PERSONAL NAVIGATOR FOR VISUAL IMPAIRED PERSON UTILIZING GALVANIC VESTIBULAR STIMULATOR

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ABSTRACT

Electronic industry is growing fast by introducing new product and technology to the society. The technology helps to enhance human daily life by promoting easy and modern life. However, the development of technology does not contribute that much to less fortunate communities. Visual impaired person have difficulties to navigate in an unfamiliar destination without any help. Introducing galvanic vestibular stimulation (GVS) can help them to navigate the desired destination. However, technology of GVS is still under development. GVS is a device that delivered small value of current to the vestibular system through electrodes placed over the mastoid area. Thus, investigation of GVS on human is needed to improve the reliability of the system. It is very helpful if an impaired person can have a GVS device that can be attach to them to help them during navigation. A coordinator is used to control the test subject movement wirelessly. In order to allow the movement, human equilibrium has to be adjusted. Due to the fact that vestibular system is the one that control human equilibrium, thus, current is injected at the back of ear using an electrode to allow disturbance to human equilibrium and effect body posture. The magnitude of the movement is control based on intensity of current injected. The result suggests that as intensity scale of current injected is increased from 0% to 100%, deflections angle of the test subject will increase from 0^o up to 47%. However, different test subjects will have different range of degree depending on their body resistance. One of the findings in the research prove that when the same magnitude of current is injected, deflections angle of test subject will be between different polarity will differ between the range of 0^o to 9.67^o.Finding of the research prove can GVS application is more suitable to be apply for a momentary usage rather than long duration application. However, GVS can still be applied to visual impaired person but if and only if the navigation is within a small range of distance.

ABSTRAK

Pembangunan pesat industri elektronik telah memperkenalkan produk-produk dan teknologi baru kepada masyarakat. Teknologi membantu untuk meningkatkan taraf kehidupan manusia dengan memperkenalkan kehidupan yang moden dan ringkas. Walau bagaimanapun, perkembangan teknologi tidak banyak menyumbang kepada komuniti kurang upaya. Individu yang mengalami kecacatan penglihatan menghadapi kesukaran untuk menavigasi di sesuatu kawasan yang baru. Dengan memperkenalkan rangsangan galvani vestibular (GVS) dapat membantu mereka untuk menavigasi ke destinasi yang diingini. GVS adalah alat yang memberikan jumlah arus yang kecil ke sistem vestibular melalui elektrod yang dipasang di kawasan mastoid. Penyelidikan terhadap kesan GVS kepada manusia perlu dilakukan untuk meningkatkan kebolehpercayaan sistem. Ianya sangat baik jika individu degan kecacatan penglihatan mempunyai alat GVS bersama mereka untuk membantu mereka ketika navigasi. Penyelaras akan digunakan untuk megawal pergerakan subjek ujian dari jarak jauh. Untuk mambolehkan pergerakan, keseimbangan manusia perlu dikawal. Disebabkan system vestibular berfungsi mengawal keseimbangan manusia, maka, arus diberikan kepada kawasan di belakang telinga untuk megubah keseimbangan manusia dan postur badan. Jumlah pergerakan berkadaran dengan keamatan arus suntikan. Keputusan menunjukkan bahawa apabila skala suntikan dinaikkan dari 0% hingga 100%, sudut pesongan subjek ujian akan meningkat dari sehingga 0% kepada 47%. Subjek ujian yang berbeza maghasilkan nilai pesongan berbeza bergantung kepada rintangan badan. Salah satu penemuan menunjukkan pada keamatan yang sama, ada kesamaan antara sudut pesongan ke kiri dan kanan tetapi dengan ralat antara 0^o hingga 9.67^o. Hasil menunjukan GVS hanya sesuai untuk aplikasi dalam masa yang singkat.. Walau bagaimanapun, GVS masih boleh digunakan untuk orang cacat penglihatan tetapi hanya untuk jarak yg terhad.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLE

CHAPTER 1

INTRODUCTION

1.1 History

The idea of GVS was originated by Alessandro Volta's (1790) while experimenting with battery. During his experiment, he accidentally placed a battery with current strength of 30V across his head. He felt a twitch and spinning in his head and heard a noise. A few years later, Breuer and Hitzig report illusory body movement during stimulation with the electrodes placed on the mastoids.

The first formal report is establish by Johan Purkyne in 1820 reporting that galvanic stimulations upset human balance and equilibrium. Then, Josef Breuer showed the vestibular origin of the induced nytagmus and balanced distortions.

GVS has been used as a technique to study the effects of applied current on the vestibular system. Study on galvanic stimulation on vestibular have been done to investigate the potential application of GVS to human activity and its performance.

1.2 Galvanic Vestibular System (GVS)

Galvanic vestibular stimulation is performed by passing small DC currents through the vestibular labyrinth using surface electrodes. Typical stimulus configurations include placing an electrode on each mastoid, one positive and one negative, to produce medial – lateral sway or horizontal / torsional eye movements. Previous research and clinical application have been limited by the requirement for relatively high sometimes painful, electric currents to produce recordable horizontal eye movements. A significant advantage of galvanic stimulation is that each labyrinth can be tested separately. However, it is not yet certain which vestibular end organs are responsible for either the eye movements or postural movements induced by such a stimulus. Offsetting this limitation, however, is the fact that galvanic stimulation is believed to excite the synapse between the hairy cell and the eighth cranial afferent nerve. As a result, galvanic stimulation can provide information regarding 'neural' versus sensory function. That is individuals with hairy cell damage with preserved eight nerve function may have normal or increased responses to galvanic stimulation. However it is technically challenging to deliver a well controlled galvanic stimulus while recording eye movements or postural sway determine the stimulation effects.

The technique provides a derived measure of vestibular function that relies upon the ocular motor system. When recording postural responses during galvanic stimulation there is an additional difficulty based on the complexity of the postural control system, which is neither linear nor time invariant. As for Vestibulo-ocular reflex (VOR) tests, recording postural sway during galvanic stimulation provides only a derived measure of peripheral vestibular function. Further, the stimulus may produce a skin sensation that cues the patient. Additional unresolved issues concerning the effect of galvanic stimulation on postural sway include the influence of head- on- torso position the waveform of the electrical stimulus, i.e. constant versus sinusoidal and the timing of the galvanic stimulus with respect to the patient's own sway. Despite these limitations and unresolved issues, however, with the advent of three dimensional videooculography and lower cost motion analysis systems galvanic stimulation may emerge as a clinically useful too. That is, low intensity galvanic currents may produce small but recordable non-horizontal eye movements and / or small but recordable postural movements that can be measured reliably using sensitive recording instruments.

This research is focusing on GVS application on an impaired person. Sensor motor system includes eyes sight and muscle movement. The information from both parts is then sending to the brain via spinal cord. Next, signal is then send to the balance-organ in the inner ear to controls every muscle of your body. Thus, we can see a reflex movement of a man through his reaction. However, an impaired person might not be able to react significantly with the situation that he is facing. This is because the inadequacy of eyesight minimizes his capability to decide either to move forward, backward, left or right. Thus, an external guide from GVS can help to improve impaired person capability. The explanations are simplified in Figure 1.1.

