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

Literature review

1.1 USAR

1.2 USAR Robots

1.3 Load-Intuitive Modules

A Load-Intuitive Module (LIM) refers to a wheel system proposed by Matthew Wilson, 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. The system is referred to as "Load-Intuitive" because it will intuitively climb over obstacles in response to increased load on the wheels. LIMs are designed to be used in low cost USAR robots, allowing them to climb over objects without the need for many actuators.

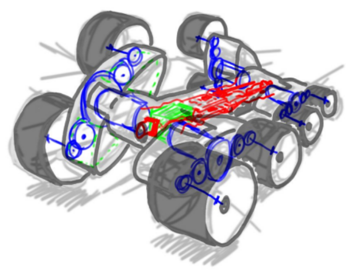

Figure 1.1: Systems layout of Wilson's LIM device (Wilson, 2013)

"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). These platforms show some success in climbing a single step, albeit inconsistently.

1.3.1 Wilson's LIM robot

Wilson designed and built the first LIM robot in 2013, shown in Figure 1.2. This robot was designed as a prototype for a low cost USAR star-climbing robot. At first Wilson considered only using LIMs for the front set of wheels, with the rear set using regular wheels. However, after performing a 2D simulation in Algodoo shown in 1.3, he concluded that using LIMs for the rear wheels was necessary as regular wheels provided little to no support to the climbing motion after the first step, presumably because the rear wheel would stop making contact with the stairs. Using LIMs for the rear wheels means they will be able to climb as well, and can always apply a forward force on the body.

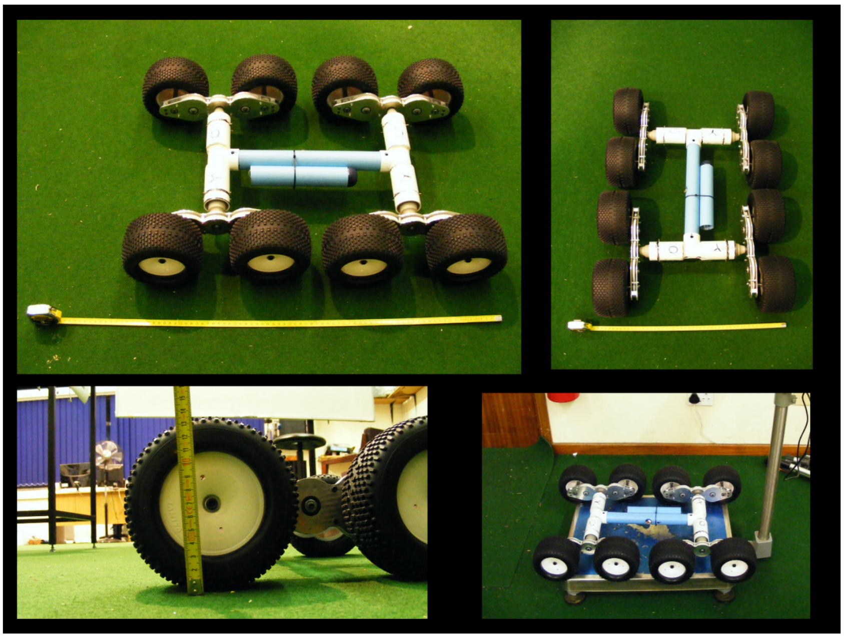

Figure 1.2: Wilson's Robot (Wilson, 2013)

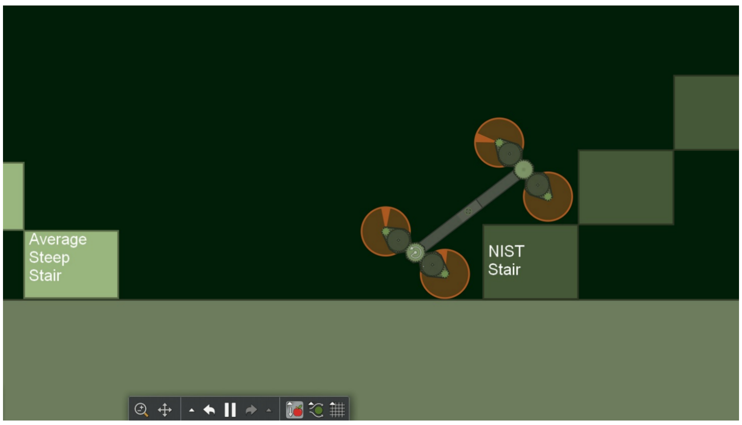

Figure 1.3: Wilson's Algodoo simulation of stair climbing (Wilson, 2013)

Wilson's robot had some limitations that prevented him from performing extensive tests. Chiefly, it was unable to climb stairs as the motors would stall upon encountering an obstacle. To validate the LIM concept in spite of this issue, Wilson split the robot in half and tested stair climbing using only the front LIMs and the chassis dragging behind as a tail. This "tail-dragging half assembly" was able to climb a single step as shown in Figure 1.4. Wilson's project ran out of time before he was able to solve the climbing motion of the complete robot, however he was able to confirm that the LIM system can climb at least a single stair in the half assembly configuration.

