CHAPTER 1: INTRODUCTION

1.1. BACKGROUND

"In the future, through technological innovations people no longer will be defined by their disabilities, but by their abilities" - These are the words of a MIT professor and double above ankle amputee Hugh Herr [1]. Technology allows him to ambulate like a normal person, and even pursue his rock-climbing hobby. Inspired by biology, biomechatronics is an interdisciplinary study of integrating biology, mechanics, and electronics.

The psychological implications of any disability are described in Maslow's theory of human motivation, based on human hierarchy of needs. Figure 1 illustrates the hierarchy of needs, with "self-actualisation" being on top of all needs [2]. By having the ability to function normal and independent and the feeling of being in control of one's own life or actions, usually associated with being successful in life.

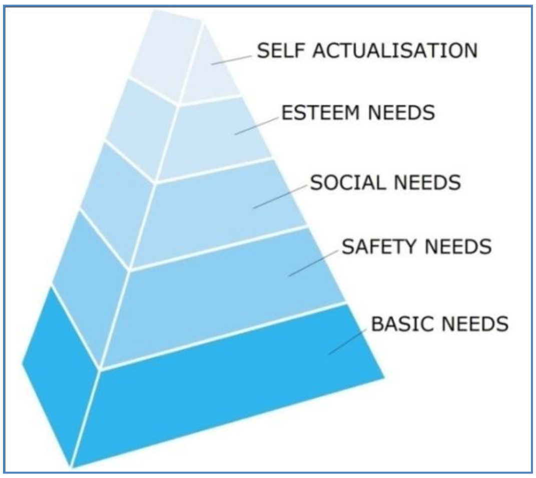

Figure 1: Maslow's hierarchy of human needs [2]

Figure 2: A prosthetic toe in the Cairo Museum [3]

The importance of the human hand in daily life is critical, since it is required in any man-made object/process and replaces eyes to the blind and ears to the deaf [4]. Evidence exists of the need for people to function independently or appear normal, such as the oldest prosthesis, shown in figure 2, which dates back to as far as 1000 BC.

People tend to have the urge to replace what they had, at least with a counterpart with equal performance. Should patients have a limb amputated, the question is, what functionality remains in their surrounding muscles and nerves, to use in prosthesis control. In some of these cases, it is not possible to use non-invasive methods to sense muscle or nerve activity. There are mainly three causes of amputations, and the percentage of occurrence are given as: Traumatic accidents (15%), tumors (5%) and diabetics (80%) [5].

The leading accidents resulting in amputations occur at work and in car accidents. In these cases, the patients usually have healthy surrounding nerves and/or their muscles remains functional. Cancer may result in the amputation of a limb. This could mean that surrounding nerves and or muscles lost their functionality as well. Although diabetes affects only 7.8% of the world population [5], it is responsible for the most amputations performed on patients. The failure of maintaining the correct glucose levels may cause damage to diabetics' nerves, and blood circulation, resulting in amputation of their limbs. Patients with spinal cord injuries (SPI) are also at risk of developing diabetes [5].

In the case of a traumatic amputation of the hand at the wrist, these patients have a fully functional forearm, which contains most of the amputated hand's muscle and motory nerves, which could be used to control a fully functional replacement prosthetic hand. In some cases patients are born without limbs, or with partially developed limbs, and the possibility to help these patients remains limited.

Machines are superior over man in the sense that human muscles gets tired, but machines are not only stronger and faster, they have no decrease in performance as long as their power source is not depleted. Hugh Herr said: "I like to say that there are no disabled people, only disabled technologies" [1]. This project focuses on the development of an upper limb prosthesis input method, inspired to help patients with amputated hands.

The ability to control a robotic arm with one's original gesture control thoughts has been a dream of many. A biometric sensor senses instructions intended for the amputated part of the patient, and communicates this information to a robotic prosthesis. The challenge lies in the input method, or sensor design, or as Jenns Clausen describes it as "Man, machine and in between", with a lot of ethical issues revolving implants to achieve the interface between man and machine [6].

