Introduction to Mechatronic

Mini segway

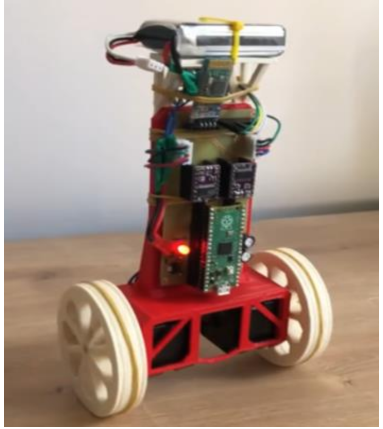
دانشگاه علم و صنعت ایران

Design and Simulation

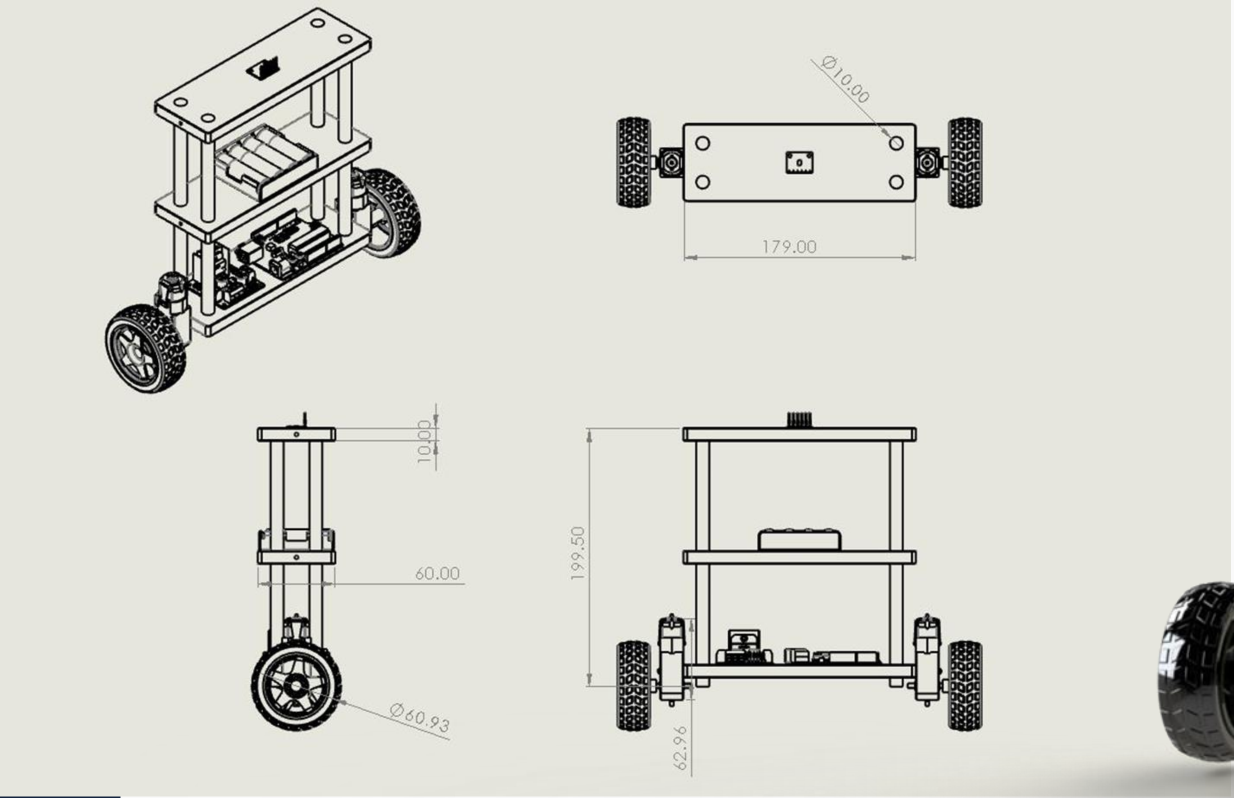
Self balancing robot

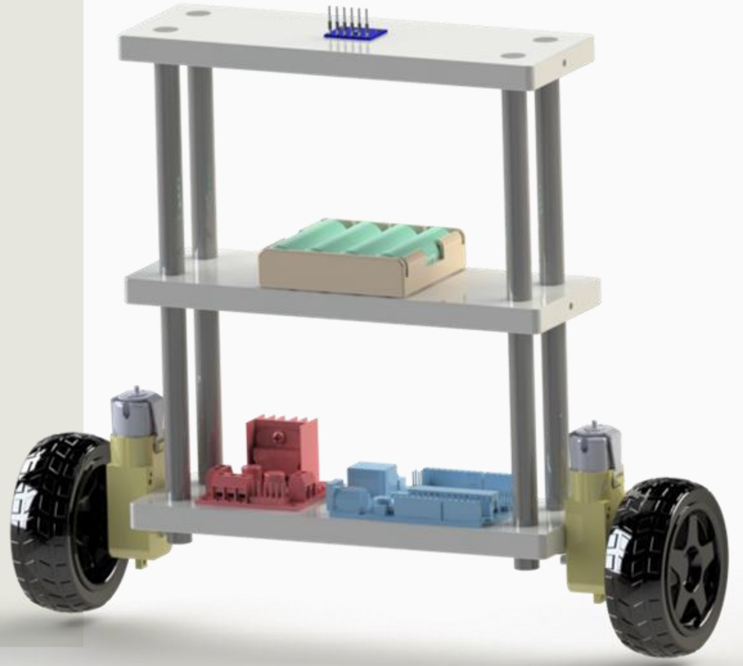
Real world examples

Similar Projects

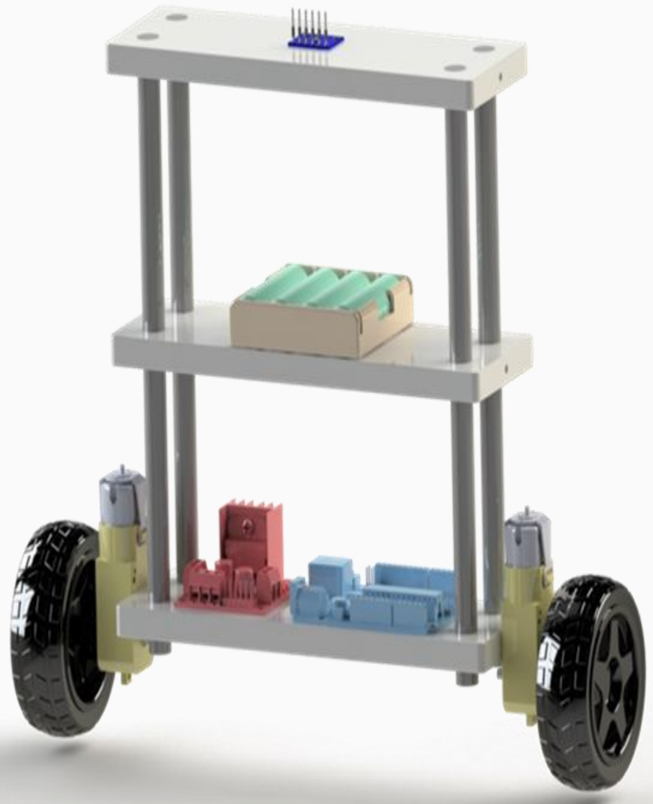


Solidworks





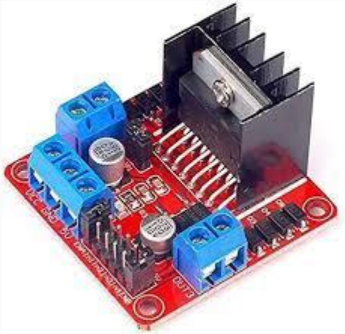
Components



Tools	Price	Weight
Motor DC	750,000IRR	150g
Drivers	750,000IRR	70g
Arduino uno	305,000IRR	90g
Wheel	200,000IRR	175g
plate	800,000IRR	400g
rod	200,000IRR	50g
MPU6050	700,000IRR	3g
Battery 9v	1,000,000IRR	50 g
Remote Control	500,000IRR	-
Total	10,000,000IRR	2100g

