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Design of Compact Signal Distribution Device for Hoffman Reflex Methodologic Applications in Sports Medicine

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DESIGN OF COMPACT SIGNAL DISTRIBUTION DEVICE FOR HOFFMAN REFLEX METHODOLOGIC APPLICATIONS IN SPORTS MEDICINE

by

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(Under the Direction of Jung Choi)

ABSTRACT

A study on the design of compact-sized signal distribution device for Hoffman reflex methodological applications in sports medicine was presented. The established conventional method for measuring and recording human or animal nervous system response to the external electrical stimulus was considered in this study. Challenges with measuring and recording techniques that introduce inaccuracies and unreliability of reflex response data obtained were analyzed; this work aims to improve the reliability of the H-reflex d measuring and recording process to reduce inaccuracies introduced to data obtained because of the conventional methodologic approach. Inaccuracies due to changes in subject muscle geometry and body part positioning were considered; the method was devised to expand the stimulus signal delivery channels to cover the entire limb length. Expanded output channels were achieved through a designed signal distribution device, which offers low impedance (≤ 150mΩ), low power dissipation (≤ 200mW), low inductance(≤1.00mH), and low resistance(≤100mΩ) signal travel path. Arduino controller controlled the distribution sequence of the signal in conjunction with a multiplexer, which determines the signal travel path through the relay activation process. The device was tested with a 5v input signal; data obtained establishes the minimum effective signal processing speed for the device to be 20ms. This processing time is lower than the required processing speed (100ms), hence distributed stimulus was effectively distributed through the output channels of the designed device. Device performance was evaluated in a simulated environment by testing actual electric stimulation from constant current stimulator at both minimum current amplitude (1mA), voltage amplitude (100v), pulse duration (50µs) and maximum current amplitude (10mA), voltage amplitude (400v), pulse duration (2ms) tested on simulated human body resistance, and response at each setting monitored on an oscilloscope. Results obtained confirm all expectations as the designed device delivered electric stimulus to the simulated human body resistance set up with minimum signal propagation delay at 75mΩ average resistance. Device usage in the methodological delivery of a stimulus to human muscle was established to improve the response data's reliability significantly. Details of the methodology, simulation, and real-time implementation results are presented, and recommendations for future work are briefly outlined

INDEX WORDS: Hoffman Reflex (H-Reflex), Alpha-motoneurons (αMNs), Muscle wave (M-wave).

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DESIGN OF COMPACT SIGNAL DISTRIBUTION DEVICE FOR HOFFMAN REFLEX METHODOLOGIC APPLICATIONS IN SPORTS MEDICINE

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DEDICATION

This work is dedicated to "He" who made it all possible "God Almighty," to the loving memory of Mr. Kazeeem Olatunde Akintunde, and also to all those whose support and contributions in various measures got me thus far.

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CHAPTER 1

INTRODUCTION

1.1 Scientific Discovery

Named after its discovery as described by Paul Hoffmann (German physiologist and physician) in 1910, extensively used as both a research and clinical tool, easily elicited throughout the body, the Hoffman reflex (H-reflex) is an electrically induced reflex like the mechanically induced spinal stretch reflex (Riann, Ingersoll et Hoffman 2004). To describe H-reflex, brief information on the monosynaptic reflex is needed. The monosynaptic stretch reflex sometimes referred to as the muscle stretch reflex, provides communication between sensory and motor neurons innervating the muscle. It involves only one synapse between the sensory and motor neuron for the reflex circuit to complete (Pierrot-Deseilligny et Mazevet 1999). An example of such is the knee jerk reflex, which takes about 50 milliseconds between the tap and the start of the leg kick.

The stretch reflex is also one of the common forms of a monosynaptic reflex. Physicians often use the “elbow tap” to test the reflex quality in an individual, as shown in Figure 1.1.1. Sufficient stimulus is needed to elicit the stretch reflex, which means the tendon must be struck with an appropriate force for a pull to occur in the muscular structure (musculature). This stretch activates the muscle spindles located in parallel inside the muscle; when the muscle is rapidly stretched, the spindles are rapidly stretched as well. If the stretching occurs at a rate beyond the spindles threshold speed, they send signals to the spinal cord via the la afferent.

When sufficiently stimulated, the alpha-motoneurons in the spinal cord will send a signal to the musculature, inducing a contraction of the stretched muscle and a relaxation in the opposite muscle. Observations of the muscles by Electromyography (EMG) sensors would show that a signal appears on the muscle just before contraction. Another signal appears on the muscle as the contraction begins (Dreger 2006).

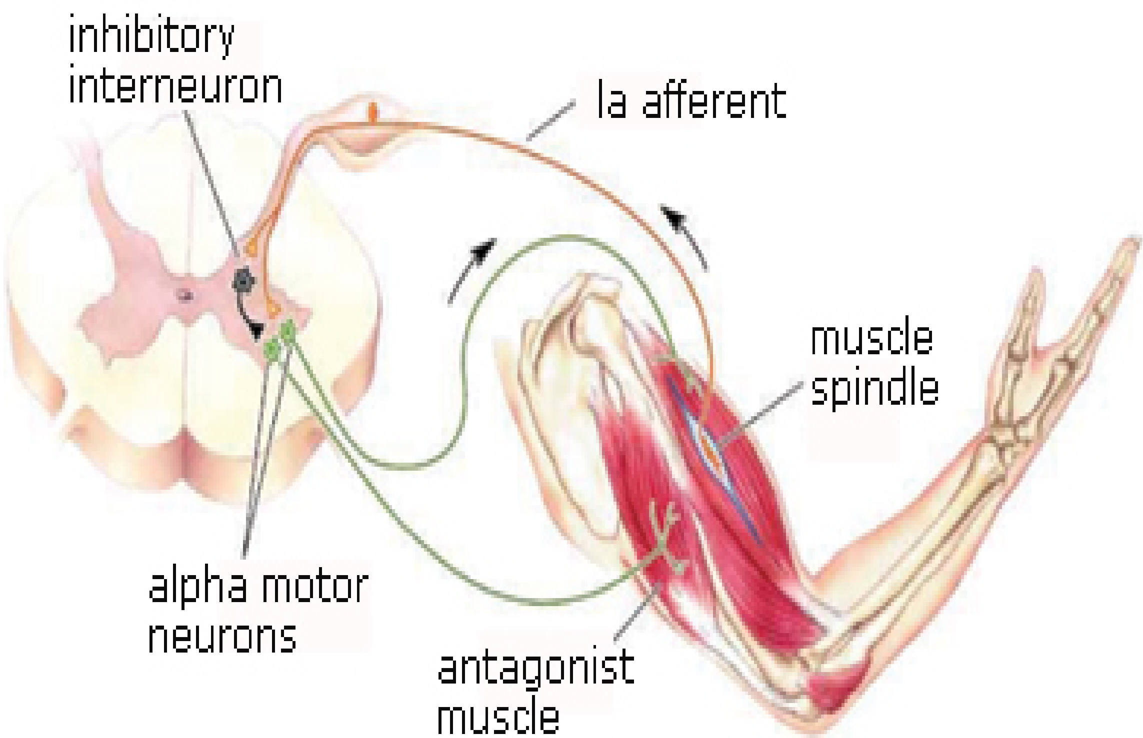

Figure 1.1.1: Stretched human upper arm reflex schematic (Dreger 2006)

The H-reflex bears a great deal of resemblance with the stretch reflex; the only difference is that for H-reflex, an external electric stimulus is applied from the body surface to contact point nerves, which then travel toward the spinal column and stimulate the alpha-motoneuron, thus sending a signal toward the musculature. The movement that occurs before contraction is termed H-reflex, while that which occurs when contraction occurs is called M-wave (muscle response). An EMG recording device could pick up both signals (Riann, Ingersoll et Hoffman 2004). The monitoring device setup schematic is shown in Figure 1.1.2.

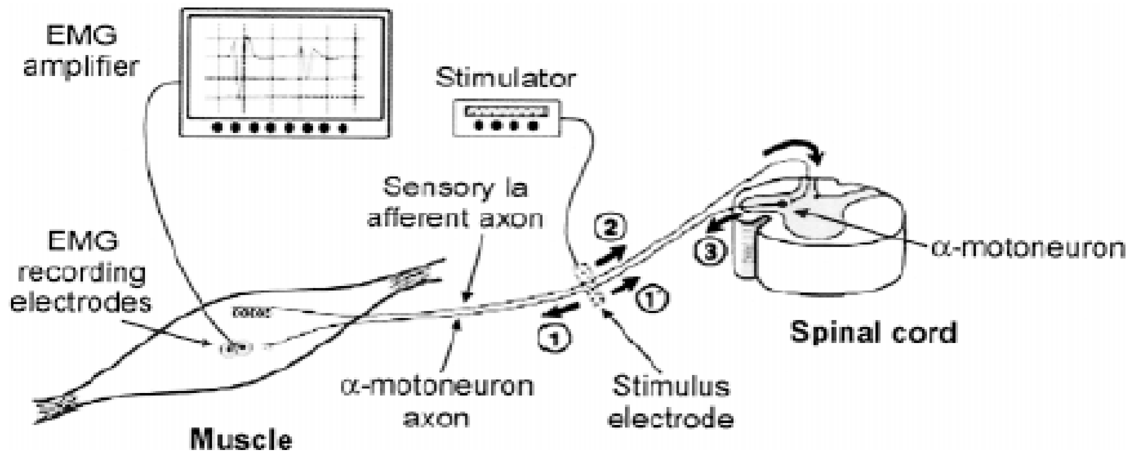

Figure 1.1.2: H-reflex monitoring system simulation device schematic setup (Pierrot-Deseilligny et Mazevet 1999).

1.2 Stimulation of H-Reflex

H reflexes are obtained by electrical stimulation of Ia afferents containing the corresponding mixed nerve. The electrical stimulus duration must be considered as it is possible to evoke H reflex with stimuli below motor threshold due to difference in diameter of Ia afferent and motor axons. The strength-duration curves for motor axons and Ia afferent differ such that the optimal stimulus duration for eliciting the H reflex is 1ms (Paillard 1955). To ensure the Ia afferents are excited at a lower threshold than motor axons, the cathode electrode is placed over the nerve of the subject muscle. The anode electrode is placed on the opposite side of the limb to ensure current passes transversely through the nerve (Hugon 1973). The bipolar stimulation must, however, be used in areas where there are many nerves to avoid the stimulus from encroaching upon another nerve. The stability of simulation conditions is key to obtaining accurate results as test simulation results could be altered if performed during a maneuver or involuntary muscle contraction (Pierrot-Deseilligny et Mazevet 1999). Changes in the H reflex test need to be monitored to ensure they are not due to a change in electrode positioning with respect to the subject nerve. The site and intensity of stimulation must be adjusted so that the test stimulus also evokes a motor wave whose stability is used to monitor the strength of stimulation conditions. Monopolar and bipolar stimulations are used for the excitation of nerves to invoke reflexes, which depends on nerve condition. A suitable stimulation method must be selected to ensure the accuracy of the results obtained. During stimulation of nerves, as the electrical stimulation intensity increases, the reflex amplitude also increases. When the motor threshold is reached, the short-latency direct motor response (M wave) appears in the EMG due to stimulation of motor axons. Further increase in the test stimulus intensity causes the moto wave to increase while the H reflex decreases. The H reflex response disappears totally when the direct motor response is maximum because the antidromic motor volley set up in motor axons collides with and eliminates the H reflex (Hoffmann 1922). This variation of the H and M responses with the test stimulus intensity is shown in the recruitment curve in Figure 1.2.1

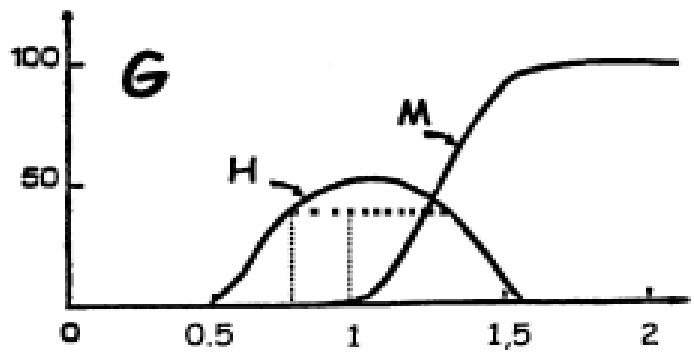

Figure 1.2.1: Motor and H-Reflex responses against electrical stimulation intensity (Pierrot-Deseilligny et Mazevet 1999).

M max, evoked by the recruitment of all motor axons, provides an estimate of the response given by the whole motoneuron (MN) pool. It is impossible to restrict the stimulus to only motor axons of the muscle tested. Hence M max must always be measured because:

(i) It provides estimates of the proportion of the MN pool tested by MSR.

(ii) Reflex expressed as a percentage of M max enables one to get rid of the changes in muscle geometry related to muscle length and contraction, provided they are assessed in the same conditions, i.e., eliminates error due to muscle geometry.

(iii) The constancy of evoking M waves is used to monitor the stability of the stimulation parameters.

In some proximal muscles, where the H reflex is not easily distinguishable from M wave (e.g., biceps and triceps brachii), the excitability of the MN pool may be tested by eliciting tendon reflexes using an electromagnetic hammer producing reproducible transient stretches (Pierrot-Deseilligny et Mazevet 1999). H reflex assesses the excitability of an MN pool, extra stimulation from a facilitating signal is deemed responsible for non-linearity and in-homogeneity within the pool. The sensitivity of the H reflex to enabling signal increases proportionately with sizes of the control reflex at low reflex amplitude. A variety of methods are available to assess presynaptic inhibition of Ia terminals in humans and to estimate the extent to which a change in H reflex amplitude reflects in monitoring condition vibration or electrical stimulation (Pierrot-Deseilligny 1997). The extent of the effect of conditioning stimulation on H reflex size modification is approached by comparing the effects of a given conditioning stimulus on the H reflex. Research has proved with various conditioning stimuli that the contribution of Ib pathways to changes induced by a given conditioning stimulation in the H reflex is insignificant (Nielsen et Petersen 1994). The conclusion suggests that the contribution of di-synaptic pathways to the changes observed in the H reflex is not significant to changes in the excitability of the motoneuron. Findings from numerous research work have established the validity of the H reflex as a tool to explore the excitability of the motoneurons in humans. However, specific methods are required to assess the response of motoneurons after activation of a given spinal path. The reliability of procedures developed to investigate MNs' spinal pathways in humans has also significantly increased due to continuous improvement of approach technique.

1.3 Monosynaptic Reflex (MSR)

Monosynaptic reflex was used in the early 1940s for investigating excitability changes in the motoneuron (MN) pool in animal studies (Pierrot-Deseilligny et Mazevet 1999). This method of reflex test allows one to assess the effect of the MN pool of conditioning volleys in peripheral afferents or descending tracts. This method revealed essential features of the input to spinal MNs. This method was found reliable from the main conclusion of experiments that used the MSR technique as the results were indifferent from experiments that use intracellular recordings (Renshaw 1940). The H reflex technique used for humans is an equivalent of the MSR method in animals and has been extensively used in physiological and pathological investigations in humans (Awiszus et Feistner 1993). Ia fibers from muscle spindle primary endings of a muscle monosynaptic excitatory projections to the motoneurons of a muscle; this is the primary cause of tendon jerk.

H-reflexes can be recorded in most healthy subjects at rest from Sol, quadriceps (Q), and flexor capercaillies (FCR) muscles. H reflexes can also be recorded from virtually all limb muscles whose parent nerve is accessible to electrical stimulation when a weak voluntary contraction potentiates the reflex by raising the motoneuron pool close to the firing threshold (Pierrot-Deseilligny et Mazevet 1999).

1.4 Measurement and recording method

The conventional method of recording the Hoffman reflex is placing bipolar surface electrodes 1.5-2 cm apart over the subject muscle. A voluntary contraction that allows the reflex discharge to occur predominantly in the contracting muscle could focus on the desired contracting muscle. Monopolar recordings, with the active electrode over the mid-section of the subject muscle and the remote electrode over its tendon, are recommended by researchers for measurement during voluntary contraction to minimize the effect of changes in muscle geometry (Pierrot-Deseilligny et Mazevet 1999). The technique for measuring and recording the H reflex is simple but requires a strict methodology to interpret the results validly. In the adopted method and interpretation of results, factors such as post-activation depression and the ability to randomly alternate control and conditioned reflexes need to be accounted for.

1.5 Objectives and Scope of Present Work

The hypothesis of the present work states that "If a compact signal distribution and acquisition device could be designed, the cumbersome procedure of investigating H-reflex signal from human muscles would be the greatly simplified and portable device for monitoring, investigating and predicting the state of fatigue and examine neuromuscular impairment in a particular human muscle would be available for deployment." To investigate this hypothesis, the design and testing of a different DC-powered signal distribution and acquisition device are required; this device also generates a stimulation signal, which is fed directly to the input channel of the constant current stimulator device. The device is to be deployed for field testing on human muscle; obtained signals are to be interpreted and compared with traditional means of acquiring H-reflex signals to establish successful functionality and reliability of different muscles status monitoring systems. This thesis is focused on the design of DC-powered one input source signal distribution to a ten output channels device which also generates a stimulating signal source.

To test the hypothesis, the following objectives (➢) and tasks (*) were set:

- ➢ Design a DC-powered device that could distribute one input signal source to ten output channels at a predetermined sequence and generate a stimulating signal.
    - Select and review circuit components to suit the size of the device intended to be designed.
    - Determine input and output channel signal selection sequence.
    - Select a suitable DC power source for the designed circuit.

- ➢ Test the effectiveness of the designed circuit with simulated DC signals.
    - Develop Arduino code to run the signal distribution trigger sequence.

