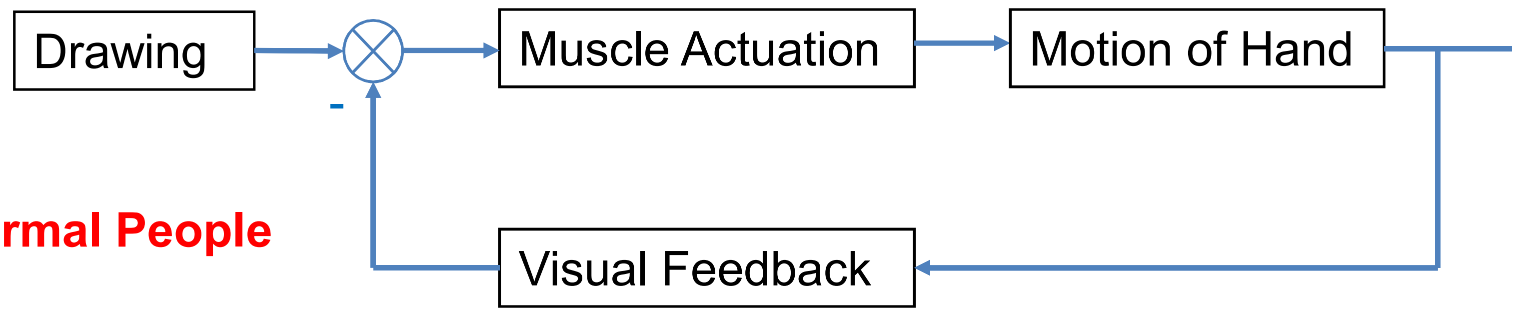
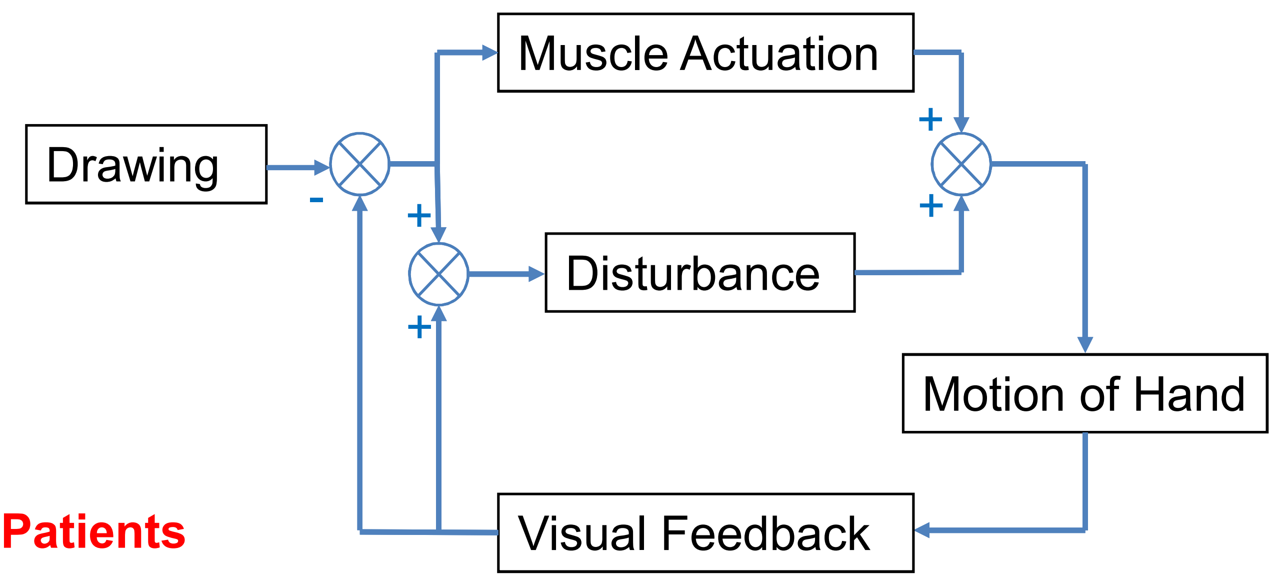
Assistive Writing Device for Parkinson’s Patient