Modules & sensors Libraries in Arduino

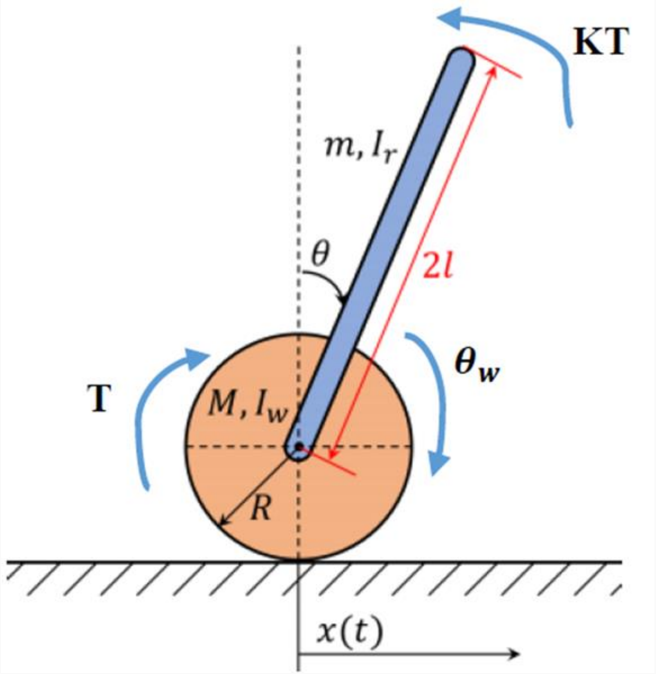
Driver L298N:
<LMotorController.h>



MPU6050:
"MPU6050_6Axis_MotionApps20.h", "I2Cdev.h" or "wire.h"

PID Controller:
<PID_v1.h>

Dynamic Equations



$$\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\partial T}{\partial \dot{q}_j}\right)-\frac{\partial T}{\partial q_j}=Q_j \qquad T=\frac{1}{2}\dot{x}^2\left[M+m+\frac{I_w}{R^2}\right]+\frac{1}{2}\dot{\theta}^2[I_r+ml^2]$$

$$Q_1=T \ \& \ Q_2=\mathrm{mlgsin\theta}-T$$

$$\begin{cases}(k_1)\,\ddot{x}+(k_2\ \cos\theta)\ddot{\theta}=T+(k_6\ \sin\theta)\dot{\theta}^2\\[2ex](k_3\cos\theta)\,\ddot{x}+(k_4\,)\ddot{\theta}=(k_5\ \sin\theta)-KT\end{cases}$$

Which:

$$\begin{cases}k_1=(M+m)R+\frac{I_w}{R}\\ k_2=mlR\\ k_3=ml\\ k_4=I_r+ml^2\\ k_5=mlg\\ k_6=MlR\\ K=40\quad Gear\ ratio\end{cases} \qquad \begin{cases}M=0.48\ Kg\\ m=1.05\ Kg\\ R=0.03\ m\\ g=9.81\\ l=0.15\ m\\ I_w=0.0043\ Kg.m^2\\ I_r=0.027Kg.m^2\end{cases}$$

Linearization and State-Space

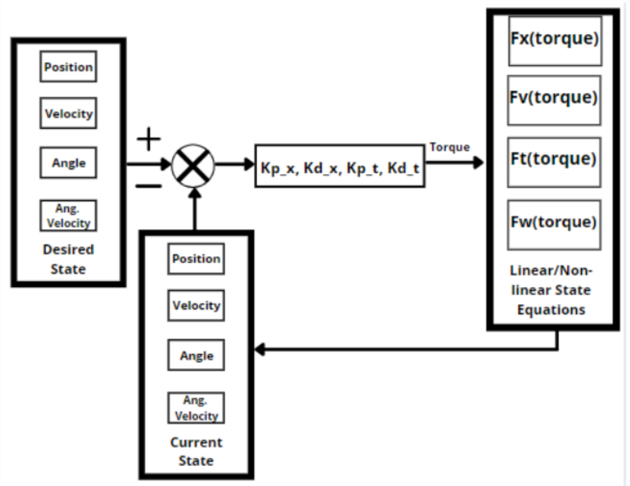
Assume: $\theta = 0 \;\rightarrow sin\theta = 0 \;\&\; cos\theta = 1$

$$\begin{cases} (k_1)\,\ddot{x} + (k_2)\ddot{\theta} = T \\ (k_3)\,\ddot{x} + (k_4)\ddot{\theta} = (k_5\,\theta) - KT \end{cases}$$

$$\begin{bmatrix} \dot{x} \\ \ddot{x} \\ \dot{\theta} \\ \ddot{\theta} \end{bmatrix} = \underbrace{\begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & \dfrac{-k_2\,k_5}{k_1\,k_4 - k_2\,k_3} & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & \dfrac{-k_1\,k_5}{k_1\,k_4 - k_2\,k_3} & 0 \end{bmatrix}}_{A} \begin{bmatrix} x \\ \dot{x} \\ \theta \\ \dot{\theta} \end{bmatrix} + \underbrace{\begin{bmatrix} 0 \\ \dfrac{(K\,k_2 + k_4)}{k_1 k_4 - k_2\,k_3} \\ 0 \\ \dfrac{(K\,k_1 + k_3)}{k_1 k_4 - k_2\,k_3} \end{bmatrix}}_{B} T$$