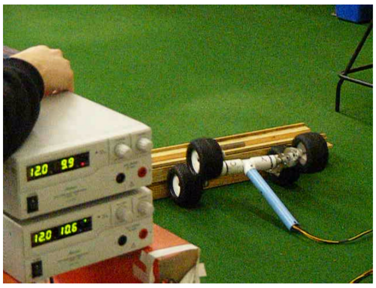

Figure 1.4: Wilson's half assembly climbing a stair (Wilson, 2013)

1.3.2 Haskel's Theseus

Haskel designed and built a LIMed robot to further test the concept, which he named "Theseus", shown in Figure 1.5. Unlike Wilson, Haskel assumes that using LIMs for rear wheels is not necessary for the stair climbing motion, and instead chooses to use a dragging tail to provide counter torque, similar to the tail-dragging half assembly used by Wilson. Theseus is much smaller and lighter than Wilson's robot.

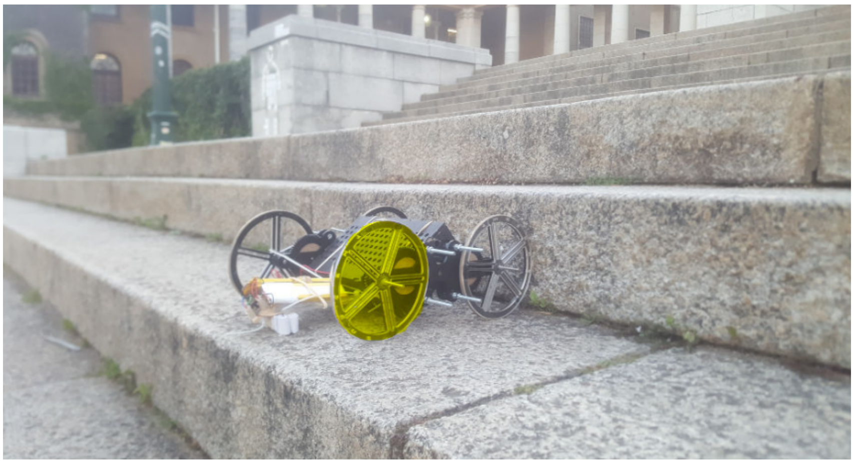

Figure 1.5: Haskel's Theseus (Haskel, 2017)

Haskel tested different concepts for the tire tread, dragging tail, and gear ratios. However, none of his configurations could consistently climb an step. In the majority of step-climbing attempts, Theseus' LIMs would flip over to mount the step, but it would not be able to pull itself up. This can be attributed to a lack of grip or a lack of torque. Haskel intended to do further work on the project, however he ran out of time due to component shortages and protests at UCT.

1.3.3 Buchanan's Ascender

Buchanan designed and built "Ascender", a robot platform using LIMs for locomotion, shown in Figure 1.6. Buchanan iterated on the design several times in order to reduce mass and increase torque. The intention was build a drivetrain that could be combined with the electronics of Haskel's Theseus to produce a successful stair climbing robot. As such, the Ascender does not include any electronic control systems, and is instead controlled externally by power supplies connected to the motors.