- Develop Arduino code to generate a stimulating signal from one of the output pins of the Arduino nano board.
- Feed the stimulating signal into the trigger input socket of the constant current stimulator.
- Channel input signal through the device for controlled distribution.
- Test device with DC input voltage at varying trigger time settings to establish circuit functionality.
- Test device minimum trigger signal limit to establish precision and set operating time frames for fast, accurate results.

➢ Deploy device for on-the-field experimental testing.

- Use the device to acquire H-reflex signals from human muscle.
- Interpret acquired signal on EMG amplifier
- Record and compare results (interpreted data) with results from the conventional method.

A device that generates a stimulation signal and distributes one input signal source sequentially timed to ten output signal channels was designed to achieve the above-listed objectives. The device circuit is comprised of the following components:

- One Arduino nano 33 BLE board.
- Two eight output channel CD4051BE multiplexers.
- Ten 2N3904 NPN transistors.
- Ten EC2-5NU KEMET relays.
- Ten 1KΩ resistors.
- 5V DC power source.
- Connecting wires.

- Printed circuit boards.

These components were used to build a circuit that generates output stimulation signal, connects, and disconnects one input source channel to ten output channels sequentially as timed by the functional program on the Arduino board. C++ programming language provided output stimulation signal generation commands and input signal timing control distribution to the output channels.

1.6 Organization of this Thesis

The remainder of this thesis is organized as follows:

In chapter 2, works of literature written from elaborate work on H-reflex discovery, applications, methodological considerations, limitations, and result's reliability challenges relevant to this research and present work are reviewed. Extraneous factors that must be accounted for and considered are also highlighted as they significantly affect the accuracy and validity of results interpretation. The importance of adopted stimulation methods on differentiating between alpha-motoneurons(αMNs), Ia afferent stimulation, and monosynaptic muscle spindle responses are also briefly presented.

In chapter 3, the methodology adopted for this work is presented. First, the problem statement, as well as the proposed solution, are discussed. Next, comprehensive details of the designed circuit, circuit architecture, circuit schematic diagram, circuit components selection, and written functional operating C++ code are discussed. Devices and software programs used for simulation implementation and testing are presented. Finally, details of field-testing environment and equipment are also discussed.

Results obtained and discussion are presented in chapter 4. First, the simulated input signal graphical results at various timing are presented to establish a response time limit for the circuit. Next, the effects of input signal timing are presented and compared with previous results to set an output signal time limit for effective signal capturing of the circuit. Finally, the actual environment implementation results are presented.

In chapter 5, the essential features of the present work are summarized, and the scope of further work is briefly outlined.

CHAPTER 2
LITERATURE REVIEW

2.1 Hoffmann Reflex (H-Reflex)

H-Reflex is both a clinical and research tool that can be used on muscles involving both spinal and cranial nerves to examine the response of the nervous system to various neurological disorders, musculoskeletal injuries, musculature recovery therapeutic measures, physical activities, which entails motor performance and exercise fitness training. This reflex has received considerable attention in the literature concerning movement control, clinical neurophysiology, and applied physiology (E. P. Zehr 2002). It could also be used to test athlete muscle response before and after training to gain insight into the state of the athlete's musculature. One of the conclusions derived from experimental research was that when the muscle is fatigued, there is a deterioration of the alpha-motoneuron pool and increased inhibition within the spinal cord; this deterioration and inhibitive condition are clinically studied to develop remedial measures for injury prevention and speedy muscle recovery.

The researcher's interest in evaluating the adaptive plasticity of the human nervous system in response to exercise training, injuries, or other types of forced influences have grown over the years for various reasons, with a specific focus on estimation of spinal reflex processing in the human subject before and after physical activities. Numerous research work has been done to determine and discuss the proper methods used to elicit the Hoffman reflex (H-reflex) and evaluate conditions of usage of this reflex in sports medicine research. H-reflex and its methodology has been used as a tool by researchers to examine neurologic disorders, neuromuscular impairments after sports injuries (Riann, Ingersoll et Hoffman 2004). Studies describing appropriate methods to elicit the H-reflex and questioning the reliability of this measurement in different muscles are extensively available in human neurophysiology literature.

2.1.1 Sensory and Motor fiber Channels of H-Reflex and M-Wave

The efficacy of synaptic transmission is measured by the amount of electric stimulation needed to evoke H-reflex, as the stimulating signal travels in the la afferent (sensory fibers) through the motoneuron of the corresponding muscle to the efferent (motor fibers). The H-reflex's afferent (sensory) portion begins at the point of electric stimulation. It results in action potentials traveling along afferent fibers until they reach a specific amplitude and synapse on alpha motoneurons. The efferent portion of the H-reflex pathway results from action potentials generated by the alpha motoneurons traveling along efferent fibers until they reach the neuromuscular junction and produce a twitch response in the electromyography (EMG) and that response is called the H-reflex. Electric stimulation of the peripheral nerve also causes direct activation of the efferent fibers, sending action potentials directly from the point of stimulation to the neuromuscular junction. (Palmieri, Ingersoll and Hoffman, 2004). This efferent arc produces a response in the EMG known as the M-wave muscle response; a schematic representation of the alpha motoneuron activation process is shown in figure 2.1.1. H-reflex is the resultant twitch response of the muscle after appropriate electric stimulation; it is like spinal stretch reflex; the only difference is that the spinal stretch reflex is induced after a muscle stretch while H-reflex is induced by electric stimulation.

2.1.2 Stimulating H-Reflex

The process of stimulating H-reflex involves applying electric stimulus directly to the skin area, which is received by the mixed nerve. The technique used to evoke H-reflex involves electrical stimulation of the peripheral nerve, which contains motor and sensory axons. This stimulation involves both afferent sensory from the point of stimulation to the spinal cord, efferent motor arcs from the alpha motoneurons in the spinal cord to the neuromuscular junction, and a direct efferent motor response (M wave) from the point of stimulation to the neuromuscular junction (Trimble et Koceja 1996). A typical example to further explain this procedure is when soleus H-reflex is to be elicited, a 1-millisecond square wave pulse is applied to the posterior tibial nerve in the popliteal fossa. The intensity of the applied electric stimulus starts from low. It gradually increases, resulting in depolarizing the primary afferent fibers (Ia afferents) arising from the muscle spindle.

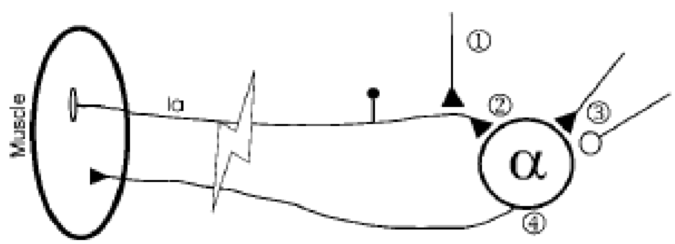

Figure 2.1.1: Alpha Motoneuron Activation Schematic Representation (Misiaszek 2003).

The nerves are activated electrically, not stimulating the muscle spindle itself. Hence the muscle spindle is effectively bypassed. Activating the Ia afferents results in action potentials propagating towards the spinal cord. Sufficient activity in the Ia afferent will cause depolarization of the presynaptic terminal, and neurotransmitters are released into the synaptic cleft at the Ia-alpha-motoneurons (Ia αMNs) synapse, eliciting excitatory postsynaptic potentials (EPSPs) in the motoneuron.

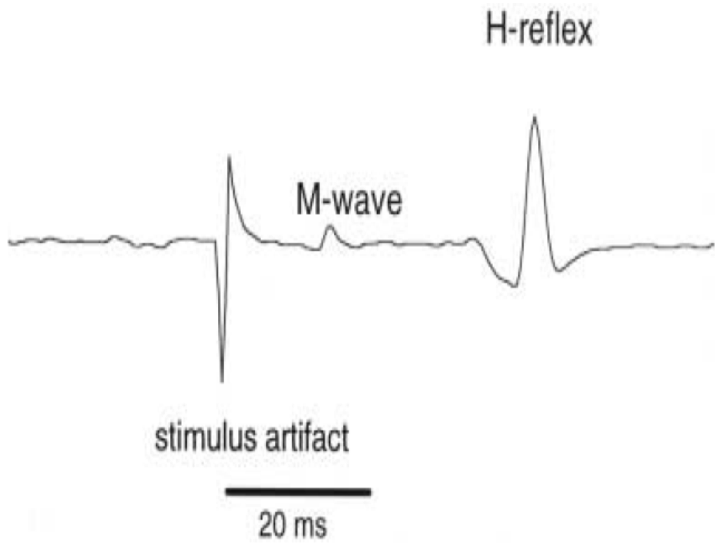

Figure 2.1.2: Schematic of Stimulus-Triggered H-reflex in Soleus Muscle (Zehr et Stein 1999).

Sufficient EPSP will depolarize the MNs, action potentials generated causes acetylcholine release at the neuromuscular junction, contraction of the muscle, and appearance of H-reflex tracing on the EMG at low levels of stimulation, the afferent fibers are preferentially stimulated due to their intrinsic properties and their larger diameter, increase in stimulus intensity increases the population of participating Ia afferent fibers which cause more MNs to be activated as they reach their threshold thus resulting from increases in the amplitude of the H-reflex.

H-reflex pathway length, which depends on the size of the limb, is critical to determining the amount of time it takes for the H-reflex to appear on the surface electromyography electrodes EMG. Before visibility on the EMG, the action potentials making up H-reflex must travel up the afferent fibers to MNs and down the motor axons to the muscle. Latency is the time it takes for the H-reflex to appear on the EMG relative to the introduction of the stimulus. The closer the muscle to the spinal cord, the shorter the latency of the H-reflex. This is the factor responsible for the difference in timing of tracing appearance on the EMG for different types of H-reflex.

2.2 Stimulating M-Wave

Continuous increase of the electric stimulus intensity beyond the required level for H-reflex results in direct stimulation of the motor axons and the presence of an M-wave. Motor axons have a higher threshold; hence, a higher-intensity stimulus is required to activate these fibers than Ia sensory neurons due to the smaller Ia sensory. A large axon provides easy to stimulate neurons; the Ia sensory neurons could be preferentially stimulated before the motor axons are activated. Action potentials are generated and fired toward the neuromuscular junction when the intensity of the stimulus reaches the depolarization threshold for the efferent fibers. This activity also causes muscle contraction; since it did not pass through the spinal cord, it is not referred to as a reflex but a muscle response termed M-wave. The action potentials for muscle response to occur following a relatively short path; hence the M-wave tracing appears on the EMG at a shorter latency than the H-reflex. M-wave appears at a somewhat shorter time frame than H-reflex due to the short travel path of the action potentials. H-reflex tracing begins to appear on the EMG at low levels of stimulation. As the stimulation intensity increases, the depolarization threshold for the motor fibers is achieved, causing the M-wave to appear in the EMG simultaneously with the H-reflex. A continuous increase in stimulus intensity beyond this point eventually results in the H-reflex reaching its maximum and then disappearing from the EMG tracing. In contrast, the M-wave achieves its maximum and remains stable.

2.3 Maximum Reflex and Maximum Motoneuron Activation (H_{max} and M_{max})

H_{max} represents a measure of maximal reflex activation; it is an estimate of the number of αMNs one can activate per state. To determine the effect of training exercise or injury on an athlete's muscle, H_{max} is measured before and immediately after the muscle activity; the results obtained will be compared. It would be expected that the resulting H-reflex would significantly decrease due to muscle inhibition which prevents the athlete from recruiting αMNs during contraction.

M_{max} represents the maximum muscle activation which involves the entire αMNs pool. Every MN that supplies the muscle of interest is considered activated once M_{max} is reached, thus producing a stable output measurement value on the EMG. Eliciting H-reflex is assumed to be possible in any muscle with the peripheral nerve accessible to stimulus. Eliciting and interpreting H-reflexes for different muscles poses different challenges depending on various conditions. Factors such as subject positioning is crucial during H-reflex testing, body composure, eye closure, head position, joint position or angle, remote muscle contractions, and muscle length affects the H-reflex amplitude. Maintaining the same hand and head position throughout testing allows reliable H-reflex measures. H-reflex amplitude varies among subjects; the differences in skin resistance, amount of subcutaneous fat, and locations of the nerve relative to the stimulus point are a few factors responsible for this variation.

The frequency of stimuli delivery during eliciting H-reflex must be carefully considered because delivering stimuli too close together decreases the amplitude of the H-reflex. Stimuli are best applied at least 10seconds apart to reduce the effect of the previous activation in the Ia afferents and depletion neurotransmitters, a phenomenon known as post-activation depression.

2.4 Normalization Procedures

Significant variation exists in the amplitude of H-reflex among subjects; to make comparisons between subjects, obtained values must be normalized. Methods of normalizaincludenclud H-reflex as a percentage of M_{max}: this method involves eliciting H-reflex as a percentage of $M_{max.}$ The stimulation intensity is adjusted to produce H-reflex with amplitude equal to a fraction of the obtained amplitude of the Mmax. For example, to elicit H-reflex that of Mmax, the Mmax amplitude is measured first. The stimulation intensity is adjusted to produce an H-reflex amplitude of 10% Mmax amplitude.

Hmax/Mmax ratio is another standardization method; Hmax is an indirect estimate of the number of utilized MNs. Mmax represents the entire pool of MNs; the Hmax/Mmax ratio can be interpreted as the proportion of the whole pool capable of being recruited. This method is based on scientific assumptions and is not so effective. A significant disadvantage of this method is that the H-reflex is less susceptible to facilitation and inhibition at a higher amplitude. Therefore, changes in Hmax may underestimate the amount of facilitation or inhibition under a given condition.

2.5 Reflex Amplitude Gain

One of the inherent difficulties with H-reflex measurements during dynamic activity is accounting for changes in muscle activity in the test muscle. H-reflex, defined as a measurement of the motor units activated by an electric stimulus, is a helpful model when the primary source of motor unit activation is the result of only the electric stimulation used to elicit the reflex. Muscle activities in the test muscle during the H-reflex measurement also contribute to the stimulus making the H-reflex amplitude not solely a function of the electric stimulation but also due to background muscle activity. The effect of background muscle activities (BEMG) is more pronounced in cases such as H-reflex assessment during dynamic activities such as walking, running, or exercising, which involves varying levels of BEMG. Changing BEMG makes it challenging to determine how much of the H-reflex amplitude is due to the stimulation and how much muscle activity is in the muscle, at the time the reflex is being elicited, and thus difficult to assess reflex modulation. H-reflex gains are used to evaluate modulation during conditions involving dynamic movements; H-reflex gain is defined as the change in H-reflex amplitude/change in BEMG. Peak to peak reflex measurement is H-reflex amplitude, while BEMG is the average rectified EMG amplitude present in the muscle for some period before the stimulation. BEMG is measured between 50 and 100 milliseconds. H-reflex gain is calculated as the slope of the relationship between the H-reflex and BEMG.

2.6 Limitations of H-reflex measurement

H-reflex is an electrically induced reflex, meaning it does not occur naturally in the human body; hence its applications relative to human movement is limited by accessibility and other influence such as muscle spindle, which adjusts the reflex output during movement. The direct connection between Ia afferents and MNs allowed the misconception that H-reflex is solely represented by MN excitability. This assumption is inaccurate and only practicable in literature because the synaptic connection between the Ia afferent and MNs is subject to presynaptic modification. Presynaptic inhibition alters neurotransmitter release at the Ia-Mn synapse and can decrease the H-reflex with no change in MN membrane potential and conductance. Presynaptic control of movement differs with age, training, or exercise. It is inaccurate to interpret changes in H-reflex size as the sole function of changes in motoneuron excitability because of presynaptic inhibition (PSI). There is conclusive evidence that proves that PSI could selectively alter the transmission in a monosynaptic reflex pathway. This mechanism has recently been demonstrated to be selective enough to different collaterals from the same muscle spindle afferent (Rudomin et al. 1998).

Meticulous attention must be placed on the adopted methodology for the H-reflex technique, and multiple factors could compromise the data obtained, thereby making interpretation nearly impossible. The interpretation of data is often marred by either one of the following overarching assumptions; the first assumption is that H-reflex is derived purely from group Ia afferents, projecting (Misiaszek 2003). H-reflex is highly modifiable.

2.7 Factors that Influence H reflex Amplitude

Presynaptic inhibition (PSI): This is mediated by the action of an inhibitory interneuron (using gamma-aminobutyric acid as the neurotransmitter) acting on the Ia afferent terminals (Riann, Ingersoll et Hoffman 2004), leading to a reduction in neurotransmitter release and a concomitant reduction in motoneuron depolarization induced by Ia activity (Rudomin and Schmidt 1999). Afferent transmission can be altered without a corresponding effect on the postsynaptic membrane. Activities in the Ia afferents, in the presence of PSI without changes in the postsynaptic membrane is possible, potential motoneurons remained receptive to other inputs that were unaffected by PSI. PSI can alter the afferent signal that evokes the H-reflex**;** however, the level of alpha-motoneuron excitable is not determined by measuring the H reflex alone.

Other factors that influence PSI of the H-reflex pathway (Brooke et al. 1997a) include afferent feedback from other peripheral receptors and descending supraspinal commands. For research and experimental purposes, the effect of many of these factors is assumed to be controlled by maintaining subject posture and position.

CHAPTER 3

METHODOLOGY

The primary aim of this research is to design a device capable of giving trigger input to a constant current stimulating device (digitmer) and distributing one output channel signal source from the digitimer between 10 channel outputs sequentially timed according to the command of the circuit operating code. Then test the designed device on human muscle for stimulus signal response acquisition. This chapter focuses on the problem statement, the proposed solution, the material list for circuit design, operating code, testing, and the implementation method used in the research. The main emphasis is on improving the technique of acquiring human muscle response reflex to stimulus signal, thereby minimizing the influence of external factors, limiting the interpretation of H-reflex data. Achieving this objective will help improve the reliability of H-reflex application as a neural probe in neurophysiology and motor control research.

