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IMechE Design Concept Challenge

Engineering Design

ACMA4008

Jónatas da Silva Ribeiro Fernandes

2306264

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1 Introduction

This essay aims to emulate the process of designing a mechanical system for a competition. The task, issued by the Institution of Mechanical Engineers, tests participant's abilities to integrate engineering principles into working physical systems. The scope of the project includes creating one or multiple 3D models, a Bill of Materials (BoM), and a technical design report.

The objective is to create an analogue, self-contained vehicle, capable of travelling down a track of variable length, engaging with a vertical target, symbolizing a charging port, and returning to its initial position, further, once docked with the charging port, the vehicle must remain stationary for several seconds to simulate energy transfer. All these tasks must be achieved without microcontrollers or the like.

Constraints of note are:

- The vehicle must operate autonomously once started
- The track will be a variable length between 1.4 and 4 meters.
- A vertical target positioned 50mm above the floor must be struck with a plunger.

This challenge tests multiple qualities fundamental to engineering, including system design, robustness, and electrical interfacing.

This report details the development process from initial concept through to result. It includes technical drawings, CAD models, a BoM, feasibility analysis and further improvements.

2 Initial Design Concepts

2.1 Four Wheel Design

The initial design consists of a 4 wheeled design, the rear wheels are powered by individual motors, whilst the front wheels can only spin freely, as they are affixed to bearings.

The chassis is built from a 4mm sheet of acrylic, cut to size, providing sufficient structural strength whilst remaining inexpensive and easy to work with.

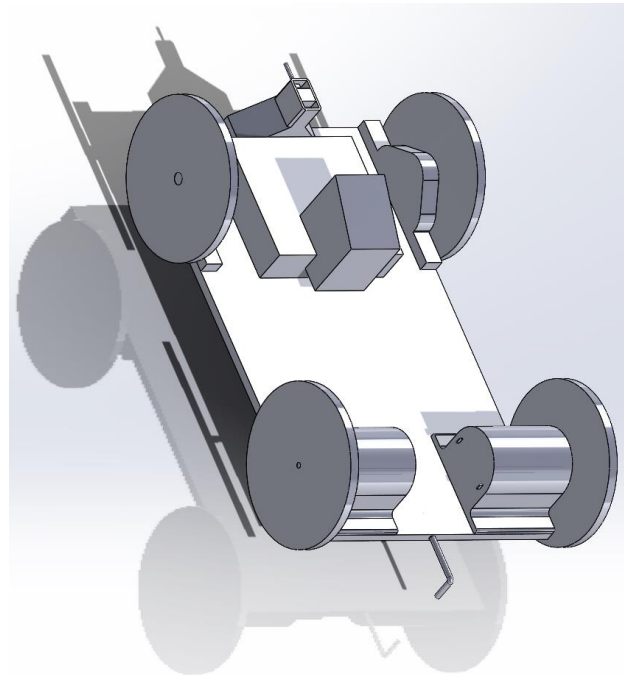


Figure 1, 4 Wheel Concept Design

2.1.1 Design Features

- Two DC Motors, coupled directly to the rear wheels
- Front wheels, mounted on bearings to mitigate unwanted resistance
- 3D Printed housings, for the motors, front wheels, and plunger switch
- Manual Button built into chassis to start vehicle
- Plunger switch wired into relays to invert the motor direction

2.1.2 Advantages

- Balanced, 4 wheels provide the vehicle with ample balance
- Symmetrical design, in theory both sides should behave identically
- Low Center of Mass, Wheel placement above the chassis results in a lower ride, increasing stability.

2.1.3 Risks

- Complex, two motors must receive identical power and at the same time to prevent veering.
- Higher energy consumption, a battery capable of supplying two motors running concurrently is required.

2.2 Three Wheeled Design

The three-wheel design looks to remediate the glaring issue with the four-wheel design, synchronicity of powered wheels. By having only one powered wheel, there can be no mismatch in power delivery. The wheels at the front remain the same.

2.2.1 Design Features

- Single DC Motor, coupled directly to the rear wheel
- Front wheels, mounted on bearings to mitigate unwanted resistance
- 3D Printed housings, for the motors, front wheels, and plunger switch
- Manual Button built into chassis to start vehicle
- Plunger switch wired into relays to invert the motor direction

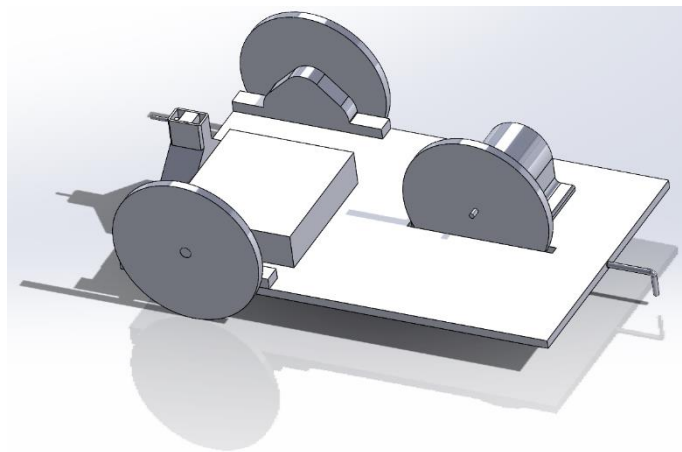


Figure 2, 3 Wheel Concept Design

2.2.2 Advantages

- Simpler Drive System, only one motor to power
- Smaller risk of veering, due to only one powered wheel