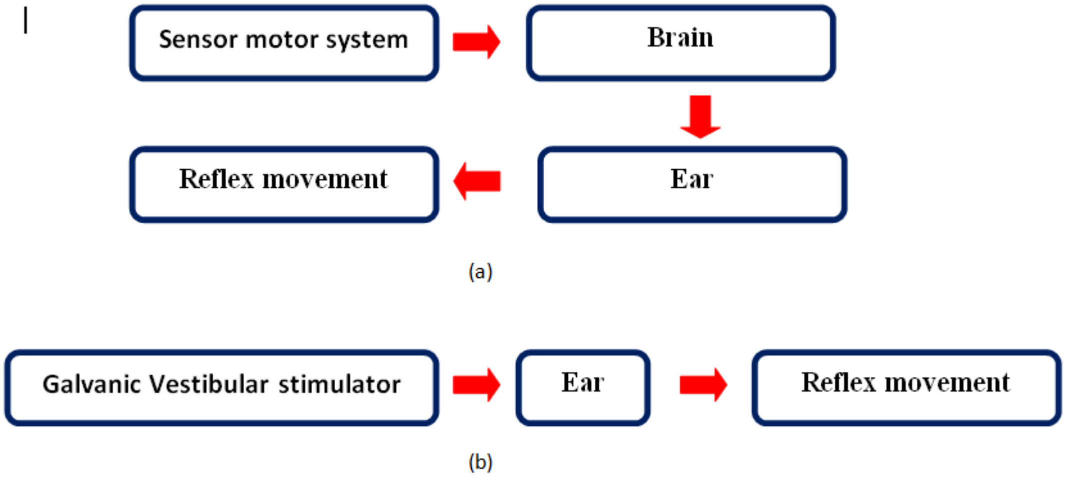

Figure 1.1: (a) Normal person balanced system control flow
(b) Impaired person balance system control flow

1.3 Problem Statement

The current situation shows fast growth of electronic industries which include large varieties of sectors. Electronics technologies have been applied to power system industry, communication, robotics, biomedical and many more. These developments give benefits to the human in promoting easy and modern life.

However, the development of the technology does not really contribute that much to disable community. Most of the impaired people are still caught in using the traditional approach to help them cope with their daily routine. For an example, a person with visual impaired is still using rod and need guidance to help them while walking.

Figure 1.2: A visual impair person in need of rod and dog to help her crossing the road

This project will be focusing to aid visual impaired patient navigation. This group of unfortunate people is lack of the ability to get alert to their surroundings due to failure of eyes to deliver impulse to the brain. Thus, the brain does not have enough information to give order to muscle movement and reaction. However, most of the blind people do not need any help to walk and navigate in a familiar surroundings. They tend to learn and adapt through experience.

Therefore, it would be very helpful to introduce a device that has the same concept just like a GPS. By that, technology of GVS is been introduced. GVS is using stimulation current to create a reflex movement to the patient during walking. However, the technology of GVS is still under development. Thus, investigation of GVS on human is needed to improve the reliability of the system.

1.5 Objective

This work is only going to concentrate on these four objectives;

I. Explore the potential of GVS for human's navigation

II. To investigate the relations between angle of deflections and magnitude of current injected the test subject.

III. To test the performance of hardware.

1.6 Scope

The scope of this project is to design a galvanic vestibular system which able to control the movement of a visual impaired person. However, in this research, normal healthy person are used as the test subject. To analogy between the visual impaired person and the test subject, all subjects are blindfolded to disable the wearer's sight. Though, the movement is limited only to the left and to the right side of the subject. Combination between wireless transmission method and polarity circuit is used to control the test subject using a display unit. In addition, in the future, the performance of GVS can be enhanced using GPS approach. Other specifications includes in this project are:

No	Description	Range
1	Voltage range	5V
2	Current range	0±2mA
3	Duration per stimulation	8s
4	Two channels	± polarity

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will discuss on the overview of the project including both method and related findings from the previous researchers. Review on the past research on the effect of GVS to human locomotion, brain response and duration of response time are stated in this chapter. Besides that, the relation of vestibular systems on human rotation and the GVS design concept is explain in this chapter.

2.2 Human balance system [3]

Human balance is the ability of the individual to maintain body’s centre mass over its base of support. A stable balance system allows humans to see and sense clearly while moving, identify orientation with respect to gravity, determine direction and speed movement and make automatic postural adjustments to maintain posture and stability in various conditions and activities. The human balance system is controlled by the combination of sensory input, integration of input and motor output.

Sensory input includes; eye, muscle and joints, and vestibular organs. Human eye gives input in terms of visual sight, muscle and joint give information of proprioceptive (touch) and ear or also call as vestibular systems give input of motion, equilibrium and spatial orientation.

The first sensory input is human eye. Eyes give information in terms of visual sight of the surrounding. Input from the eyes is sensed by sensory receptors; rods and cones. When light strikes the rods and cones, impulse will be send to brain. Therefore, that is how a human identifies and reacts to other objects.

Muscle, skin and joints provide proprioceptive information to the brain. Proprioceptive is define as pertaining to proprioception, or the awareness of posture, movement and changes in equilibrium and the knowledge of position, weight, and resistance of objects as they relate to the body [4]. Proprioceptive involves sensory receptors that are sensitive to stretch or pressure in the surrounding tissues. With any movement of body parts, sensory receptors will respond by sending impulses to the brain. For example, when the front soles of the feet touch the surface, sensory receptors will detect changes of pressure in body and detect the quality of the surface (for example: hard, soft, slippery or uneven).

Ears organ provides vestibular system that gives control of motion, equilibrium and spatial orientation. The inner part of ear consists of utricle, saccule and three semicircular canals. Both utricle and saccule detect gravity control vertical orientation and linear movement. Semi circular canals detect rotational movement. Each of the canals contains endolymphatic fluid that will give pressure to canal’s sensory receptors in case of movement. Then, sensor receptor is responsible to send movement information to the brain. Asymmetrical impulse will be sent to the brain if both canals of right and left side detect the same movement.

Sensory input will be sent to the brain. Brain will integrate impulse received from the sensor unit. The main part of brain that will involve is cerebellum and cerebral cortex. Brains will regulate the information based on the previous learning memory and come out with information to the muscles that control movements on how to react in order to maintain balance and avoid any obstacle during walking.

Balance system is being controlled by the entire sensorimotor input. Feedback mechanism will be disrupted if one of the sensor input is damaged. Hence, balance system will be distorted.

