media viewer such as video goggles. This would help the user to feel total immersion in the remote environment. This system could immensely benefit a variety of sectors such as military, medicine, disaster management etc. for carrying out dangerous or physically intensive tasks.

I. INTRODUCTION

The field of robotics has made considerable progress over the past few decades. More and more research has been focused on developing completely autonomous robots free of any kind of human control. Although many barriers have been broken, the intelligence of robots is not even close to human intellect. In order for robots to be useful today, they are still dependent on human guidance. Most of the industrial and service robots need explicit programming to achieve desired objectives. Many applications require direct teleoperation. Teleoperation is difficult when there is a need to control complex robots such as humanoid robots having many degrees of freedom. The idea of using tele-operated robots for carrying out tasks in remote environments was first proposed by Marvin Minsky[10]. Advances in telecommunications have enabled considerable progress in this area. The focus shifted from simple tele-operation to telepresence, where the operator can have the feeling of being present in a remote location by having some control over the remote environment and receiving real-time feedback. Amongst the earliest works in this field, was by Hightower *et al*. [9]in which the steering wheel of a car in a remote location could be controlled by a human operator. The use of an anthropomorphic entity at remote environment was proposed. The remote presence technology has been used extensively for controlling mobile robots in hostile remote environments such as outer space, bomb-diffusion, radioactive waste dumping, extreme temperatures such as fire rescue or underwater exploration etc. Commercially sold robots such as Rovio and Spykee try to provide the users with video and audio feedback from a simple mobile robot present in the remote environment thus providing remote presence capabilities. A very good example where tele-robotic technology has found great applications is in the field of medicine [14]. Very recently, Cisco has introduced the Health Presence platform which aims to improve the doctor-patient collaboration during virtual visits [12].

It is common nowadays to perform delicate surgeries using tele-operated robots [15], [14]. Such applications have shown how human expertise can be transferred from one location to another via a robot embodiment. More industrial applications of such technology are used in virtual CAD modelling where users can create and interact with virtually created CAD models. The primary criteria for the remote presence system to work satisfactorily is that the operator should be able to conveniently control the robot and receive rich feedback from the remote environment. This paper proposes a novel method of constructing such a remote presence platform& propose that a humanoid robot be used in the remote environments primarily because humanoid robots have sensory and manipulator abilities close to that of a human being. They contain numerous sensors such as cameras, microphones, sonar etc. which can provide rich data feedback from the remote environment. For convenient control of the humanoid robot in the remote environment, the paper proposes the use of a Brain Computer Interface. Study by Bell *et al*. [3]has proven the utility of BCI devices for controlling the complex devices such as humanoids. The system proposed in this work also makes use of a personal media viewing device which can display the video captured from the humanoids camera. It is believethat such a system would closely simulate the feeling ofactually being present in the remote environment. In Section II, discussion on the proposed system design of the remote presence platform and the related problems that need to be addressed. Section 3 discusses the decision filtering strategy. In Section 4, the experimental setup and the results to validate the system are presented.

II. SYSTEM DESIGN

Overview: This section presents the software and hardware architecture of the proposed system. The system mainly consists of a non-invasive BCI device, a personal media viewing device, a wearable PC and the humanoid robot which would be controlled in the remote environment[2]. This section presents the hardware and the software design of the proposed system. Fig 1 shows the hardware setup to be worn by the user and Fig 2 shows the complete block diagram of the remote presence system.

Hardware architecture: In this subsection details about the hardware used for building the system are discussed. EEG Device: The BCI device used for experiment-ation is the EmotivEpocNeuro-headset [5]. The EmotivEpoc is a low cost Brain Computer Interface device intended to be used as a controller for gaming purposes. The device is based on recognition of patterns in Electro- Encaphalographic signals. EEG signals are the electric nerve responses generated by the human brain. The frequencies of the EEG signals characterize the thought pattern. Broadly, the signals are divided into 4 bands- α (8-12 Hz), β (12-30 Hz), θ (4-7 Hz) & δ (0-4 Hz) Each part of the brain is responsible for various activities. A higher frequency in that particular part of the brain indicates that the particular part of the brain is more active than others. This sets the fundamental basis for understanding the thoughts by analyzing EEG signals. The Epoc device consists of 14 EEG electrodes.

