

Master Thesis

Design and implementation of a remote controlled segway

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This is the abstract

Contents

1	Objective	4
2	Design	5
2.1	Flywheel design	5
3	Mechanical analysis	9
3.1	Reference frames	9
3.2	Inclination control	9
3.3	Flywheel torque	9
3.4	Hypothesis	10



Figure 1: Picture of a commercial *segway hover-board*

1 Objective

The objective of this project is to build a dynamic robot in order to experiment with reinforcement learning algorithm with real data. We wish to make this experiments easy and cheap to reproduce so we will try minimize its components and fabrication cost.

The chosen robot is inspired in a *segway hover-board*, similar to the one in Figure 1. The two wheels are controlled with classic control algorithms and the inclination of the central body is controlled with a reinforcement learning algorithm.



Figure 2: Isometric render view



Figure 3: Front render view

2 Design

The design of the body is done with a 3D design software Free-cad. All part files are uploaded to the GitHub repository <https://github.com/tarragoesteve/TFM> under the hardware folder. You can see the main views on Figure 2, 3, 4 and 5

We included three actuators in the robot because we want to control 3 degrees of freedom (inclination and speed of both wheels). Furthermore we introduced a fly-wheel to control the inclination of the body.

We ensured symmetry along the axis formed by all motors in order to have an equilibrium in all possible inclinations without the need of external forces. We also took in consideration that the reinforcement learning algorithm starts being clumsy so none of the configurations should intersect with the ground. Figure 5 illustrates this restriction.

2.1 Flywheel design

To control the inclination of the body two strategies were taken in to account. Creating torque by a pendulum or by a the acceleration of flywheel. In order to experiment with both of them we designed a part to allow both configuration by placing weights in different spots, figure 7.

One of the weight can be placed along a rail so when it has radius different from

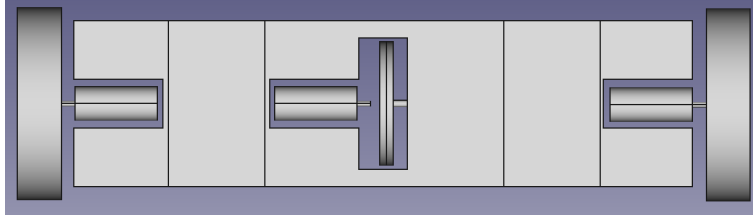


Figure 4: Top render view

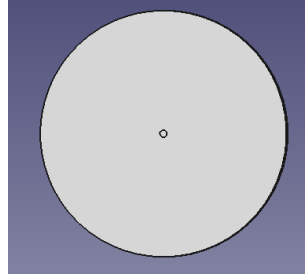


Figure 5: Side render view

maximum the flywheel has a torque. The pendulum torque τ , considering the masses are cylinders of width w and radius r_c , and the flywheel has a radius r_f is the following:

Each mass weights:

$$m = \rho * w * \pi * r_c^2$$

All mass will be compensate the opposed one except the two with different radius. The maximum torque take place when these two masses are aligned horizontal with respect the ground.

$$\tau_{max}(r_c) = m * (r_f - r_c) - m * r_c = m * (r_f - 2 * r_c)$$

In order to maximize it we first compute the derivative:

$$\frac{\partial \tau_{max}(r_c)}{\partial r_c} = \frac{\partial m}{\partial r_c} * (r_f - 2 * r_c) - m * 2$$

$$\frac{\partial m}{\partial r_c} = 2 * \rho * w * \pi * r_c$$

An make it zero to find the maximum:

$$\frac{\partial \tau_{max}(r_c)}{\partial r_c} = 0$$

Substituting and simplifying we get:

$$\frac{\partial m}{\partial r_c} * (r_f - 2 * r_c) = m * 2 \Rightarrow 2 * \rho * w * \pi * r_c * (r_f - 2 * r_c) = \rho * w * \pi * r_c^2 * 2$$

$$\Rightarrow r_c * (r_f - 2 * r_c) = r_c^2 \Rightarrow (r_f - 2 * r_c) = r_c \Rightarrow r_f = 3 * r_c$$

The circumradius R from the center of a regular polygon to one of the vertices is related to the side length s by

$$R = \frac{s}{2 * \sin \frac{\pi}{n}}$$

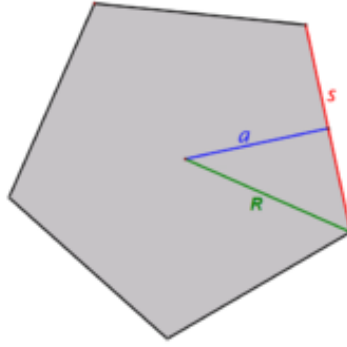


Figure 6: Polygon parameters

In our case:

$$R = r_f - r_c;$$

$$s = 2 * r_c$$

Substituting in the circumradius equation we get $n = 6$, so we will use 6 masses in our flywheel.

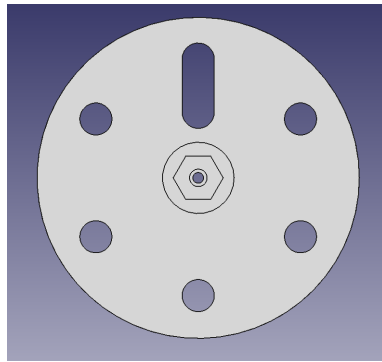


Figure 7: Fly wheel side render view

3 Mechanical analysis

3.1 Reference frames

In order to study the behaviour of the robot we will use the following frames:

- Absolute frame: From a fix object in the room.
- Body frame: From the body of our robot.

3.2 Inclination control

In order to keep the inclination at a certain angle we must be able to compensate all the torque beeing applied to the body.

Assuming that the body is well balanced, the sum of all the torques in the motor axis applied to the body is equal to the sum of the torque applied by the motors:

$$\tau_{body} = \sum \tau_{motors}$$

The torque of the motors produce a reaction in the body oposite to the torque that the motors deliver to the wheels and the flywheel.

$$\tau_{body} = -\tau_{right-wheel} - \tau_{left-wheel} - \tau_{flywheel}$$

If we want to control the inclination θ , we must be able to control τ_{body} in a range $\tau_{body} \in (-\epsilon, \epsilon)$. Observe that the angular acceleration of the body is liniarly dependent with the torque it recieves. In the limit case $\epsilon = 0$. In order to simplify the calculations we will assume $\epsilon = 0$.

$$0 = -\tau_{right-wheel} - \tau_{left-wheel} - \tau_{flywheel} \Rightarrow \tau_{right-wheel} + \tau_{left-wheel} = -\tau_{flywheel}$$

In other words, we must compensate the torque of the wheels with the torque of the flywheel.

3.3 Flywheel torque

The flywheel torque is only limeted by the motor specifications. Note that at max speed the torque is zero.

$$\tau_{motor}(w)$$

Here we have the factory specifications of our motors:

- Operating voltage: between 3 V and 9 V
- Nominal voltage: 6 V
- Free-run speed at 6 V: 176 RPM

- Free-run current at 6 V: 80 mA
- Stall current at 6V: 900 mA
- Stall torque at 6V: 5 kgcm
- Gear ratio: 1:35
- Reductor size: 21 mm
- Weight: 85 g

3.4 Hypothesis

Assuming that the body is well balanced