Group 4 Members: Jagatpreet Singh Nir, Mingda Ju, Xuyang Sun, Zimou Gao

Special Case



Normal People



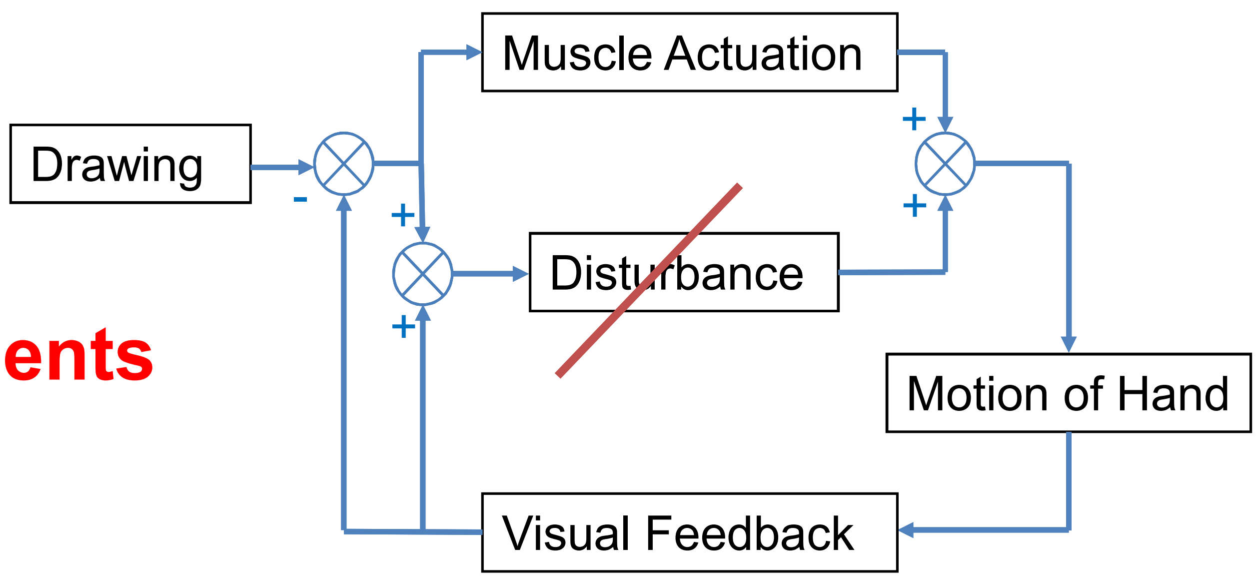
Patients

Methodology and Design Requirements

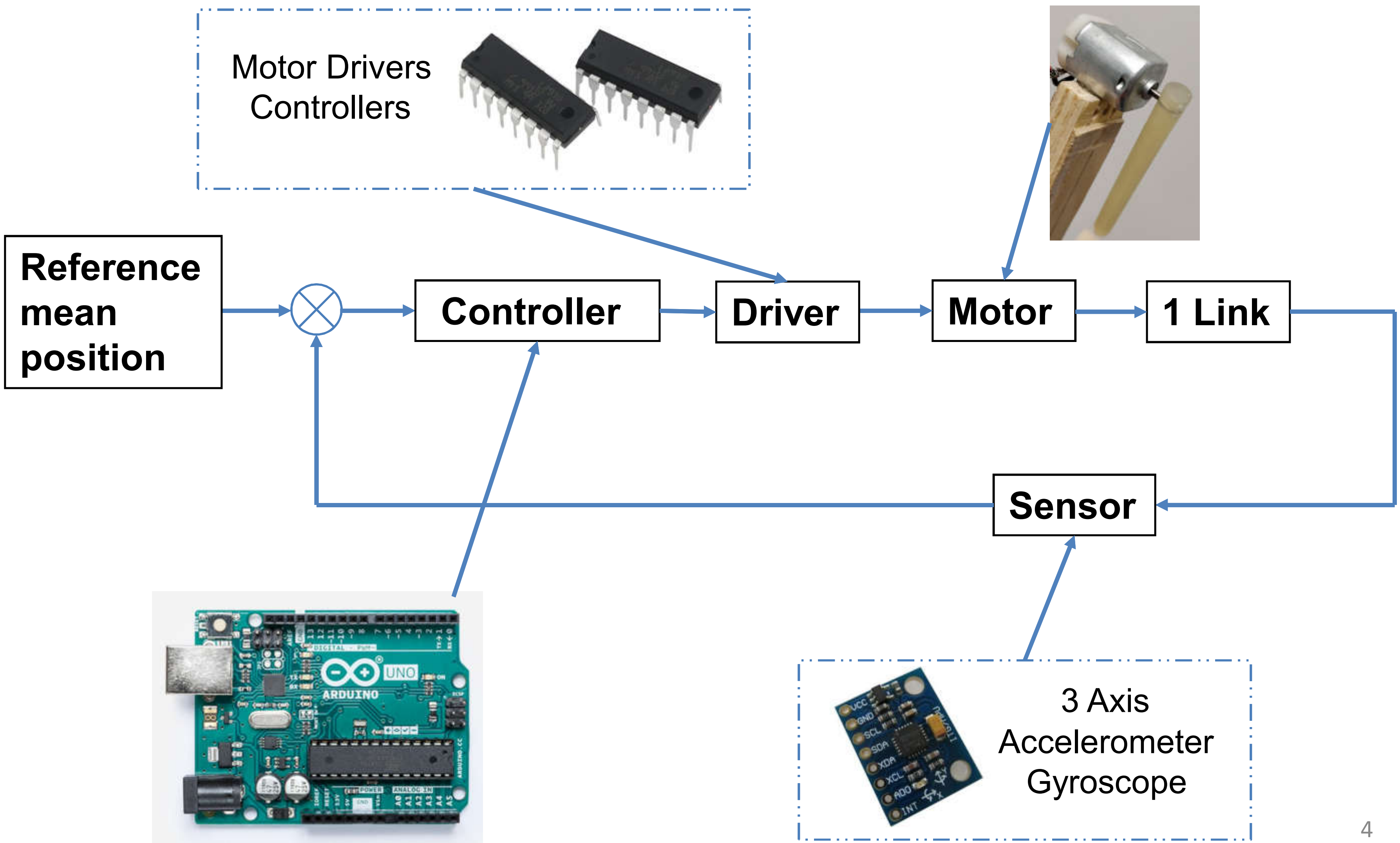
$$\theta = f(x) + U_{voluntary} + D_{forearm} \quad \mathbf{-S(u)}$$

