USING BLUETOOTH AS THE CONNECTING INTERFACE BETWEEN ARDUINO AND A BRAIN-COMPUTER INTERFACE

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THIS DISSERTATION IS SUBMITTED AS A PARTIAL REQUIREMENT TO OBTAIN DEGREE OF BACHELOR OF SCIENCE WITH HONOURS

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ABSTRACT

Brain-controlled interface (BCI) is a new technology derived from electroencephalography (EEG), which allows human to send commands through BCI via electrical activity from their brain instead of moving their limbs. BCI used in this paper uses Bluetooth technology to send data information received from brain activities of human and allows computer to process the data to be transmitted to robotic limbs or Arduino robot used in this paper, and hence allowing movements to occur. Bluetooth technology offers short-range data transmission with very low power consumption. This project aims to write a program to connect BCI and Arduino robot via Bluetooth in which the expected outcome would be a stable wireless connection of BCI and Arduino via Bluetooth without any other Bluetooth or Wi-Fi interference. It also aims to write a program to establish a bridge between BCI and Arduino motor and make sure it functions without any distraction. For this, HC-05 Bluetooth Module will be used as the bridge between BCI and Arduino. Different tests were done to ensure stability of the Bluetooth connection such as interference test, obstacle test and load test. There was no interference from other electromagnetic signal sources i.e. Wi-Fi and Bluetooth due to frequency hopping feature. Obstacles such as walls, doors and iron pipes between walls cause diffraction and absorption, which weakens the Bluetooth signal. The connection is also tested with LED only and Arduino robot, which uses different power, but the load does not affect Bluetooth connection. As for the conclusion, a stable Bluetooth connection is established.
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CHAPTER 1

INTRODUCTION

1.1 Project Background

World’s most well known cosmologist, Professor Stephen Hawking, suffers from Amyotrophic Lateral Sclerosis (ALS), which is dysfunction of motor neuron in his brain. Despite that, he owns a computer-based communication system which has been sponsored and provided by Intel Corporation. This system mainly controls the wheelchair using his cheek movement, besides controlling the computer system. However, the system still requires assistance from people around him to move him around. Not every people who suffer from ALS or other nervous system failure disease is as lucky as Professor Hawking to own a high-technology wheelchair to assist his communication. At year 2013, Levi Hangrove, PhD, a scientist for Bionic Medicine, developed a system to use neural signals to improve limb control of a bionic leg. However, this requires a person to be able to at least stand on himself, with or without assistive tools. Invention of brain-controlled devices has brought a new light to people with ALS. By using EEG biosensors, signals from brain could be detected and processed as digital signals and sent to device using Bluetooth technology.

EEG biosensor, or electroencephalography, is the recording of electrical activity along the scalp, whereby the electrical activity comes from brain. EEG measures voltage fluctuations resulting from ionic current flows within the neurons of the brain, which are the brainwaves.
A brain-computer interface (BCI) system is specifically designed to detect the mental state of its user so as to carry out the user's desired action. The study of BCI as a field emerged from the desire for new assistive technology, targeted at handicapped patients, especially those paralyzed (Cashero, 2011).

Mostow et al.'s study, the Reading Tutor had recorded students' EEG signals for BCI system but it still cannot be considered as a complete BCI system, as computer keyboard, mouse and microphone are still needed for interaction whereby patients with total motor neuron failure couldn't do. However, technology nowadays made complete BCI system possible.

Bluetooth technology is a wireless technology standard for exchanging data over short distances from fixed and mobile devices. It is a standard wire-replacement communications protocol primarily designed for low-power consumption. Total remote system could be achieved combining BCI system and Bluetooth to aid handicapped patients for remote control devices such as remote table and other assistive devices.

1.2 Purpose

The aim of this project paper is to develop a program for Bluetooth connection between BCI and Arduino Bluetooth Module and make sure there is no frequency distraction from other Bluetooth devices.

1.3 Objective

The objectives of this paper are to:

(a) Design algorithm for writing program to establish a bridge between BCI and Arduino Motor.

(b) Develop the program using Arduino Bluetooth Module.