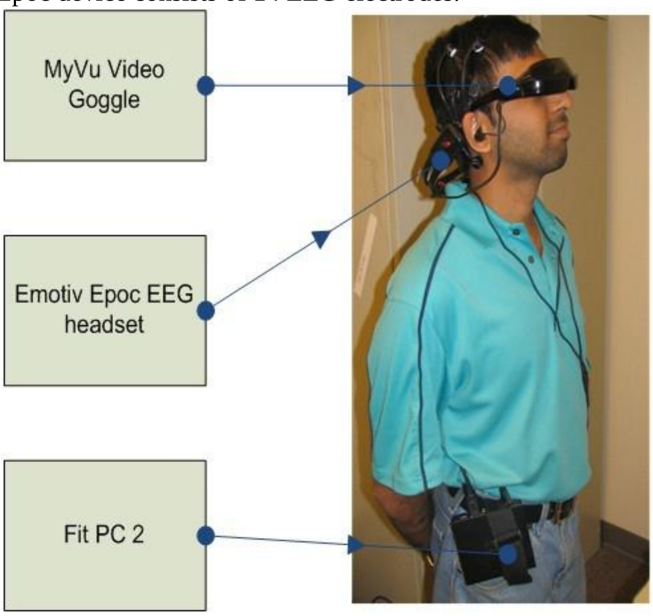

Fig. 1: The hardware setup consisting of the Video-Goggles, BCI Device and Embedded PC

The electrodes are placed on the scalp according to the International 10-20 format. The electrodes can sample data at the rate of 2048 Hz. The device is connected to the computer using a Bluetooth interface. Since the device has been created for gaming, arrangements have been made so that the system follows real time requirements. The device does not require a separate amplifier unit which reduces the cost drastically and allows mobility for the user. *Video Goggles:* Video goggles generally use a LCD or O-LED (Organic LED) display magnified by tiny lenses. This gives the wearer the sensation of viewing a very large screen (equivalent to 60 inches). Advanced goggles also allow for stereo vision capability. It is proposedthat the use of such video goggles because it eliminates the need for a display screen. The proposed system makes use of the MyVu video goggles [7]. *Fit PC*-2: The Fit PC-2 is a self contained CPU which can fit on the palm [6]. It includes a 1.6 GHz Intel Atom Processor, 1 GB DDR-2 RAM, 4 USB ports and a Wi-Fi and supports the Windows XP OS.

