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Design, model and build a USAR robot platform

Mechatronic Project 478
Final Report

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Executive summary

Title of Project
Design, model and build a USAR robot platform
Objectives
Create a model to describe the kinematics of a Load Intuitive Module (LIM). Build a prototype Urban Search and Rescue (USAR) device which uses LIMs to climb stairs. Validate the model using the prototype.
What is current practice and what are its limitations?
The current practice for USAR platform ranges widely, but the most successful platforms use tracks with paddles for locomotion. These devices are effective but very expensive, so there is a need for low cost expendable USAR robots.
What is new in this project?
This project will introduce a model to describe a less expensive stair climbing robot platform using LIMs.
If the project is successful, how will it make a difference?
The model developed in this project can be used to inform future USAR designs.
What are the risks to the project being a success? Why is it expected to be successful?
The main risk to this project is that it does not build a working prototype in time. This risk will be mitigated through careful planning and consideration of previous pitfalls.
What contributions have/will other students made/make?
In 2013, Matthew Wilson developed the LIM system as a masters project at the University of Cape Town (UCT). Further development on the system was done in final year projects at UCT by students Jordan Haskel, Murray Buchanan, and Richard Daniel Powrie in 2017, 2018, and 2019 respectively.
Which aspects of the project will carry on after completion and why?
USAR devices using LIMs as a platform can be designed, built and tested.
What arrangements have been/will be made to expedite continuation?
All calculations, designs, and code will be made available to future students.

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Chapter 1

Introduction

1.1 Background

During disasters such as earthquakes, Urban Search And Rescue (USAR) robots are used to detect victims in hazardous environments where first responders would otherwise be put at risk. Advanced USAR robots can explore and map the environment while overcoming obstacles, and deliver supplies to victims who cannot be immediately evacuated. USAR robots were first used in the aftermath of the September 11 attacks on the World Trade Centre, where they had limited success as they would frequently get stuck or damaged. Since then, designs for USAR robots with many different locomotion methods have been considered and compared in competitions such as the RoboCup Rescue Robot League and the DARPA Robotics Challenge. At present, USAR robots are typically only successful at surveillance; due to the extreme conditions in disaster zones and the urgency of rescue operations, first responders will rarely consider using USAR robots.

Another problem limiting the use of USAR robots is cost; USAR robots are prohibitively expensive so rescue organisations use them sparingly. There is a need for low-cost, expendable USAR robots. In 2013, Matthew Wilson proposed an automatically-shape-shifting platform that uses a Load Intuitive Module (LIM) in the place of regular wheels, shown in Figure 1.1 (Wilson, 2013). The LIM system uses a two outer "minor wheels" placed on a central hub that can be rotated as a "major wheel". The minor wheels are geared to the central hub such that they drive the vehicle, however if they experience high resistance, for example from hitting an obstacle, the torque will cause the major wheel to rotate instead, flipping one of the minor wheels over the obstacle to automatically climb it. This is a strong concept for an inexpensive stair-climbing robot as it only uses a single motor for both normal driving and climbing obstacles.

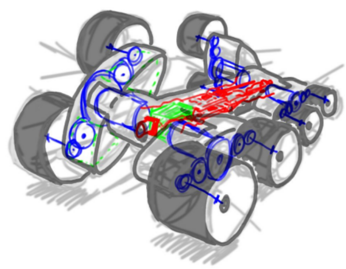

Figure 1.1: Systems layout of Wilson's LIM device (Wilson, 2013)

"LIMed" robot platforms (platforms using LIMs for locomotion) were built individually by four final year students at UCT (Wilson, 2013), (Haskel, 2017), (Buchanan, 2018), and (Powrie, 2019). One of these robots is shown in Figure 1.2. These platforms show some success in climbing a single step, albeit inconsistently. Powrie noted that a mathematical model that accurately describes the kinematics of the system could be developed to optimise the design of LIMed robots. This project is a continuation of these students' work.

