Super complex and long thesis title

First middle last name

Institute of Design, Robotics and Optimisation
School of Mechanical Engineering
University of Leeds

Submitted in accordance with the requirements for the degree of *Doctor of Philosophy*

March 2022

This work is dedicated to the flying Spaghetti and his noodly ways.

Declaration

The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others.

Rory Peter Turnbull
March 2022

Acknowledgements

I would like to thank me, myself and I for writing this thesis.

Abstract

Some things were done that resulted in stuff.

Table of Contents

List of Figures

List of Tables

List of Code Listings

Nomenclature

Acronyms / Abbreviations

ν Poisson's ratio

$14DOF-LL$ Fourteen DOFs Lower Limb Exoskeleton

$16DOF-UL$ Sixteen DOFs Upper Limb Exoskeleton

$6DOF-LL$ Six DOFs Lower Limb Exoskeleton

$6DOF-UL$ Six DOFs Upper Limb Exoskeleton

ADL Activity of Daily Living

AOI Area of Interest

AoI Area of Interest

C^* Effective Dissipation Coefficient

$cHRI$ cognitive Human-Robot Interaction/Interface

$CMA-ES$ Covariance Matrix Adaptation Evolution Strategy

CoF Coefficient of Friction

CoT Cost of Transport

CSA Cross-sectional Area

DOF Degrees of Freedom

E^* Composite Elastic Modulus

EMG Electromyography

FSR Force Sensitive Resistor

GRF Ground Reaction Force

HCF Hunt-Crossley Force

HRI Human Robot Interaction

hyfydy High Fidelity Dynamics Physics Engine

IMUs Inertial Measurement Units

JBI Joint Based Interaction

EFF modified Elastic Foundation Force

MOCO OpenSim MOtion and COntrol optimiser

MR Measuring Resistor

NormSD Normalised Standard Deviation

nRMSE Normalised Root Mean Square Error

PCB Printed Circuit Board

pHRI physical Human Robot Interface

RMSE Root Mean Square Error

ROM Range of Motion

SCONE Simulated Controller OptimizatioN Environment

SID Specification Identifier

Chapter 1

Introduction

1.1 Background

First off explain stuff like Human Robot Interaction (HRI) then add to nomenclature in the code and it will show up when you compile

Next make a list of things. This can be bullet points or numbers

- Things
- Stuffs
- More things

Fig. 1.1 Example figure but landscape.

(a) (b) (c)

Fig. 1.2 Subfigure example (a) don't panic, (b) panik (c) and another thing.

Things and stuff are written but now I want a footnote[1]

Cite a person using bibtex, you can get menedeley to export your whole library [1]

1.2 Motivation for Research

1.3 Aims and Objectives

nice numerical list

1. Where is the optimal contact position for the attachment of an assistive robotic exoskeleton to the limbs of the end user?
2. How does the attachment location contribute to exoskeleton-human joint alignment?
3. What is the relationship between attachment position and user metabolic expenditure?

1.3.1 Aims

1.3.2 Objectives

1. Things
2. Stuff

1.4 Project Scope

italic text

[1] Look a footnote, how exciting

Fig. 1.3 Project scope flow diagram with areas of interest highlighted in red

1.5 Contributions of this Research

1. things
2. stuff
3. more

1.6 Thesis Organisation

sometimes paragraph look better to break up formatting

Chapter 2: Literature Review -

Chapter 3: Name -

Chapter 4: Name -

Chapter 5: Name -

Chapter N: Summary, Conclusions and Future Work - This chapter summarises the work conducted during this research. Discusses simulations result implications and how they compare to the preliminary work and literature. The conclusions made from this work and finally recommendations for the further development of the work are set out.

Chapter 2

Literature Review

Generally nice to have a chapter overview before the introduction. Here you talk about the chapter and how it fits in the thesis rather than your subject.

2.1 Introduction

90°

nice big sideways table

- **Body -** The simulations bones and links. They are defined by relating the position of a joint relative to a parent and child body. Where the body being inserted is the child body.
- **Joint -** Used to connect two bodies. A joint is specified when inserting a new body. Joint types selection depends on the desired functionality.
- **Geometry -** Used as interaction objects or simply providing body visualisation.

This is what a table looks like, easiest to build them as you want in excel then put the & symbols in. Refere to a table like this: Table 2.2

Maths equations (Equation 2.1)

$$E_i^* = \frac{E_i}{1-\nu_i^2} \tag{2.1}$$

Where E_i^* = composite elastic modulus for a given material, E_i = the elastic modulus for a given material and ν = material Poisson's ratio.

Maths formatting is done between dollar signs

Table 2.1 Shoulder, clavicle, elbow, wrist, hand, spine, hip, knee, ankle and foot Degrees of Freedom and Range of Motion. * Where a DOF exists due to joint structure, but the movement has not quantified been quantified in the literature