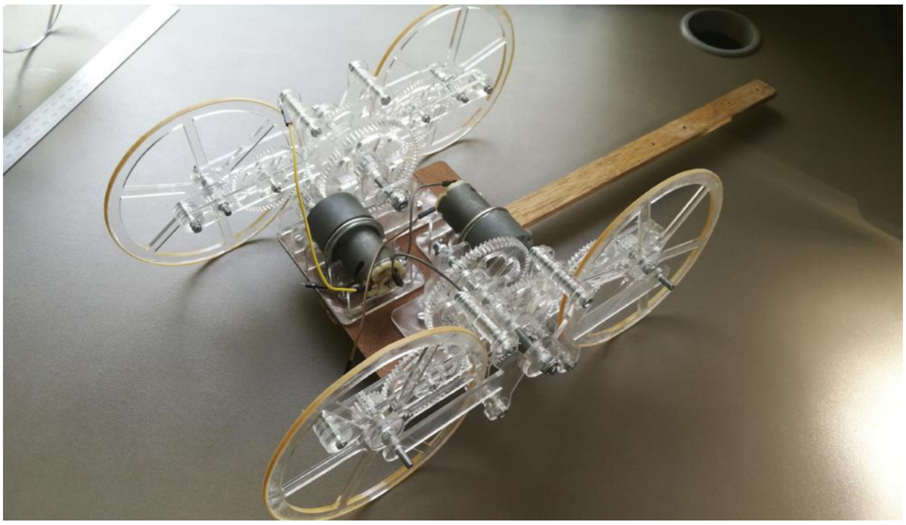

Figure 1.6: Buchanan's Ascender (Buchanan, 2018)

Buchanan's testing showed that the Ascender was able to climb a single step of 120 mm in 6 out of 10 attempts, and a step of 140mm in 2 out of 10 attempts. Buchanan noted a flaw in the design; after the LIMs flip over as part of the climbing motion, the body of the robot would lodge itself onto the the edge of the step and the wheels would spin freely, a phenomenon referred to as beaching. The LIMs would then spin until the top wheel makes contact with the top of the step, from there it would either grip and pull the robot up the step as intended, or it would dislodge the body and the robot would fall off the step. A successful climb is shown in Figure 1.7. Buchanan also reported that the Ascender was fragile to the point that it broke during the testing. Buchanan did not test the Ascender's ability to climb a staircase, but he concluded that it would be able to as a staircase is simply repeated single steps.

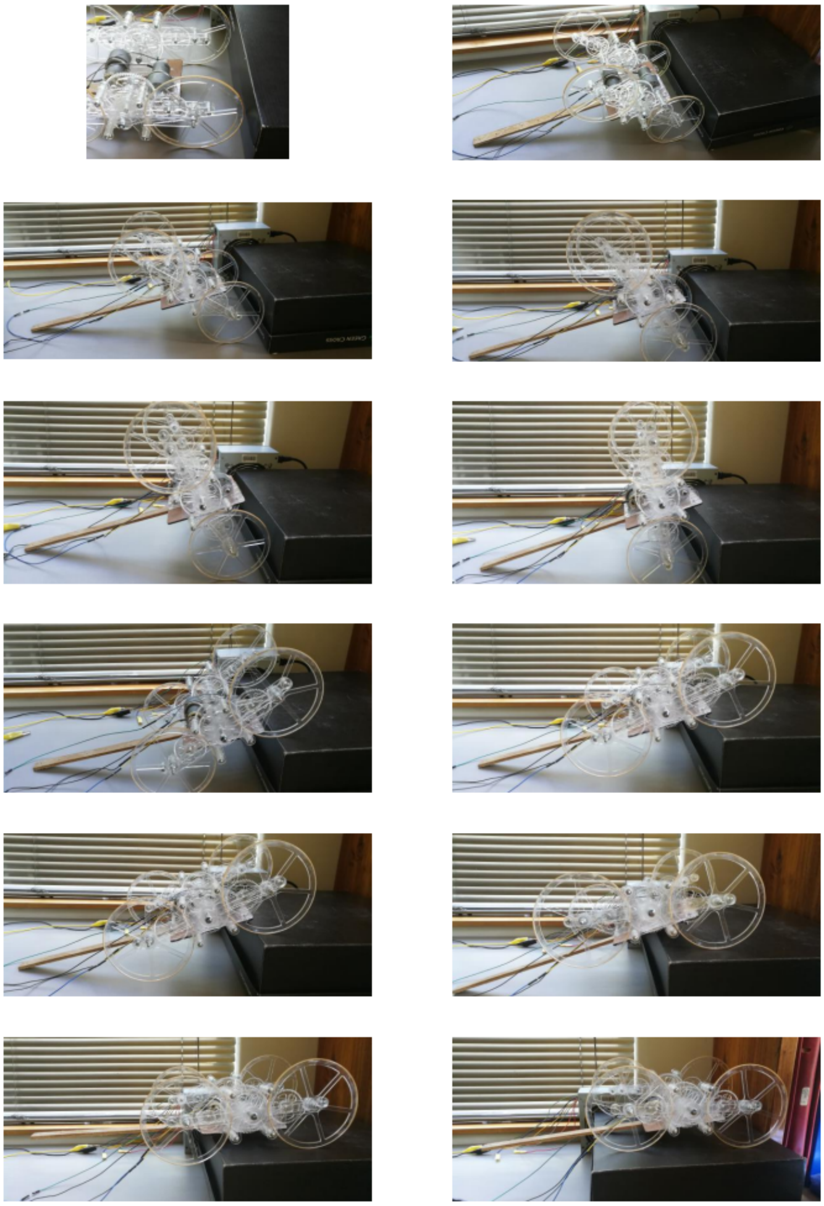

Figure 1.7: Buchanan's Ascender climbing a step (Buchanan, 2018)

