# Title page

SAMUEL MARCUS WILLIAMS

***THESIS SUBMISSION***

**DR PAUL POUNDS**

**Fucking kill me already**

# Abstract

200-300 words written last

# Executive summary

1 page

# Contents

[1 Title page 1](#_Toc514938059)

[2 Abstract 2](#_Toc514938060)

[3 Executive summary 3](#_Toc514938061)

[4 Contents 4](#_Toc514938062)

[5 Introduction 7](#_Toc514938063)

[6 Background and Problem breakdown 8](#_Toc514938064)

[6.1 Existing Technologies and limitations 8](#_Toc514938065)

[6.1.1 HULC 8](#_Toc514938066)

[6.1.2 EskoGT 8](#_Toc514938067)

[6.1.3 Raytheon XOS Exoskeleton 8](#_Toc514938068)

[6.1.4 Warrior Web 8](#_Toc514938069)

[6.1.5 Hybrid Assistive Limb (HAL) 9](#_Toc514938070)

[6.2 Force Based Mechanicsms 9](#_Toc514938071)

[6.3 Proximity as a solution 9](#_Toc514938072)

[6.3.1 Less exhausting 9](#_Toc514938073)

[6.3.2 Intuitive 9](#_Toc514938074)

[6.3.3 Won’t flail out of control and be unstable 9](#_Toc514938075)

[6.4 Cases for use 9](#_Toc514938076)

[6.4.1 Justification of capabilities (tested movements) 9](#_Toc514938077)

[6.4.2 Stand still under standard conditions 9](#_Toc514938078)

[6.4.3 Actuation of movement 9](#_Toc514938079)

[6.4.4 Walking 9](#_Toc514938080)

[6.4.5 Up stairs 9](#_Toc514938081)

[6.4.6 Sitting 10](#_Toc514938082)

[6.5 Justification of demo scope (lower body only) 10](#_Toc514938083)

[6.6 Task division between participants 10](#_Toc514938084)

[6.7 Justification of controls and perception systems required 10](#_Toc514938085)

[6.7.1 Detecting the pilot’s proximity 10](#_Toc514938086)

[6.7.2 Detecting the suit’s position 10](#_Toc514938087)

[6.7.3 Force application of the system by the pilot to the environment 10](#_Toc514938088)

[6.7.4 Control system for decision making 10](#_Toc514938089)

[6.7.5 System communication from control & perception software to actuation system 10](#_Toc514938090)

[7 Scope 11](#_Toc514938091)

[7.1 Assumptions 11](#_Toc514938092)

[7.2 Equipment 11](#_Toc514938093)

[7.3 Demonstrable capabilities 11](#_Toc514938094)

[7.4 Stuff out of scope 11](#_Toc514938095)

[7.5 Variation on original scope 11](#_Toc514938096)

[8 Pilot’s proximity 12](#_Toc514938097)

[8.1 Requirements 12](#_Toc514938098)

[8.2 Possible solutions 12](#_Toc514938099)

[8.3 Justification of chosen solution 12](#_Toc514938100)

[8.4 Components list of chosen solution 12](#_Toc514938101)

[8.5 Performance 12](#_Toc514938102)

[9 Force application from pilot to system to environment 13](#_Toc514938103)

[9.1 Requirements 13](#_Toc514938104)

[9.2 Possible solutions 13](#_Toc514938105)

[9.3 Justification of chosen solution 13](#_Toc514938106)

[9.4 Components list of chosen solution 13](#_Toc514938107)

[9.5 Performance 13](#_Toc514938108)

[10 Control system for decision making 14](#_Toc514938109)

[10.1 Requirements 14](#_Toc514938110)

[10.2 Possible solutions 14](#_Toc514938111)

[10.3 Justification of chosen solution 14](#_Toc514938112)

[10.4 Components list of chosen solution 14](#_Toc514938113)

[10.5 Performance 14](#_Toc514938114)

[11 Communications 15](#_Toc514938115)

[11.1 Requirements 15](#_Toc514938116)