2.2.3 Risks

- Stability, three wheels are less stable than four. The design aims to be symmetrical, but weight imbalances could pose an issue with tipping
- Traction, a single wheel with a single motor could be prone to slipping, especially with acrylic wheels. If this were to happen, any mechanical counting of distance would immediately become inaccurate
- Chassis complexity. This design requires a hole in the chassis, to retain the back edge for the pin required in every design. This is far more complex than what is essentially an acrylic rectangle.

2.3 Risk Mitigation

For both concepts, risks and how to mitigate them were considered:

TYPE	RISK	MITIGATION
4 Wheel	Motor Speed Mismatch	Identical motors
3 Wheel	Instability	Careful weight distribution, low center of gravity
Both	Veering off track	Large, wide wheels for better traction and wide chassis.

2.4 Design Choice

Ultimately, the four-wheel design was chosen as the final design., as shown in chapter 3. The three-wheel design was promising, but the instability from asymmetry and complexity with motor placement, coupled with the four-wheeler's better performance saw it best fit as a backup, in case further testing of the four-wheeler design exposed performance issues.

3 Final Design and Bill of Materials

3.1 Design

Constructed from 4mm thick acrylic sheet, measuring 200mm in length and 120mm in width, the chassis supports all the

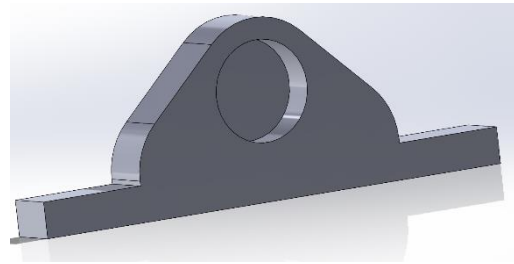


Figure 3, Front Wheel Housing

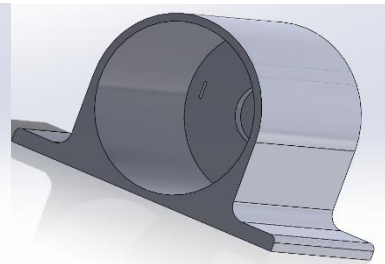


Figure 4 Motor Housing

components present in this build. Front wheel sockets, housings for switches and batteries are joined to the acrylic by adhesive. Acrylic binds well to plastics and using screws was decided against, as they make experimentation with placement of parts much harder.

The Switch Casing, Motor Casing and Front Wheel Mount are intended for 3d printing, making a bespoke yet inexpensive enclosure for the required parts.

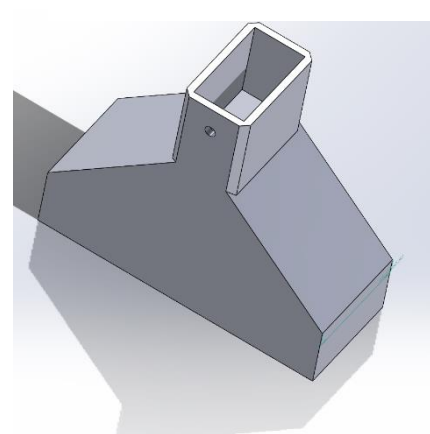


Figure 6, Switch Housing

Both the front and back wheels are also cut out of 4mm thick acrylic with a diameter of 68mm. The front wheels have an inner hole of diameter 5mm, whilst the rear wheels have an inner hole diameter of 2.4mm.

Commercially available bearings are chosen for affixing of the front wheels, measuring at 5mm inner diameter, 14mm outer shell diameter, and 5mm deep. An inexpensive 5mm thick steel rod is cut to size for the purpose of joining the front wheels and the bearings.

Two inexpensive motors are selected, they are adjoined to the rear wheels directly, hence the difference in diameters for the rear and front wheels.

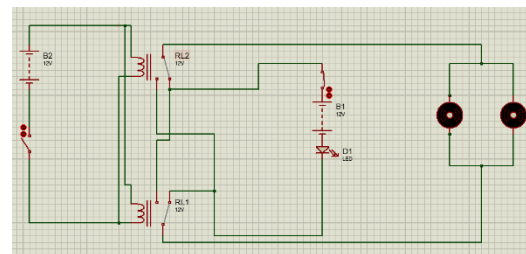


Figure 7, Incomplete Electrical Circuit

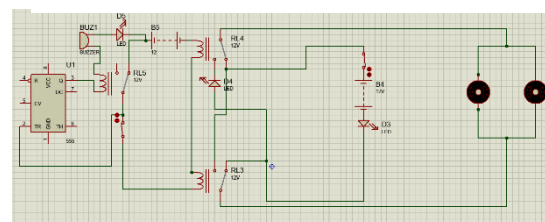


Figure 8, Electrical Circuit Draft

The switch meant to emulate a charging port is also commercially available, a small rod, 12mm long, is 3D printed to be fixed on the end of the switch. 10mm of the rod will protrude out of the switch casing and ahead of the vehicle.