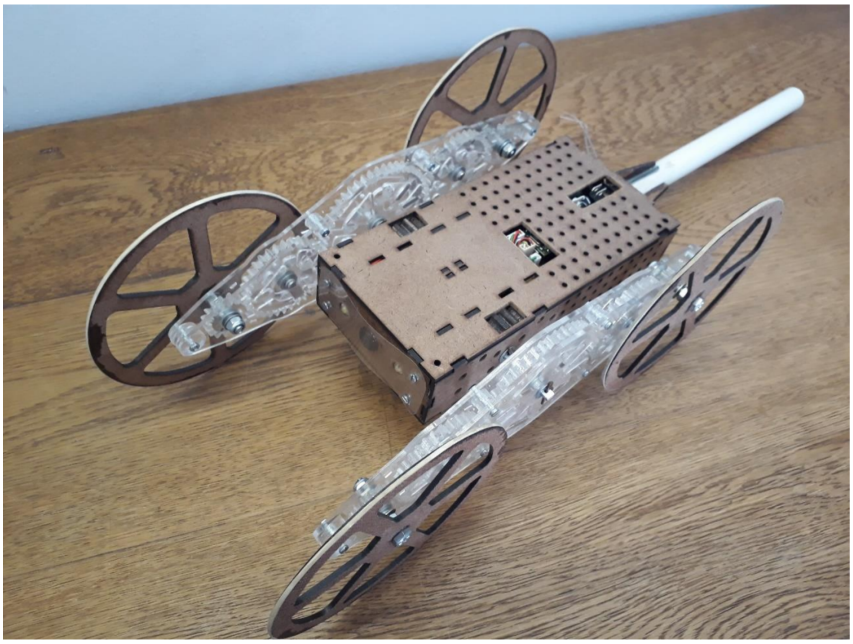

Figure 1.2: Powrie's "Di-Wheel" robot (Powrie, 2019)

1.2 Objectives

The aim of this project is to create a model that can be used to inform future USAR designs. The following objectives were identified to meet this aim:

1. Create a model to describe the kinematics of a LIM.
2. Build a prototype USAR device which uses LIMs to climb stairs.
3. Validate the model using the prototype.

This project does not intend to create a fully functioning USAR robot, but rather a prototype of the platform that a USAR robot may use.

1.3 Motivation

Many designs for USAR locomotion exist, however highly capable devices are prohibitively expensive. There remains a need for USAR devices that are both affordable and effective, and LIMed USAR robots could fill that role in the near future. Designers will be able to use the model produced in this report to design and optimise LIMed USAR robots. These robots use fewer actuators so could be cheaper than existing USAR robots. Lowering the cost of USAR robots is a priority as it makes them more accessible to rescue organisations.

Chapter 2

Planned Activities

2.1 Review Literature

Study work by previous students on LIMed robots. Additionally, research existing solutions for USAR platforms and identify methods that are applicable to this project.

2.2 2D Simulation

Perform a simple 2D simulation of a LIMed robot platform to gain a greater understanding of how it functions.

2.3 Create Model

Create a mathematical model to describe the kinematics of a LIMed robot platform. This will be presented in a way that describes how the degrees of freedom will move as a function of the platform's state and the torque applied to it.

2.4 Compile Design Requirements

Determine the requirements for the system, including functions that the platform must be able to perform and the cost of the platform. List these requirements in a way that they can be used to evaluate different concepts.

2.5 Design Platform

Compare concepts for a LIMed robot platform, then select the preferred concept based on its ability to meet the design requirements. Then create a detailed design of the robot platform.

2.6 Simulate Platform

Perform a mature simulation of the designed platform to ensure it will meet the requirements.

2.7 Produce Prototype

Construct a prototype of the robot platform. This will involve a combination of manufacture by the MMW, and assembly of the components.

2.8 Validate Model

Test that the model accurately describes the kinematics of a LIMed system through experimentation using the prototype.

2.9 Finalise Report

Document the entire project, including the process of creating a model, designing and production of the prototype, and experimentation. Comment on whether the model can be used to accurately describe the LIM system.

Please see Appendix A for the budget and time allocation of these activities.

Chapter 3

Risk Assessment

The main risk to the feasibility of the project is that there will not be enough time to build a fully functioning robot platform. The projects preceding this one all encountered complications when building robot platforms that they were unable to solve within the time constraints of their projects. This risk will be mitigated by completing activities in a timely manner as described in the Gantt. Chart, as well as careful planning and consideration of previous pitfalls.

There is also the risk that it will be impossible to create a closed form model to describe the dynamics of the system. If this is the case, simplifications and numerical methods will be used to produce the model.

There is a considerable risk that the project will exceed the allowed cost. This is because the prototype may require hardware such as high powered motors, custom parts, encoders, controllers, and possibly batteries, which may have a considerable cost. This will be mitigated by using hardware from the university where possible, as well as carefully considering the cost of components.

Chapter 4

Conclusions

USAR robots are a promising technology for disaster response. Reducing the cost of these robots will make them more accessible. The proposed project will provide a model to describe the kinematics of USAR robots that use LIMs for locomotion to reduce costs, and will produce a prototype of a USAR robot platform to show that the model is accurate. The result of these activities will be a validated model that can be used to inform future USAR designs using LIMs.

The project activities have been outlined and the project risks have been assessed and mitigated. The expected duration of the project is 8 months and the expected budget is R265 400.

Appendix A

Planning Details

This appendix contains an approximate budget and Gantt chart for the planned activities.