[11.2 Possible solutions 15](#_Toc514938117)

[11.3 Justification of chosen solution 15](#_Toc514938118)

[11.4 Components list of chosen solution 15](#_Toc514938119)

[11.5 Performance 15](#_Toc514938120)

[12 Holistic integration of requirements 16](#_Toc514938121)

[13 Demo 17](#_Toc514938122)

[14 Recommendations and further research 18](#_Toc514938123)

[15 Conclusion 19](#_Toc514938124)

[16 References 20](#_Toc514938125)

[17 Appendices 21](#_Toc514938126)

[17.1 Code 21](#_Toc514938127)

[17.2 PCBs 21](#_Toc514938128)

[17.3 CAD drawings 21](#_Toc514938129)

# Introduction

A powered exoskeleton, or exoskeleton, is wearable technology the amplifies and augments the pilot’s physicality. Through direct mechanical assistance via actuators, the pilot’s effective strength may be increased. By supplementing the strength required to complete a task the energy requirements of the task may be reduced; effectively increasing the pilot’s endurance. Possible applications for exoskeletons include: military operations, emergency & rescue, physical/manual labour, and medical applications.

Two major factors impact the viability of exoskeleton technology: power supply, and control. This thesis shall address one facet of the difficulties or exoskeleton control. Current exoskeleton control methods are inadequate due to mechanical constraints and the limitations of the control methods. Imperfections in mechanical design may result in a limited range of movement affecting the suits utility (e.g. A rigid spine in a confined space). Current methods of control use either force-based sensors or preprogramed movements. Finite sets of preprogramed movements are insufficient for dynamic environments and are only suitable for applications where the pilot is incapable of properly piloting the system kt. Force based methods encounter stability problems and may increase the exertion required to complete a task kt.

Instead this thesis will focus on the development of a novel power exoskeleton control method based on detecting the pilot’s position relative to the suit to maintain a constant offset; specifically focusing on the development of the controls and perception systems required to direct an exoskeleton.

An offset-based control system, by maintaining a constant offset from the user, may exist as a concentric outline (or *bubble*) of the user, mirroring their actions. Thus, to control the system the pilot simply needs to assume the desired position of the suit, and the suit shall mimic them. By mimicking the user’s actions, the suit is more intuitive that force based and preprogramed methods. The resulting system requires no physical contract with the pilot to control. With no physical contact required to operate the system the energy required from a pilot to complete a task with a load is effectively the same as completing the task with no load. Therefore, with any arbitrary load the user has the endurance to perform the task as if there no load at all.

# Background and Problem breakdown

## Existing Technologies and limitations

Exoskeleton technology began in 1890 kt, with Nicholas Yagin, with the development of a passive device that used compressed gas to assist in human movement. However, it was not until the 1960s that the first attempt at a practical power exoskeleton was developed. The Hardiman kt, created by General Electric, was ground-breaking but non-viable due to its extreme weight (double its maximum load) and control problems. The suit, when used as a complete system instead of in parts, was subject to dangerous violent uncontrolled movements and the master-slave control system suffered debilitating lag.

Prospective uses for exoskeletons usually involve a scenario where a human user may require the strength and endurance of a machine, but circumstances result in wheeled vehicles are undesirable. Examples of possible applications include:

Military Operations:

Rescue and evacuation missions:

Medical Systems:

Construction & Physical Labour:

Since the Hardiman, exoskeletons have been plagued by the same two major problems that have prevented their use in real world applications: power to weight ratio/power supply and control. The following outlines current developments in exoskeleton technologies.

### HULC kt

The Human Universal Load Carrier (HULC) is battery-powered lower extremity exoskeleton initially developed by Berkeley Robotics and Human Engineering Laboratory, before entering an exclusive licensing agreement with Lockheed Martin in 2009. The system uses hydraulics to amplify the pilot’s knees and hips while supporting a load of 90kg. Designed for military applications it claims six hours of battery and uses force-based sensors for control.

