WIRELESS EAR-EEG SENSOR

ABDUL RAUF BIN AB RAZAK

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WIRELESS EAR-EEG SENSOR

by

ABDUL RAUF BIN AB RAZAK

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ABSTRAK

Pemantauan otak berdasarkan elektroensefalografi (EEG) dalam kehidupan seharian telah dipanjangkan dengan keupayaan mudah alih yang terhad dan masa persediaan sistem yang panjang oleh sistem pemakaiaan yang sedia ada, begitu juga dengan sistem implan yang invasif. Kaedah untuk merekod isyarat EEG daripada dalam telinga yang juga dikenali sebagai telinga-EEG, telah dicadangkan dan telah membawa kepada pendekatan yang bijak, tidak mengganggu pengguna, dan mesra pengguna terhadap pemantauan activiti otak. Konsep rakaman telinga-EEG telah diuji dengan menggunakan beberapa paradigma EEG piawai, penanda aras dengan EEG piawai pada kulit kepala, dan kelayakan untuk digunakan adalah terbukti. Sistem ini menawarkan beberapa kelebihan termasukalah kedudukan elektrod yang tetap, keselesaan pemakai, kekukuhan kepada gangguan elektromagnet, maklum balas kepada pengguna, dan mudah untuk digunakan. Projek ini juga perlu untuk merancang sistem pengambilalihan EEG tanpa wayar untuk memudahkan pemantauan pesakit. Dalam kata lain, tujuan kajian ini dilakukan adalah untuk merekabentuk penderia telinga-EEG tanpa wayar untuk pemantauan yang lebih baik. Perkembangan sistem EEG tanpa wayar juga sesuai untuk aplikasi seperti kawalan jauh peranti, menyelamat dan sebagainya.

WIRELESS EAR-EEG SENSOR

ABSTRACT

The brain monitoring based on the electroencephalography (EEG) into everyday life has been prolonged by the limited portability and long setup time of current wearable systems as well as by the invasiveness of implanted systems. A method for recording the EEG signal from the outer ear called ear-EEG, has been proposed which leading to the discreet, unobtrusive, and user-friendly approach to the brain monitoring. The ear-EEG recording concept is tested using several standard EEG paradigms, benchmarked against standard on-scalp EEG, and its feasibility proven. This system offers number of advantages including fixed electrode position, user comfort, robustness to electromagnetic interference, feedback to the user, and ease to use. This project also supposed to design a wireless EEG acquisition system for easily monitoring of the patients. In the other word, the purpose of this study is to design a wireless ear-EEG sensor for better monitoring. The development of wireless EEG system is also suitable for the application such as remote control of devices, rescue, and so on.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Chapter 1 introduces the overview of wireless ear-EEG mechanism. Electroencephalogram (EEG) is defined as electrical activity of an alternating type recorded by the metal electrodes and conductive medium from the scalp surface. Electroencephalography (EEG) is a well establish technique providing valuable insights into the brain activity, with application both in clinical practice and in basic and applied neuroscience. EEG is one of the most common source of information used to study brain function and neurological disorder and also used as a highly complex signal [1] [2]. The brain is an important part of the human which controls entire part of human body voluntary or involuntary. When brain cells are activated, local current flows are produced. Brain cells will be activated when there are brain activities such as movement, senses, thinking, blinking eyes and many more. The currents that flow during synaptic excitations of the dendrites have been measured by EEG [3]. EEG promises a significant characteristics including non-destructive, pain less, side effect less, and accurate interpretations for some brain disease like epilepsy, memory loss, Alzheimer and autism [4].

The limited portability and long setup time of current wearable system as well as by the invasiveness of implanted system has been restrained the integration of scalp-EEG into everyday life. After many consideration, it been explored that there are potential to record the EEG signal in the ear canal which leads to a discrete, unobtrusive and user-friendly approach to the brain monitoring. This wearable system is designed to be comfortable over long periods of time. The ear-EEG earpieces are customized to each user similar with the hearing-aids earplugs. The personalized earpiece secures tight contact between the recording electrodes and the skin, hence ensure good quality of recoding [5] [6] [7]. The other benefits of using personalized earpiece are electrode positions held in-place, comfortable to wear, robustness to electromagnetic interference, feedback to the use and ease to use. The ear-EEG recording concept has been tested using several standard EEG paradigms, benchmarked against standard scalp-EEG, and its compatibility proven [8].

EEG systems also can be made small enough not to trouble the user and wireless signal transmission if possible. Traditional EEG systems require bulky, elongate assembly and application time, typically involving the patient to wear it on their scalp which leads to painful and unpleasant experiences. The application time and discomfort make these traditional systems challenging to use in the populations affected by dementia for example, where cooperation with lengthy clinical procedures is often difficult [9] [10].

1.2 Problem Statement

One important requirement in conducting this project is to make the EEG recording wearable over a long period of time. There are many factors that make robust wearable systems a significant challenge. One of the factors is the wet nature of conventional electrodes which required us to use of conductive gel to allow the connection between the electrodes and the scalp. This method makes them unsuitable for 24 hours use. That is mean that the recording quality will degrades considerably once the gel dries out.