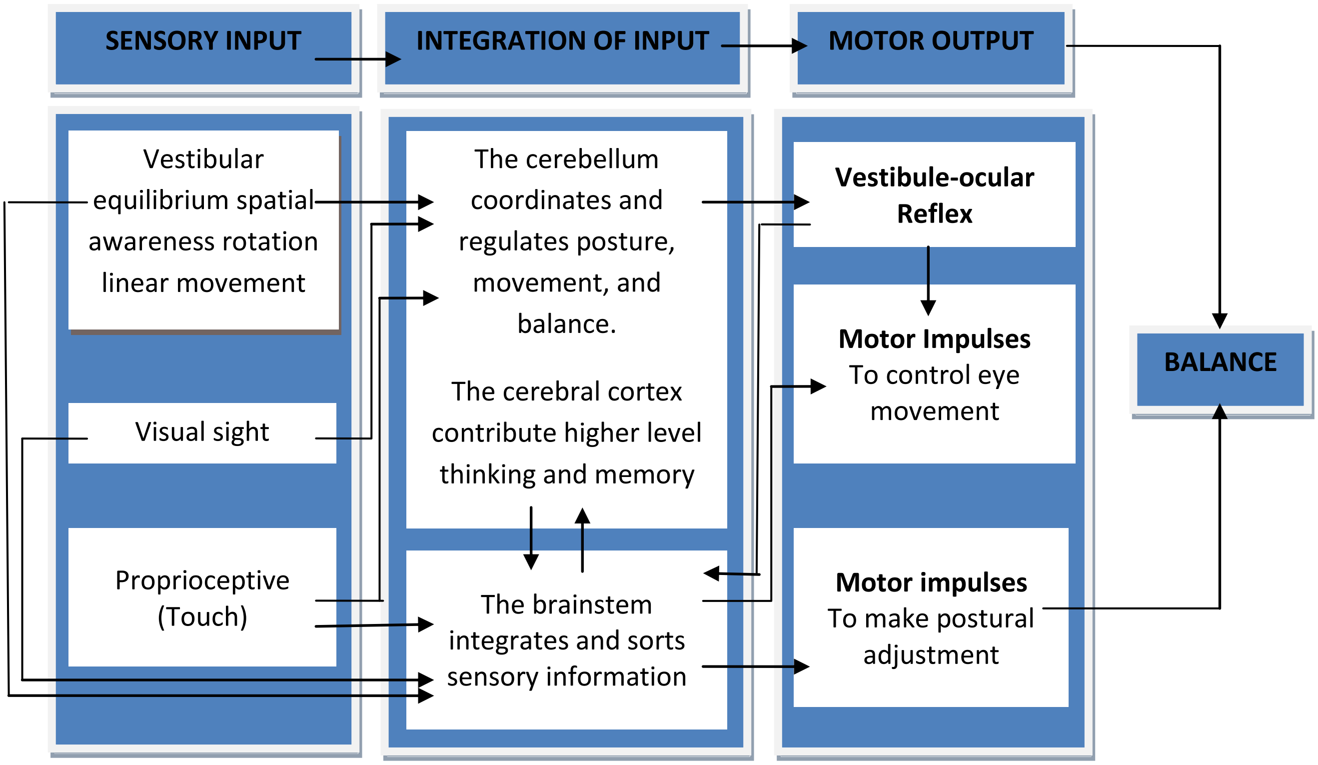

Figure 2.1: Human balance system mechanism

2.3 Vestibular System

Sensory from various input source give information to human brain on spatial equilibrium. At the early stage of GVS history, Volta experienced dizziness and unbalance sensation when two electrodes are placed at the back of mastoid area. GVS device will triggered human equilibrium system and balance receptor in vestibular system. This includes the semicircular canals, the saccule, and the utricle shown in Figure 2.2. Equilibrium and balance can be broken down into static equilibrium, maintenance of the head position in response to gravity, and dynamic equilibrium, maintenance of the head position in response to rotation, acceleration, and deceleration [5]. Both saccule and utricle provide static and dynamic sensory orientation information.

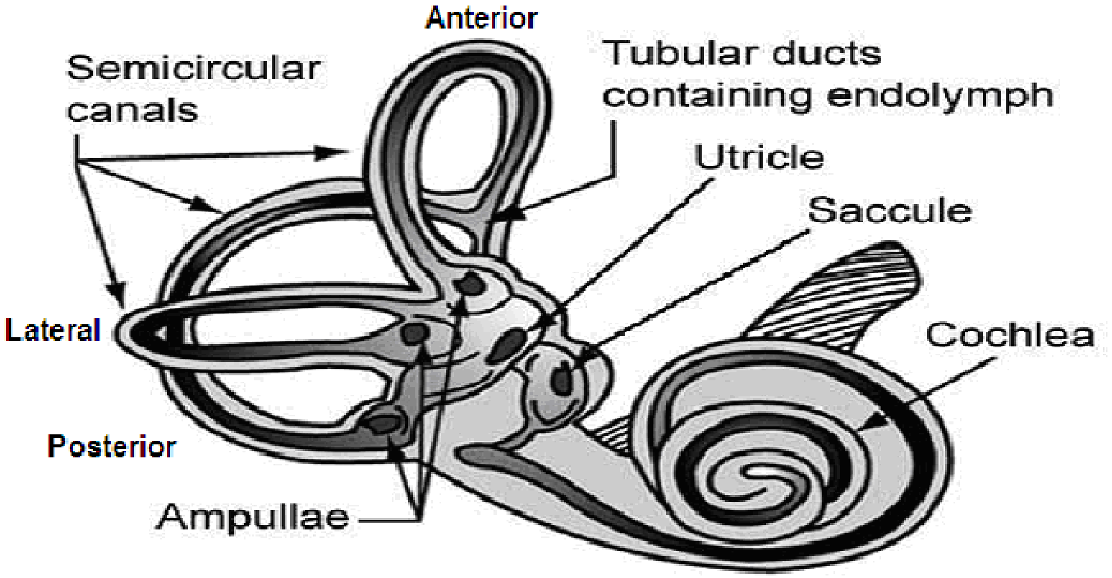

Figure 2.2: Inner ear structure including the semicircular canals and otolith organs, which detect rotational and translational head motions respectively

2.3.1 Dynamic motion sensing by the semicircular canals

The semicircular canals provide dynamic rotational sensory orientation information. At the base of each semicircular duct lies a dilation of the canal called an ampulla [5]. Located inside of each ampulla are crista. In each of the ampulla consist of both crista and sensory cells. The sensory cells are covered by cupula. Cupula is a viscous gel-like substance [6]. Once human head move, semicircular ducts and hair cells tends to move too. However, due to inertia, endolymph (calcium particle) will be lag behind. The different acceleration are sensed by the hair cells [5]. This hair deflection causes a depolarization of nerves, and the resulting impulse notifies the brain that a change in acceleration has taken place. The deflection of the cupula resulting from a head turn is demonstrated in Figure 2.3.