The HULC was abandoned as” it proved impractical, exhausting users instead of supercharging them” kt and has been succeeded by the TALOS project kt.

### EskoGT kt

In 2010 the original developer of the HULC, Esko Bionics revealed the Exoskeleton Lower Extremity Gait System (eLEGS). With a maximum battery life of 6 hours and maximum gait of 3.2m/s kt, the system uses pushbuttons and force-motion sensors for control. Specially design for medical applications, the exoskeleton uses preprogramed movements to aid the mobility of stroke and spinal injury patients.

The suit is ill suited for dynamic environments, with its finite range of movements prohibiting stairs and uneven surfaces. While the suit may assist those with “upper extremity motor function of at least 4/5 in at least one arm”, the suit is slower than a wheelchair and is not an improvement on standard human movement

### Raytheon XOS Exoskeleton

The 2008 Raytheon XOS Exoskeleton developed by Raytheon is a full body exoskeleton that can support up to 23kg on each arm kt. The suit uses force-based sensors for control. Despite claims that the exoskeleton would be ready for production by 2016, they have made no public comments on progress since 2011.

### Warrior Web

The Warrior Web non-rigid exoskeleton was first demostrated at the 2016 DARPA Demo Day. Developed by DARPA, it used preprogrammed commands to assist wth the users ankle motions. However, it was unpredictable in uneven terrain, malfunctioned, and could not transition readility between a walking and running state. kt (Cornwall, 2015).

### Hybrid Assistive Limb (HAL)

In 1997 Cyberdine unveiled the Hybrid Assistive Limb (HAL). The HAL’s iterations include a battery-powered lower extremity exoskeleton and a full body exoskeleton. Through a combination of bioelectrical sensors and force sensors the HAL measured muscle contracts to trigger preprogrammed movements.

The system has had mixed success, and despite applying for USA FDA approval in 2014, the HAL is yet to be permitted for use in the US kt

## Force Based Mechanisms

## Proximity as a solution

### Less exhausting

### Intuitive

### Won’t flail out of control and be unstable

## Cases for use

### Justification of capabilities (tested movements)

### Stand still under standard conditions

Steady state

Info required by system

* Pilot location
* Suit location
* Force applied by pilot to suit
* Force applied by suit to environment

### Actuation of movement

Movement

Info required by system

* Pilot location
* Suit location
* Force applied by pilot to suit
* Force applied by suit to environment

### Walking

Real time movement

Info required by system

* Pilot location
* Suit location
* Force applied by pilot to suit
* Force applied by suit to environment

### Up stairs

Force application

Info required by system

* Pilot location
* Suit location
* Force applied by pilot to suit
* Force applied by suit to environment

### Sitting

Regulated force application

Info required by system

* Pilot location
* Suit location
* Force applied by pilot to suit
* Force applied by suit to environment

## Justification of demo scope (lower body only)

## Task division between participants

## Justification of controls and perception systems required

### Detecting the pilot’s proximity

### Detecting the suit’s position

### Force application of the system by the pilot to the environment

### Control system for decision making

### System communication from control & perception software to actuation system

# Scope

## Assumptions

## Equipment

## Demonstrable capabilities

How to demonstrate on the demo rig the capacity to complete the below activities:

* Standing still
* Walking
* Stairs
* Sitting

## Stuff out of scope

## Variation on original scope

# Pilot’s proximity

## Requirements

## Possible solutions

## Justification of chosen solution

## Components list of chosen solution

## Performance

# Force application from pilot to system to environment

## Requirements

## Possible solutions

## Justification of chosen solution

## Components list of chosen solution

## Performance

# Control system for decision making

## Requirements

## Possible solutions

## Justification of chosen solution

## Components list of chosen solution

## Performance

# Communications

## Requirements

## Possible solutions

## Justification of chosen solution

## Components list of chosen solution

## Performance

# Holistic integration of requirements

# Demo

# Recommendations and further research

# Conclusion

# References

# Appendices

## Code

* Firmware in C
* Matlab

## PCBs

## CAD drawings