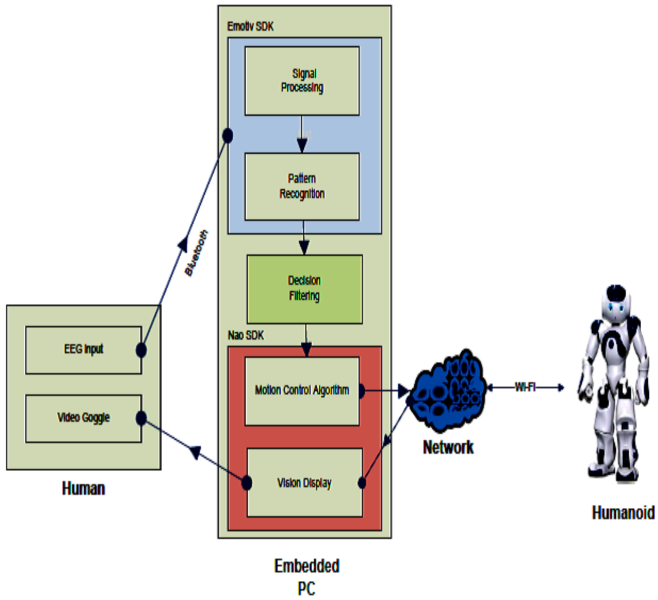

Fig. 2: System Block Diagram

Nao Humanoid Robot :The Nao Humanoid robot created by Aldebaran Robotics (France) is the state of art humanoid robot platform [4]. It is the standard platform used for the RoboCup competition. It has 26 degrees of freedom. It is equipped with the x86 AMD Geode micro-processor, 500 MHz, 256 MB RAM and 1 GB of flash memory. It can be connected wirelessly to a network using the Wi-Fi interface. The Bonjour Client helps in automatic network discovery and IP address assignment. The robot is equipped with 2 VGA cameras one pointing straight ahead and one pointing towards the floor. Inertial units and Force sensors on the feet help the robot to maintain balance while walking and other activities. It also has an ultrasonic measurement unit to detect and avoid obstacles. The robot is also equipped with 4 microphones and 2 speakers.

Software architecture: The software is developed on the wearable PC by using various Software Development Kits associated with the various hardware devices. The software architecture of the system can well understood by referring to Fig. 2

Nao Software Development Kit: The Nao Humanoid robot comes with an object oriented SDK for programming. The programming language used is C++. The SDK contains various functions running in real time for motor actions, sensory data acquisition. Motor action commands can be high level such as walking or low level such as moving individual joint angles.

Emotiv Software Development Kit:The Emotiv software already contains programs which allow for pattern recognition in EEG signals. The program is called Cognitive Actions suite which can classify the active thoughts of the user. Basically, a scenario is provided where the user can control the motion of a virtually generated cube such as PUSH, LEFT, ROTATE etc. The software has to be trained for each user before it can be used. The pattern recognition in EEG signals is implemented in the Cognitive Suite using proprietary algorithms based on the concept of presence of Mu-Beta rhythms in various parts of the brain[8]. The Emotiv Research edition SDK allows us to get the raw EEG data as well as the data directly from the Cognitive suite. In this work,Cognitive Suite based detection results to control the actions of the humanoid robot were used. An important goal in the future is to develop algorithms which will use the raw EEG data for pattern recognition so that it is most suited for robot control. For this system, there was a try to improve upon the detection results it got from the Cognitive suite by introducing a decision filtering block. The goal of the decision filter block is to identify whether the current thought is genuine or a falsely detected one. A heuristic approach is taken to remove the false positives, in order to get reliable signals for the robot control. Now, shall briefly describe the working of the system as a whole. The user is equipped with the Epoc EEG Headset, the Video Goggles and the Embedded PC. The thoughts of the user are sensed by the device and transferred to the embedded PC via Bluetooth. Digital signal processing operations are performed within the SDK to improve the signal to noise ratio[1]. These signals are converted to the feature space and then classified by the pattern recognition algorithm. Both of the above procedures are implemented in the Cognitive suite. The output of the Cognitive Suite is the decision about which action the user is thinking. This output is evaluated by the decision filter which predicts whether it is a genuine thought or a thought that is wrongly classified. Hence can get a dependable control signal. This signal is applied to the robot‟s control software which commands the robot to action corresponding to human thoughts[13]. The video feedback from the robot‟s camera is fed to the operator‟s video goggles so that the operator can see the remote environment. The communication between the operator setup and the robot setup can occur through any TCP/IP network. Hence, the whole system gives the user a feel of being actually present at a remote location through the humanoid robot embodiment. The idea and design of the whole system is an important contribution of this work.