The other important factor in EEG recording is the position of the electrodes and the rigidity of the electrodes on the skin. The rigid on-scalp electrodes can be uncomfortable and limit the reliability of recordings.

Movement also reduces the signal quality, and this problem is commonly handle with using these two strategies. Firstly, recording signals will be recorded subjects show exact manner are discarded, which results in asynchronous brain and behaviour sampling. Secondly, only movement-constrained behaviour is allowed. It involves skin mounting number of wired sensor and connecting electrodes to the main acquisition unit and the PC. This problem also lead to the non-user-friendly, uncomfortable to wear, and inconvenient for mobilization, and also result in stigmatization of users and limits the use in clinical or controlled environments [10] [11].

One way to solve this problem correlated with wearable EEG is the use of semi-implanted electrodes, which will offer high quality recordings with well-organized and rigidly held in-place electrodes. These problems suggest the solution which lead to the important characteristics that a fully wearable EEG system must exhibit. The following characteristics are:

- Discreet: A wearable system should not be clearly visible.
- Unobtrusive: The recording device should be comfortable to wear and should bother the user as little as possible. It is necessary to ensure high fidelity of recordings when users are monitored in their natural environment.
- Robust: The device must be embedded into the system that ensures the electrodes are firmly held in-position and will not become easily dislocate during recording.
- User friendly: The devices should easily be maintained by the user, resulting in reduction in operational costs. User must be able to insert the device themselves without assistance of a trained person.

Therefore, ear-EEG systems fulfils the above requirements, as it exhibits a high degree of comfort and excellent long-term wearable device, reduced number of electrodes and thus a compromise in recording quality [8]. In the case of mobilization EEG system, small and wireless systems will minimize movement of the electrode wires. Electrode wire is a major source of electromagnetic interference, which will dramatically degrades EEG signal quality [12].

1.3 Objectives of Research

The purpose of this study is to design, verify and develop a wireless ear-EEG sensor by using Digital Brain Electric Activity Mapping KT88-3200 machine. The following main objectives are therefore set:

1. To design the customized earpiece for ear-EEG system.
2. To verify the recording ear-EEG signal.
3. To develop the wireless ear-EEG sensor that enables the truly simultaneous acquisition of brain activity.

1.4 Scope of Project

The focus of this project is on the designing the device that comfortable to wear and produce a good quality of recording EEG signal. In order to improve the system and device, there are several attentions due to its limitation of the project. Basically, this study has been divided into two parts which are hardware developments and software developments. This project specifically focuses on the ear-EEG recording as well as the wireless system to improve the quality of the recording. This project has been divided into three main phases which will the project flows. This project also will be using the Arduino Uno as a microcontroller and a circuit to eliminate the noise produced while the signal is transmitted wirelessly.

1.5 Thesis Outline

Arrangement of the thesis chapters were prepared in a way that the whole project could be expressed clearly from the literature review to the methodology part.

Chapter 1 which is Introduction part, it described the details about research background, problem statement, objectives, scope of research and this thesis outline.

Chapter 2 which is Literature Review, which described the previous works by the earlier researchers.

Chapter 3 which is Methodology, reveals the objectives of the project which explains the entire works from the beginning until the end. Details related to the data also presented.

Chapter 4 which is Result and Discussion, shows the performance and final results based on the wireless ear-EEG sensor recording signal. The projection problem encountered is discussed in this chapter.

Chapter 5 which is Conclusion, concludes the project and give the suggestion of improving that can be done in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This section presents some review paper conducted by previous researches. The previous studies contain critical points of current and prior knowledge, including substantive findings and the theoretical and methodological contributions related to the present research. EEG is a medical image technique that's read scalp electrical activity generated by the brain structures. Thus, the procedure is completely non-invasive to patients, normal adults, and children. It also can be applied repeatedly with virtually no risk or limitation [3].

Over the year, the evolution of EEG hardware technology and various number of wireless multi-channel systems have been developed that deliver good quality EEG and physiological signals in a simpler way, more convenient and comfortable design than traditional systems. Combination between advances in signal detection and quantitative analysis techniques, wireless system are an ideal candidates for relatively rapid and tolerable clinical assessment of potentially challenging [9].

2.2 EEG

The electrical activity produced by the cerebral cortex nerve cells hold much information. It is represented by the signal known as EEG [13]. Hence, EEG has become one of the most important ways to analyze brain activities in clinical studies. EEG is a recorded electrical activity produced by the brain. EEG signals are measured through electrodes placed on the scalp by putting a small amount of conductive gel between the electrodes and scalp. Millions of neurons inside the brain generate small electric voltage fields that form an electrical reading that can be detected and recorded through electrodes placed on the scalp. Typically, an EEG amplitude is in a range of 0.5µV to 100 µV [3].