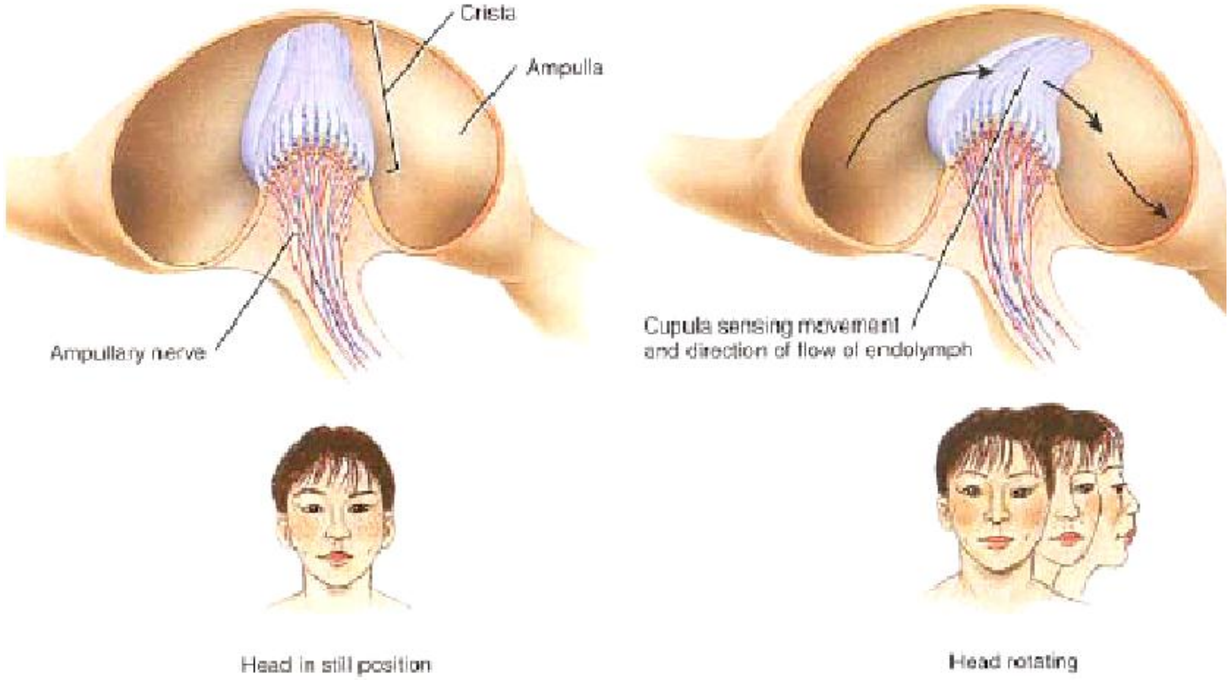

Figure 2.3: Cupula response to a rotating head. When endolymph fluid which consist of calcium particles inside the semicircular canal lags the head rotation, causing a deflection in the cupula to sense a change in head motion [5].

In addition, the inner ears of the body have three canals: anterior, posterior, and lateral (also known as the horizontal canal) explain on how human brain decides the different axis movements of the head. Each canal is oriented to detect motion about different axes of the head. For an example once human head move to the right, the afferent activity from the right horizontal canal increases and the firing rate from the left canal decreases [7]. These inversely related changes in firing rates both contribute to the brain's sensing of the change in yaw that took place.

2.3.2 Static and dynamic motion sensing

The inner ear consists of utricle and saccule which provide static and dynamic translational sensory information [5]. The wall of utricle and saccule regions consists of thousands of hairs. As stated earlier, these hairs are responsible to detect acceleration. Residing on the macula, Otolithic masses are comprised of a membrane that causes deflections in the hairs. Orientation sensations occur when a change in the position of the head causes the weight of the otoliths to bend the membrane and ultimately the bundles of hairs residing in the macula [8]. The static information provided indicates the orientation of the head relative to gravity. Figure 3 provides an example of a change in static equilibrium with the tilt of the head down. The dynamic information provided by the utricle and saccule sense when you are speeding up or slowing down. This sensation can be felt in an accelerating or decelerating car or elevator. The sensory information is used to inform ocular and muscle systems that a change in orientation has taken place [9].

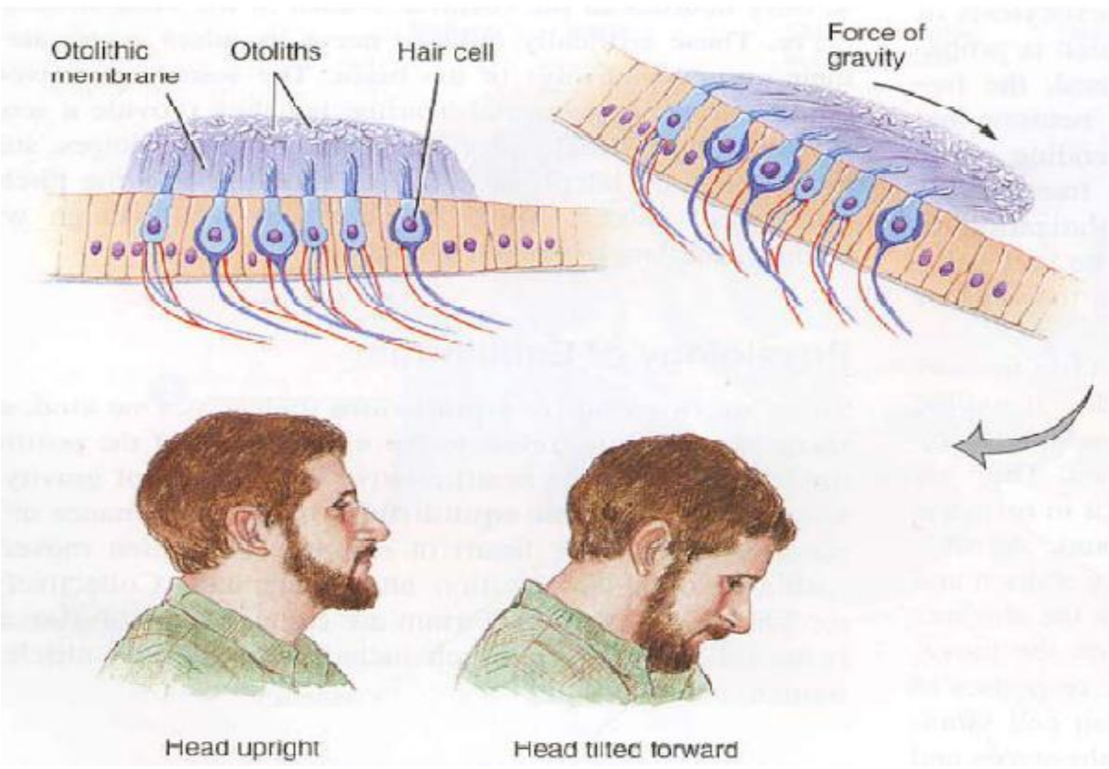

Figure 2.4: Macula and otolith response to head nod. As the head tilts forward the force of gravity pulls the otolithic masses, which deflect the hair cells in the macula and sense a change in orientation has taken place [5].