1.3.4 Powrie's Di-Wheel robot

Powrie developed a robot using LIMs, however in his report he referred to LIMs as Di-Wheels. His reason for renaming them is that the behaviour of the LIMs does not only respond to external loads on the wheels, it also depends on the torque applied by the motors. He chose the name "Di-Wheel" in reference to a similar design by the name of "Tri-Wheel", which used three minor wheels instead of two, developed by Smith et. all (Smith *et al.*, 2015). Powrie's Di-Wheel robot is larger and more robust than Buchanan's Ascender, while being lighter than Wilson's LIMed robot. It is shown in Figure 1.8.

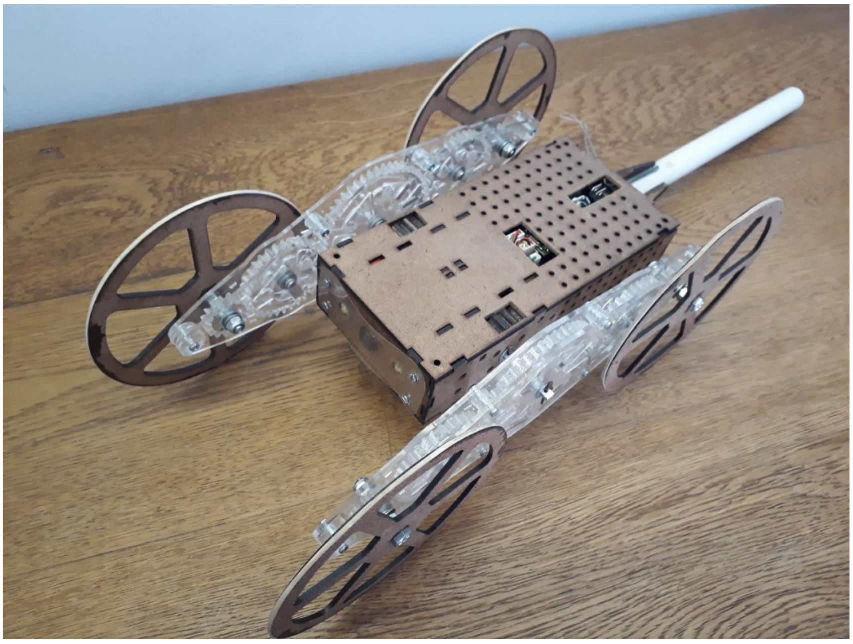

Figure 1.8: Powrie's Di-Wheel Robot (Powrie, 2019)

The Di-Wheel robot was successful in climbing a single step of 220 mm, shown in Figure 1.10. Further testing was not performed as noise from the robot's motors would interfere with the control system, preventing untethered driving. Powrie ran out of time before he was able to solve this issue. Powrie also found that when both motors are powered on, one of the LIMs would flip first, putting all the weight on the other LIM so preventing it from flipping. The result is that the robot would fall on its side, as seen in Figure 1.9.

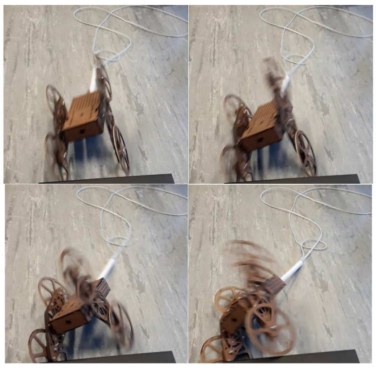

Figure 1.9: The Di-Wheel robot falling due to unsynchronised LIMs (Powrie, 2019)