Generally, EEG waveforms are sorted into different classes by the shape, frequency, and amplitude of the signals. The placement of electrodes on the scalp during recording the signals must be considered as well. The EEG amplitudes plays the important roles in determining the different states, and it depends on external simulations. The basic frequency bands are categorized into five states which are alpha, beta, delta, theta and gamma. The frequency bands are described in Table 1.

Table 2.1: Brain wave classification

Brainwave Types	Frequency Range	Mental States and Conditions
Delta (δ)	0.1 to 3.0Hz	Dreamless sleep, non-REM (rapid eye movement) sleep, unconscious.
Theta ()	4 to 7 Hz	Intuitive, creative, recall, fantasy, imaginary, dream
Alpha ()	8 to 12Hz	Relaxed but not drowsy, tranquil, conscious.
Low Beta ()	12 to 15Hz	Relaxed yet focused, integrated
Midrange Beta	16 to 20Hz	Thinking, aware of self and surrounding
High Beta	21 to 30Hz	Alertness, agitation
Gamma ()	30 to 100Hz	Motor function, higher mental activity

2.3 Ear-EEG

After many consideration, the proposed ear-EEG is approach and this approach radically new in which it records the EEG signals from within the ear canal. It is achieved by embedding electrodes on a personalized earpiece. Ear-EEG uses the same principles as the standard recordings obtained from the scalp electrodes. In electrophysiological terms, before the bioelectrical signals from the cortex reaching the ear canal, the signal are degraded by the cerebrospinal fluid, skull, and skin, as is the case with conventional scalp measurement [8]. The ear-EEG concept displays a high degree of comfort, outstanding long term wearable design, at the expense of a reduced number of electrodes and thus a compromise in spatial resolution [14].

The ear sensing technology have been proven to provide a good EEG signal for brain computer interface applications with steady-state response. This technology also has more recently been used for monitoring other physiological responses, such as cardiac activity. This wearable system also has been designed to be comfortable over long periods of time and with the electrodes are firmly placed inside the ear canal, which promises the good quality of recording [5]. The EEG signal measured from the ear electrodes was found to reflect the same cortical activity as that from nearby scalp electrodes by comparing event related potential (ERP) waveforms from the mismatch response chart. It was also found that referencing the ear-EEG electrodes to another within-ear electrode affects the time-domain recorded waveform which relative to the scalp recording, but not the timing of individual components. Previous researcher have concluded that the spectrogram-based analysis, timing of ERP components, and signal strength for sources close to the ear yields similar performance between ear-EEG and traditional EEG [1].

Based on the research handled [8], its state that there are important advantages of ear-EEG compared to the conventional methods of recording are summarized as follow:

- The earpieces are personalized, comfortable to wear, discreet and easy to put in place by user themselves.
- The spatial localization of the electrodes and embedded on the surface of the earpiece is very accurate. This leads to perfect repeatability of the experiments since the electrodes will always be placed in the same position relative to signal sources and with the same distance between electrodes.
- The electrodes are held firmly in place because of the tight fit between the personalized earpiece and ear canal.

- Muscle artefacts are greatly reduced as there are no muscle fibre in the ear canal and common source of muscle artefacts such as mouth, eyes and face muscle are located far away.
- The earpieces provide a rigid support for the electrodes and leads from the electrodes to the electronic instrumentation can be embedded within the earpiece, providing a robust, integrated device that easy to wear and operated by the users themselves.

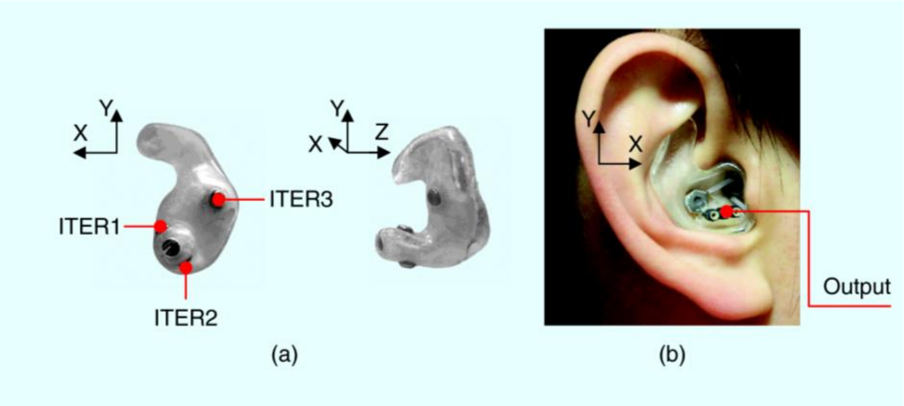
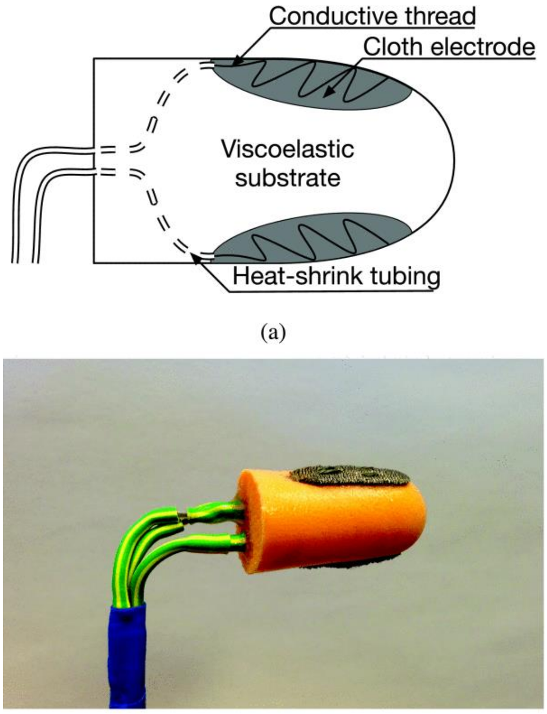