$f(x)$ is the dynamic model of the fore-arm
$U_{voluntary}$ is the torque exerted by the patient to control the hand and forearm.
$D_{forearm}$ is the disturbance torque generated from other muscles of the patient.

Patients



Methodology and Design Requirements



Methodology and Design Requirements

- Design requirements

1. The device can cancel out the tremors.

2. The device must be light weight.

3. The device should be easy to wear and easy to switch on/off.

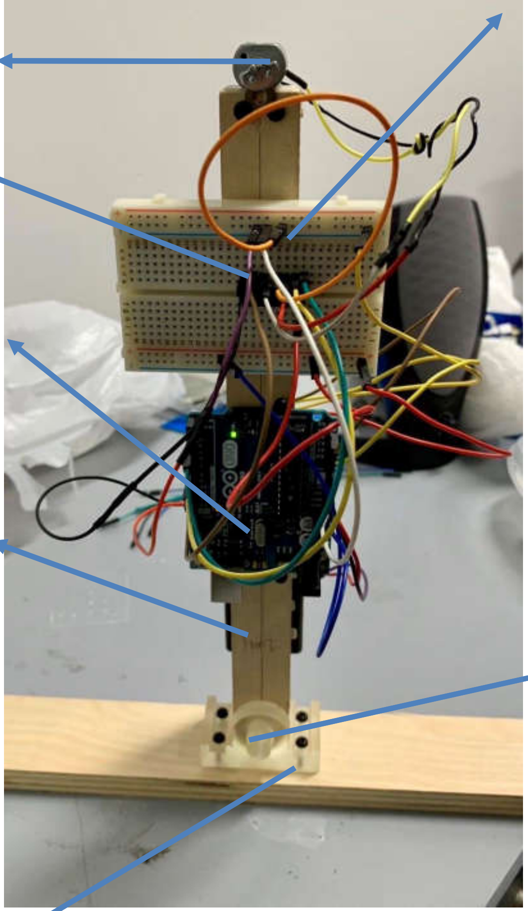
4. The device must be operated on battery power.

Introduce the prototype

Parts Included In The Prototype

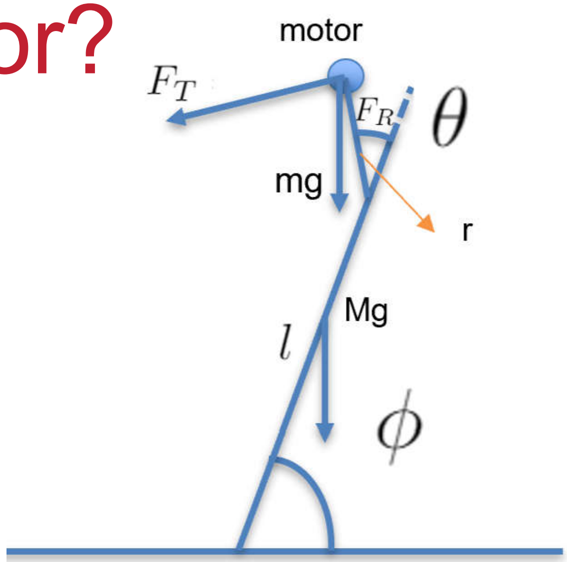
Item	Mass(gram)	Inertia($kg \cdot m^2 \times 10^{-4}$)
Arduino	27.22	4.6
Breadboar	86.18	36.22
MPU-6050	18.14	3.56
Motor	19.54	14.24
Battery(9v) and holder	43	2.1
Button cell and holder	5.27	0.64
Total	241.6	68.50