Electromyography (EMG) allows the recording of muscle activity by measuring the electrical potential over muscles caused by the action potentials of their motor units. First studies done by Francesco Redi dates back to 1666, and the first actual recording was done by Marey in 1890 [7]. EMG is divided into two catagories, the non-invasive surface EMG (sEMG) and the invasive intramuscular/indwelling EMG (iEMG) type. sEMG could be the most elegant design approach, as no medical surgery procedures are required to have a device implanted. By considering the rate at which technology improves, it would also be unwise to insert an implant that becomes outdated in a short time.

Biomechatronics is a field recently introduced at the North West University (NWU), with the development of a complete functional upper limb prosthesis arm as final goal. Figure 3 shows how this goal is divided into a series of proposed sub-projects. The first project (this project) involves the development of the sensing device, called a human-machine interface (HMI). Future projects may involve the testing of current control systems, or the development of new control systems intended to give an artificial hand human-like movement. The possibility of a multiple input control system could also be studied. The final project involves the mechatronic prosthetic design.

This study is intended to initiate the development of further projects in this field. It includes the sEMG sensor design and the required hardware and firmware to be able to capture an electromyogram live (in digital format) in Matlab®/Simulink®. Future projects may then use this developed sensing device as a development platform to test decoding algorithms and further digital signal processing (DSP) using Matlab®/Simulink®, and finally control a prosthesis arm in real time.

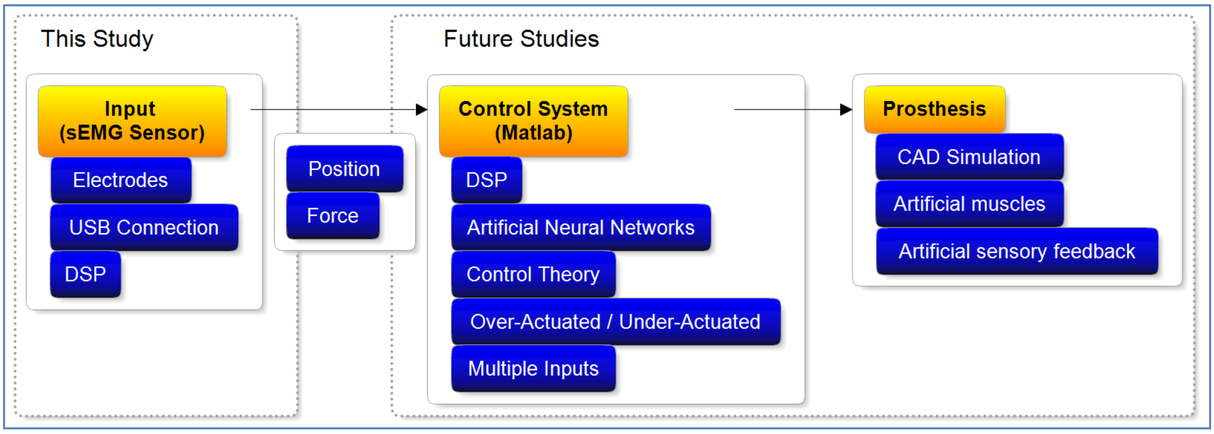

Figure 3: Biomechatronics at the NWU

1.2. PROBLEM STATEMENT

The goal of the study is to develop an inexpensive, non-invasive EMG based sensor device that can be interfaced with Matlab/Simulink®. This will allow future studies on signal processing algorithms and proportional prosthetic control structures using this sensor device as a development platform.

1.3. SCOPE OF PROJECT PROBLEM

The restrictions given to guide the study include the research of a non-invasive EMG-based sensor (HMI) for an upper limb (forearm). The sensing platform will include sEMG sensor hardware. The Matlab®/Simulink® environment will receive the information made available by the sensing platform. The information could further be used to extract force and position information for control purposes.