3.1 Problem Statement

This thesis focuses on minimizing the impeding limitations to H-reflex data acquisitions and interpretation, thereby improving its reliability as an investigative tool in neurophysiology and neural circuitry. At the same time, the conventional method of recording muscle response to external stimulus involved the use of positive and negative electrode pairs placed at specific locations over corresponding muscle. This traditional method utilizes one channel only, hence response could only be acquired from a source at the point of electrode contact on the muscle. If this method of stimulus-response acquisition could be extended to multiple acquisition channels, then the electrode pairs could be placed at various locations on the corresponding muscle. This multiple acquisition point would improve the accuracy of stimulus-response acquisition, minimize external factors responsible for limitations in response data interpretation, and improve the method's reliability in motor control neurophysiology. The proposed approach is to design a circuit with channels extending the signal acquisition pathway to achieve the set objective.

3.2 Proposed Solution

The motivating idea behind this work stems from the quest to solve the inherent problem of moving the response acquisition electrode pair from one point on the subject muscle to another during the acquisition of muscle response to externally induced electrical stimulus, by having a multichannel device to which a bunch of electrode pairs could be connected. This ten-output channel is connected to one source input that takes the signal from the constant current simulator and supplies 5v stimulus trigger input to the current stimulator. The designed multichannel device was connected to the stimulator, and the entire system was set up to obtain corresponding muscle reflex responses. The result was interpreted and compared with the conventional acquisition method to establish the new approach's relative effectiveness.

3.3 List of Material for Circuit Design

The major components used in the device circuit design and their specifications are listed in Table 3.3.1.

Table 3.3.1: Designed Circuit Components Specifications.

Component	Specifications		Unit
Arduino Nano (All I/O pins PWM enabled)	Microcontroller	nRF 52840	
	11 Digital I/O Pins	D2-D13	
	8 Analog Input Pins	A0-A7	
	Operating voltage	3.3	V
	Input Voltage Limit	3.5 – 21	V
	DC current per I/O Pin	15	mA

Table 3.3.1: Designed circuit components specifications.

Component	Specifications	Range	Unit
Multiplexer (CD4051BE)	Supply DC Voltage (V+ to V- referenced to Vss terminal)	-0.5 - 20	V
	V_{DD} - V_{EE} = V_{SS}	0	V
	DC Input signal Voltage	-5 – +5	V
	Operating Frequency	20 – 60	MHz
Transistor (2N3904)	V_{CE} – Collector Emitter Voltage	0.5 - 40	V
	V_{CB} – Collector Base Voltage	0.5 - 60	V
	V_{EB} – Emitter Base Voltage	0.5 – 6	V
	I_C – Collector current	0.5 - 200	mA
	Operating Temperature	-55 - 150	°C
Relay (EC2-5NU)	Coil Voltage VDC	5	V
	Solder Temperature	280 - 350	°C
	Switching Current	0.1 - 2	A
	Maximum Switching Power	60	W
	Maximum Switching Voltage	220 VDC, 250 VAC	V
	Operating time	2	ms

	Minimum Contact Ratings	10 mVDC, 10µA	V, A
Resistor(1KΩ)	Wattage	0.125-1	W
	Tolerance	±5	%
	Voltage Rating	1 - 350	V
28 AWG 0.15mm	Voltage rating	0.1-250	V

The schematic diagram for the PIN layout of the multiplexer is shown in Figure 3.3.1. The multiplexer is an electronic component that acts as a switch with multiple output channels; it is operated on DC voltage and takes a 3-bit input trigger signal from the Arduino board. The signal is programmed to trigger one of the eight output channels per time.

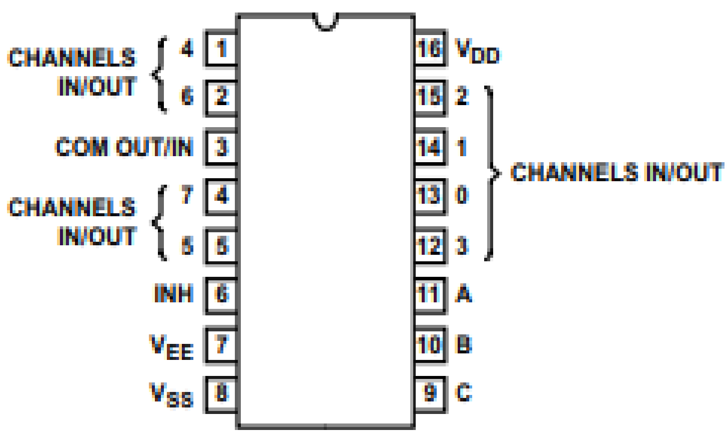

Figure 3.3.1: Schematic Diagram of Multiplexer Pinout (CD4051BE Multiplexer Data Sheet).

The transistor architecture shown in Figure 3.3.2 is an electronic component used to control the switching operation of the relay coil. The transistor used in this circuit is an NPN and takes the input to the base pin from one of the output channels of the corresponding multiplexer.

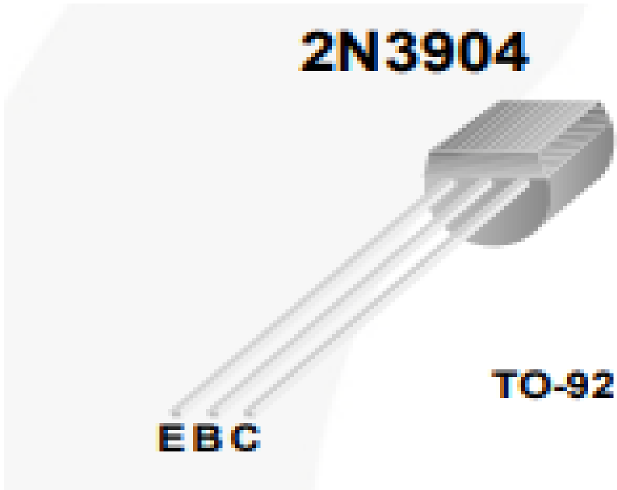

Figure 3.3.2: Transistor Pin Terminal Label (2N3904 Transistor Data Sheet).

The relay used in building this circuit has its schematic pin layout shown in Figure 3.3.3. 5V input voltage is connected to the positive terminal of the activating coil, while the output signal from the corresponding transistor is connected to the negative terminal. This allows the intermittent switching operation of the transistor to control the relay coil activation.

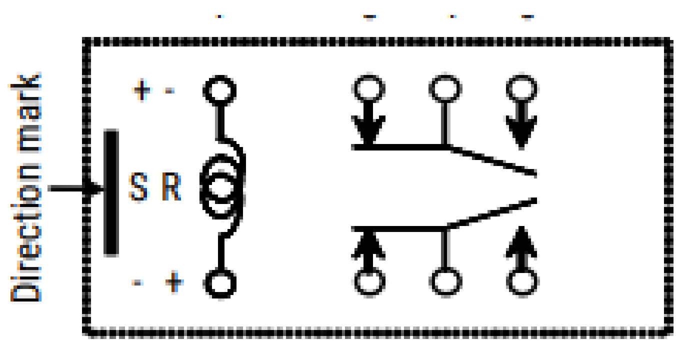

Figure 3.3.3: Schematic Diagram of Relay PIN layout (EC2-5NU Relay Datasheet).

Arduino board layout architecture is shown in Figure 3.3.4. This programmable microcontroller board is used to design analog or digital circuits and devices for suitable DC applications. The Arduino NANO is used for this circuit design, and it supplies an input signal to the multiplexer according to the dictates of the operating code.

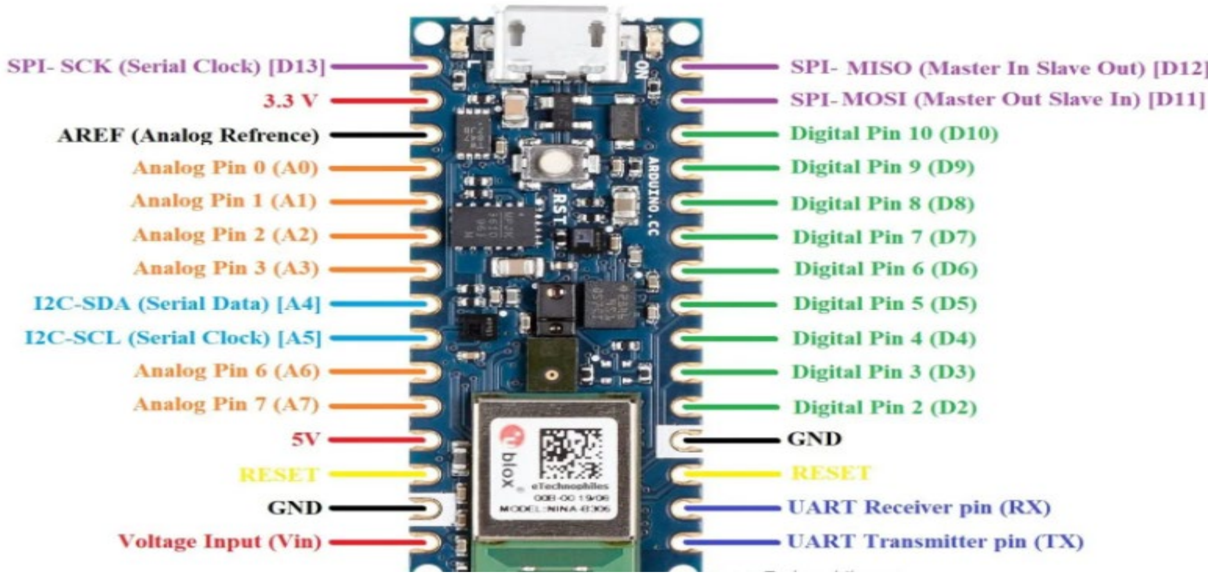

Figure 3.3.4: Arduino Board Architectural Pin Layout (Arduino NANO Data Sheet).

The resistor used in the circuit is a 1KΩ low power consumption resistor. The architectural diagram is shown in Figure 3.3.5. This component is used to limit current flow to the base of the transistor so that it operates at saturation limit for efficient switching.

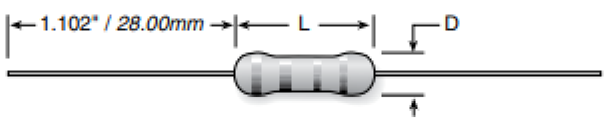

Figure 3.3.5: Resistor Architectural Diagram (1KΩ Resistor Data Sheet).

3.4 Signal Distribution and Trigger Circuit.

The design of this circuit is the improvement focus area for the entire H-reflex signal acquisition system. The circuit was designed to provide multiple channel output for a single input source and generate stimulating input for the constant current simulator device. The controlling signal originates from the Arduino microcontroller's operating code, powered via four 1.2V 1900mAh AA batteries connected in series to obtain a cumulative 4.8V 1900mAh. The power is connected via a type C USB serial port on the Arduino board. The positive terminal of the DC power cable from the power supply battery is routed via a switch to cut the power supply to the Arduino board. A push-button is wired to the panel to start the programmed code operation on the microcontroller for one cycle. The three primary functions of the Arduino board in this device are listed below:

- Provide controllable/programmable input signal for multiplexers.
- Supplies 5V DC power needed for the multiplexers and relays.
- Supplies stimulus signal needed for the constant current stimulator.

3.4.1 Input Signal Control Circuit.

This is the Arduino board's signal, which controls the multiplexers' electronic switching operation. Digital output pins D2- D7 are connected through 28 AWG 0.15mm connecting wires to the input pins labeled A, B, C on each multiplexer. D2, D3, D4 are connected to pins A, B, and C of Multiplexer 1, while D5, D6, D7 are connected to pins A, B, and C of multiplexer 2. The wiring schematic of the connection between digital pins of Arduino board(microcontroller) and multiplexer input control signal pins is shown in Figure 3.4.1.

The multiplexers are powered by a 5V DC power supply supplied from the 5V pin on the Arduino board shown in figure 3.3.4.V_{DD} (pin 16) and Com OUT/IN (pin 3) are connected to the 5V supply pin on the Arduino board. Each digital output pin on the Arduino board is activated according to the dictate of the operating code. This activation signal fed to the multiplexer input signal pins controls the output channel pin switching operation.

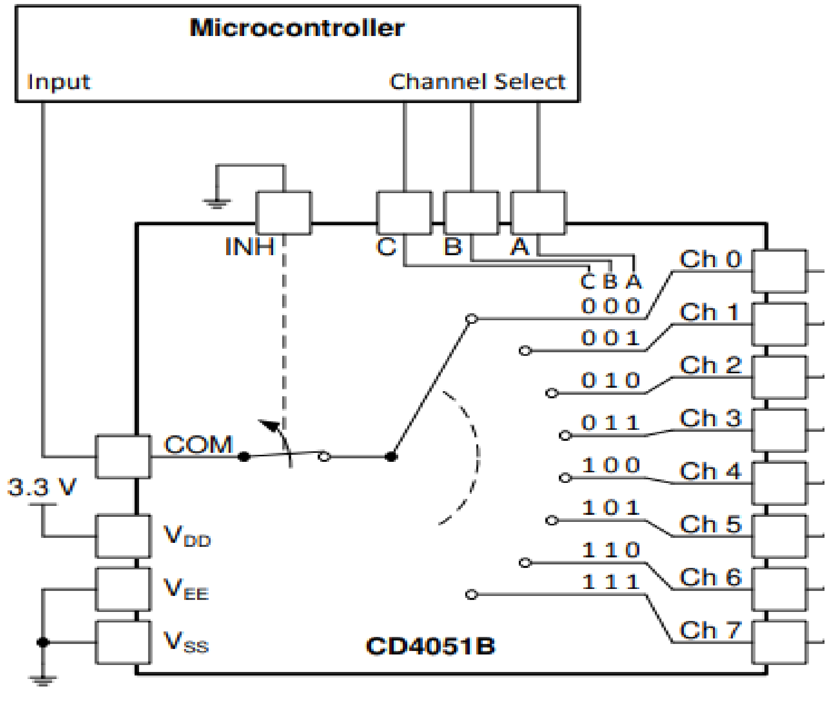

Figure 3.4.1: Wiring Connection Schematic of Arduino Pins and Multiplexer Input Pins.

The multiplexer has eight analog output channels whose switching operation is controlled by three digital input signals. The input signal uses 3 bits binary combination to select and energize a specific analog output channel, which is activated depending on the binary combination of the input signal. Five output channels are utilized on each multiplexer for the circuit design; VEE, V_{ss}, and INH pins are connected to the GND pin on the Arduino board.

The wiring connection loop for the input signal control is shown in Figure 3.4.2. This circuit runs on written operating code running on the Arduino microcontroller; it allows analog signals to be sequentially controlled via digital input binary operation.

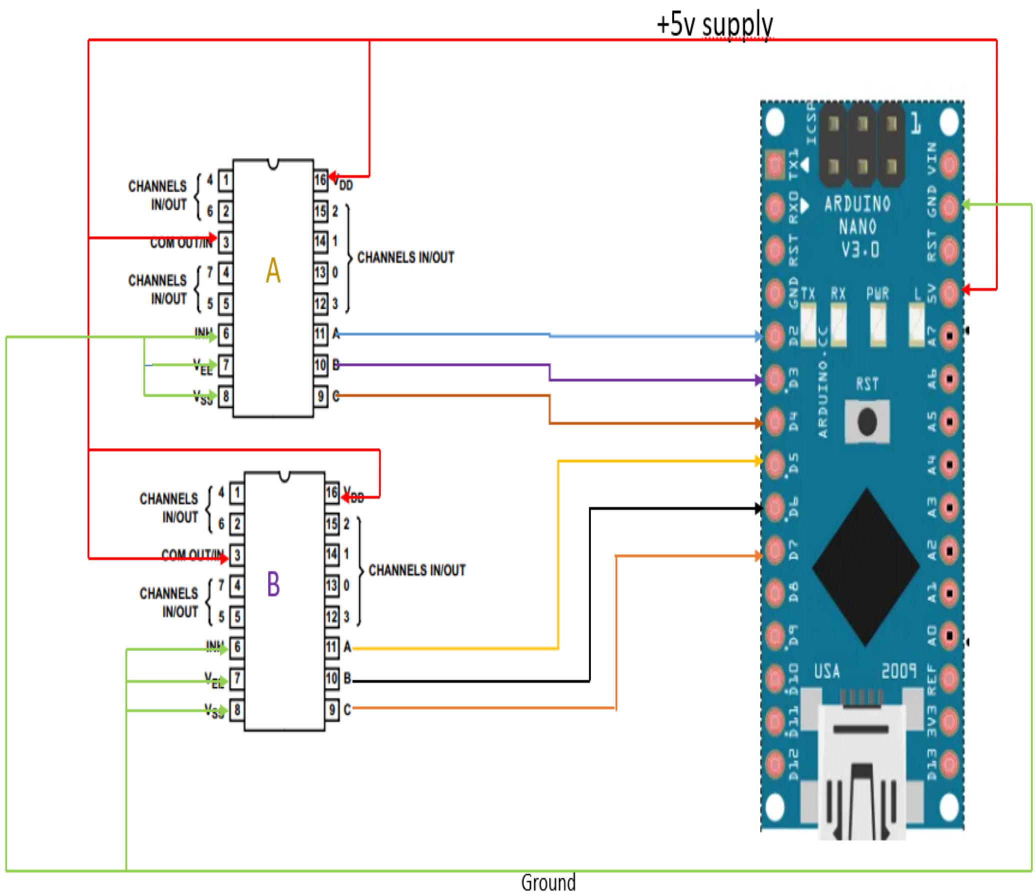

Figure 3.4.2: Input Signal Control Circuit Wiring Diagram.