An electric circuit, composed of batteries, resistors, relays, switches, capacitors motors and transistors ensure the dc motor polarity reverses once the front switch is activated. A simple delay of around 10 seconds is activated once polarity reverses, turning on a red LED and sounding a buzzer, after which the vehicle begins to move backwards. As the time it takes the vehicle to reach the wall is recorded, to get back to the original position to motors simply must run for the exact same duration, just in reverse.

3.2 Bill of Materials

Item:	Description:	Quantity:	Notes:
Baseplate	Acrylic rectangle	x1	200x120x4mm
Motor	DC 6V Motor	x2	RS 238-9715
Front Wheel	Acrylic Circle	x2	68x4mm, 5mm inner diameter
Rear Wheel	Acrylic Circle	x2	68x4mm, 2.4mm inner diameter
Metal Shaft	Steel Cylinder	x2	5x10mm
Bearing	Ball Bearing	x2	RS 261-2679
Switch	On/Off Switch	x1	RS 185-8229
Plunger Switch	On/Off Switch	x1	RS 686-6764
Green LED	Indicator LED	x1	RS 228-6004
Red LED	Indicator LED	x1	RS 228-5562
Buzzer	Piezo Buzzer	x1	RS 535-8275
Relay	Coil Relay	x2	RS 303-370
Battery	4x AA Battery Holder	x2	RS 185-4643
Capacitor	Part of 555 IC circuit	x1	4.7mF
Resistor	Part of 555 IC circuit	x1	2.2mΩ
Wire	Assorted wires		
555 IC	Delay Circuit	x1	RS 709-2110
Counter IC	Counter for distance measuring	x1	RS 732-0691
Screw	Measures Distance	x1	RS 397-4954

4 Design Review and Feasibility Analysis

To ensure a successful development process, clear and solid design specifications must be adhered to. They act as the guidelines for every other process of the design pathway, these of course, are present in the brief from IMechE.

The key requirements are as follows:

- The vehicle must fit within a 400x400x400mm cube.
- Plug must sit 10mm in front of the rest of the vehicle.
- Back screw must be no more than 6mm from the ground, vertically.
- The vehicle must be fully analogue, no micro-controllers.
- The vehicle must engage with a target on a vertical wall, some distance from the starting line.
- Vehicle must be entirely self-contained.
- Vehicle must complete all auctions autonomously, bar the initial turning on.
- Vehicle must retrace path back to starting position, once engaged with wall.

4.1 Design Review

The final design succeeded in a myriad of the measuring criteria. It can go forward in a straight line once switched on, the front plunger does automatically reverse the polarity of the motors. The acrylic body and wheels, coupled with off the shelf steel rods are a timeless choice for such projects. 3D printing of custom casings for components provides a sleek, efficient and inexpensive solution to a complex issue.

It should be noted that the “555” IC portion was not entirely completed. A mock-up of the whole circuit is available, however, integrating the chip correctly proved difficult.

In theory, if set up properly it will cause a 10 second delay. The same can be said for the counter, no easy way to integrate it into the circuit presented itself, however, it should allow the circuit to keep track of how much time has elapsed since switch on and use the timer to run the motors in reverse for the same duration.

A decision was made early on to go with the foundational tier, which seems like the more difficult one out of the two. Although the advanced tier requires the vehicle to pivot or in some way translate the fake charging port to two separate targets, the benefits of being able to use microcontrollers vastly outweigh the small amount of effort required to create a pivotable charger. The foundational tier with its analogue requirements better aligns with the spirit of the competition, requiring out of the box solutions.

5 Conclusion and Recommendations

5.1 Conclusion

The project successfully developed a mechanical and electrical design concept. And partially successfully developed an electrical solution.

The system effectively conveys the plausibility of solving this problem without the help of microcontrollers using relays for reversing motor polarities, timer integrated circuits for maintaining stasis for a given period, and counter integrated circuits for storing distance travelled.

There is, of course, room for improvement.

5.2 Further Work

Considering the design criteria is incomplete, a massive improvement would be to finalize the electrical circuit to complete the task successfully. This means integrating a timer IC and a counter IC into the main circuit.

Further, better motors would increase accuracy of power distribution in a two-motor approach. Experimentation with widening the base to improve the vehicles alignment with the intended vector could prove successful.

In a finalized design, creating a custom printed circuit board could remove messy wires and create a more intuitive circuit for quick repairs or modifications.

5.3 Final Remarks

The designed vehicle represents the potential of a reliable and simple solution to the problem set by the IMechE challenge. With further development of the inner workings, it is likely to perform strongly.

6 References

Fernandes, J. (2025) *Figure 1-8*.