Figure 1.1: Ear-EEG earpieces used in the preliminary study, for different orthographic planes. (a) The earpiece shown is for the right ear and has three electrodes (denoted by ITER1, ITER2, and ITER3). (b) The fitted earpiece. [8]

A new in-ear sensor has been developed for high quality long-term EEG monitoring. It has been designed with two key components which are viscoelastic substrate and conductive cloth electrodes. The substrate compromises a medium-density memory foam which enable the earpiece to accommodate to most ear canal shapes and to redistribute external pressure along the entirety of its surface post insertion. The electrodes within the proposed earpiece have been constructed from conductive fabric and can accommodate all the required deformation of the underlying viscoelastic substrate without losing any of the desirable electrical properties [15].



(a)

(b)

Figure 2.2: Proposed in-ear EEG sensor on a viscoelastic substrate. (a) Earpiece construction diagram. (b) Photo of the earpiece. [15]

2.4 Wireless EEG System

Good quality EEG can be obtained in such adverse recording conditions as naturally walking outdoors. Various fields may benefit from the wireless EEG technology, such as EEG recording from individuals who have difficulties in sitting still. Fundamentally, mobile EEG enables the truly simultaneous acquisition of brain activity and natural behaviour, which may be of interest in social neuroscience and emotion research [12].

Issues that occurs in the problem statement indicate that we need substantial progress in developing technology which are convenient, wireless and wearable EEG monitoring. A few such developments lead to the commercially available EEG systems such as Neurosky’s Mindwave, Mindset and Necomimi and many more wireless EEG

[10]. The research conducted [11] has proposed and simulated the architecture of IR based wireless EEG recording system. The gain of the signal accomplished by instrumentation amplifier. The 4th order low-pass filter has been used to have a sharp cut-off frequency and better response compared to the 2nd order. To verify the performance of the proposed system, a sinusoidal testing signal is used. It is apparent that the received signal is constructed without distortions.

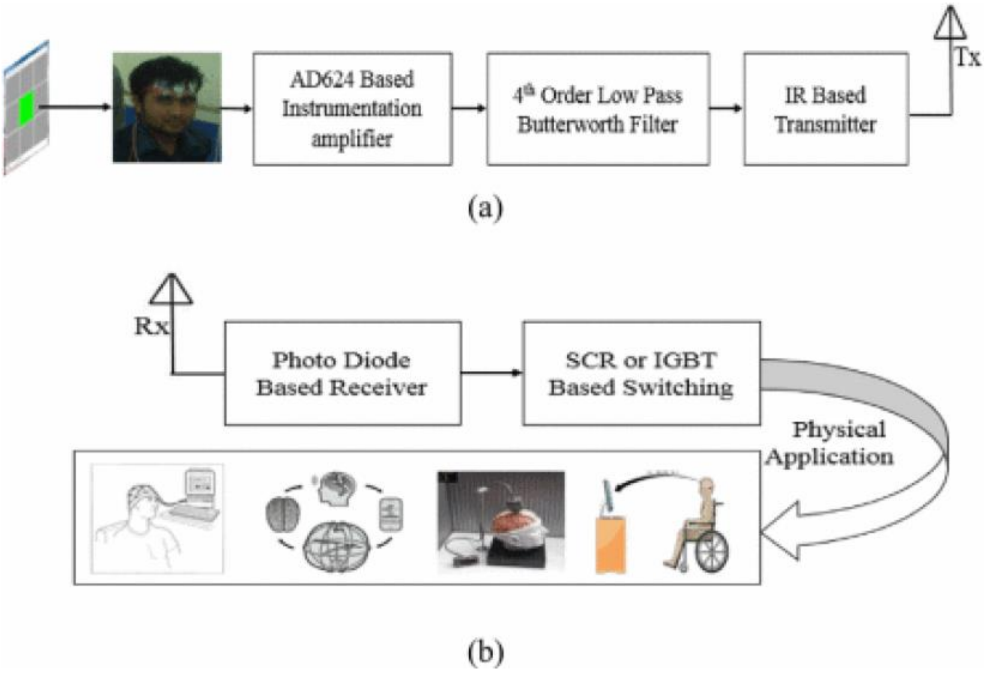


Figure 2.3: Block diagram of proposed system (a) acquisition & transmission. (b) receiver & control circuit. [11]