The sensing platform forms part of a hardware-in-the-loop (HIL) system. To verify HIL systems, the subsystems inside the system must be tested inside the complete system [8]. Currently, the complete system does not exist, but the sensing platform hardware design needs to be validated and verified. Although the system will be implemented for verification purposes, the focus remains on the sensing platform hardware design.

A forward control path will be implemented to show the possibility for prosthesis control. Control systems are usually be associated with closed-loop systems, but the demonstration of a functional forward open-loop system will be sufficient to verify the hardware design.

1.4. ASSUMPTIONS

This study focuses on upper limb function, depicting the function of the hand. This means that the patient has a wrist amputation. The patients' amputation is due to an accident, which means that the nerve and muscle functionality in the upper arm is comparable to that of normal persons. Implants must comply with medical specifications and technology upgrades are difficult to perform with invasive HMI methods, therefore non-invasive HMI methods are preferred. The Matlab®/Simulink® environment is the software package selected to implement control systems, DSP and simulations.

The EMG signals will be recorded from concentric muscle contraction, which means that the hand will be allowed to open/close freely without any obstruction such as holding an object.

1.5. ISSUES TO BE ADDRESSED

1.5.1. SENSOR PLATFORM DESIGN

The two important issues considered in EMG sensor design are listed. Special care should be taken when designing the amplifier circuits due to the noise and small signals being measured. Secondly the type of electrode also impacts the performance of the sensor.

AMPLIFIER DESIGN

Commercial EMG sensors' performance level is not always a reflection of what suppliers claim [9], and they are not affordable to be used in prosthesis control. An analog EMG front end will be designed to sense and amplify EMG signals. This will be achieved by investigating the principles of EMG and design an EMG sensor based on the specifications derived by the findings.

ELECTRODE DESIGN

The cost of AgCl electrodes result in sEMG being an expensive HMI. The possibilities and result of less expensive alternatives are researched.

1.5.2. MATLAB®/SIMULINK® INTERFACE

A need exists for the development of a hardware platform with the capability to connect to the Matlab®/Simulink® environment to test algorithms and control systems. This need is addressed by the development of a hardware platform that is able to connect an analog sEMG front end to Matlab®/Simulink® via the personal computer's (PC) Universal Serial Bus (USB).

1.5.3. EMC

Digital circuits are not compatible with analog circuits. The high frequency/switching rate of voltage in digital circuits may add noise to analog circuits on the same printed circuit board (PCB) [10 - 13]. EMG signal amplitudes are small, which require large amplifier gains. EMI is always an issue in amplifiers, but is addressed with EMC in mind when selecting components, and by taking care of component placement and circuit routing of a PCB design.

1.5.4. SENSOR PLATFORM VALIDATION

The performance parameters given by existing EMG systems will be used as measures to validate the sensing platform' hardware design.

1.5.4. HIL VERIFICATION

As mentioned in the project scope, the sensing platform forms part of a hardware-in-the-loop (HIL) system. The verification process for HIL sub-systems involves the testing of the complete system [8]. As the complete system does not exist currently, the verification of the hardware will be done using an implementation of a simple control system. Although the control system will be implemented for verification purposes, the focus remains on the sensing platform's hardware design.

1.5.5. RESEARCH GROUP EXPECTATIONS

The main focus for the sensing platform is research-related, with no intensions of commerialisation. The functionality and cost requirements are governed by what the research group ate the NWU need.

FUNCTIONALITY

The functionality of the sEMG sensing platform is described by controllability (how well the sensors sense a patient's muscle activity) and the repeatability (how well the sensors could give a standardised signal output when used for various patients). The success of the studies that could emerge from this study relies on the successful management of risk and cost.

CONTROLABILITY

The future studies rely on the linearity and responsiveness of the system, as it will affect the controllability of the final prosthetic arm. Although not the goal of the study, the implementing of a proportional control algorithm (to verify the hardware design) will demonstrate the possibility for proportional control in real time. Proportional control is defined as one in which the amplitude of the hand motor voltage, and thus its speed and force, varies in direct proportion to the amplitude of the EMG signal generated by the wearer [14-15].