Table A.1: Estimated cost per activity

Activity	Engineering time		Running costs	Facility use	Capital costs	MMW Labour		MMW Material	TOTAL
	hr	R	R	R	R	hr	R	R	R
Review Literature	25	11250	500						11750
2D Simulation	25	11250	100	150					11500
Create Model	50	22500	200						22700
Compile Design Requirements	25	11250							11250
Design Platform	100	45000	500	500					46000
Simulate Platform	75	33750	300	1000					35050
Produce Prototype	100	45000	3000	2000	3500	50	15000	1500	70050
Validate Model	25	11250	500	300					12050
Finalise Report	100	45000	100						45100
Total	525	236250	5200	3950	3500	50	15000	1500	265450

This budget is based on a standard rate of R450/h.

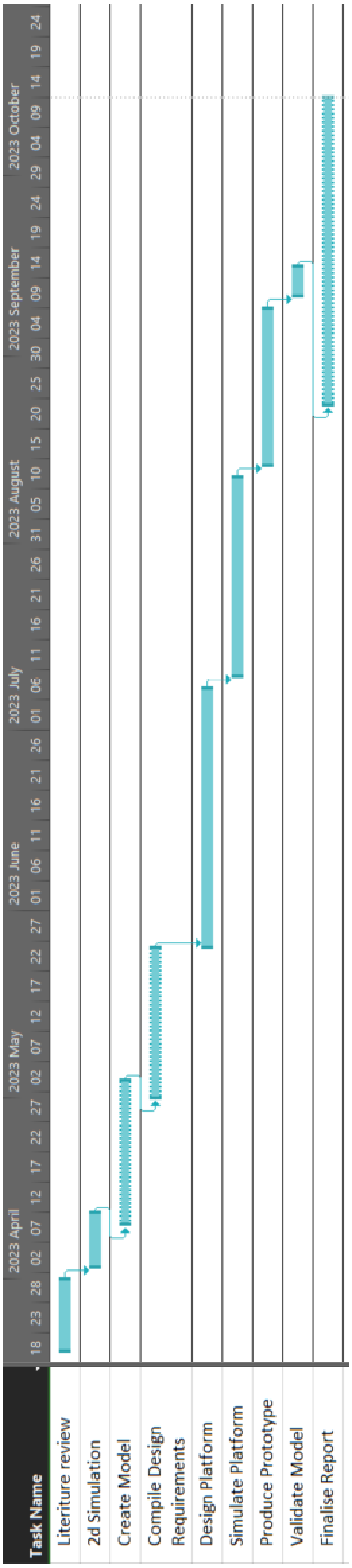

Figure A.1: Gantt Chart

Appendix B

ECSA Outcome Self Assessment

Table B.1: ECSA outcome self assessment

ECSA outcome	Application
Demonstrate competence to identify, assess, formulate and solve convergent and divergent engineering problems creatively and innovatively.	The design aspect of this project will require creative solutions to overcome the limitations of previous designs.
Application of scientific and engineering knowledge: Demonstrate competence to apply knowledge of mathematics, basic science and engineering sciences from first principles to solve engineering problems.	Producing the mathematical model will require kinematic calculations.
Engineering Design: Demonstrate competence to perform creative, procedural and non-procedural design and synthesis of components, systems, engineering works, products or processes.	A prototype of a USAR platform will be designed and produced.
Engineering methods, skills and tools, including Information Technology: Demonstrate competence to use appropriate engineering methods, skills and tools, including those based on information technology.	The project involves a CAD drawing and simulation of the platform, which will be based on information technology.
Professional and technical communication: Demonstrate competence to communicate effectively, both orally and in writing, with engineering audiences and the community at large.	All deliverables, including the proposal, progress report, final report, and presentation will demonstrate competent and effective communication.
Individual, Team and Multidisciplinary Working: Demonstrate competence to work effectively as an individual, in teams and in multi-disciplinary environments.	This project is done individually, with some input from the project supervisor.
Independent Learning Ability: Demonstrate competence to engage in independent learning through well-developed learning skills.	Research will be done in the literature review.

Appendix C

Resource use and end of life strategy

This project will build a prototype device that has a motor, a controller, wheels, and several custom parts such as gears and frames. A battery is unlikely to be included as it may be too expensive for a prototype build which can otherwise be wired to a power supply. The prototype will likely benefit from having a low mass, so there is already an incentive to use materials sparingly. Before construction, the design will be simulated to ensure that it meets requirements; this will mitigate the chance that a second prototype will need to be built. Upon completion of the project, the prototype will be disassembled and the motor, controller, and wheels can be reused in future projects. The custom parts are specific to this design so will not be suitable for most reuse applications; they shall be recycled. If the materials are such that they cannot be recycled, then they shall be disposed of instead. These materials will be chemically inert (not hazardous).

List of references

Buchanan, M. (2018). Ascender.

Haskel, J. (2017). A cost effective, tele-operated observation search and rescue robot.

Powrie, R. (2019). Di-wheel robot.

Wilson, M. (2013). Development of a low-cost, mid-sized, tele-operated, wheeled robot for rescue reconnaissance.