(c) Test the program to ensure it functions without distraction.
1.4 Problem Statement

How to connect Arduino Motor to BCI wirelessly? Bluetooth technology is used as BCI used in this project paper, Neurosky only supports Bluetooth connection, and because only a short distance exists between BCI and Arduino Bluetooth module. A stable and non-distracted connection needs to be established to ensure smooth movement of the robot.

1.5 Hypothesis

A stable and working Bluetooth connection is established between BCI and Arduino board by writing a program that will prevent distraction of frequency and port from other Bluetooth devices.

1.6 Scope of Study

In the proposed research, a study about wireless Bluetooth connection is done and a connection between BCI and Arduino board is established.
CHAPTER 2

LITERATURE REVIEW

2.1 Bluetooth Architecture

Figure 2.1 shows the part that specifies or implements the medium access and physical layer procedures between Bluetooth devices, which is called the Bluetooth Baseband. When two or more devices are connected with the same physical channel, a piconet is formed. In the piconet, there are two (2) components:
(i) Master: The Bluetooth device where communication is initiated. It sets the time and broadcasts its clock to all slaves providing the hopping pattern at a fixed frequency.

(ii) Slave(s): The state/signal by master device to all devices are given to all devices. The device is an active slave if it continues transmits or receives data from master, and if it does not, it is a passive slave. By enabling RF receives periodically, passive slaves continuously checking if there is a connection request from the master.

In the piconet, there will be one Bluetooth device acts as the master and more than one and no more than seven slaves can be used in the piconet, as shown in Figure 2.2.

![Figure 2.2 Piconets with (a) single slave operation, (b) a multi-slave operation and (c) a scatternet operation (http://developer.bluetooth.org)](image)

2.1.1 Hop Selection

There are six types of hopping sequence – five basic hop system and one adapted set of hop locations used by adaptive frequency hopping (AFH). These sequences are (developer.bluetooth.org):

(i) A page hopping sequence with 32 wake-up frequencies distributed equally over the 79 MHz, with a period length of 32.
(ii) A page response hopping sequence consisting 32 response frequencies in correspondence to current page hopping sequence. Master and slave use the same sequence by using different rules.

(iii) An inquiry hopping sequence consisting 32 wake-up frequencies distributed equally over the 79 MHz, with a period length of 32.

(iv) An inquiry response hopping sequence consisting 32 response frequencies in correspondence to current inquiry hopping sequence.

(v) A basic channel with a very long period length, which in a short time interval does not show repetitive patterns, and distributes the hop frequencies equally over the 79 MHz over a short time interval.

(vi) An adapted channel hopping sequence derived from basic channel hopping sequence uses the same channel mechanism and may be less than 79 frequencies. It is only used in place of basic channel hopping sequence. All other hopping sequences are not and shall not be affected by hop sequence adaptation.

2.1.2 Bluetooth Pairing

The Secure Simple Pairing (SSP) protocol is the most widely used pairing protocol for Bluetooth. The protocol specifies the necessary steps for two Bluetooth devices to establish a secure connection. It consists of the following six phases as shown in Figure 2.3 (Haataja & Toivanen, 2010):

(i) Capabilities exchanged: Devices that are pairing for the first time or are re-pairing, exchange their input/output (IO) capabilities in order to determine suitable association model to use for the pairing. For devices with access to displays and keyboards, the Numeric Comparison (NC) model will be used.

(ii) Public key exchange: Public-private key pairs and the Diffie-Hellman key is generated by the devices before exchanging the keys.

(iii) Authentication stage 1: For NC mode, a 6-digit number is displayed on both devices attempting to make a connection. The users need to compare and confirm the numbers before completing the pairing process. If the numbers are identical, the users will select yes for the pairing to proceed.
(iv) Authentication stage 2: The devices exchange the values, compare and verify their integrity.

(v) Link key calculation: The devices compute the link key using their own Bluetooth addresses, the previously created values, and the Diffie-Hellman key constructed during phase 2.

(vi) LMP authentication and encryption: Creation of the encryption keys.

Once the devices do the pairing process, a connection is established between the devices.