2.5 EEG Pattern

Visual comparison of short EEG epochs revealed striking similarities. The ear-EEG amplitudes are reduced compared to the scalp channels, but the individual waveforms can be identified and appear similar between scalp and ear EEG channels. To ease the visual comparison of signals we displayed ear-EEG with increased sensitivity. Sensitivity adjustments in the intra-ear channel make the use of low-cut filters at 2 Hz necessary in order to keep some parts of the record visually interpretable. Panel B shows a K-complex. In panel C a sleep spindle is observed. Whereas the K-complex is less distinct in the ear-EEG channels than in standard EEG, the rapid oscillating morphology of the sleep spindle is fairly distinct in the intra-ear channel [6].

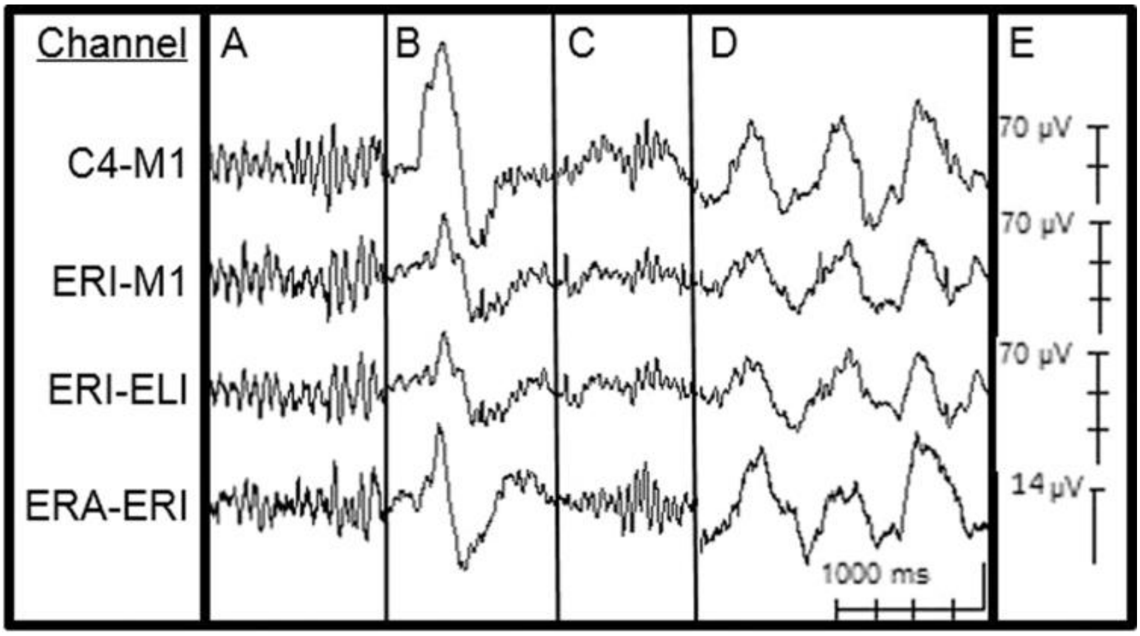


Figure 2.4: Combined EEG Montage showing the similarities between scalp-EEG and ear-EEG [6].

Combined EEG montage showing scalp-channel C4-M1 (top) with three different ear-EEG channels (below). ERI-ELI is the inter-ear referenced Ear-EEG and ERA-ERI is the intra-ear referenced Ear-EEG channel. A) Resting alpha with closed eyes. B) K-complex. C) Sleep spindle during N2 D) N3, slow wave sleep. Discontinuities in the record are marked with vertical lines. Note use of different sensitivity settings throughout as indicated in panel E. Low cut filtering in the Intra-Ear channel, 2 Hz in A, 1 Hz in B and C, 0.5 Hz in D.

2.6 Chapter Summary

By referring to the mechanisms described in section 2.3 and 2.4, those mechanism have been selected in this project. Ear-EEG was selected because of this concept exhibits a high degree of comfort and excellent long-term wearable design, at the expense of a reduced number of electrodes and thus a compromise in spatial resolution. In addition, mobile EEG enables the truly simultaneous acquisition of brain activity and natural behaviour, which may be of interest in social neuroscience and emotion research. Therefore, in this study, we are going to combine these two mechanisms into one device which promises number of advantages including discreet, unobtrusive, robust, user-friendly, and mobilization of the device.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter covers the details of various topics directly related to the process in designing wireless ear-EEG sensor. Three main phases covered in this chapter. Firstly, it covers the process in designing the earpiece and covers the electrode placement in the ear that will be used during recording. In this phase, the signal recordings are recorded directly from ear electrodes to the KT88-3200 which the machine is explained in detail in section 3.5.1. For the phase two, the signal recordings go through the microcontroller such as Arduino before the signal is recorded in EEG software. Lastly, the signal recording will be transferred to the machine wirelessly.