Table 3.4.1: Utilized multiplexer output signal pin arrangement

Multiplexer 1			Multiplexer 2		
Channel	Pin Number	Binary	Channel	Pin Number	Binary
A	1	001	F	1	001
B	2	010	G	2	010
C	3	011	H	3	011
D	4	100	I	4	100
E	5	101	J	5	101

The utilized output channel on each multiplexer is wired to one terminal of the resistor, connected to the base leg pin of the transistor. The binary code for the utilized channel on each multiplexer is shown in Table 3.4.1.

3.4.2 Stimulus Trigger Output signal

The stimulus trigger output signal is the 5V from the digital output pin, which is fed to the stimulus input channel of the current stimulator device. The operating signal distribution code activates the output from the microcontroller. The stimulus is energized before each multiplexer analog output channel is activated, i.e., the device is programmed to send the stimulus signal to the digitimer stimulator before activating each output channel on the multiplexer. A 5v supply from the Arduino digital output pin eight is connected to the shielded connector wire's core conductor(+ve) while the ground on the Arduino board is connected to the shielded wire (-ve) as shown in Figure 3.4.3. The connector is then connected to the 5v input of the stimulator; this input serves as a trigger signal for the entire H-reflex signal acquisition setup system.

3.5 Main Signal Distribution Circuit.

This circuit executes the primary operation of the compact signal distribution and acquisition device. The circuit wiring connection was done with 28 AWG 0.15mm connecting wires. The digitally controlled analog output signal from the output channel of the multiplexer is connected to one terminal of the 1kΩ resistor whose other terminal is connected to the base terminal of the corresponding transistor. Each output channel is used on the two multiplexers in this circuit, and the 3 bits binary combination for the activation is shown in Table 3.4.1. The collector leg of the transistor was then connected to the negative terminal of the relay coil, a 5v input supply from the Arduino board was connected to the positive leg of the same relay coil. The emitter leg of the transistor was connected to the ground supply from the Arduino board. This procedure was repeated for the other nine resistors, transistors, and relay connections. Each completed a circuit that takes the input to its resistor from each analog output signal channel from the multiplexers. This means the signal from pins 001, 010, 011, 100, 101, 110 on multiplexer A were connected through resistors 1, 2, 3, 4, 5 to the base terminal leg of the transistors A, B, C, D, E, and the collector terminal leg of transistor A, B, C, D, E was connected to the -ve terminal portion of relay coils A, B, C, D, E.

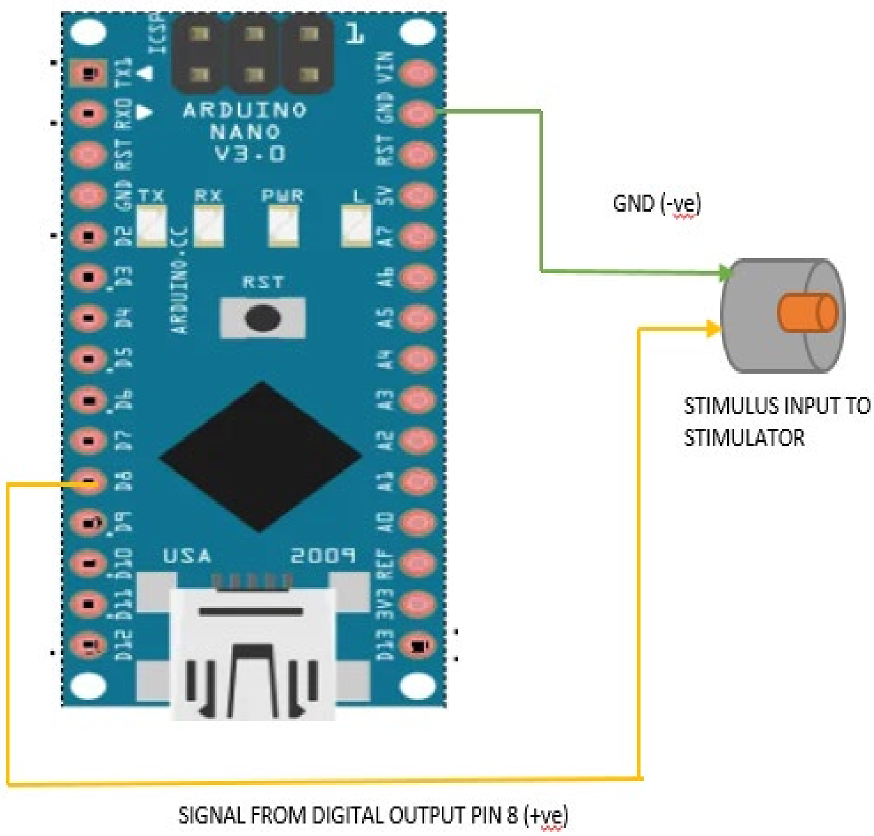

Figure 3.4.3: Stimulus Trigger Wiring Schematics.

Signal from pins 001, 010, 011, 100, 101, 110 on multiplexer B were connected through resistors 6, 7, 8, 9, 10 to the base terminal leg of the transistors F, G, H, I, J and the collector terminal leg of transistors F, G, H, I, J was connected to the -ve terminal leg of relay coils F, G, H, I, J as shown in Figure 3.5.1. With this circuit connection arrangement, the output channel signal from a terminal pin of each multiplexer activates each transistor through the resistors; the signal from the collector terminal leg of each transistor energizes the corresponding attached relay coil. The activation of the relay coils causes its normally closed terminal to become opened and its normally open terminal to become closed. This circuit operation process was used to effect output intermittent switching operation needed for the compact signal distribution device design. The circuit permits the control of analog output signal via digital input control signal for this device.

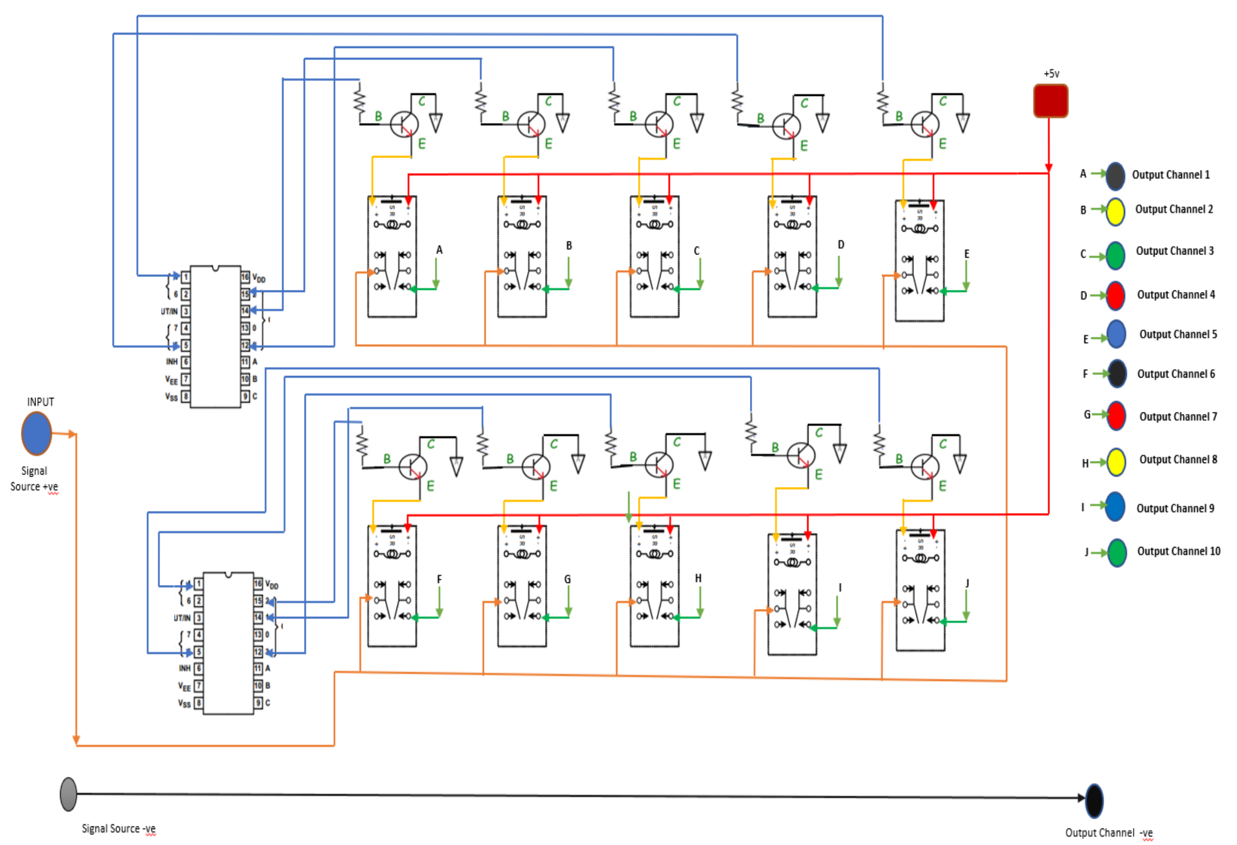

Figure 3.5.1: Main Input Signal Distribution Circuit Schematic Diagram.

3.6 Relays Input and Output Signal Distribution.

One input signal source channel was connected to the common terminal leg of each relay in the circuit, as shown in Figure 3.6.1. The common terminal on each relay shares an input signal between the normally closed terminal leg and the normally opened terminal leg. This indicates that the input signal energizes the normally closed channel without relay coil input, while the normally open channel is energized only by the activation signal from the transistor to the relay coil.

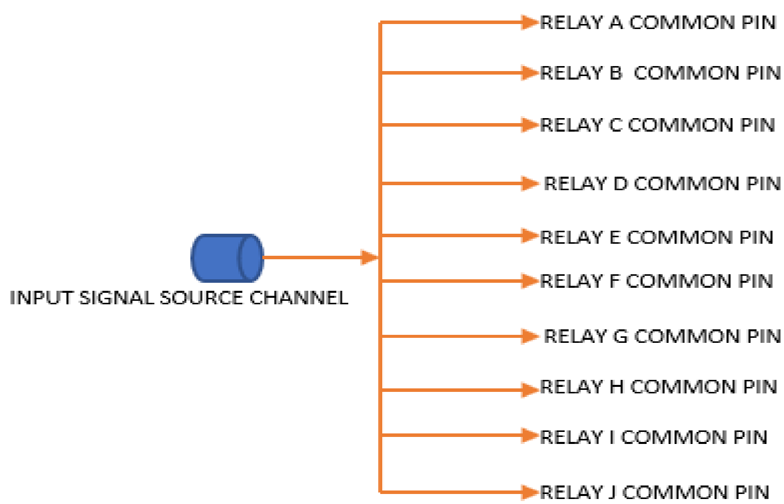

Figure 3.6.1: Single Source Input Signal Distribution to Relays Schematic Diagram.

The Normally Open (NO) terminal leg of the common input leg connected to the input signal is wired individually on relays A – J and to the output channel A – J shown in Figure 3.5.1. The wiring of the input and output signal to the relays was done with a thicker wire gauge 28 AWG 0.5mm to withstand current flow through the wires without burning the circuit. Signal transfer from the relay common terminal to the Normally Open (NO) terminal leg on all the circuit relays is shown in Figure 3.6.2.

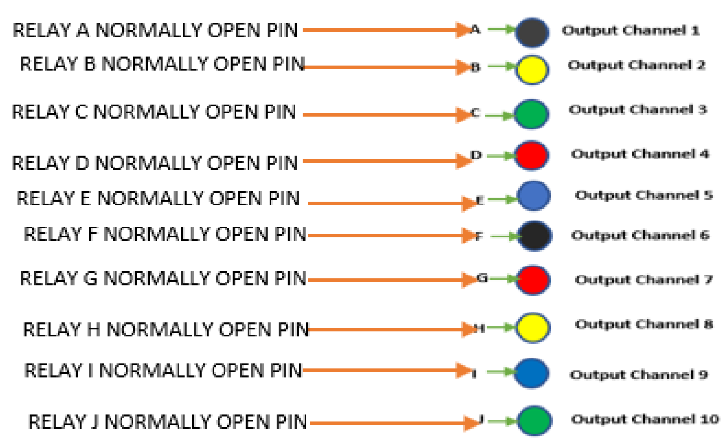

Figure 3.6.2: Relay Terminal Wiring Connection to Output Channels.

Signal transfer from the input source channel to the output channel is done by the relay making and breaking contacts between NC and NO terminals; the operating code through the Arduino microcontroller, multiplexers, and transistors control the sequence and timing for the signal transfer operation between all the ten relay output channels. Real circuit components, including the Arduino board as connected and wired on the Printed Circuit Board (PCB), are shown in Figure 3.6.3.

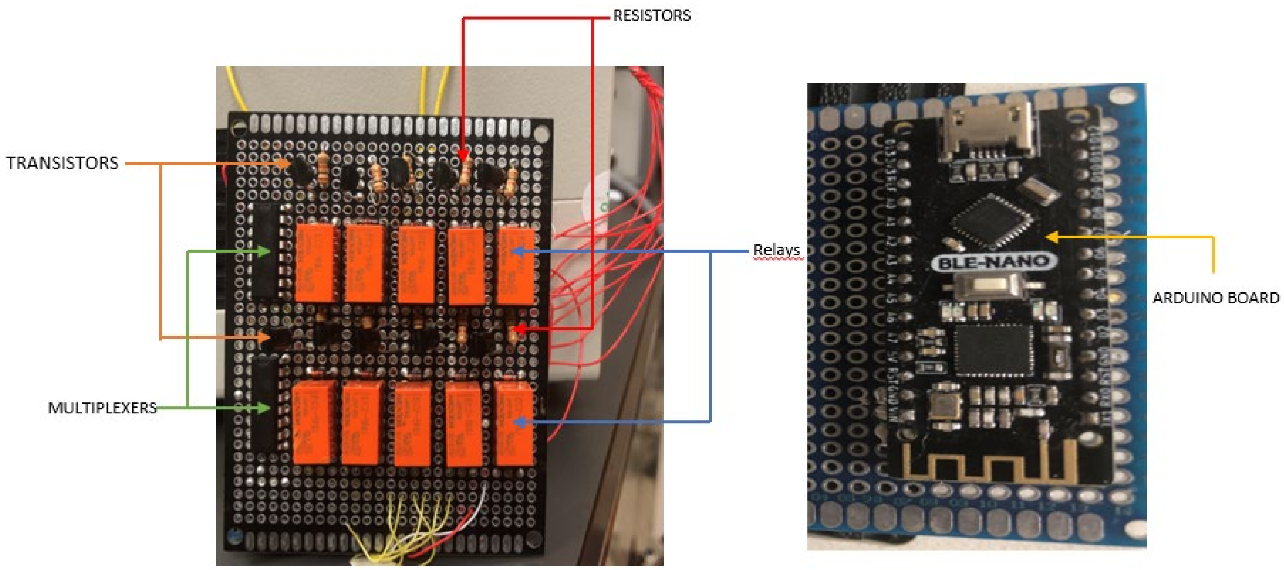

Figure 3.6.3: Real Circuit Components Connections on Printed Circuit Board.

Normally Open (NO) terminal legs of each relay were connected to the compact circuit box through the contact connectors. The connectors allow easy connection and disconnection of circuit pins into the output channels for the overall system setup. This designed signal distribution device was used in conjunction with the Digitimer Constant Current Stimulator (model DS7A), wire probes connector (connected to electrodes), and sticky electrode pads (connected to the human body) to set up the complete H-reflex experimental measurement and recording system used for this research work.

3.7 Experimental System Setup.

For this research work, the experimental system set was segmented into three parts which include:

- Preliminary experimental testing.

- Simulated Experimental Circuit Testing With Digitimer Stimulator.
- Real-time operating environment system testing.

The testing conditions listed above vary by the type of equipment involved and desired results; they were carried out to establish the full functionality of the designed compact digital signal distribution device, to investigate the device behavior in a simulated environment, and to establish the expected results in real-time operating conditions. The designed device is used in conjunction with other devices that make up the entire system set-up to carry out these tests. Other devices used in the experimental system set-up are listed as follows:

3.7.1 Constant Current Stimulator (Digitimer)

The Digitimer of choice for this research is the DS7A High Voltage Constant Current Stimulator. This device is used to stimulate nerves and muscles in the human body; it produces a brief pulse of up to 100mA for transcutaneous stimulation at preselected pulse duration. The device has two current output ranges (x1 and x10), which amplifies the current output to the desired output range. The adjustable compliance voltage of the device is up to 400 volts, as shown in Figure 3.7.1. The front panel also has the single stimulation shot button, while the back panel shown in Figure 3.7.2 has the Trigger in a socket, which allows an external voltage change to trigger the unit. This input could be triggered by either TTL logic pulses, foot or hand switch presses, or a front panel single shot button. The external trigger source to this input socket is connected through a BNC c. Flashing amber indicates a valid input trigger to the device’s good input trigger. Depending on the selected range, the current amplitude control of output pulses varies between 0 - 10mA and 0 -100mA. A voltage amplitude control switch present on the front panel controls the output maximum pulse; this sets the maximum voltage that can occur on the electrodes and is continuously variable between 100 – 400 V. The output enabled switch must be in the ON position for the unit to generate output pulses.