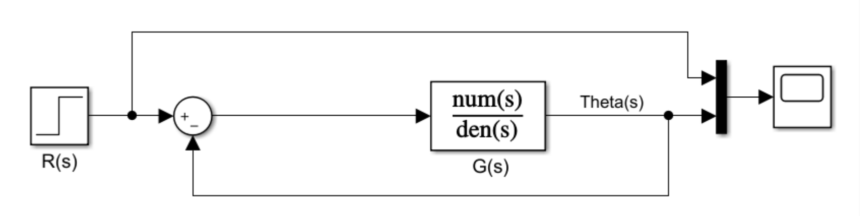
$$\begin{bmatrix} \dot{x} \\ \ddot{x} \\ \dot{\theta} \\ \ddot{\theta} \end{bmatrix} = \underbrace{\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}}_{C} \begin{bmatrix} x \\ \dot{x} \\ \theta \\ \dot{\theta} \end{bmatrix} + \underbrace{\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}}_{D} T$$

Control



I. Assuming Linear metho, we can .Control the system 1 Input & 1-Output
II. We can control Theta using MPU6050:

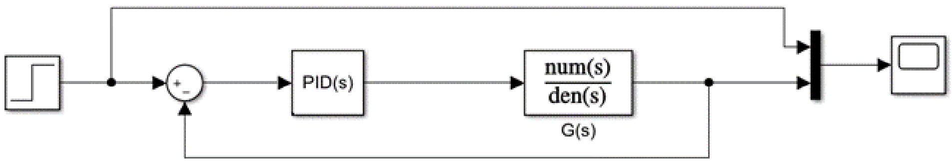
$$G(s) = \frac{\theta(s)}{T(s)} = \frac{-s^2(k_3 + K.K_1)}{s^4(k_1k_4 - k_2.k_3) - s^2.k_1k_5}$$



PID

روش های مختلفی برای بدست آوردن ضرایب کنترل PID وجود دارد:

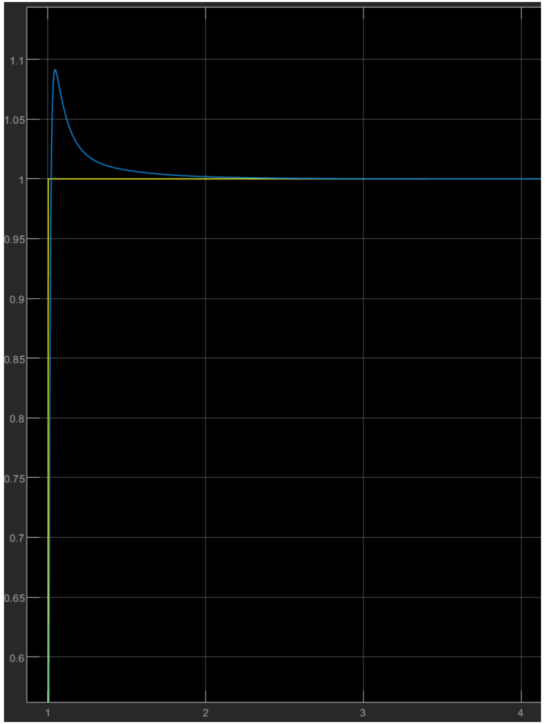
- ✓ Trial & error
- ✓ Zigler-Nicohles
- ✓ PSO-Based PID controller
- ✓ Tune(MATLAB)
- ✓ Pole placement

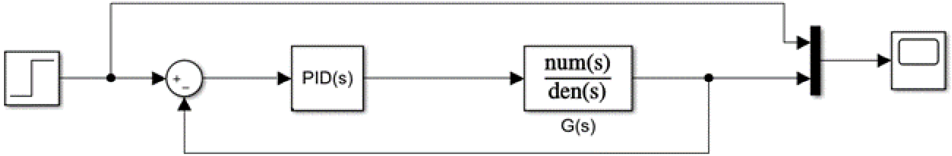


Another methods:

- LQR
- RL
- astorm-hugglund

PID in Simulink (MATLAB)