3.2 Mechanical Components

3.2.1 KT88-3200 Digital Brain Electric Activity Mapping

KT88-3200 Digital Brain Electric Activity Mapping collects EEG signal with electrodes, via integrated amplification, A/D transformation, PC auto-analysis, FFT, to form electroencephalogram that displays with color depth. The product is applicable for checking such diseases as epilepsy, intracranial inflammation, cerebrovascular diseases and brain tumors. Electrodes is used to connect the hardware and software. In the process of measurement, all the measuring lead lines should be connected to corresponding leads on the scalp without hanging in the air. The KT88-3200 EEG System was used to collect EEG data. The system is designed with sensor locations according to the International 10 – 20 system coordinates.

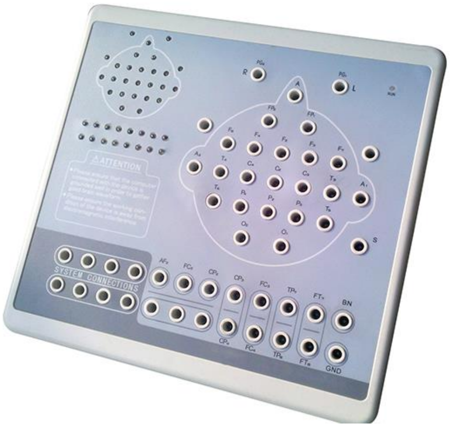


Figure 3.1: KT88-3200 Digital Brain Electric Activity Mapping

3.2.2 Copper Tape

In this study, copper tape is used as a recording electrode in ear. Copper has many extremely useful properties including good electrical conductivity, good thermal conductivity, and corrosion resistance. A good electrical conductivity is the same as a small electrical resistance. An electric current will flow through all metals however they still have some resistance which mean the current needs to be pushed by the battery in order to keep flowing. Current flows easily through copper thanks to its small electrical resistance.

Figure 3.2: Copper tape

3.2.3 Solid Silicone Rubber/ Sealant

To alleviate this problem, the earpiece material must be soft, easy to fit, robust and suitable to self-administer. Silicones have special properties compared to other adhesives based on organic polymers because silicone have a different chemical backbone. They remain highly elastic at low temperature and have a good temperature stability. Silicone are nearly inert to chemicals and have excellent resistance to moisture and weathering.

Figure 3.3: Solid silicone sealant/ rubber.

3.3 EEG32 Software

The EEG software is used to record the brain activity in the form of waveforms. It can detect the changes in our brain's activities. In the acquisition interface, the left is the acquired wave to display the patient's EEG at real time and the right is the acquisition control panel to display various of premiums events and control the acquired methods.

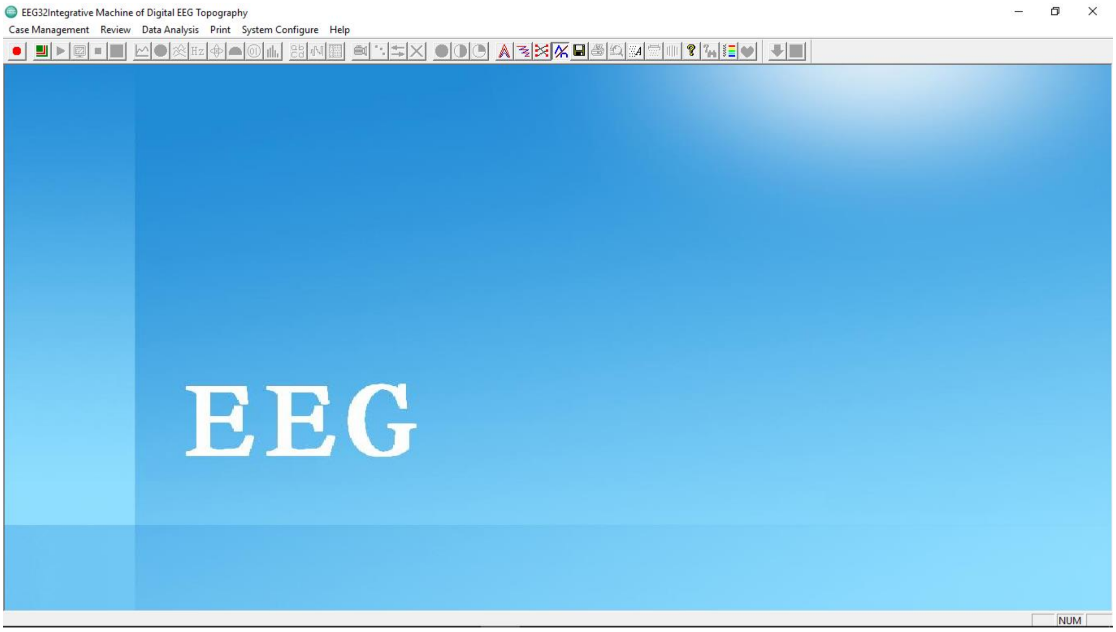


Figure 3.4: The acquisition control interface of EEG

3.4 Electrical and Electronic Components

3.4.1 Arduino Uno Microcontroller

The microcontroller use in this project is Arduino Uno. Arduino Uno is an ideal microcontroller because it is not to small and not big for the robust design. The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins of which 6 can be used as PWM outputs, 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller by simply connect it to a computer with a USB cable or power it with AC-to-DC adapter or battery to get started. The language that been used for Arduino is C++ language, which the language is less complex than others PIC microcontroller.