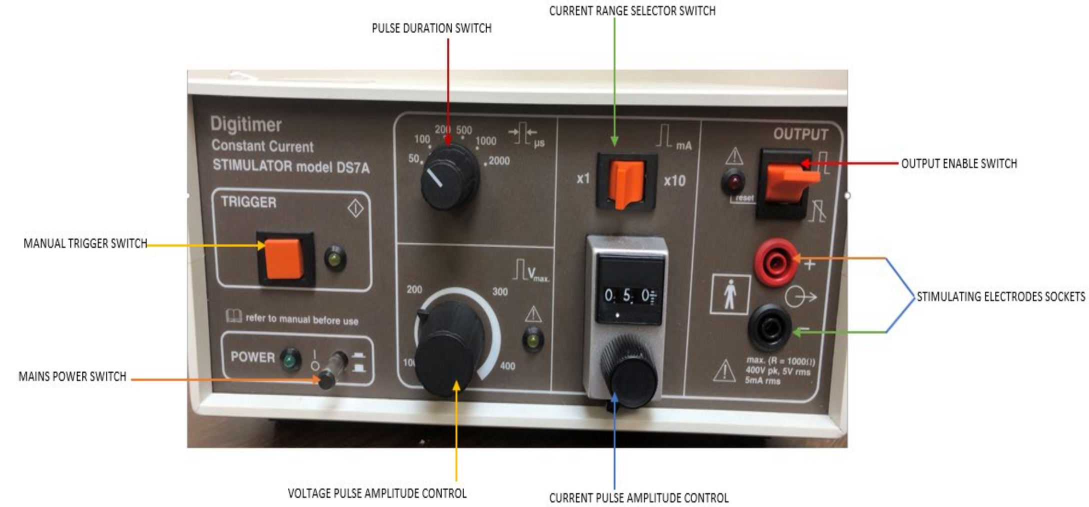

Figure 3.7.1a Constant Current Stimulator DS7A Front Panel.

Figure 3.7.1b: Constant Current Stimulator DS7A Back Panel.

3.7.2 Compact Signal Distribution Device

This is the designed device included in the H-reflex stimulating signal system setup. It was designed to improve stimulating signal distribution efficiency to stimulating electrodes attached to human muscles and nerves. This improvement creates a single multichannel source stimulating signal distribution to ten channels to which stimulating electrodes are connected. The signal distribution is controlled by a digital signal from the Arduino board, fed to the multichannel digital input of the electronic switch (multiplexer). This device also generates the stimulating voltage trigger 5v, which is provided to the trigger input socket connected through a BNC cable to the back panel of the digitmer. The positive and negative electrodes output socket of the DS7A current stimulator is connected to the device single source channel shown in Figure 3.7.1. This input is sequentially distributed through some electrical and electronic components to ten output channels by the operating code on the Arduino microcontroller. Each shot of stimulating signal is accompanied by a corresponding output channel trigger operation of one of the output channels to which stimulating muscle electrodes are connected. This incorporation of this device in the H reflex acquisition and recording system allows ten electrodes attached to the output channels on the designed device to be connected to human muscle, thereby improving the efficiency of both the stimulating signal delivery to the muscle or nerve as well as stimulating response (H-Reflex) recording and acquisition on EMG. This device was designed with features such as a power supply switch that supplies power from a 5V DC battery to the microcontroller and components on the circuit. A one-cycle trigger push button was also embedded in the design, which triggers the microcontroller code operation on one cycle run, allowing the control of input stimulating signal from the distribution device point in the entire system. Depending on the need for adjustment, this feature could be modified to run continuously to generate a constant loop signal for practical purposes.

The preliminary testing of this device was done at a constant loop to enable proper visualization of repeated signals and accurately check the signal cycle timing repetition. The location of the power switch, push-button, stimulating output signal trigger wires, output, and input channels on this device are shown in Figures 3.7.3a, b, and c.

Figure 3.7.2a: Designed Compact Signal Distribution Device Features 1.

Figure 3.7.2b: Designed Compact Signal Distribution Device Features 2.

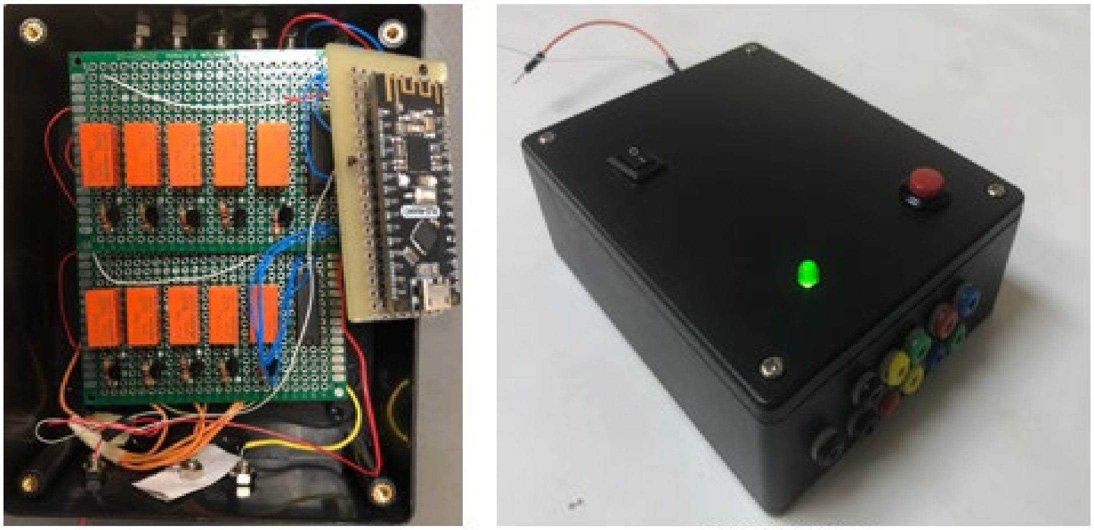

Figure 3.7.2c: Designed Compact Signal Distribution Device Features 3.

3.7.3 Data Acquisition Device (DAQ)

This is a multifunction I/O device that offers a mix of I/O with varying channels, sample rates, output rates, and other features which meet laboratory and research measurements. The USB-6353 data acquisition device was used in this research in conjunction with LabView software to log signal data from output channels of the designed compact digital signal distribution device onto a waveform chart for proper visualization of output response to the input signal. Data obtained from the DAQ was used to plot the graphs, representing the fundamental analysis of the signal processing capability of the signal-designed distribution device. USB-6353 offers advanced timing functionality, synchronization technology, independent re-triggerable analog and digital channels for signal acquisition and measurement tasks. Data obtained from this setup constitute the preliminary circuit signal processing testing results used to establish the signal processing time limit and efficiency of the designed compact digital signal processing device.

DAQ picture and LabView block diagram used for the output channels data acquisition are presented in the Appendix section. The preliminary investigation section shows graphical representation, and snapshots of results are shown in chapter 4, the initial investigation section.

3.7.4 Oscilloscope, Probes, and Electrodes (Sticky Pads).

The oscilloscope was used in conjunction with the digitmer stimulator during experimental simulated digitimer stimulator testing of the designed circuit. The compact signal distribution device output channels were displayed on the oscilloscope in the waveform. The output signal waveform and variations with time were displayed graphically on the oscilloscope screen. This is used to analyze the signal distribution circuit's operating properties (size and frequency). Probes are polarized cable connectors used to transfer electrical signals. They are used to establish a connection between a stimulator and the circuit under test. The stimulating electrodes are polarized multi-layer adhesive hydrogel connected via thin wires to deliver transcutaneous electrical nerve stimulation signal to the subject muscle. They were connected to one end of the primary probe and the stimulating signal socket on the digitimer stimulating device.

3.8 Preliminary Experimental Testing.

This experimental testing was carried out on the compact signal distribution device to visualize the graphical representation of signal data processed through the circuit. The procedure was carried out by connecting each output channel to the selected input channel on the Data Acquisition Device NT-6353. A 5v DC input was fed to the input channel of the device +ve to +ve signal channel and -ve to the common terminal. LabView software, a tool for analyzing, displaying, and storing data, was used to build a signal monitoring and interpretation interface. The software provides built-in templates for virtual input and output instruments (VIs) suitable for making analog and digital signal processing, measurement, and recording applications. With LabView software simulation, analyzing and monitoring circuit operational functionality is easily assessed to verify real-time input signal processing speed and frequency. The data representation from the signals is graphically displayed on the waveform chart embedded in the LabView structural program.

The LabView interface program used for this research work includes waveform chart (virtual output device), DAQ assistant (virtual data acquisition device), Write To File Measurement File (virtual signal conversion to numeric data). With these Vis on the built interface, the signal processing operation of the circuit was verified, and components response speed limit was established. A schematic diagram of the VI interface was included in the appendix, schematic representation of this preliminary system setup is shown in Figure 3.8.1

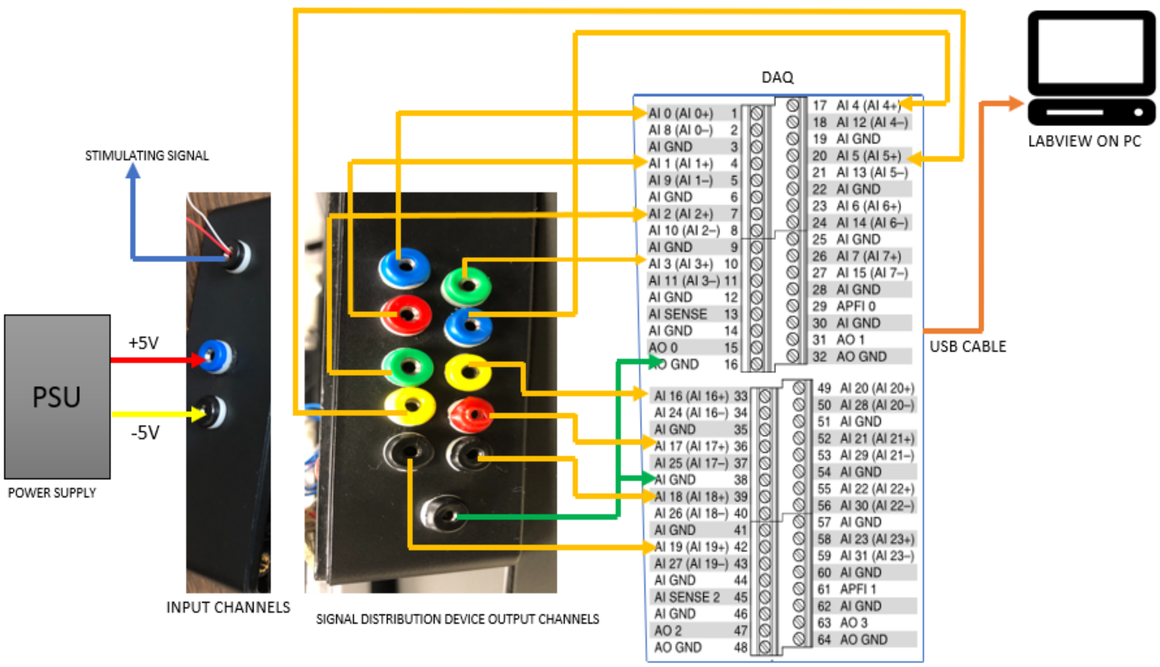

Figure 3.8.1: Schematic Diagram of Preliminary Testing Setup

Minimal noise interference on the output channels was achieved by grounding each output channel with a 1kΩ resistor called a pull-up resistor.The pull-up resistor ensures the only processed signal is obtained from the output channels; it acts as a noise filtering procedure. Circuit operation was simulated with a 5v DC supply to the input channel and variable operation timing to establish a limited time frame at which the circuit gives reliable processed signal output results.

Data from the Write To Measurement File VI was converted to Excel files from which graphical results were plotted. The collective output signal from all channels is displayed on the waveform chart VI; the data from Excel files were necessary to visually analyze signals from each output channel individually.

3.9 Simulated Experimental Circuit Testing With Digitimer Stimulator.

These simulated testing conditions were set up to visualize the designed circuit's real-time response in simulated operating conditions. The stimulation output signal from the designed compact signal distribution device was connected to the digitimer constant current stimulator DS7A TRIGGER IN socket via a BNC cable; the output enable switch on the digitimer was flipped to the reset position, output voltage amplitude control was set to minimum 100v, the pulse duration switch and output current control switch were also set to the minimum. One end of the polarized connection probe was connected to the Isolated Output Sockets on the Digitmer Stimulator -ve to the black socket and red to the +ve socket. The other end was connected to the input channel of the signal distribution device.

Output channels (A-J) of the signal distribution device were connected to a simulated human body resistance circuit. The human body resistance simulated circuit comprises one 1.2KΩ resistor connected in parallel to one 600Ω and one 1nF capacitor connected in series to each other. A schematic diagram of the entire setup is shown in Figure 3.9.1. Output signals from the digitmer, simulated human body resistance circuit, and the stimulation trigger signal were fed to the oscilloscope to enable visual monitoring of stimulation responses. Voltage and current amplitude pulses gradually increased, while the pulse duration was also increased to suit selected current and voltage at the output sockets.

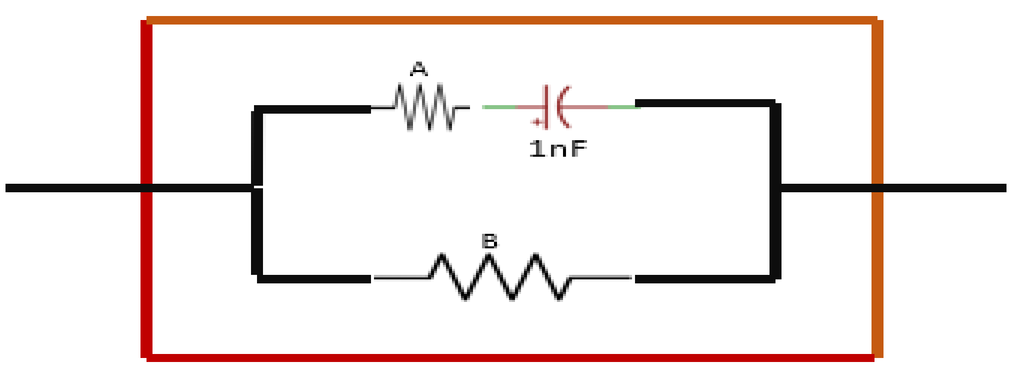

Figure 3.9.1: Simulated Human Body Resistance Setup Schematic Diagram.

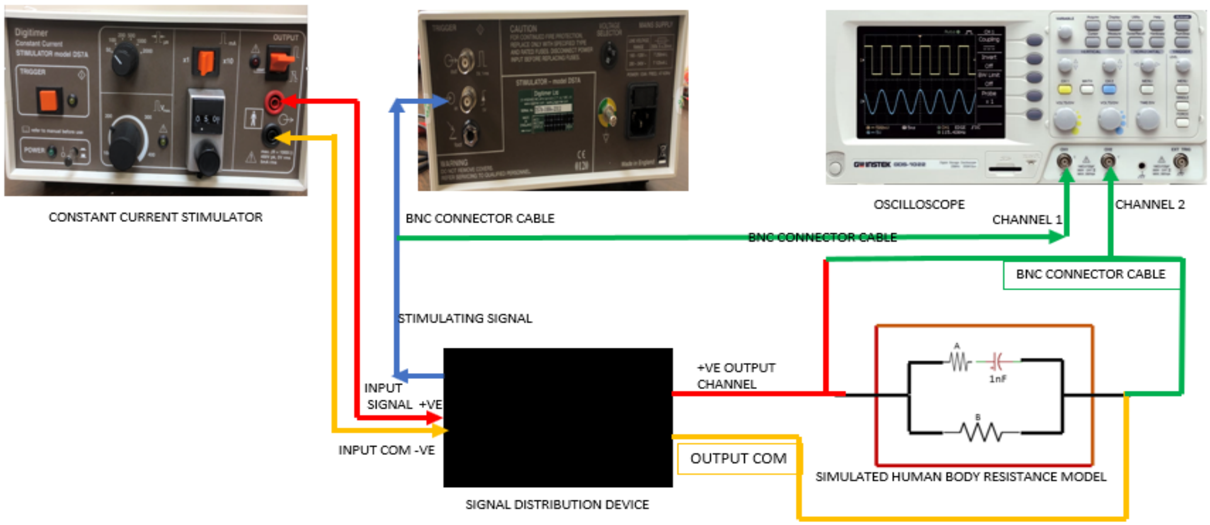

Figure 3.9.2: Simulated Circuit Testing System Setup Schematic Diagram.

The output sockets will be connected to sticky pad electrodes in actual life usage of this human muscle stimuli response monitoring system setup. The expected output response time is in microseconds, voltage amplitude in mV, and current amplitude in mA. To obtain an accurate response, the oscilloscope time-division settings were adjusted to 250mS, and voltage division settings were also changed to 10mV. The expected output response from the trigger input signal is an intermittent 5v supply. The expected output from the output sockets to the electrode in real-life testing conditions or simulated human body resistance circuit is Milli voltage at present pulse duration (between 50µs - 2ms) in 6 steps.

3.10 Real-Time Operating Environment Testing.

This testing was done in a real environment; the human muscle stimulating response monitoring system was deployed for field operation. The system was set up similar to the simulated environment system, but the electrodes were connected to actual human muscles in this case. The Isolated Output Sockets from the digitimer were connected to the input source channel of the signal distribution device. Each output channel from the device was plugged into stimulating electrodes placed on the human subject muscle or nerve of interest, in this case, a (knee cap). The stimulating electrodes were placed 1cm apart on the human knee cap. Multiple electrode usage for the kneecap stimulation increases the efficiency of monitoring and collecting the muscle and nerve response to stimuli from the electrodes' point of contact.

Stimuli response from all connected electrodes point of contact on human subjects increases response data interpretation efficiency on EMG. This improvement was attributed to an increase in the surface coverage area of electrodes on the human body part. The increased number of electrode pads on the stimulated nerves allows effective response to stimuli data capture interpreted on the EMG device. This response due to stimulation of the alpha-neuron of the associated muscle or nerve, when interpreted, could be used to determine the state of the muscle as well as predict deterioration, fatigue, and depletion in muscle activities which is a clear indication of strenuous activities or muscle associated diseases.

CHAPTER 4
RESULTS

This chapter presents the results of experimental testing, simulation, and real-time implementation of the H reflex measuring and recording setup system. First, the preliminary results of testing the signal distribution device with a simulated 5v input signal are discussed. Next, the results obtained when the designed device was coupled with digitimer constant current simulator, connecting probes, electrodes pads, and oscilloscope to simulate operating environments and conditions are presented. Finally, the results from the real-time operation of the reflex measuring and recording system in the physical environment (physical human results) are shown.