III. DECISION FILTERING

Since the signals used are directly from the SDK, these signals are not optimized for the control of a mobile robot. Especially it observed a number of false positives. In our application, false negatives are acceptable, whereas false positives are not since false positives will cause faulty robot movements. Also have to take sufficient precautions for avoiding false positives. Hence, this block has been introduced. Using a heuristic technique, the probability of false positives can be greatly reduced. From the Cognitive Suite SDK, it can get 2 parameters such as the action the user is thinking about and the strength of the thought or equivalently the confidence of the SDK in detecting the users thought. The intuition that are relying upon is that, if the system is detecting the same thought for a sufficient duration of time as well as it is strongly confident about it, means that the thought is a genuine one. One method proposed is the integral over the thought (action) power function (ITPF). A thought cycle is defined as the time for which the system is detecting the same thought continuously [11]. A global threshold is set based on which the current thought cycle is accepted or rejected.The decision filter accepts the thought as genuine if is greater than a predefined threshold value. The threshold value is set heuristically by performing multiple trials under controlled conditions. The control action corresponding to thought is applied to control the robots movement. Fig. 3 explains the working of the decision filtering block. The first row shows the observed thought actions obtained from the SDK.

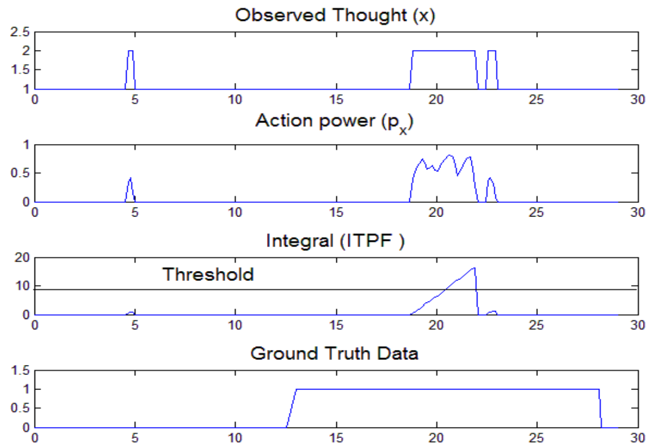

Fig. 3: The figure shows various parameters such as the thoughts, the power associated, ITPF and the ground truth data. It can be clearly seen that the spurious observations are removed by thresholding.

The second row shows the thought power function. The third row shows the integral over the thought power function. The integral is taken on individual thought cycles. The ITPF value isvery small for thoughts whose duration as well as power is less. From Fig. 3 shows the actual data obtained from experimentation. The last row shows the ground truth data. The ground truth was obtained by asking the user to push a button while he was thinking. From this it can be understood whether it was a true positive or not. It can be seen from the figure that a spurious thought occurring at time sec. was rejected by thresholding (threshold was set to be 9). Also, the thought at time sec. was rejected, thus preventing multiple movements. Hence, the decision filtering block is absolutely essential to provide reliable control signals for the robot.

IV. EXPERIMENTAL EVALUATION

The hypothesis proposed in this work is that a robot present at the remote location can be controlled using the visual feedback and EEG based BCI device. It is clear that the success of the system hinges on the performance of the BCI device. Hence, focus on validating the performance of the BCI device for the scenario of robot control. The experimentation has been done in two parts. In the first part it validated the performance of the SDK provided with Epoc. In the second part tested the efficacy of the decision filtering block and test whether getting reliable control signals is possible or not. A simulated robot to do the experiment since it is faster and easier to observe the results were used.

Validation of the EmotiveEpoc BCI device: The first experiment involves validation of the device in the lab environment where there are a lot of noise sources, audio and visual distractions for the user. The validation was done for the Cognitive suite, provided in the Emotive research SDK by training the system 10 times with training data of 8 seconds each &tried 2 actions per user for less complexity. The user had to move a graphically generated block on screen either forward or to the left by his thoughts. Also gave each user a sequence of 35 random actions such as MOVE LEFT, MOVE FORWARD, HOLD STILL. The number of times the user could move the block successfully in the given direction were recorded. It employed 4 volunteers for this experiment. Out of these 4 volunteers, volunteers „1‟ and „2‟ had used the system previously for 2 weeks whereas volunteers 3 and 4 were completely new to the system. The results for this experiment are presented in table I. The metric of performance is percentage of correct classification (PCC). From this experiment it was observed that the average rate of correct classification is 78.35%. It was also observed that the volunteers who had used the system for a few weeks before could give extremely good results. The conclusion from this experiment is that the BCI device gives acceptably good results. Also, with sufficient practice, users can develop expertise in using the BCI devices.