REPEATABILITY

Variation of body types amongst people results in variation in sEMG signals, as the signal has to pass from muscles through the fat-layers underneath the skin of patients. A Calibration feature will be built into the sensor to ensure that the sensor output can be repeated if used by various patients.

RISK MANAGEMENT

The importance of risk management in studies is important to ensure that goals are reached. This study is the pilot study in the field of biomechatronics at the NWU, with a strong influence in the success in reaching the future goals. The dependent studies that could emerge from this study relies on the success of this study, otherwise the time spent on the future studies will be wasted.

The tree main studies identified in the process to reach the future goal are as follow:

- Input sensing platform involves electronic/firmware development - this study.
- The processing done in Matlab®/Simulink® environment requires software implementation - future study.
- The Output section of the future goal involves electronic/firmware and mechanical design - future study.

The problem with multiple disciplined studies is that a lot of time is wasted if the developer/researcher has to look into problems that are not related to his/her field of study. For example, should there be a hardware issue with hardware, it would affect the software study's success, and force the software developer/researcher to look into the hardware issue. The software developer/researcher's worst nightmare occurs when it is not clear whether the problem is software or hardware related.

To minimise risk for the future software and mechanical studies, the sEMG sensing platform will include the input sensor and the output section electronics/firmware to ensure that the hardware platform developed in this study is tested from the input through to the output of the system. The chosen electro-mechanical output device is a PDM servo, which could be connected to the sensing platform.

COST MANAGEMENT

Cost is important in research, as research could only be done if funding is available. The cost of purchasing an existing sEMG system is very high, which limits the possibility of research to only a few institutions. The aim is to develop an affordable sEMG sensing platform without sacrificing quality and accuracy, otherwise the exercise would only waste other's time and funds.

The system layout in the process to reach the future goal is as follow:

- Input sensing platform development involves electronic/firmware development - this study.

- The processing done in Matlab®/Simulink® environment requires software implementation done on a personal computer (PC) - future study.
- The Output section of the future goal involves electronic/firmware and mechanical design - future study

As part of risk-minimisation, the sEMG sensing platform will include the input sensor and the output section electronics/firmware to ensure that the hardware platform developed in this study is tested from the input through to the output of the system. This would also reduce cost as the input/output hardware could be combined into a single platform.

The sEMG electronics research involves research into using less expensive electrodes to address the cost issue.

1.6. OVERVIEW OF DISSERTATION

Chapter 2 focuses on the on the biomechatronic procedure “learning from nature”. The concepts of EMG are next described in this section.

Chapter 3 includes the information about electrodes, EMG and EMI in terms of mathematical modeling, required to characterise the sEMG HMI system.

A systems engineering approach is followed to analyse the required system’s functionality and the interfaces between the system and its environment. A Functional analysis (functional block diagram & system architecture) is performed to create an understanding of the system, and design for “the system”. This is followed by muscle, electrode and EMG mathematical modeling in the conceptual design (chapter 4).

The detailed design of the sEMG platform starts with a revised functional block diagram to include the specifications derived from the project requirements. The hardware design, the firmware, software and calibration algorithms are developed in this section.

The performance of the sEMG platform is discussed in chapter 6. Simulations with and without visual feedback demonstrate the effect of visual feedback on the accuracy of gesture mimicry.

Chapter 7 is the validation and verification process of the sEMG platform. The hardware performance is compared to other past projects to ensure that future projects (dependent on the accuracy of the sEMG platform) will not be adversely affected. The results obtained from this study verify the functionality of the sEMG platform.

Chapter 8 concludes with a discussion on the use for the sEMG platform. The discussion concludes with possibilities for proportional control algorithm possibilities through sEMG. Recommendations for future work include more research on force decoding algorithms and feedback control loops.