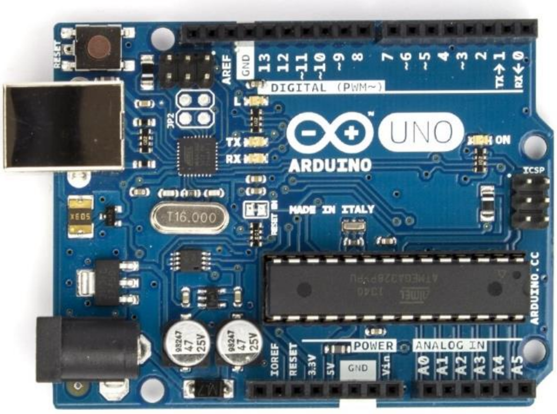


Figure 3.5: Arduino Uno microcontroller board

3.4.2 Transceiver Module NRF24L01

This transceiver module used to make a wireless communication between two microcontrollers. First Arduino will collect analog signal from four ear electrodes, then the signal will transfer to the other Arduino wirelessly through NRF24L01 module. The NRF24L01 transceiver module was chosen because of its properties. It uses the 2.4 GHz band and it can operate with baud rates from 250 kbps up to 2 Mbps. If used in the open space and with lower baud rate its range can reach up to 100 meters. Each channel can have up to 6 addresses, or each unit can communicate with up to 6 other units at the same time. The power consumption of this module is just around 12mA during transmission, which is even lower than a single LED. The operating voltage of the module is from 1.9 to 3.6V, but the good thing is that the other pins tolerate 5V logic, so we can easily connect it to an Arduino without using any logic level converters.

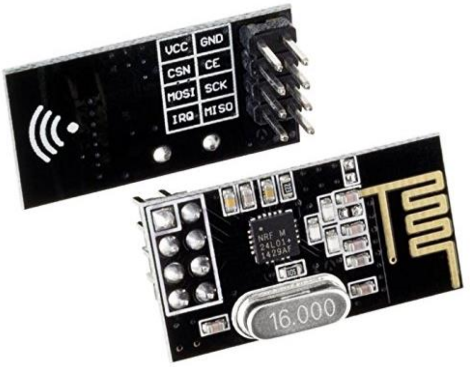


Figure 3.6: Transceiver module NRF24L01

3.4.3 LM741 Operational Amplifier

The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. The amplifiers offer many features which overload protection on the inputs and outputs, no latch-up when the common mode range is exceeded, as well as freedom from oscillations. LM741 can be used in many applications such as comparators, multivibrators, DC amplifiers, summing amplifiers, integrator or differentiators, and active filters.

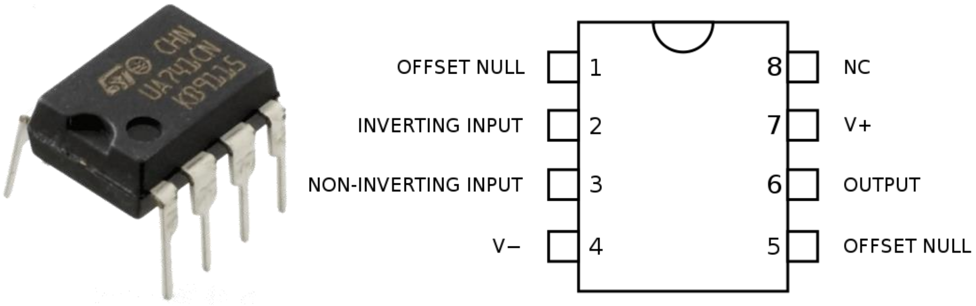


Figure 3.7: LM741 operational amplifier

3.5 Ear-EEG Concept and Mechanism

The concept plays an important role in the development of new products or devices. In the other hand, mechanism come after the own concept have been set. The basic concept to create new design after number of studies have been conducted. The mechanism concept that have been highlighted in this study are the personalized earpiece and the electrode placement in ear.

3.5.1 Personalized earpiece

The design of the earpiece is based on the research conducted by the previous researches. The current ear-EEG system employs individuals earpieces that are custom made for the user's ear using the same processes as that in the manufacturing of the customized hearing aid ear-plugs [14]. All the previous material used for in-ear EEG sensors like plastic have proven to be too stiff and rigid. It provides uneven distributed pressure along the outer surface of the device, when put inside the ear canal, providing loose and intermittent electrode to skin contact, susceptible to motion artefacts [15]. The material use for this study is solid silicone rubber. Solid silicone rubber, like other rubber will always feel soft and bendy in contrast to the inflexible plastics. Because of those characteristics, it will ensure the comfortability, easy to put in place, and help the electrode to held firmly in place for a long time of recording. The earpiece that proposed in this study was shown in the figure below.