4.1 Signal Distribution Device Preliminary Testing Results

Results presented here were obtained from testing the signal distribution device to establish the switching operation time limit for the device. This is the minimum switching operation time limit for the device to acquire accurate processed signal results. The system was set up by connecting each output channel on the signal distribution device to a multichannel data acquisition device (NI USB-6353). The input channel was supplied with a 5v DC simulated input signal and the waveform chart from Lab-view software was used for the signal processing visualization. Data obtained from this experimental setup establishes the minimum operational time frame for the circuit, i.e., the fastest effective input to output switching operation time frame the device can process. The time limit was started at 1000 milliseconds(ms) and gradually reduced to 10ms; The waveform chart and graphical plot of data obtained for each operating time are shown in the following data representation figures. Each output channel on the signal distribution device was connected to a 10KΩ resistor called a pulled-up resistor. Each of the ten output channel results from wave chart on Labview software from 1000ms to 10ms are presented as follows:

The wave chart snapshot picture of the device output channels preliminary testing result is shown in Figure 4.1.1. With the pull-up resistors (minimizes signal fluctuation error) attached to each output channel, the perfect input 5v signal was captured at the output channel as shown on the chart's y-axis, representing input signal amplitude.

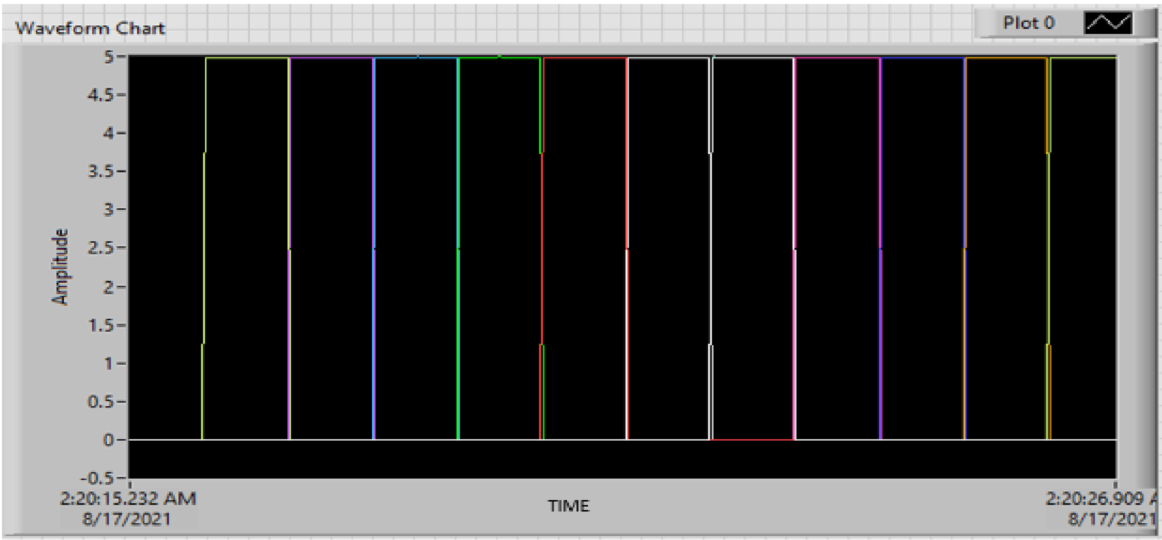

Figure 4.1.1: Wave chart for Ten Output Channels at 1000ms Time Frame.

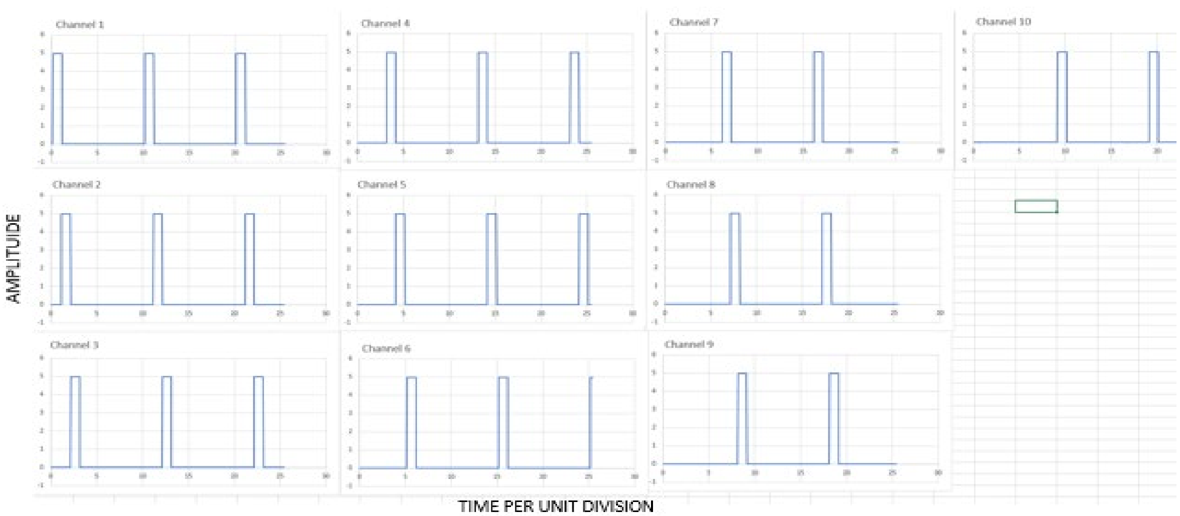

Figure 4.1.2: Graphical Representation of Individual Output Channels at 1000ms Time Frame.

The individual bar in Figure 4.1.1 represents the output signal obtained from each of the ten channels on the signal distribution device; the vertical axis represents the magnitude of the acquired signal while the horizontal axis represents the signal time frame. At a 1000ms operating time frame, each output channel signal confirms the exact data signal capture of the circuit as observed from the amplitude of each output channel. The amplitude of the signals obtained from the output channels, as shown in Figure 4.1.1 and Figure 4.1.2, is five units, with the input signal being 5v; this indicates the perfect switching operation of the device. Data from the last signal obtained from the output channel number ten falls on unit 10 on the x-axis, which indicates 1 unit represents 100ms and 10 units mean 1000ms. This proves the exactness of the circuit timing operating sequence and the accuracy of the input signal distribution device. After confirmation of input signal processing accuracy (switching operation between output channels), the next step was taken to establish the time limit for the accuracy of circuit processing speed. To achieve this purpose, the input signal processing time was further reduced to 500ms shown in Figure 4.1.3 and Figure 4.1.4, 100ms, 50ms, 30ms, 20ms, and 10ms, respectively. Snapshot pictures of the signal processing operation waveform chart obtained at the output channels are presented as follows:

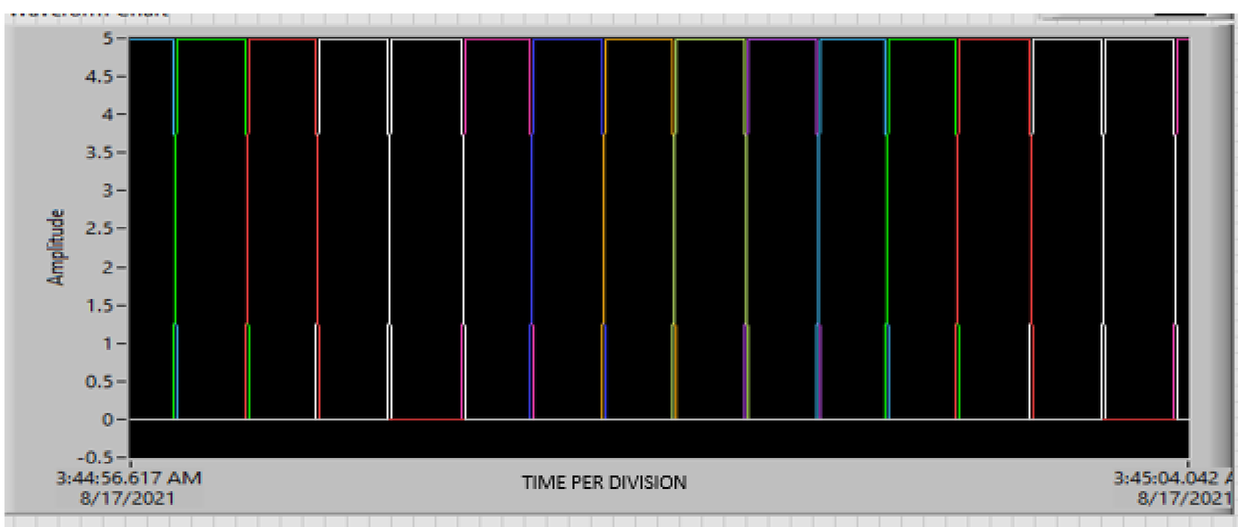

Figure 4.1.3: Wave chart for Ten Output Channels at 500ms Time Frame

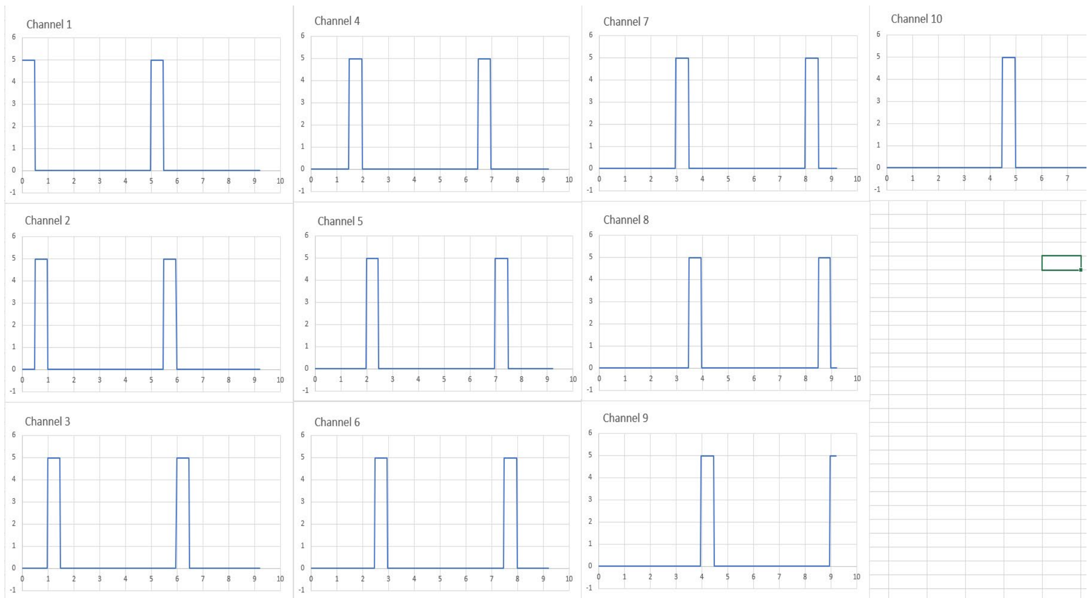

Figure 4.1.4: Graphical Representation of Individual Output Channels at 500ms Time Frame.

The accuracy of the designed circuit during the preliminary testing operation was further established at a 500ms time frame. Both waveform charts for output signal and graphical representation of data obtained are shown in Figure 4.1.3 and 4.1.4, respectively. The amplitude of the output signal on the y-axis was five units corresponding to the 5v input signal. The timing sequence accuracy was also proven by unit division on the x-axis, with the last signal lapsing on exactly five units on the x-axis, as shown in Figure 4.1.4. a and Figure 4.1.5, respectively. This means each of the ten output channels got a sequentially timed signal at exactly 0.5 units on the x-axis equivalent to 50ms on the x-axis of the time reference chart.

Details of individual output channel circuit timing graphical representation for all testing time variation was shown to present an in-depth view of the switching operation accuracy of the circuit. The circuit operation time frame (switching speed) was further reduced to 100ms as discussed earlier, 50ms, 40ms, 20ms, and finally 10ms. Snapshots of the waveform chart on Lab-view and graphical representation of the data obtained are shown in the figures and labeled accordingly. It was observed that the circuit's switching operation efficiency declines steadily at a time frame below 20ms. At operating time below 20ms, it was shown from data captured from the circuit output channel that the output signal begins to cross path, indicating that the speed of relay switching operation below 20ms operating time was too fast for individual channel settling time. At 10ms seconds, it was observed that some output channel signals were not captured; this indicates that the signal processing speed at 10ms was too fast for the circuit to actuate all the components of the circuit. The skipped output signal indicates that the relays were not activated at this signal processing speed; this is termed signal Jumping. This signal path crossing at switching operating speed below 20ms and the eventual output signal jumping at 10ms operating speed led to the conclusion that the designed compact signal processing device has a processing speed of 20ms since valid output data capturing began to decline at an operating time frame below 20ms. This is the signal processing time operation speed below which the circuit efficiency decreases noticeably, as shown in graphical data representation and waveform chart pictures.

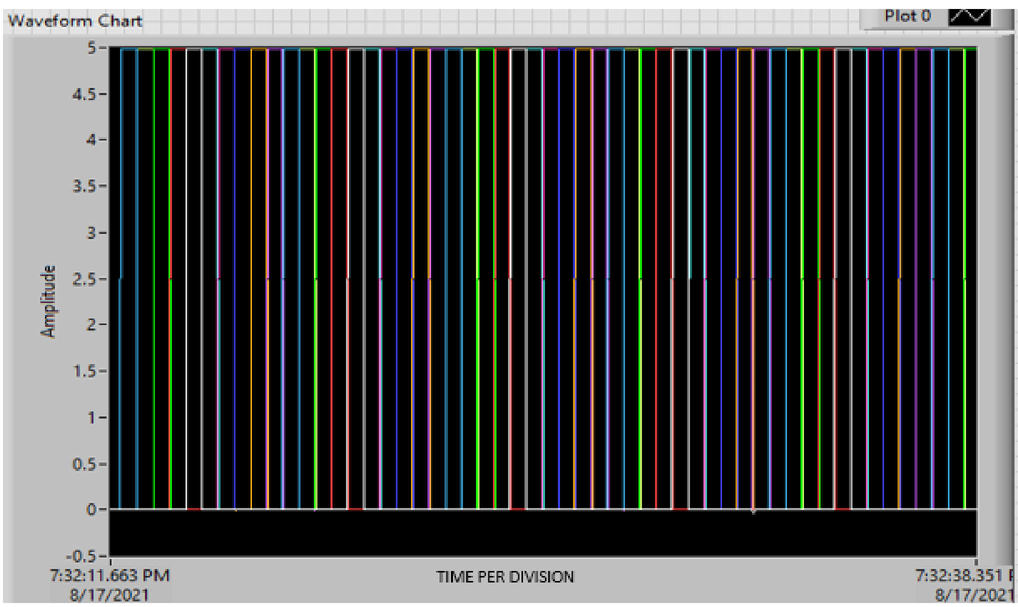

Figure 4.1.5: Wave chart for Ten Output Channels at 50ms Time Frame.

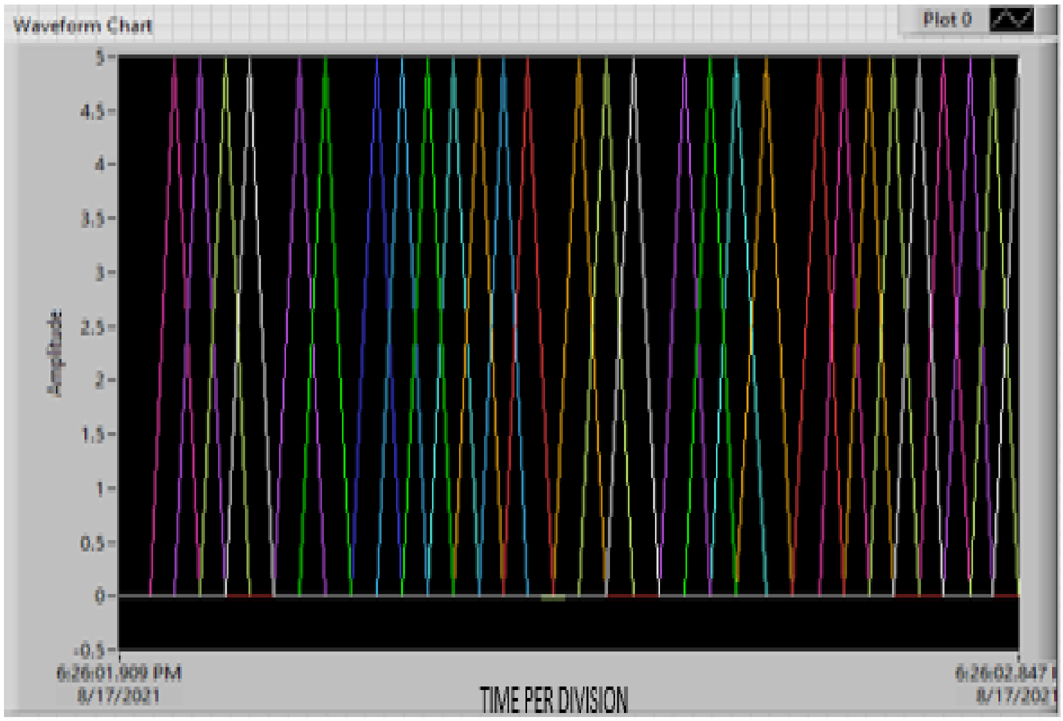

Figure 4.1.6: Graphical Representation of Individual Output Channels at 10ms Time Frame.