Breadboard
Vibration motor
motor driver
Arduino
battery



pin
base

Can We Balance the Pendulum With Vibration Motor?



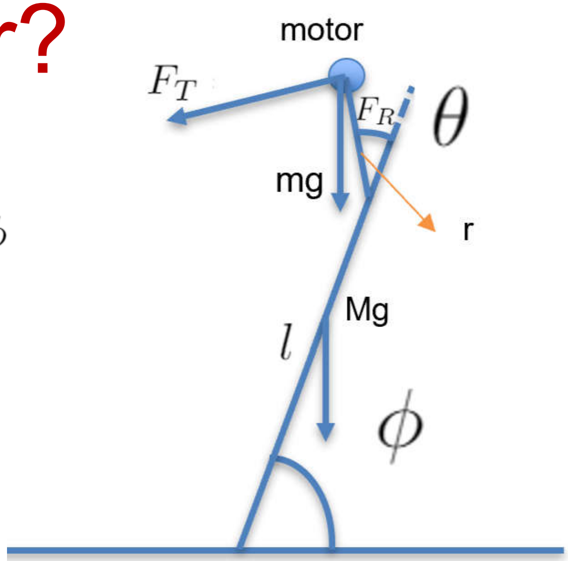
$$F_R = m\omega^2 r = m\dot{\theta}^2$$
$$F_T = m\dot{\omega} r = m\ddot{\theta} r$$
$$\vec{F_R} = F_R[-\cos(\theta+\phi)\hat{\imath} - \sin(\theta+\phi)\hat{\jmath}]$$
$$\vec{F_T} = F_T[-\sin(\theta+\phi)]\hat{\imath} + cos(\theta+\phi)\hat{\jmath}]$$

$$I\ddot{\phi} = \frac{l}{2}(\cos\phi\hat{\imath}+\sin\phi\hat{\jmath})\times Mg(-\hat{\jmath}) + \mathrm{l}(\cos\phi\hat{\imath}+\sin\phi\hat{\jmath})\times\vec{F_T} + l(\phi\hat{\imath}+\sin\phi\hat{\jmath})\times\vec{F_R} + l(\cos\phi\hat{\imath}+\sin\phi\hat{\jmath})\times mg(-\hat{\jmath})$$

$$\boxed{\ddot{\phi} = \frac{m\dot{\omega}r}{I}\cos\omega t - \frac{m\omega^2 r}{I}\sin\omega t - \frac{1}{I}\left(\frac{Mgl}{2} + mgl\right)\cos\phi}$$

Achieve Desired Function

Can We Balance the Pendulum With Vibration Motor?



$$\ddot{\phi} = \frac{m\dot{\omega}r}{I}\cos\omega t - \frac{m\omega^2 r}{I}\sin\omega t - \frac{1}{I}(\frac{Mgl}{2} + mgl)\cos\phi$$

In our case, we decided to neglect gravity

$$\ddot{\phi} = \frac{m\dot{\omega}r}{I}\cos\omega t - \frac{m\omega^2 r}{I}\sin\omega t$$

YES!

$$\Delta t\frac{\ddot{\phi}}{mr} = -\frac{1}{I}\int_0^{\Delta t}[K\sin(t)\cos(Kt\cos t) + K^2\frac{1+\cos 2t}{2}\sin(Kt)]dt$$

Achieve Desired Function

How to Control the Pendulum?

$$I\ddot{\phi} = \frac{l}{2}(\cos\phi\hat{\imath}+\sin\phi\hat{\jmath})\times Mg(-\hat{\jmath})+\mathrm{l}(\cos\phi\hat{\imath}+\sin\phi\hat{\jmath})\times\vec{F_T}+l(\phi\hat{\imath}+\sin\phi\hat{\jmath})\times\vec{F_R}+l(\cos\phi\hat{\imath}+\sin\phi\hat{\jmath})\times mg(-\hat{\jmath})$$