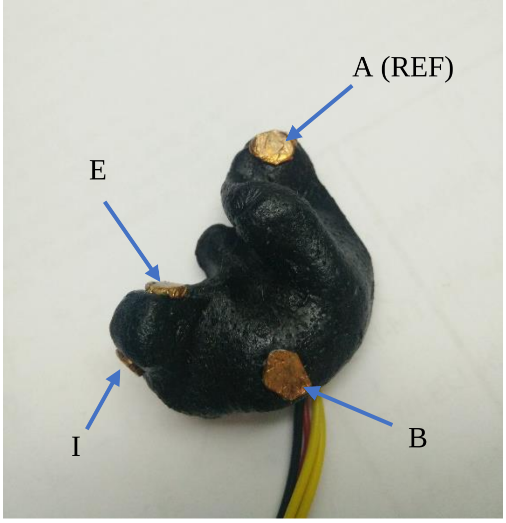


Figure 3.8: Personalized earpiece

3.5.2 Electrodes Placement in Ear

The ear-EEG device consists of four recording electrodes embedded in the earpiece resting within the outer portion of the external acoustic meatus and protruding outside to occupy the cavum and concha [16]. Copper electrode is used as a recording electrode. The corresponds letter is used to specify the position of the electrode in the ear. Capital A's being in the concha while capital B's in the cavum. Capital E and I's are situated opposite to each other inside the external acoustic meatus which means E's were placed on the upper side of ear canal while I's on the downside of ear canal. The position of the electrode has been shown in Figure 3.8 and Figure 3.9.

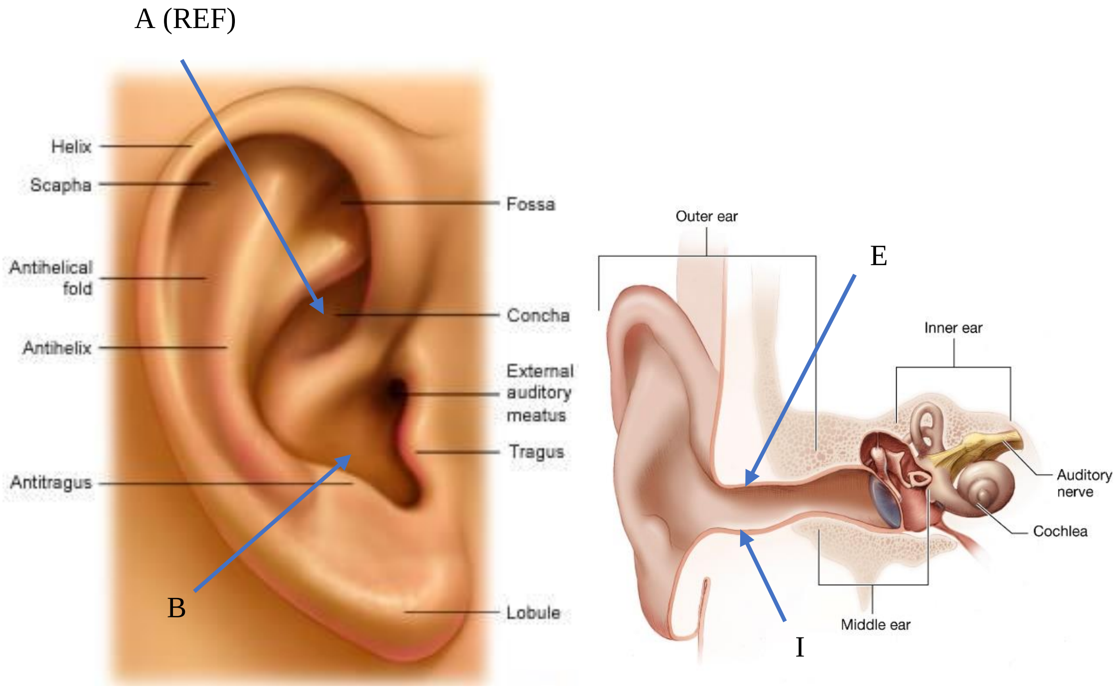


Figure 3.9: Ear anatomy and actual position of ear-electrode

3.6 Experimental Setup

Several stages have been prepared in order to implement this project flow. At the very first stage, the concepts of the design as well as the mechanisms of this project is being studied. The concept on how to design and selecting the right materials of the ear-EEG is the first and the most important issues that need to overcome. The background research has been done so that the flaws, problem, and errors can be found as well as how to find the way to solve it.

In the design part which also the first phase of this project, the idea of concept is to make a personalized earpiece that is tight to the ear and comfortable to wear. At the beginning of this project, the earpiece is made by the 3D printer which result in loose surface contact between electrodes and skin and hard to put it on the ear. After many consideration and reading the previous research, the earpiece is developed by using earmold technique. After that, the process in selecting the right materials can be