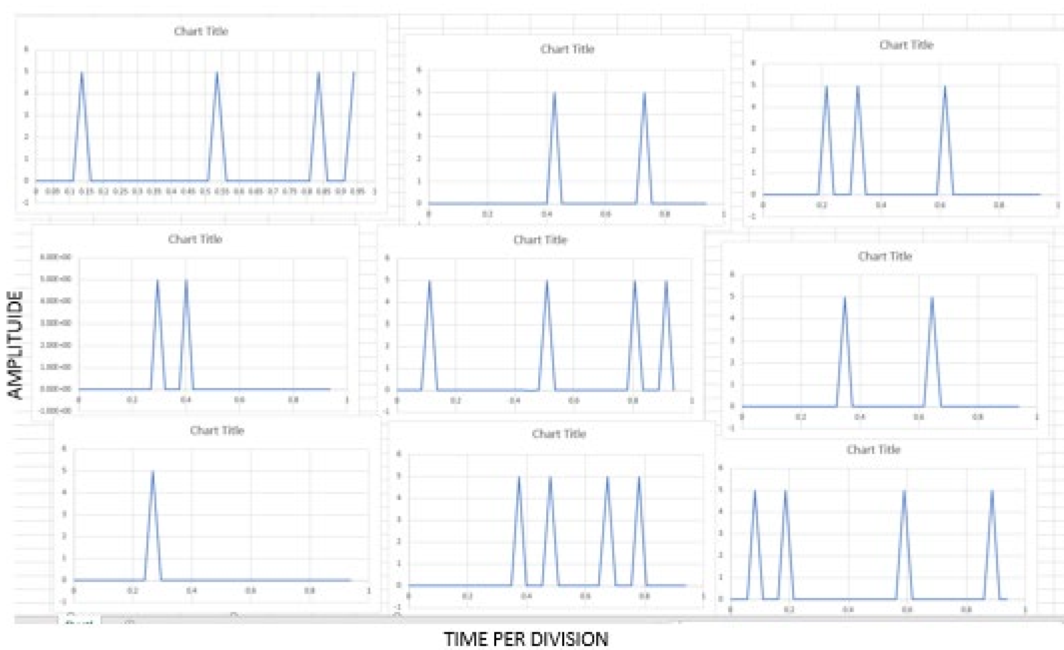

Figure 4.1.7: Wave chart for Ten Output Channels at 10ms Time Frame.

4.2 Signal Distribution Device Simulated Human Body Resistance Testing Results.

This testing experiment was carried out on a panel circuit board containing arrays of simulated human body resistance of different resistance values to evaluate a human muscle's expected response to the stimulating output signal from the compact signal distribution device. Trigger input signal 5V and response of the simulated resistance circuit were monitored and measured on the oscilloscope. It was observed from the output response on the oscilloscope that the stimulating output signal delivered to the simulated human body was in millivolts. This output signal voltage varies in magnitude and is inversely proportional to the simulated body resistance, i.e., the magnitude of voltage decreases with increased body resistance. The ten output results are shown in Table 4.2.1. Graphical measurement of output results on the ten channels from the oscilloscope is also shown in Figure 4.2.1-10.

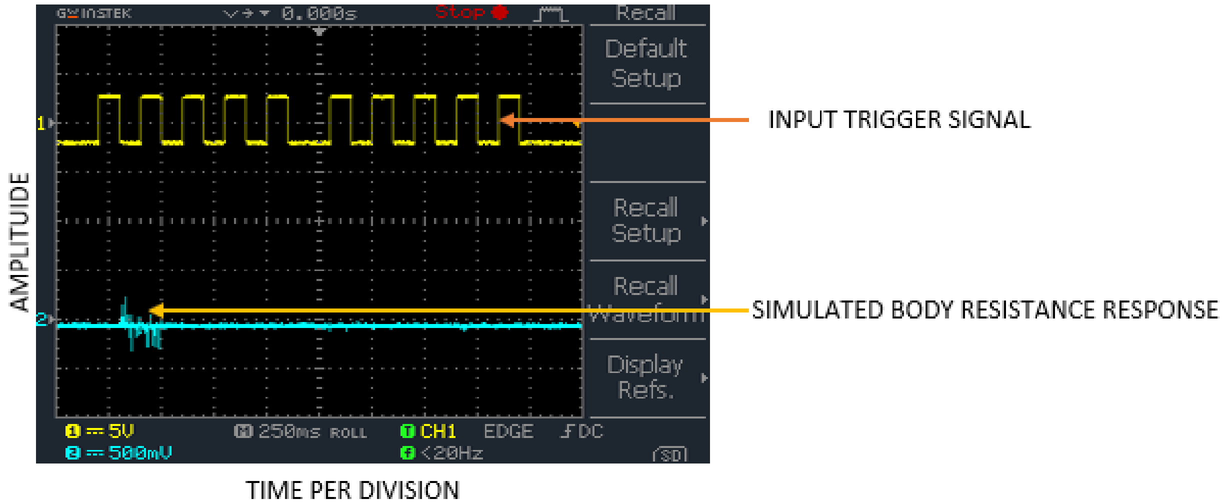

Figure 4.2.1: Channel 1 Simulated Human Body Resistance Result.

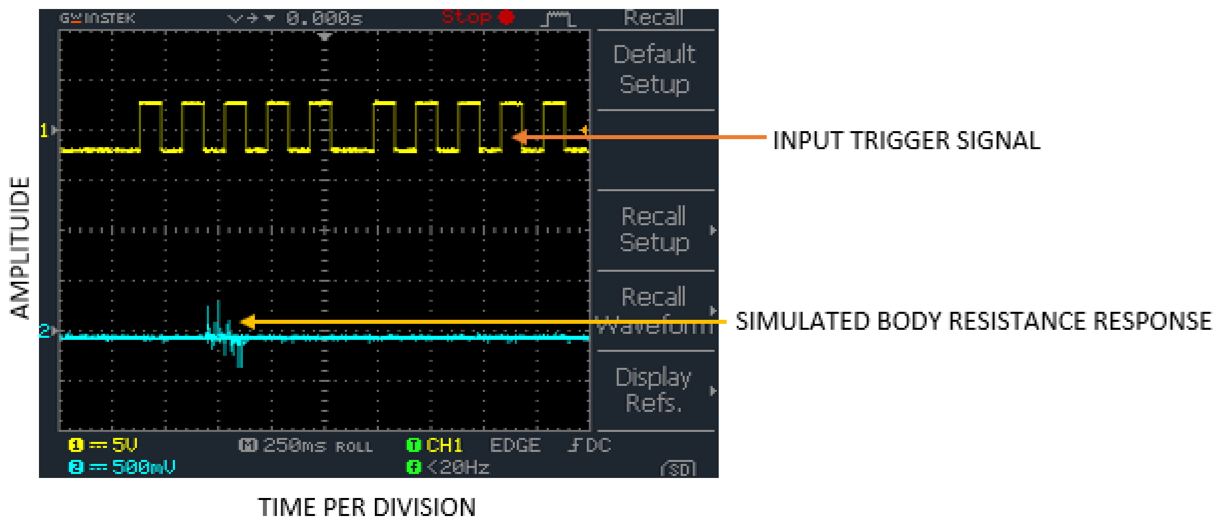

Figure 4.2.2: Channel 2 Simulated Human Body Resistance Result.

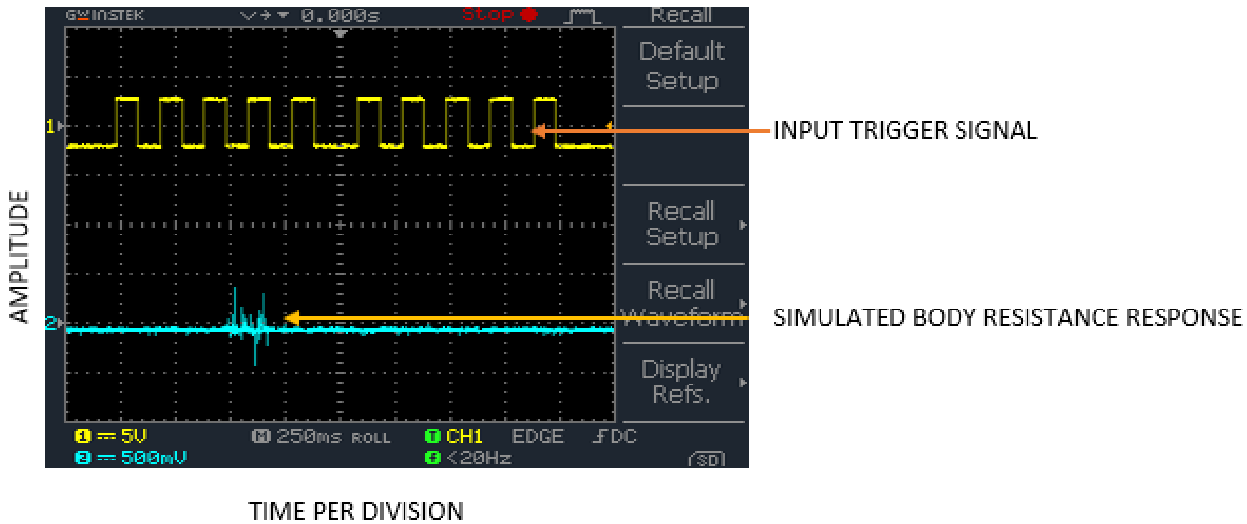

Figure 4.2.3: Channel 3 Simulated Human Body Resistance Result.

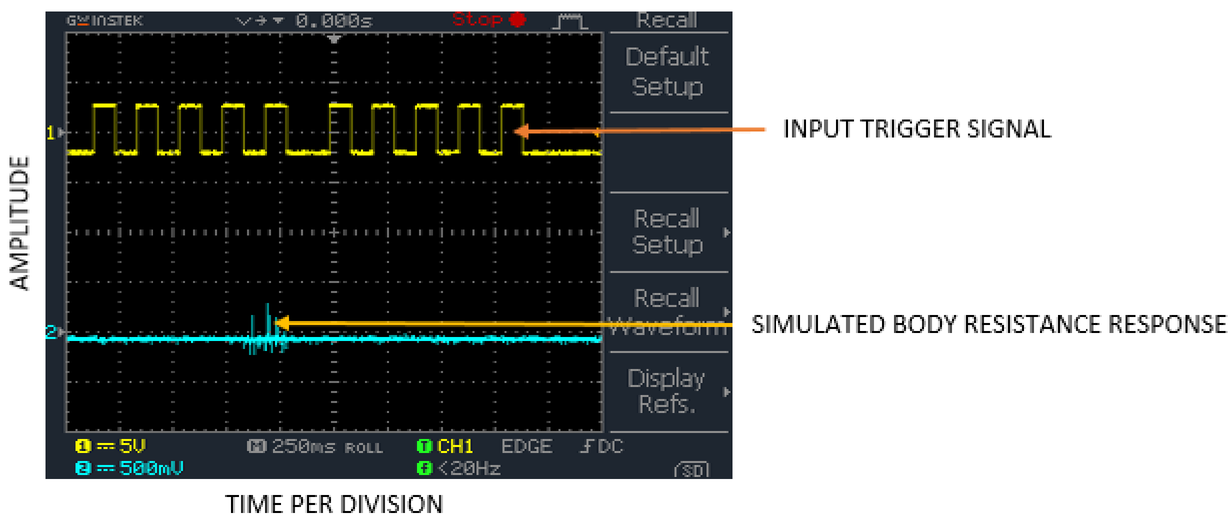

Figure 4.2.4: Channel 4 Simulated Human Body Resistance Result.

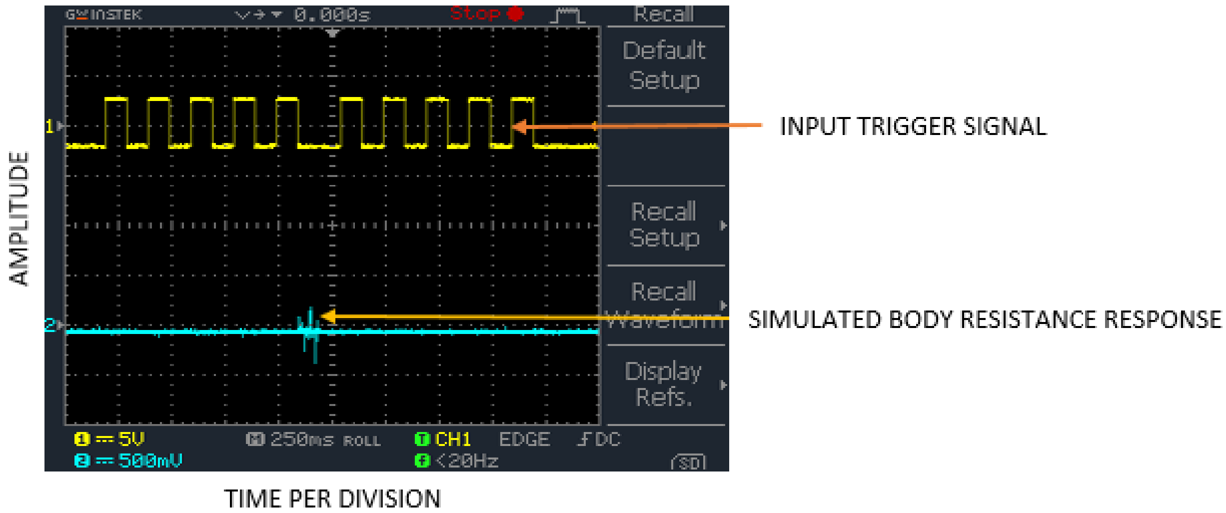

Figure 4.2.5: Channel 5 Simulated Human Body Resistance Result.

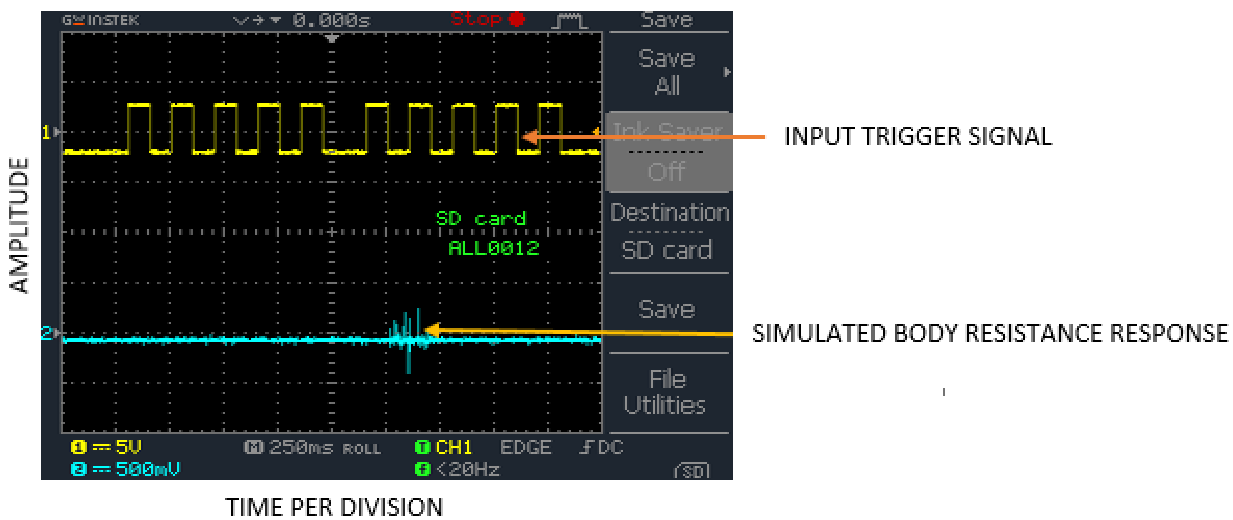

Figure 4.2.6: Channel 6 Simulated Human Body Resistance Result.

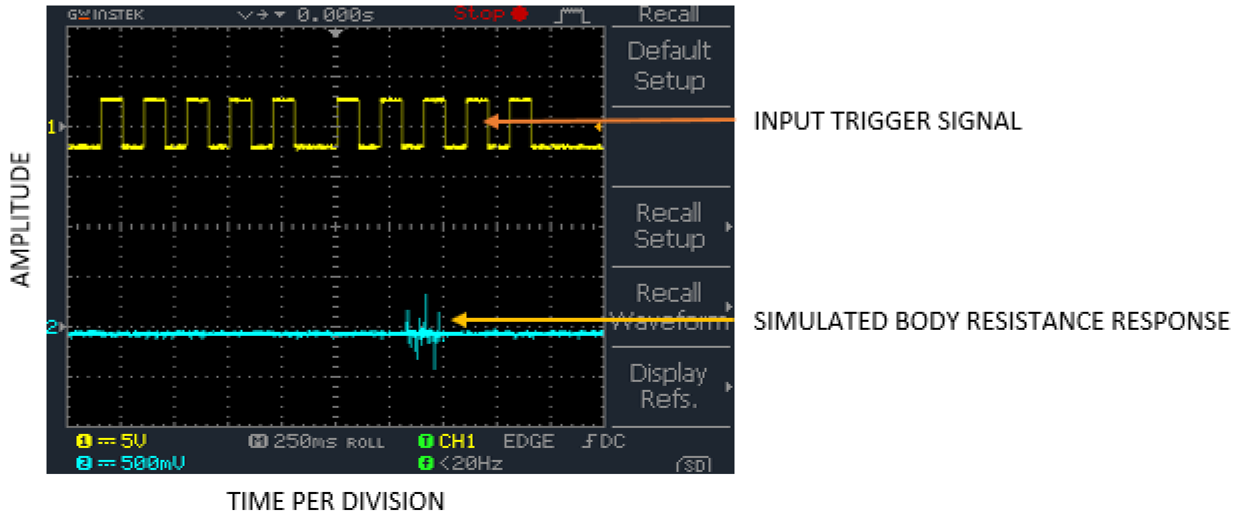

Figure 4.2.7: Channel 7 Simulated Human Body Resistance Result.