The utricular macula and the saccular macula also reside in different planes for motion detection. The utricular macula is inclined backwards by 30 degrees from the horizontal plane, detecting lateral and vertical motions. The saccular macula is aligned with the vertical plane, primarily detecting vertical and anteroposterior accelerations. Within both maculae are two regions of reversed hair cell polarity. When a change in acceleration takes place the different regions will either increase or decrease firing rates. The brain interprets the area of varying firing rates into motion detection [7].

2.4 Electrical Safety

Human body is exposed to hazard when electricity flows through the body. In order to understand the hazards associated with electricity, the basic principle of electricity and its effects on human are essential.

Electricity included three major parts which are voltage, electric current and resistance parts. Voltage is defined as electrical potential differences between two points of conductive material. It initiates the flow of current charge/ current. The rate of flowed charge is measured in Ampere unit, whereas, resistance is assumed as the obstruction which limits current flow. It is the nature of electricity to always take the path of least resistance.

The issue with electricity occurs when human body become part of the electricity path where too much of electricity can cause cardiac attack to human body. However, the effect of current to human depends on the magnitude of current flow. Figure 2.2 shows the relation between magnitudes of current with the human body.

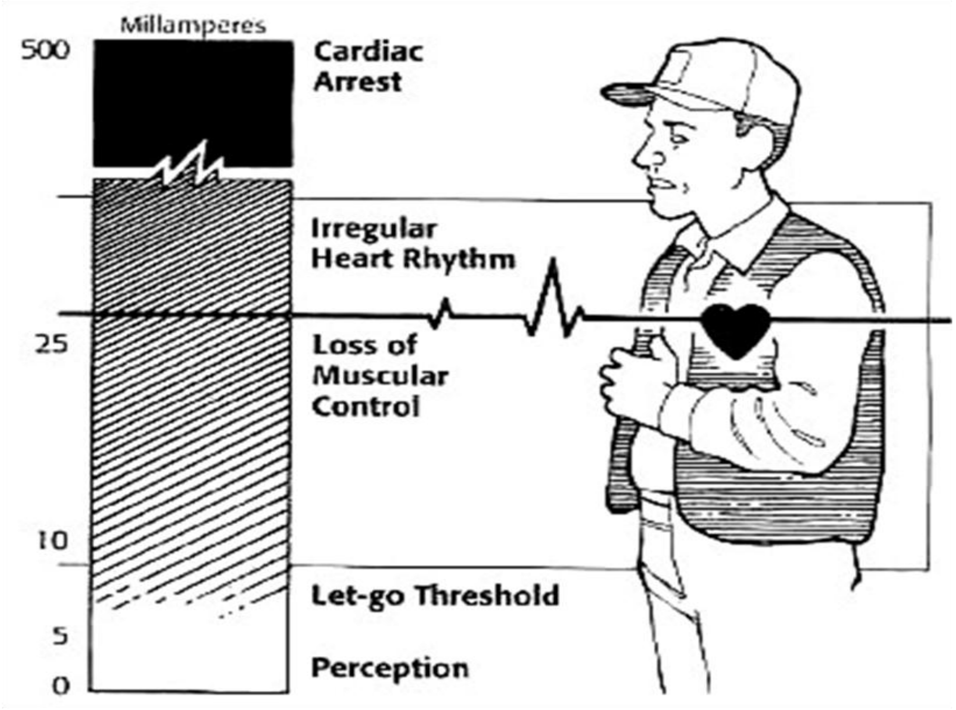

Figure 2.5: Relation between magnitude of current and its effect on human body [5].

Figure 2.5 shows the magnitude of current above the “let go” threshold will result in loss of muscular control, irregular heart rhythm and finally, inevitable cardiac arrest. The person will experienced irregular heart rhythm and eventually experiencing cardiac arrest. In order to prevent any harm to human, each electric device should include with good insulation and grounding. If the protective insulation of the device is defective, electric current will find different paths in order to reach the ground. Human is considered as a conductive object that will let current to flow through the body towards the ground. Therefore, if the leakage current is big enough, cardiac arrest might occur.

However, the effect of electric shock in human body depends on several factors; duration of contact to current, amplitude of current, path the current takes through the body, and resistivity of the human body [5]. The surrounding also influences electrical conductivity of the human. A person in a wet condition is more exposed to electrical shock rather than a person in a dry ground. Thus, proper installation of electrical device is essential to protect both human and the device itself.

In the discussion of electrical safety of GVS, the same safety thresholds apply. Improper stimulation of the body can cause resistive heating, skin irritation, nerve damage, and heart problems. Each of these safety concerns is addressed in relationship to the experiments conducted.

2.4.1 Effect of Electricity on Heart

The main concern when dealing with electric shocked is the human heart. Based on [6] , the leading cause of death with shocks or stimulation under 300 volts is cardiac ventricular fibrillation. Ventricular fibrillation can cause heart attack and sudden death. Typical threshold for humans is within 75 mA to 400 mA [7]. In order to avoid ventricular fibrillation of the heart during stimulation:

1. Avoid reaching high level that can result in ventricular fibrillation. Thus, for safety precaution of the experiment, the maximum current should exceed 2mA.
2. Avoid electrode placement that can cause current to take heart as the main path. For example, avoid placing one electrode on the sternum and the other one at the back of body during stimulation.

2.4.2 Duration of Exposure

As stated earlier, one of the factors that contribute to electrical shock to human is the duration of contact to current. Stimulation time of up to 2000 hours can cause nerve damage. “At greater charge densities damage was seen as increased bone growth and cell death” [6]. A GVS system used an electrode to be applied at the back of ears to stimulate vestibular system. As brain and vestibular system is located side by side, thus, time duration of each stimulation should not exceed 20 minutes per stimulation [8].

2.4.3 IEC 60601-1 Medical safety regulations

This International Standard applies to the basic safety and essential performance of medical electrical equipment and medical electrical systems which refered as ME equipment and ME systems. This safety regulation is used as the benchmark rules before designing any medical equipment [8]. The safety requirements in terms of earthing aspect, protective under normal condition, protective under fault condition are stated in this regulation.

Thus, based on IEC requirements, a proper design should be able to fulfill both design requirements and safety aspect. Therefore, in case of accident, the design should be able to give isolation between electrical part and the patients. Moreover, in this project, the GVS is designed to shutting down itself in case of failure or burn out of the hardware.

2.5 Galvanic Vestibular Stimulation Response

Otolithic and semicircular canal responses results from vestibular stimulation at low current intensities resulting in direction sway. However, the galvanic vestibular response is complex and modifiable by many factors, including; standing posture, head and trunk position, and support surface properties.