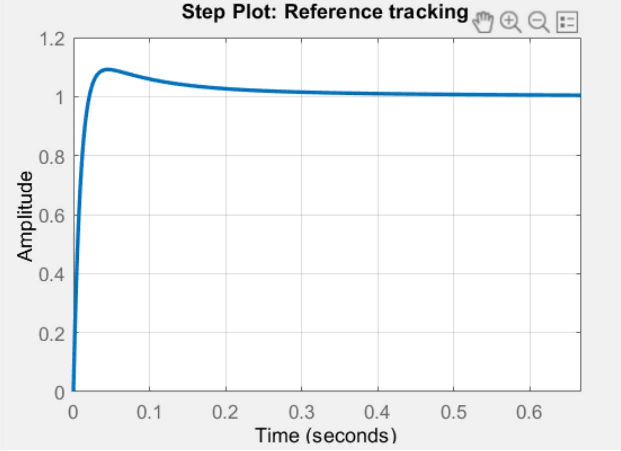


Signal Statistics

	Value	Time
Max	1.092e+00	1.046
Min	0.000e+00	1.000
Peak to Peak	1.092e+00	
Mean	6.587e-01	
Median	1.000e+00	
RMS	8.049e-01	

$$PID(s) = P + I\frac{1}{s} + D\frac{N}{1 + N\frac{1}{s}}$$

P=-1.82
I=-3.88
D=-0.13
N=13689



Simscape

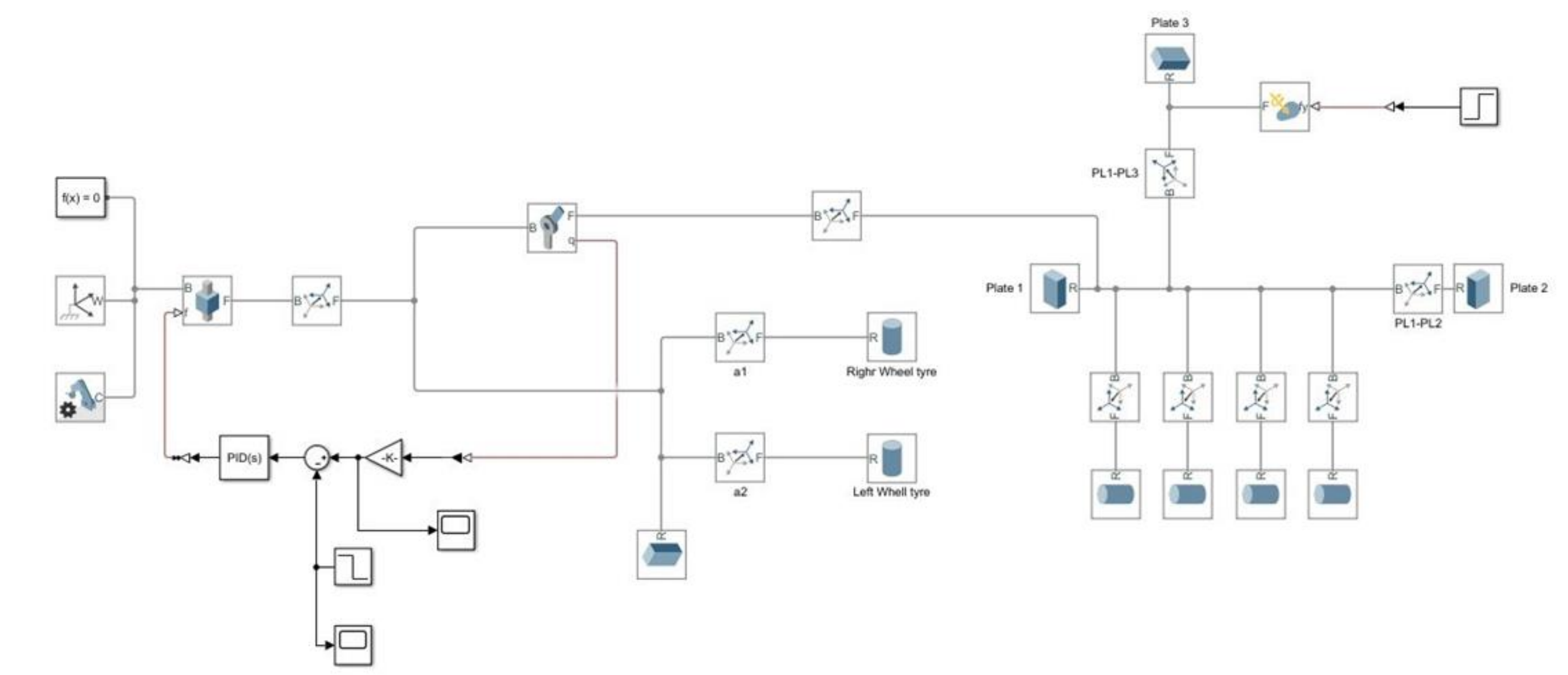
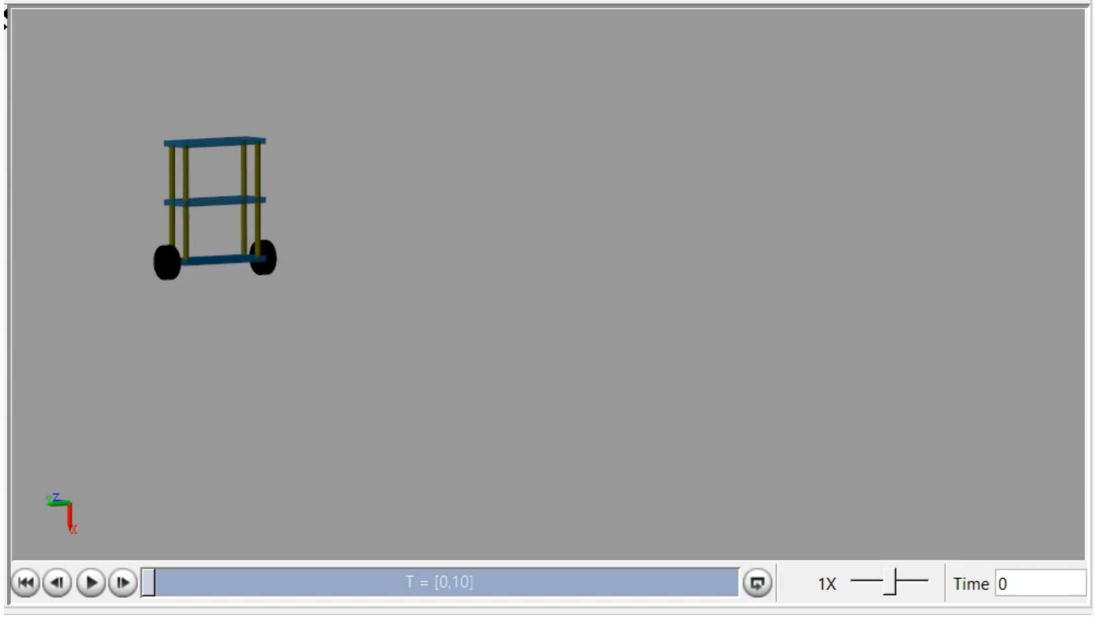
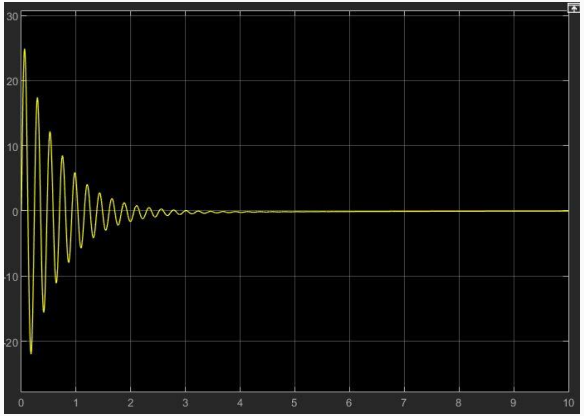


Plate 3
PL1-PL3
f(x) = 0
Plate 1
Plate 2
PL1-PL2
PID(s)
-K-
a1
Righr Wheel tyre
a2
Left Whell tyre

Simulation in Simscape





Suggestions & Feature Plans

1-First(or second order, Kalman) Filter for the IMU data.
2-Rotational command.
3-Design controller for overload endurance.
4-…

References

1. https://github.com/br3ttb/Arduino-PID-Library/blob/master/PID_v1.h
2. https://github.com/jrowberg/i2cdevlib/tree/master/Arduino/MPU6050
3. https://grabcad.com/
4. https://www.arduino.cc/
5. https://thecaferobot.com/store/
6. https://doi.org/10.1016/j.ifacol.2018.06.091
7. https://www.researchgate.net/publication/354860030_Kinematic_Control_of_2-wheeled_Segway
8. DOI: 10.12928/TELKOMNIKA.v18i5.14717
9. https://www.youtube.com/watch?v=lrbtAVTKnJo
10. https://www.youtube.com/watch?v=9W5S5nqRegU