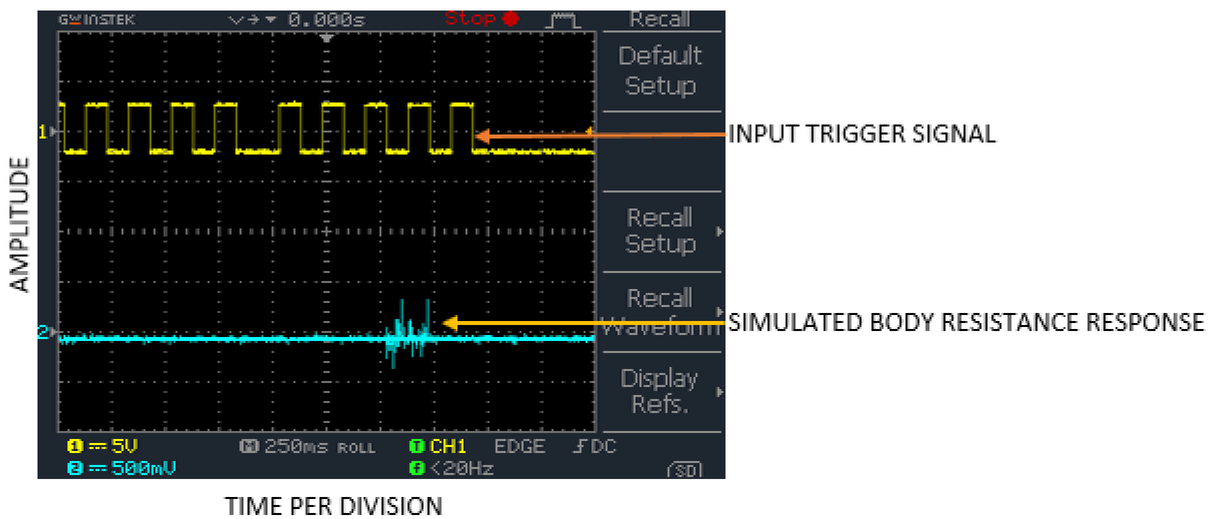

Figure 4.2.8: Channel 8 Simulated Human Body Resistance Result.

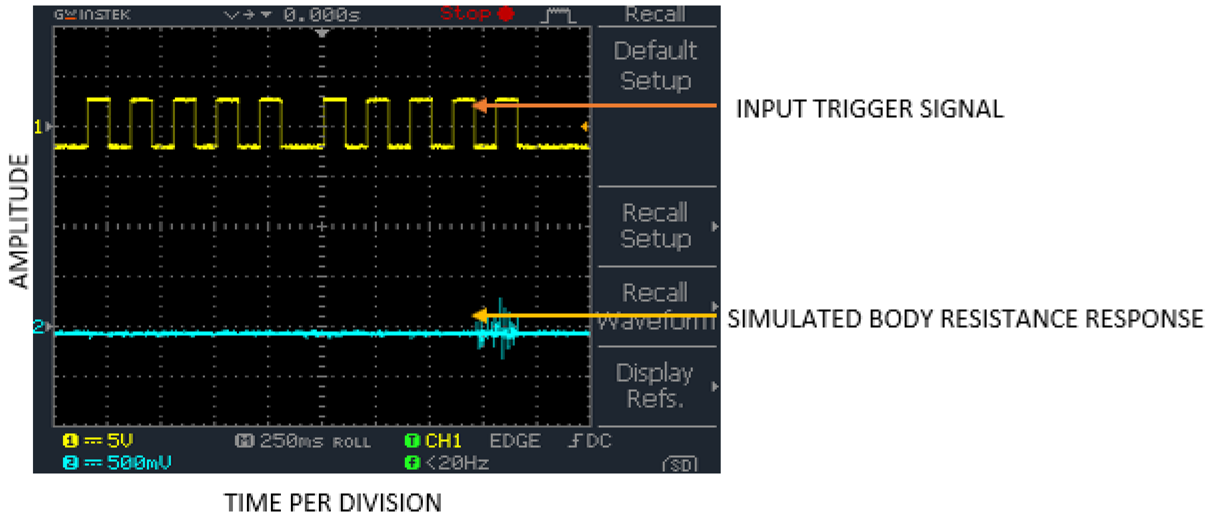

Figure 4.2.9: Channel 9 Simulated Human Body Resistance Result.

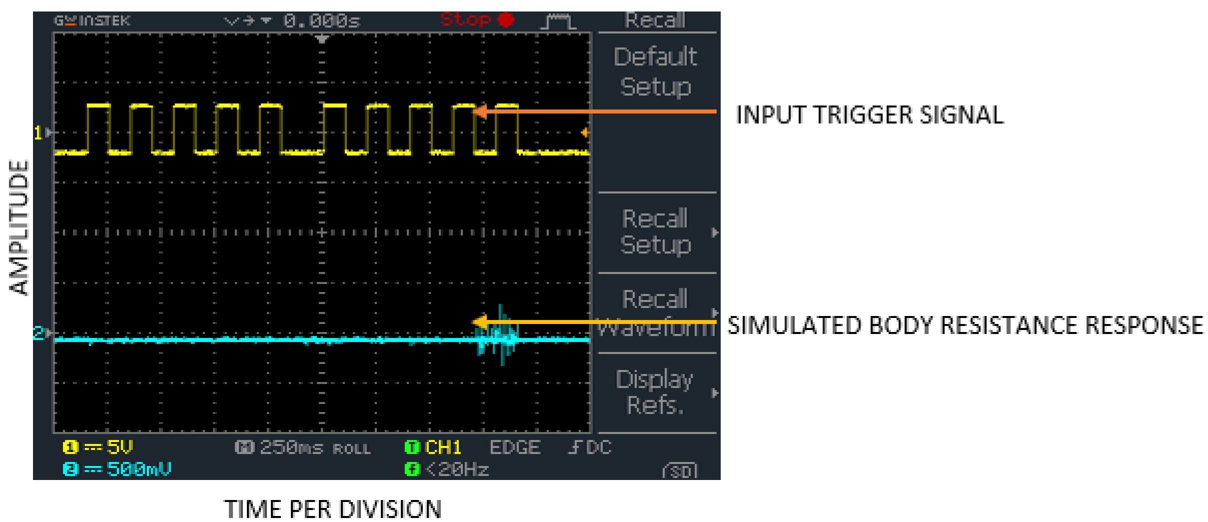

Figure 4.2.10. Channel 10 Simulated Body Resistance Result.

Table 4.2.1. Average Voltage Output Channel Response Measured from Simulated Body Resistance.

Output Channel	Simulated Human Body Resistance Value (kΩ)			Measured Response (mV) Average of $\mathbf{V_{p-p}}$
	Actual		Measured	
	A (Ω)	B (kΩ)		
1	740	2.362	2.33	2.05
2	685	1.988	1.96	1.91
3	688	1.949	1.72	1.89
4	629	1.646	1.62	1.98
5	678	1.462	1.44	2.00
6	670	1.339	1.32	1.94
7	555	1.343	1.17	1.87
8	598	1.190	1.11	1.79
9	680	1.107	1.08	1.83
10	602	0.900	0.88	1.70

The output stimulating voltage from simulated human body resistance shown in the table above is the observed signal's average peak to peak voltage. This observed signal was a continuous analog signal that could not be discretized. The analog Vp-p voltage value signifies the voltage measurement of the response obtainable from the human body (knee muscle for this research) simulated resistance. This occurs within a time frame of microseconds (ms); the signal distribution device allows this response to be measured at a different location along the entire length of the subject muscle. This improves the efficiency of response acquisition data used to determine the health state of the muscle in question. The interpretation of results obtained is done on an EMG device with maximum signal amplitude indicating the limit of excitability of the motoneurons in the Ia afferent muscle.

The depletion in the level of excitability with a corresponding increase in stimulating signal could be used to analyze and determine the maximum fatigue stretch limit of human muscle. This data, when interpreted on an EMG device, gives an insight into the alpha-motoneuron and nerve ending activities of the muscle; this information is used to determine when an athlete needs rest from exercise to avoid muscle cringe, and anticipate diseases whose effects are related to the neuro-musculature of the human body.

CHAPTER 5

CONCLUSION

This chapter concludes with a summary of salient features of the current work and an outline of potential future work under active consideration.

5.1 Summary of Present Work

The present work analyzed a study on the methodological consideration of H-reflex measurement, application, and limitations. The hypothesis of this research was based on a proposed solution aimed at reducing inaccuracies of data obtained and improving the reliability of muscle reflex measurement methodology application in sports medicine and athletic training research. First, a brief history of muscle response to electrical voltage stimulation was considered, and various methods for stimulating nerves and percutaneous muscles were also considered. To present the hypothesis of this research work, the stimulation method was considered alongside limitations, and factors that affect the accuracy of measured reflex were discussed in detail. Relevant literature on clinical and research applications in the neuromuscular study of body defects and diseases was reviewed, focusing on athletic training-related research for evaluating musculoskeletal injuries, therapeutic modalities, and kinesiology research. Objectives and tasks for testing the hypothesis within the scope of the study were laid out; this brought our focus on improving the reliability of measured reflexes to obtain valid and reliable results. Details of the established conventional method of measuring H-reflex were presented, and proposed improvement, which involves the design model of a multiple output channels device for applying percutaneous electric stimulus to the subject nerve or muscle, was also presented. Results obtained from testing the designed device for the fastest operating time response were presented. These results were used to establish the effective time response limit of the switching operation circuit for effective input to output signal capturing. The device was tested for an operating time range from 1000ms - 10ms, and data obtained establishes the maximum practical limit for minimal active time to be at 20ms.

The device was tested on ten different simulated human body resistance values, the deployment of the device in a simulated operating environment for stimulation signal distribution was successfully demonstrated. Results were obtained to establish the designed compact digital signal distribution device; the device was able to process stimulus signal from the digitimer and deliver the signal to simulated human body resistance while the response is viewed on the oscilloscope. The response varies in millivolts according to the resistance of the human body. These results prove that the compact signal distribution device can be implemented in the measuring system set-up for H-reflex, and expanding the signal distribution channels for percutaneous stimulus delivery to muscles and mixed nerves reduces the time it takes for the subject muscle to respond to an electric stimulus after delivery and this fast-action response time improves the validity and reliability of measured H-reflex.

5.2 Future Work

The scope of the present work involves the consideration of multiple stimulus output channels for H-reflex data capturing system setup and response time improvement without altering the neural drive to the subject muscle geometry.

The following areas can be considered shortly for further work:

- Wireless Communication of H-reflex data to EMG: The response data obtained from human muscle can be captured on a device and communicated wirelessly to the EMG device for accurate time interpretation and recording. This will eliminate errors due to signal processing time response, speed, and reduce inaccuracies due to muscle geometry and subject positioning changes.

- Output Signal Extended Application: Stimulus from compact signal distribution device could be extended through another device and fed to another set of bipolar electrodes used for real-time monitoring and recording stimulating conditions.

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APPENDIX A: APPARATUS FIGURE

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APPENDIX B: DESIGNED CIRCUIT CONTROL CODE

```
// Ten Channel Output Compact Digital Sigñal Distribution Device for H-reflex Methodological Application.
// Pin definitions:
// Six input pin multiplexer:

 int delayTime1 = 100; // Time (milliseconds) to pause between LEDs
 int delayTime2 = 100; // Time (milliseconds) to pause between LEDs
 const int Pushbutton = 9;  // pushbutton 1 pin
 int ledPin1 = 2;
 int ledPin2 = 3;
 int ledPin3 = 4;
 int ledPin4 = 5;
 int ledPin5 = 6;
 int ledPin6 = 7;
 int ledPin7 = 8;
void setup()
{
 // put your setup code here, to run once:
 // set six pins to be outputs:
  pinMode(Pushbutton, INPUT);
  pinMode(ledPin1, OUTPUT);
  pinMode(ledPin2, OUTPUT);
  pinMode(ledPin3, OUTPUT);
  pinMode(ledPin4, OUTPUT);
  pinMode(ledPin5, OUTPUT);
  pinMode(ledPin6, OUTPUT);
  pinMode(ledPin7, OUTPUT);
}

void loop() {
 // put your main code here, to run repeatedly:
 int PushbuttonState = 0;   // variables to hold the pushbutton states
  PushbuttonState = digitalRead(Pushbutton);
    if (PushbuttonState == LOW) { // Run the code once the moment push button is pressed
    action();
  }
}
void action() {

  digitalWrite(ledPin6, LOW);  //Turns off LED #4 (pin 6)
  digitalWrite(ledPin5, LOW);  //Turns off LED #5 (pin 5)
  digitalWrite(ledPin4, LOW);  //Turns off LED #6 (pin 4)

  digitalWrite(ledPin7, HIGH);   // Relay 1
  delay(delayTime2);
  digitalWrite(ledPin7, LOW);
  digitalWrite(ledPin6, LOW);  //Turns off LED #4 (pin 6)
  digitalWrite(ledPin5, LOW);  //Turns off LED #5 (pin 5)
  digitalWrite(ledPin4, HIGH); //Turns ON LED #6 (pin 4)
  delay(delayTime1);             //wait delayTime milliseconds
```

```
delay(delayTime2);
digitalWrite(ledPin7, LOW);
digitalWrite(ledPin6, LOW);  //Turns off LED #4 (pin 6)
digitalWrite(ledPin5, HIGH);  //Turns on LED #5 (pin 5)
digitalWrite(ledPin4, LOW);  //Turns off LED #6 (pin 4)
delay(delayTime1);             //wait delayTime milliseconds

digitalWrite(ledPin7, HIGH);  // Relay 3
delay(delayTime2);
digitalWrite(ledPin7, LOW);
digitalWrite(ledPin6, LOW);  //Turns off LED #4 (pin 6)
digitalWrite(ledPin5, HIGH);  //Turns on LED #5 (pin 5)
digitalWrite(ledPin4, HIGH);  //Turns on LED #6 (pin 4)
delay(delayTime1);             //wait delayTime milliseconds

digitalWrite(ledPin7, HIGH);  // Relay 4
delay(delayTime2);
digitalWrite(ledPin7, LOW);
digitalWrite(ledPin6, HIGH);  //Turns on LED #4 (pin 6)
digitalWrite(ledPin5, LOW);  //Turns off LED #5 (pin 5)
digitalWrite(ledPin4, HIGH);  //Turns on LED #6 (pin 4)
delay(delayTime1);             //wait delayTime milliseconds

digitalWrite(ledPin7, HIGH);   // Relay 5
delay(delayTime2);
digitalWrite(ledPin7, LOW);
digitalWrite(ledPin6, HIGH);  //Turns on LED #4 (pin 6)
digitalWrite(ledPin5, LOW);  //Turns off LED #5 (pin 5)
digitalWrite(ledPin4, LOW);  //Turns off LED #6 (pin 4)
delay(delayTime1);             //wait delayTime milliseconds
digitalWrite(ledPin6, HIGH);  //Turns on LED #4 (pin 6)
digitalWrite(ledPin5, HIGH);  //Turns on LED #5 (pin 5)
digitalWrite(ledPin4, LOW);  //Turns off LED #6 (pin 4)

digitalWrite(ledPin3,  LOW);  //Turns off LED #1 (pin 2)
digitalWrite(ledPin2,  LOW);  //Turns off LED #2 (pin 3)
digitalWrite(ledPin1,  LOW);  //Turns off LED #3 (pin 4)
delay(delayTime1);
digitalWrite(ledPin7, HIGH);   // Relay 6
delay(delayTime2);
digitalWrite(ledPin7, LOW);
digitalWrite(ledPin3,  LOW);  //Turns off LED #1 (pin 2)
digitalWrite(ledPin2,  LOW);  //Turns off LED #2 (pin 3)
digitalWrite(ledPin1, HIGH);  //Turns on LED #3 (pin 4)
delay(delayTime1);             //wait delayTime milliseconds

digitalWrite(ledPin7, HIGH);  // Relay 7
delay(delayTime2);
digitalWrite(ledPin7, LOW);
digitalWrite(ledPin3, LOW);  //Turns off LED #1 (pin 2)
digitalWrite(ledPin2, HIGH);  //Turns on LED #2 (pin 3)
digitalWrite(ledPin1, LOW);  //Turns off LED #3 (pin 4)
delay(delayTime1);             //wait delayTime milliseconds
```

```
digitalWrite(ledPin7, HIGH);  // Relay 8
delay(delayTime2);
digitalWrite(ledPin7, LOW);
digitalWrite(ledPin3, LOW);  //Turns off LED #1 (pin 2)
digitalWrite(ledPin2, HIGH);  //Turns on LED #2 (pin 3)
digitalWrite(ledPin1, HIGH);  //Turns on LED #3 (pin 4)
delay(delayTime1);              //wait delayTime milliseconds

digitalWrite(ledPin7, HIGH);  // Relay 9
delay(delayTime2);
digitalWrite(ledPin7, LOW);
digitalWrite(ledPin3, HIGH);  //Turns on LED #1 (pin 2)
digitalWrite(ledPin2, LOW);  //Turns off LED #2 (pin 3)
digitalWrite(ledPin1, LOW);  //Turns off LED #3 (pin 4)
delay(delayTime1);              //wait delayTime milliseconds

digitalWrite(ledPin7, HIGH);    // Relay 10
delay(delayTime2);
digitalWrite(ledPin7, LOW);
digitalWrite(ledPin3, HIGH);  //Turns on LED #1 (pin 2)
digitalWrite(ledPin2, LOW);  //Turns off LED #2 (pin 3)
digitalWrite(ledPin1, HIGH);  //Turns on LED #3 (pin 4)
delay(delayTime1);              //wait delayTime milliseconds
digitalWrite(ledPin3, HIGH);  //Turns on LED #1 (pin 2)
digitalWrite(ledPin2, HIGH);  //Turns on LED #2 (pin 3)
digitalWrite(ledPin1, LOW);  //Turns off LED #3 (pin 4)
}
```