2.5.1 Postural responses to GVS

Many studies had been done to see the effect GVS on different condition of human posture. Day et al. has investigated the effect of GVS during standing subject and sitting. The investigation found that orientation sensations and relatively tilts are much smaller when the test subject is seated rather when standing. The effect of GVS to seated subject helps to investigate the vestibular contribution to head-neck stabilization [11]. However, while standing, the body tilt increased as the width of stance decreases. The experiment also found that GVS is able to control the whole body movement rather than just the head [10].

GVS is also applied to a subject while walking. When GVS is injected to the subject, walking trajectory of the subject change depending on the polarity of the electrode attach to them. All walking subject will sway towards the anode. Threshold current is determined when the subject feels some sensation in the area where an electrode is attached. Based on earlier research by [12] on magnitude effects of GVS on the human trajectory prove that stronger stimulations result in larger walking deviation as in Figure 2.6.

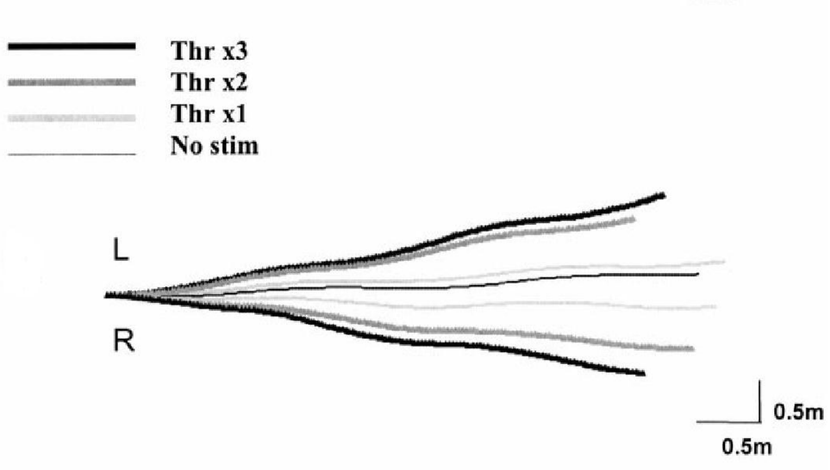

Figure 2.6: Test subject displacement data show that; 1. GVS polarity has a significant effect on locomotor trajectory 2. The increasing magnitude of the response is conjunction with an increase of the magnitude of GVS. **Thr X1** shows that walking trajectory at first threshold current. **X2** stand for double the threshold and **X3** is triple of the threshold [12].

2.5.2 Brain Response

Study on the effect of GVS to brain activity had been done by Patrick A. Forbes using Functional Magnetic Resonance Imaging (fMRI). The findings have established seven areas in the brain which experiencing increment of activation. However, there is also one area that shows decrease in activity.

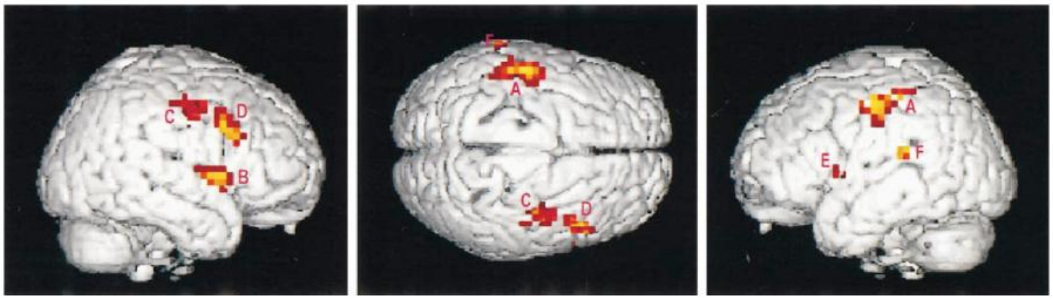

Figure 2.7: Areas of neuron activity of brain from right, upper and left position when GVS is applied [13]

The study found that all subjects show similarities in brain activity with GVS application. Each subject comprises seven spot of neuron activity. However, there is variability within area, which may cause due to movement of the head during stimulation.

2.6 Sensation response time

A study by [14] have explained perceived response time on different situations. Figure 2.8 shows the analysis when human response to GVS, touch, light and sound. The time stimulation is estimated by having the test subject pushing a button upon stimulation. Response time for GVS takes longer than the detection time for light and sound. Barnett-Cowan et al. also found that combination between both visual and vestibular sensation is necessary to detect simultaneously. The findings show that human brain response time varies depending on types of stimulation.

