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Remote Navigation of Turtle by Controlling Instinct Behavior *via* Human Brain-computer Interface

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Abstract

Brain-Computer Interface (BCI) techniques have advanced to a level where it is now eliminating the need for hand-based activation. This paper presents a novel attempt to remotely control an animal's behavior by human BCI using a hybrid of Event Related Desynchronization (ERD) and Steady-State Visually Evoked Potential (SSVEP) BCI protocols. The turtle was chosen as the target animal, and we developed a head-mounted display, wireless communication, and a specially designed stimulation device for the turtle. These devices could evoke the turtle's instinctive escape behavior to guide its moving path, and turtles were remotely controlled in both indoor and outdoor environments. The system architecture and design were presented. To demonstrate the feasibility of the system, experimental tests were performed under various conditions. Our system could act as a framework for future human-animal interaction systems.

Keywords: brain-computer interface, turtle (*Trachemys scripta elegans*), remote navigation, instinct behaviour, escape behavior

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1 Introduction

A repeated theme in fiction involves people imagining themselves in the body of another human or that of an animal. For example, the premise of the movie "Avatar" was that a human can exist in another body, with that body controlled by a remotely connected mind. Of course, we cannot expect to realize the technology described in the movie in the near future. However, recent advances in electronics and computer technology have allowed researchers to approach this appealing topic. A novel technique for interfacing between humans and machines, based on human thought or neural responses, has been developed. This development is called a "Brain-Computer Interface" (BCI). Using this technique, it is possible to read human thought and use that ability to control machines. Previous BCI studies have successfully controlled a humanoid robot[1–5]. Rao *et al.* demonstrated the possibility of sending information extracted from one brain directly to another brain through direct brain-to-brain communication[6]. Yoo *et al.* created a "Brain-to-Brain Interface" (BBI) system that combines a BCI with a "Computer-to-Brain Interface" (CBI) that could be used to establish a functional link between the brains of different species (*i.e.* humans and Sprague-Dawley rats)[7].

On the other hand, there have been several attempts to control animals by stimulation in order to draw on their high levels of locomotion and energy efficiency. In general, animals exhibit superior locomotion and survival abilities as a result of their adapting to the environment over millions of years. Therefore, their bodies are optimized in terms of locomotion and energy efficiency.

Some researchers have tried to control animal movement by applying invasive control methods. Daly

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et al. designed a wireless flight control system for moths that consisted of a 3 GHz to 5 GHz non-coherent pulsed ultra-wideband receiver system-on-chip[8]. Sato and Mahabiz proposed a beetle flight control system which provided electrical stimuli to the beetle's wing muscles[9]. Tsang *et al*. suggested the possibility of the remote flight control of a moth by using micro-fabricated Flexible Neuroprosthetic Probes (FNPs)[10]. Sun *et al*. proposed the automatic navigation of rat-robots using the General Regression Neural Network (GRNN) method[11]. Sanchez *et al*. designed hybrid cockroach robots which applied electrical stimuli to the prothoracic ganglia *via* a remotely operated backpack system and implanted electrodes[12].

There have also been studies for controlling an animal's movement through non-invasive control methods. Holzer and Shimoyama proposed a bio-robot system for controlling an insect (*Periplaneta Americana*) with electrical stimuli[13]. Butler *et al*. suggested a virtual fence system for containing cattle that used sound stimuli[14]. Britt *et al*. were able to navigate a well-trained dog using commands provided through wireless devices[15]. Lee *et al*. succeeded in controlling an untrained turtle's walking paths by inducing obstacle-avoidance behavior[16]. Pi *et al*. proposed a non-invasive remote control system for rat-robot *via* ultrasonic, epidermal and LED photic stimulators[17].

Using the technologies mentioned above, it is possible to develop a system to control an animal's behavior using human BCI technology. To realize this, however, the system architecture and interfacing techniques require further development. In this paper, we propose a conceptual system that is capable of remotely guiding an animal's moving path by controlling its instinctive behavior (*e.g*. escape behavior) using a simple stimulation device controlled by a human's brain signals. As the target animal, the turtle was chosen because it has good cognitive abilities, is capable of distinguishing the wavelength of visible light[18]. It is known that turtles recognize a white light source as an open space and so move toward it[19,20]. Also, turtles show specific avoidance behavior patterns by external visual obstruction[16]. Further, it has a hard shell on which devices can be mounted. Also, our objective was to invoke instinctive behavior, specifically, the escape behavior that induces the operant responses that cause the animal to move away from an ongoing punishing or obstructing stimulus. In particular, this reactive behavior is connected to those instincts which protect the body and which must be evoked and directed in a consistent manner by a stimulus[21–23]. In our previous research, this instinctive behavior was utilized to control the turtle's path. As a result, coherent patterns in the turtle's trajectory were observed[16].

In our concept system, a Head-Mounted Display (HMD) is adopted as the user interface. The combination of the wearable BCI and HMD enables users to become more immersed in the control of the turtle. The human operator wears the integrated BCI-HMD system, while the turtle is equipped with devices for stimulation, wireless communication, and imaging. Based on the images acquired from the cyborg turtle, the human uses thought to command the turtle. These thought commands are recognized by the wearable BCI system. Using Wi-Fi, these commands are transmitted to a stimulation device attached to the turtle's upper shell. Then, the turtle is induced to move by the stimulation device that invokes the turtle's instinctive behavior. Finally, the human acquires updated visual feedback from the camera mounted on the turtle's upper shell. In this way, the human can remotely navigate the turtle's trajectory.

To check our system's operability and applicability, three tests were conducted in both indoor and outdoor environments. An indoor test was performed to confirm the responsiveness of the stimulation device and to check the basic operability of the cyborg system. Outdoor tests were also performed to check the availability and applicability of the system under real-field conditions. All of the tests were successfully implemented and the results were found to point to the usefulness of the concept system for extended applications in a real environment.

2 System

2.1 System architecture

The principal objective of the proposed system is to provide a control feedback loop for remotely guiding a turtle by means of human thought alone. To close the loop, the human operator is provided with visual information (such as a real-time video stream) from the cyborg turtle that he or she is controlling.

Fig. 1 illustrates the architecture of our proposed system. The overall system consists of two main