Figure 2.3 Bluetooth Pairing Process (Pieterse & Olivier, 2014)
2.1.3 Logical Transports

Between master and slave(s), there are different types of logical transports. Five logical transports are defined:

(i) Synchronous Connection-Oriented (SCO) logical transport
(ii) Extended Synchronous Connection-Oriented (eSCO) logical transport
(iii) Asynchronous Connection-Oriented (ACL) logical transport
(iv) Active Slave Broadcast (ASB) logical transport
(v) Parked Slave Broadcast (PSB) logical transport

2.1.4 Logical Links

Five logical links are defined:

(i) Link Control (LC)
(ii) ACL Control (ACL-C)
(iii) User Asynchronous/Isochronous (ACL-U)
(iv) User Synchronous (SCO-S)
(v) User Extended Synchronous (eSCO-S)

2.2 Bluetooth Module

Bluetooth module is used to send and receive data from brain-controlled interface via wireless Bluetooth. There are several types of Bluetooth modules which is compatible with Arduino, as for example, Arduino Bluetooth Module and HC-05 Bluetooth Modem.
2.2.1 Arduino Bluetooth Module

Figure 2.4 shows an Arduino Bluetooth Module, a microcontroller board originally was based on the ATmega168, but now is supplied with the 328 and Bluegiga WT11 Bluetooth module. It supports wireless serial communication over Bluetooth in short range. It has 14 digital input/output pins, 6 analog inputs, a 16 MHz crystal oscillator, screw terminals for power, an ICSP header, and a reset button.

Each of the 14 digital pins on the Bluetooth Module can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions in Arduino software. Meanwhile some pins have specialized functions as listed below (arduino.cc):

(i) Serial: 0 (RX) and 1 (TX). Used to receive (RX) and transmit (TX) TTL serial data. These pins are connected to the corresponding pins of the Bluegiga WT11 module.

(ii) External interrupts: 2 and 3. These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value by using attachinterrupt().

(iii) PWM: 3, 5, 6, 9, 10 and 11. Provide 8-bit PWM output with the analogWrite() function.

(iv) BT Reset: 7. Connected to the reset line of the Bluegiga WT11 module, which is active high.

(v) LED: 13. There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.
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(ii) External interrupts: 2 and 3. These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value by using attachInterrupt().

(iii) PWM: 3,5,6,9,10 and 11. Provide 8-bit PWM output with the analogWrite() function.

(iv) BT Reset: 7. Connected to the reset line of the Bluegiga WT11 module, which is active high.

(v) LED: 13. There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.
Some precautions when using Arduino Bluetooth Module as below:

(i) It is easier to break and more vulnerable compared to other Arduino boards.

(ii) There is no polarity protection (reversing power and ground pins) for Arduino and is subtle to damage due to voltage fluctuation.

(iii) Not to connect to pin 7 because pin 7 is reserved for master reset of the module.

(iv) Arduino Bluetooth Module is able to support voltage from 2.5V to 12V but higher voltages will damage the module and it needs to be replaced.

2.2.2 HC-05 Bluetooth Modem

Figure 2.5: HC-05 Bluetooth Modem (playground.arduino.cc)

Figure 2.5 shows a Bluetooth modem, HC-05, which is compatible with Arduino Mega 2560 board. It operates from 1.8V to 3.6V. This modem could be made into either master or slave device in a Bluetooth system. It has built-in AFH (adaptive frequency hopping) feature to reduce interference in the Bluetooth connection.

Setup of HC-05 modem to Arduino board is done as shown in Figure 2.6 (playground.arduino.cc).

(i) LED is connected to any pin except pins 2 or 3.

(ii) Bluetooth model has 4 pins: PWR, GND, Rx and Tx, each of them are connected to 5V pin, GND pin pin 3 and pin 2 respectively.
(iii) When everything is connected, a small green LED will start blinking on the Bluetooth modem.

Figure 2.6 Setup of Bluetooth Modem to Bluetooth Module
(http://playground.arduino.cc)

Wiring code is uploaded into Arduino Mega 2560 Board using a serial port.