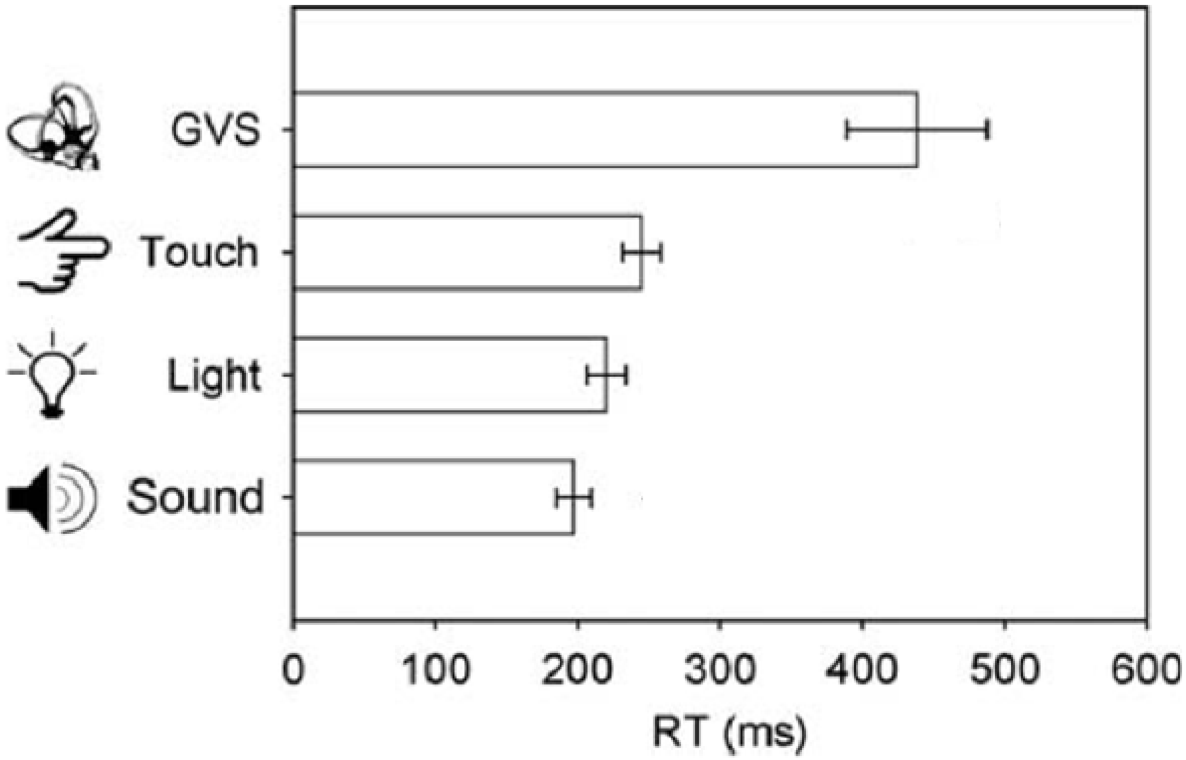

Figure 2.8: Human response on different type of stimulations

2.7 Stimulation Signal

GVS required current injection to allow stimulation to human’s mastoid area. The stimulus waveform can give different effect during testing. One of the common issues which being discusses in GVS technology is the types of current waveform applied to tested subject’s ear. Some of them compare between the usages of rectangular current and the non rectangular current [1], whereasevaluatesf the previous study evaluate thstimulation between sine wave simulation and direct current waveform in GVS device [15]. However, the results are in favour of direct current/rectangular current waveform compare sine wave/non rectangular type.

It was found that sine wave simulation cause strongest side-effect due to alternating stimulation [15]. The effect can be either nausea or dizziness feeling or both. Constant alternating stimulation results in motion sickness effect comparable to vestibular equilibrium effects. However, the usage of non-rectangular current is still applicable but in need of some modification. It is a must to ensure that the rise time of the current is short enough and fast. This is to ensure that the nerve membrane does not accommodate and able to transfer the action potential wanted [1]. However, [15] argue that the both types of current waveform (either sinusoidal or DC) are applicable for GVS application, but depends on the activities tested. Yet, the theories are still not well understood and less research was done on this issue. Thus, a constant DC is chosen as the stimulation signal to the vestibular system. Figure 2.9 will conclude the explanations above.

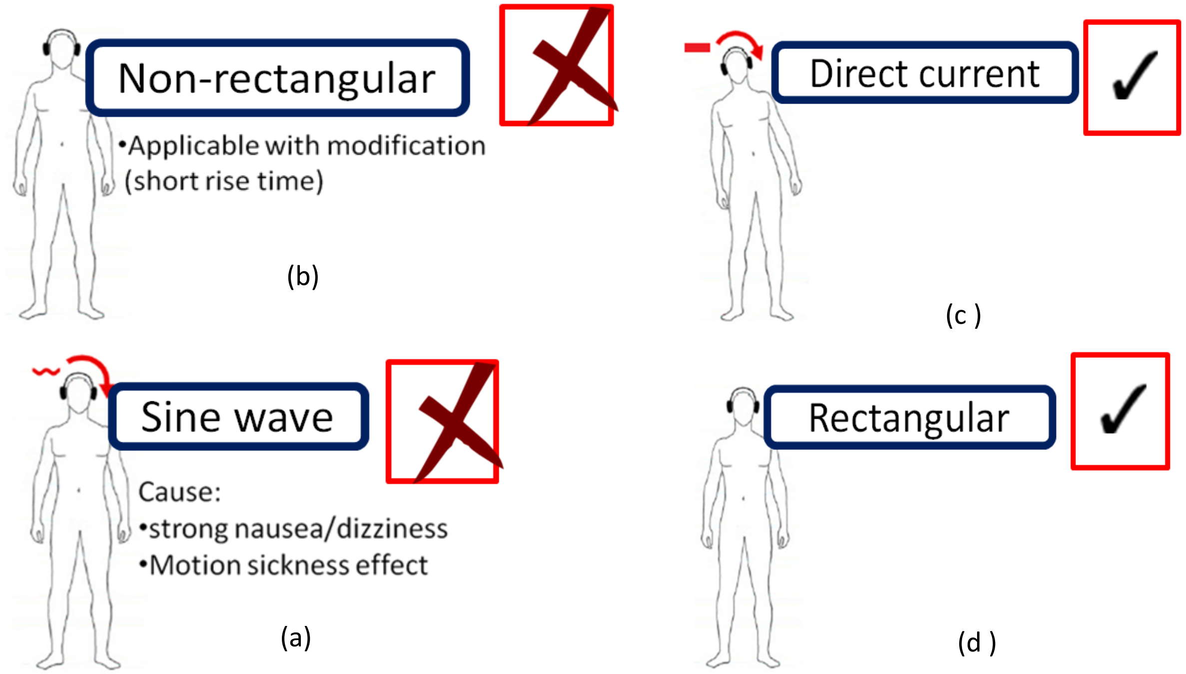

Figure 2.6: Types of stimulation signal compatibility on human (a) sine wave; (b) non-rectangular; (c) direct current; (d) rectangular

2.8 Electrodes

The selection and choice of the electrodes depend on the selectivity and the gradation of excitation required. Generally, the types of electrode can be divided into two different types;

i) Surface (cutaneous)
ii) Subcutaneous

However, the surface electrodes are widely used by the previous researchers [1] [15] [12] [16]. The electrodes are placed directly on the skin surface where the stimulus condition is required. This is to ensure that sensory activation can be obtained from the stimulation.

This type of electrode is more preferable because of their ability to maintain low impedance and give even current distribution of current during stimulation. Low impedance condition is a must to ensure that the stimulus effect can be observed at minimum current. In fact, this type of electrode is more flexible. It helps to ease the application so that it can be placed and removed easily. Moreover, it is able to reduce side effect such as irritation and burning effect to the skin [1].

Working configuration of the electrode is monopolar configuration and bipolar configuration. Monopolar electrodes required two different sizes of electrodes. One of them is placed directly on the nerve skin and the other one is placed remotely. On the other hand, the bipolar electrodes comprise the same size and are placed over the site to be excited. Researcher in [15] defines bipolar configuration of electrodes as two electrodes of the same size but different polarity.

2.9 Electrode Tissue Interface

GVS system needs the injected current to be delivered to the inner parts of the ears and next give the signal to humans by using external electrodes. It is critical enough to take notes on the behaviour of the electrodes when interact to the skin and the maximum current density allow on each test subject. However, due to the fact that human resistance varies due to many factors, thus, it is hard enough to set the limits of the highest current allowed.

In order to prevent any damage to the skin or burn to the tissue, [[17] suggest that the for a current density of 25.46 A/m^2 , stoation can be applied up until 20 minutes without bringing any harm to the test subject. However, the stimulation should be at minimum sensation. Thus, by using 1cm radius electrodes and 2mA stimulation the current density is less than 6.37 A/m^2 is safe enough for prolonged periods of time.

Based on [18], the tolerable are being appliedwhen currents is been applied to the skin is at a current density of 0.5 mA/cm^2. An empirically derived formula for the maximum painless current is as:

$$I = \frac{28.6\,A}{48.3 + A}$$

$$I = current\ in\ mA$$

$$A = area\ in\ cm^2$$

Using this formula, for an electrode with a radius of 1cm, indicated that the maximum current is at 1.75 mA. Thus, considering the threshold current fir GVS is between 0mA to 2mA, it is expected that the test subject will experience some minor discomfort during stimulation. However, this formula is derived from an empirical data, thus, the effects may vary from person to person.