Validation of the complete set up: To validate the effectiveness of the decision filtering strategy, initially, an experiment with a simulated robot was conducted. It was mentioned briefly that the decision filter is a heuristically designed block.

Experiment with Simulated Robot: Finally, Fig. 5 shows the experiment done with the humanoid robot. A test path was set up shown approximately by the yellow line. The operator was asked to move the robot along the path. Retro-reflective markers were attached to the robots head. The motion was tracked and recorded by the Vicon MX optical motion capture system. Some motion paths are shown in Fig. 5. The thick red line shows the ideal path to be followed by the robot. The ideal path was obtained by recording the motion of the robot when it was controlled using a joystick.

Table I: Device Validation

USER NUMBER	PERCENTAGE OF CORRECT CLASSIFICATION (%)
1	95.65
2	85.71
3	65.38
4	66.67

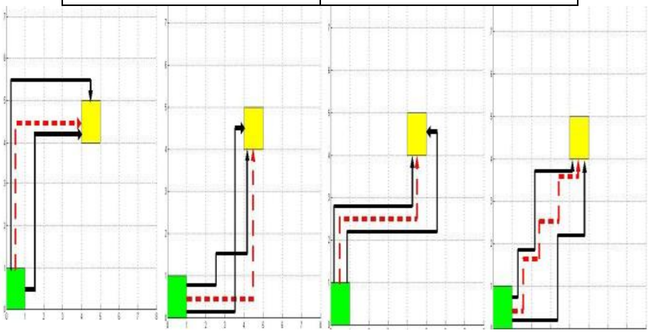

Fig. 4: Simulated robot control experiment. The goal for the user was to hit the yellow target by controlling the motion of the robot in 4 directions. The user was asked to follow the path shown by red dotted lines. The solid black lines show the actual path obtained by human control using EEG headset.

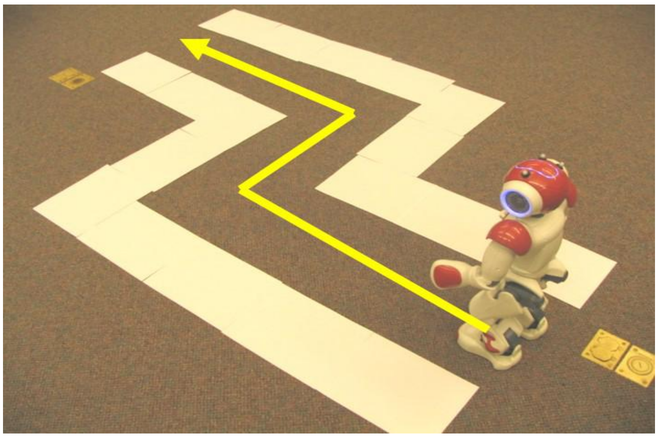

Fig. 5: The figure shows the test path to be followed

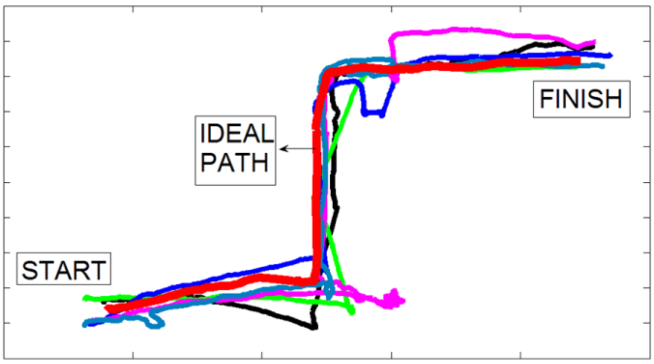

Fig.6: The bottom figure shows the observed paths. The thick red path is the path obtained when the robot was controlled using a joystick

In the experiment with humanoid robot, it can be seen that the user is able to move the robot from the start to finish with very few false movements. Therefore it concludes from these experiments that the system is able to provide reliable motion control signals using only the human user‟s thoughts.