Motion	Shoulder	Clavicle	Elbow	Wrist	Hand	Thoracic Spine	Lumbar Spine	Hip	Knee	Ankle	Foot
Flexion	45°	–	145°	80°	–	20-43°	40-60°	120°	120°	–	–
Extension	180°	–	0-5°	70°	–	–	20-35°	10°	5°	–	–
Abduction	50°	–	–	41°	*	–	–	70°	–	–	–
Adduction	180°	–	–	30°	*	–	–	70°	–	–	–
Lateral Flexion	–	–	–	–	–	6-30°	16-18°	–	–	–	–
Lateral Extension	–	–	–	–	–	5-31°	18-21°	–	–	–	–
Lateral Rotation (Inversion)	80°	–	–	–	–	20-43°	15-18°	50°	25°	–	(12°)
Medial Rotation (Eversion)	90°	–	–	–	–	29-56°	16-19°	50°	25°	–	(23°)
Pronation	–	–	–	-90°	–	–	–	–	–	Multi. DOF	
Supination	–	–	–	85°	–	–	–	–	–	Multi. DOF	
Retraction (Posterior Translation)	–	12°	–	–	–	*	*	–	*	–	–
Protraction (Anterior Translation)	–	40°	–	–	–	*	*	–	*	–	–
Elevation (Superior Translation)	–	60°	–	–	–	*	*	–	*	–	–
Depression (Inferior Translation)	–	3°	–	–	–	*	*	–	*	–	–
Plantarflexion	–	–	–	–	65-110°	–	–	–	–	40-55°	–
Dorsiflection	–	–	–	–	0°	–	–	–	–	10-20°	–
Medial Translation	–	–	–	–	–	*	*	–	*	–	–
Lateral Translation	–	–	–	–	–	*	*	–	*	–	–
Valgus Rotation	–	–	–	–	–	–	–	–	–	–	–
Varus Rotation	–	–	–	–	–	–	–	–	–	–	–
Anterior Rotation	–	3°	–	–	–	–	–	–	–	–	–
Posterior Rotation	–	30-50°	–	–	–	–	–	–	–	–	–
Natural DOF	3	2	1	3	20	72	30	3	6	1	1
Per Joint Unit					2	6	6				

Table 2.2 Summary of pressure experienced at the physical human-robot interface, including comfort levels and capillary compression pressure.

Reference	Pressure [kPa] Comfortable	Discomfort	Damage	Pain	Conditions
Schiele et al. [2]	1.3-4	>4	–	–	While completing tasks
Kermavnar et al. [3]	<14.1	14.1-27.5	–	43.4-60.3	Dynamic loading over short periods
Ryan et al. [4]	–	–	4-4.7	–	Capillaries occlusion - minimum stress
Cho et al. [1]	–	–	9	–	Injury possible from
Agam et al. [5]	–	–	>6.27	–	Average capillary pressure

Chapter 3

Conclusions and Future Work

Generally chapter description.

3.1 Assessment of Research Objectives

1. ***Objective text from ch1 obj 1*** How you met the objective etc
2. ***Objective text from ch1 obj 2*** How you met the objective etc
3. ***Objective text from ch1 obj 3 etc...***

3.2 Discussion

3.3 Conclusions

3.3.1 Key area 1

-
-
-
-
-

3.3.2 Key area 2

-
-
-

3.4 Future Work

This section sets out recommendations for future work, which would aid the continued development of designs and models set out in this research.

3.4.1 area 1

1. ***Actuation -***
2. ***Tracking shear forces at the interface -***

3.4.2 area 2

1. ***Addition of assistance -***
2. ***Simulated movement -***
3. ***Soft tissue model -***

References

[1] Kilhyun Cho, Yeonghun Kim, Dooyoung Yi, Moonki Jung, and Kunwoo Lee. Analysis and Evaluation of a Combined Human-Exoskeleton Model Under Two Different Constraints Condition. *International Summit on Human Simulation (ISHS)*, pages 23–25, 2012.

[2] A Schiele. *Fundamentals of Ergonomic Exoskeleton Robots*. Thesis, Technische Universiteit Delft, 2008.

[3] Tjaša Kermavnar, Kevin J. O'Sullivan, Vincent Casey, Adam de Eyto, and Leonard W. O'Sullivan. Circumferential tissue compression at the lower limb during walking, and its effect on discomfort, pain and tissue oxygenation: Application to soft exoskeleton design. *Applied Ergonomics*, 86(June 2019), 2020.

[4] D W Ryan and P Byrne. A study of contact pressure points in specialised beds. *Clinical Physics and Physiological Measurement*, 10(4):331–335, 1989.

[5] L. Agam and A. Gefen. Pressure ulcers and deep tissue injury in wheelchair users: A bioengineering perspective. *International Journal of Therapy and Rehabilitation*, 15(2):90–99, 2008.

Appendix A

Appendix Example

I am an appendix. Add stuff here that is important but also not that important. Like code.

```
# Overall composite measure
CompositeMeasure {
  # Measure for gait, minimum speed = 1.0 m/s
  GaitMeasure {
    name = Gait
    weight = 100
    threshold = 0.05
    termination_height = 0.85
    min_velocity = 1.0
  }
  # Metabolic energy measure as defined in [Wang et al. 2012]
  EffortMeasure {
    name = Effort
    weight = 5
    measure_type = Wang2012
    use_cost_of_transport = 1
  }
  # Degree of Freedom composite measure
  CompositeMeasure {
    name = DofLimits
    symmetric = 1
    # Stops ankle hyper extension
    DofMeasure {
      weight = 0.1
      dof = ankle_angle
      position { min = -60 max = 60 squared_penalty = 1 }
    }
    # Stops knee hyper extension
    DofMeasure {
      weight = 0.01
```

```
      threshold = 5
      dof = knee_angle
      force { min = 0 max = 0 abs_penalty = 1 }
    }
    # Ground reaction force measure
    ReactionForceMeasure {
      name = GRF
      start_time = 1
      weight = 10
      max = 1.4
      abs_penalty = 1
    }
  }

```

Listing A.1 Original measures included for gait control optimisation in SCONE base model