In comparing the findings between method [17] and [18], it is assumed that, even though that the maximum intended current density of this project will be less than 25.46 A/m^2, but experiencetest subject will experienced some sensation and discomfort during the testing. Yet, it is still under minimal effects and does not bring any serious harm to subjects.

2.9.1 Human Skin Anatomy

The skin covers the entire external surface of the human’s body. It serves as the protective barrier that prevents internal tissues from sometimes-hostile environment. Other important functions include sensory perception, immunologic surveillance, thermoregulation, and control of insensible fluid loss [19].

Throughout the body, the skin’s characteristics vary in terms of thickness, colour, texture and many more. For instance, the head contains more hair follicles than anywhere else, while the soles of the feet contain none. The soles of the feet and the palms of the hands are much thicker [20] compare to other parts of the body. A human’s skin structure as in Figure 2.10 is made up of three main layers; epidermis, dermis and subcutaneous fat layer (hypodermis).

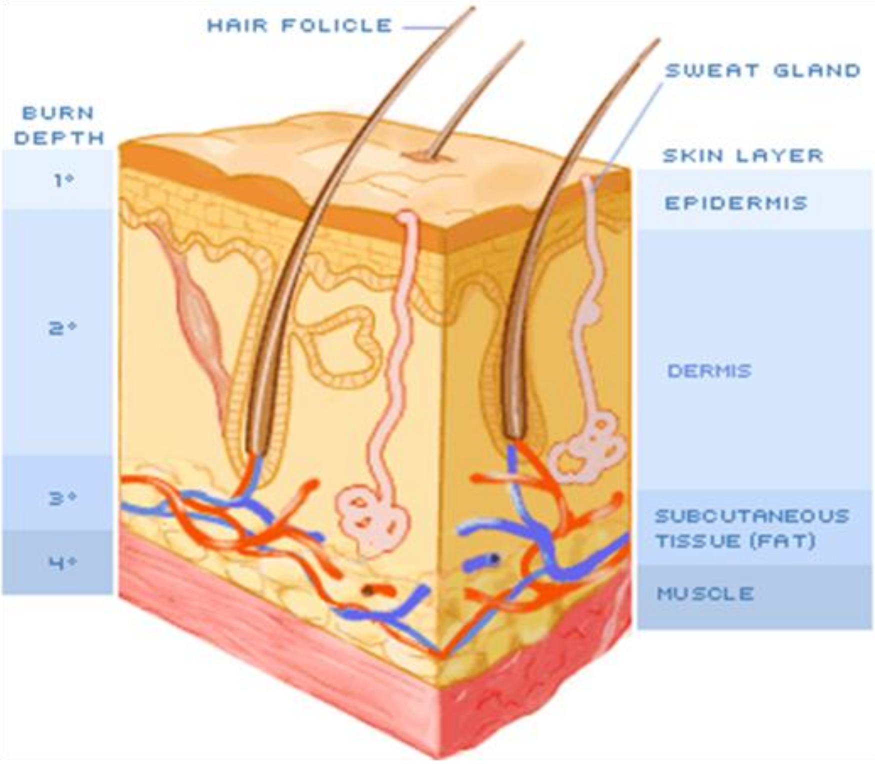

Figure 2.10: Human's skin anatomy

Each layer has its own function. First layer (epidermis) specialized in producing melanin (pigment) and act as the frontline defense of the immune system in the skin. Dermis consists of 3 types of tissue which is collagen, elastic tissue and rectangular fibres. The dermis contains many specialized cells and structures. This layer consists of hair follicles, oil, scent, sweat glands, blood vessels and nerve. Nerves transmit the sensations of pain, itch and temperature. The third layer, subcutaneous , is a layer of fat and connective tissue that houses larger blood vessels and nerves [21]. However, size of fat layer varies depends on each person individual and the position throughout the body.

Male skin is characteristically thicker than female skin in all anatomic locations. Children have relatively thin skin, which progressively thickens until the fourth or fifth decade of life when it begins to thin. This thinning is also primarily a dermal change, with loss of elastic fibres, epithelial appendages, and ground substance [22].

2.9.2 Electrode – Skin Impedance

The relations between electrodes, skin and tissue systems can be simplified in a single model as in Figure 2.11. The tissue/skin interface is typically modeled as an RC (resistor and capacitor) network.

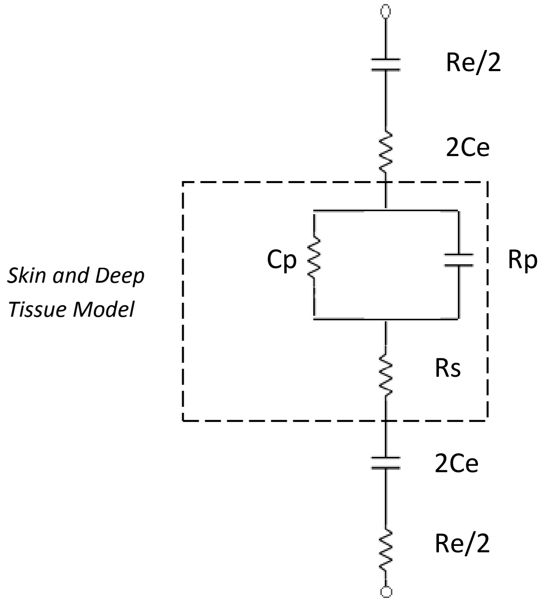

Figure 2.11: Electrical model of tissue-electrode interface. Rp and Cp model the skin with Rs modelling bulk tissue. Electrode-electrolyte interface are represented by Re and Ce. [23]

From the model, it is clear that the Rp and Cp combination is a frequency dependence on the frequency. However, [29] found that by removing the most outer layer of the skin (stratum corneum) will eventually remove this parallel Rp and Cp impedance and at the same time remove any frequency dependence. Boxtel [23] suggest that the removal of stratum corneum will reduce the magnitude of skins impedance.

Though, the total impedance of skin tissue can vary in magnitude depending on the frequency, skin treatment, electrode type and whether any conductive gels are used [23]. Thus, in order to increase the effectiveness of GVS, conductive gels are placed on human skin to reduce the impedance between electrode and tissue. W. Beslo state that for a well treated skin, tissue-electrode impedance can be as low as 8kΩ whereas the worst case of untreated skin can reach up to 100kΩ.

CHAPTER 3

METHODOLOGY

3.0 Introduction

This chapter will describe the method for this project to achieve the desired objective. This project is divided into two phases, first is to develop the hardware system in order to produce two ways of different polarity current as an output and the second is to make this system work in wireless condition for data transfer between the display unit and controller. Further explanation of project planning, software and hardware developments sampling, analysis method and expected result will be discussed later.

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