V. CONCLUSION

This work presented a novel idea and a platform for remote presence through a humanoid robot embodiment. A special strategy called decision filtering was proposed to improve the results by reducing false positives. The merit of the system was evaluated by validating the BCI device and the complete system. It was seen that decision filtering successfully removes false positives. Thus, reliable signals for controlling the robot motion were obtained from the thoughts of the human. The human user was able to control the motion of the simulated robot as well as the humanoid robot.The proposed platform can be used for many experiments involving Human-Robot interaction using BCI devices. For the future works investigation needs to be done to derive optimal algorithms for pattern recognition in EEG signals for robot motion control. The given system can be augmented with haptic devices to provide multimodal control to the user. Such a remote presence system can have many practical applications such as tele-operating humanoid robots to work in hostile environments, laborious work or simply working in a remote environment.

REFERENCES

[1] Ansar. “Visual and haptic collaborative tele-presence”. Computers & Graphics, 25(5):789–798, October 2001.
[2] Bauer, M., Heiber, T., Kortuem, G., and Segall, Z. “A Collaborative Wearable System with Remote Sensing”. In Proceedings of the 2nd IEEE international Symposium on Wearable Computers (October 19 - 20, 1998). ISWC. IEEE Computer Society, Washington, DC, 10.
[3] Christian J. Bell, PradeepShenoy, RawichoteChalodhorn, and Rajesh P. N. Rao. “Control of a humanoid robot by a noninvasive brain-computer interface in humans”. Journal of Neural Engineering, 5(2):214+, June 2008.
[4] http://www.aldebaran-robotics.com/en, Nao Humanoid Robot, Aldebaran Robotics, France
[5] http://www.emotiv.com/, EmotivEpoc EEG Headset
[6] http://www.fit-pc.com/web/, Fit-PC2 CPU system
[7] http://www.myvu.com/, MyVU personal multimedia viewers.
[8] J. D. Millan, F. Renkens, J. Mourino, and W. Gerstner. “Noninvasive brain-actuated control of a mobile robot by human EEG”. Biomedical Engineering, IEEE Transactions on, 51(6):1026–1033, May 2004.Y.
[9] J. Hightower, “Development of Remote Presence Technology for Teleoperator Systems”, Naval Ocean System Centre, 1986.
[10] M. Minsky, “Toward a remotely manned Energy and Production Economy .”MIT AIL, 1979.
[11] N. Roy, G. Baltus, D. Fox, F. Gemperle, J. Goetz, T. Hirsch, D. Magaritis, M. Montemerlo, J. Pineau, J. Schulte, and S. Thrun. “Towards personal service robots for the elderly,” June 2000.
[12] Nick Augustinos and Ash Shehata, Cisco IBSG Healthcare Practice, Cisco HealthPresence, Transforming Access to Healthcare, Jan 2009
[13] Nijhholt A, , “BrainGain: BCI for HCI and Games,” The Society for the Study of Artificial Intelligence and Simulation of Behaviour, April, 2008.
[14] Satava R.M., Simon I.B., “Teleoperation, telerobotics, and telepresence in surgery.”,EndoscSurg Allied Technologies. (3):151-3, Jun 1993
[15] Sheridan TB. Telerobotics, Automation, and Human Supervisory Control. Cambridge, MA: MIT Press, 1992.