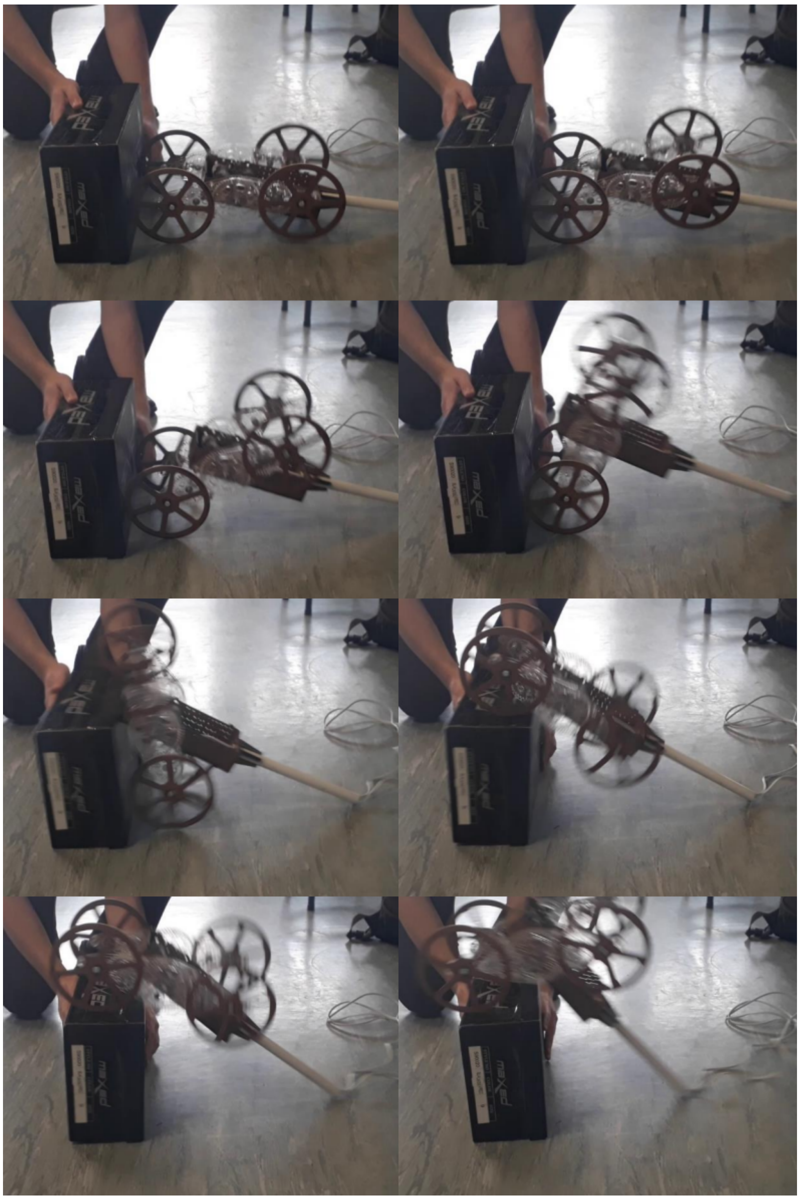

Figure 1.10: Powrie’s Di-Wheel robot climbing a step (Powrie, 2019)

1.3.5 Gearing

Chapter 2

Content chapter

Unless the chapter heading already makes it clear, an introductory paragraph that explains how this chapter contributes to the objectives of the report/project.

2.1 Heading level 2

2.1.1 Heading level 3

2.1.1.1 Deepest heading, only if you cannot do without it

Equations: An equation must read like part of the text. The solution of the quadratic equation $ax^2 + bx + c = 0$ given by the following expression (note the full stop after the equation to indicate the end of the sentence):

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2b}. \tag{2.1}$$

In other cases the equation is in the middle of the sentence. Then the paragraph following the equation should start with a small letter. Euler's identity is

$$e^{i\pi} + 1 = 0, \tag{2.2}$$

where e is Euler's number, the base of natural logarithms.

The `amsmath` has a wealth of structure and information on formatting of mathematical equations.

Symbols and numbers: Symbols that represent values of properties should be printed in italics, but SI units and names of functions (e.g. sin, cos and tan) must not be printed in italics. There must be a small hard space between a number and its unit, e.g. 120 km. Use the `siunitx` package to typeset numbers, angles and quantities with units:

`\num{1.23e3}`	$\rightarrow$	1.23×10^3
`\ang{30}`	$\rightarrow$	$30°$
`\qty{20}{N.m}`	$\rightarrow$	$20\,\mathrm{N\cdot m}$

Figures and tables: The `graphicx` package can import `PDF`, `PNG` and `JPG` graphic files.

Table 2.1: Standard ISO paper sizes

Paper	Sizes	
	W [mm]	*H* [mm]
A0	841	1189
A1	594	841
A2	420	594
A3	297	420
A4	210	297
A5	148	210

Figure 2.1: Water plants

Appendix A

ECSA Outcome Self Assessment

Table A.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 B

Mathematical proofs

B.1 Euler's equation

B.2 Navier Stokes equation

Appendix C

Experimental results

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.

Smith, L.M., Quinn, R.D., Johnson, K.A. and Tuck, W.R. (2015). The tri-wheel: A novel wheel-leg mobility concept. In: *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 4146–4152.

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