Linearization about ω

$$\boxed{F(x,u) = \begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix} = \begin{bmatrix}\frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2}\\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2}\end{bmatrix}(x - x_0) + \begin{bmatrix}\frac{\partial f_1}{\partial u}\\ \frac{\partial f_2}{\partial u}\end{bmatrix}(\omega - \omega_0)}$$

$$\dot{\mathbf{x}} = \begin{bmatrix}0 & 1\\ A & 0\end{bmatrix}\tilde{\mathbf{x}} + \begin{bmatrix}0\\ -1\end{bmatrix} H\sin(\omega_0 t + \gamma)(\omega - \omega_0)$$

Achieve Desired Function

How to Control the Pendulum?

$$\boxed{\omega = \frac{-K_p\tilde{x}_1 - K_d\tilde{x}_2}{H\sin(\omega_0 t + \gamma)} + \omega_0}$$

Where $H = \sqrt{a_1^2 + a_2^2}, \gamma = \tan^{-1}\frac{a_2}{a_1}$

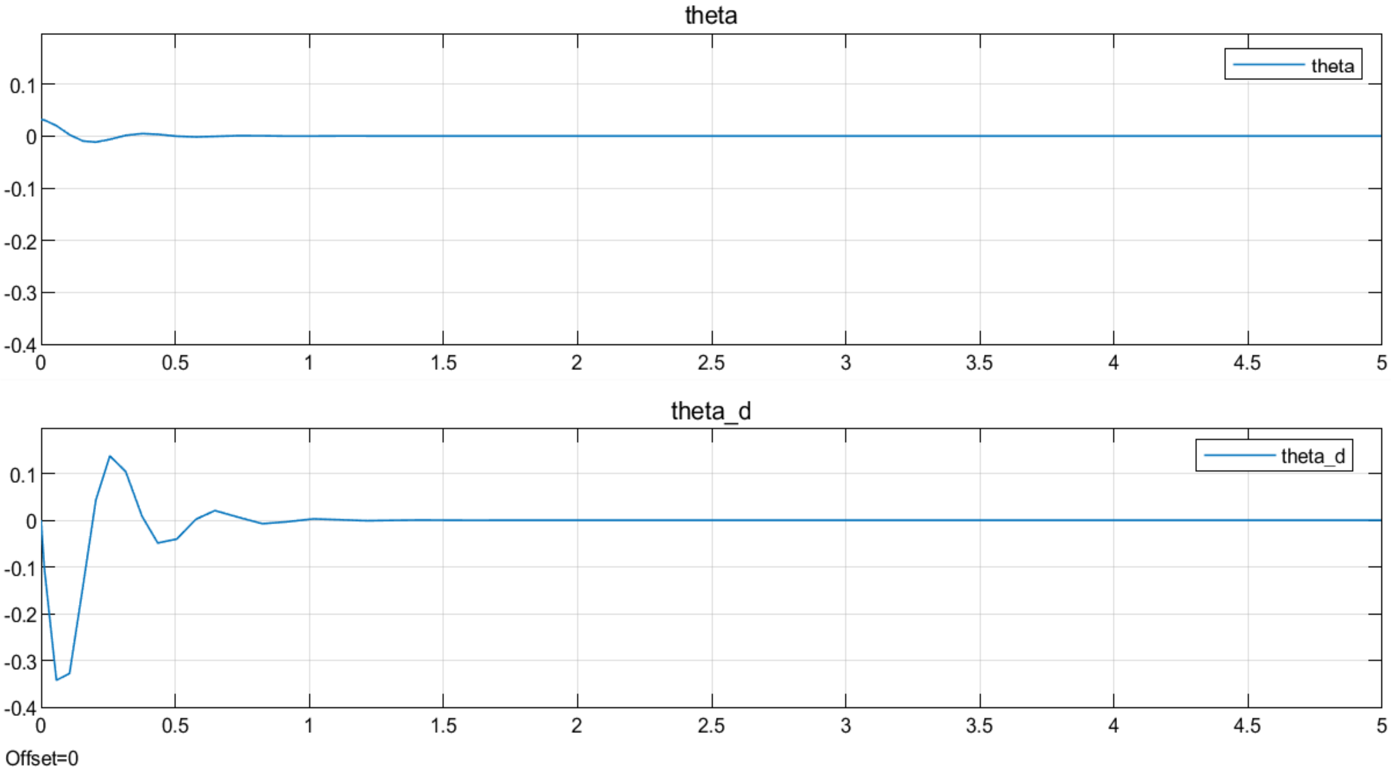
$$\begin{bmatrix} \frac{\partial f_1}{\partial u} \\ \frac{\partial f_2}{\partial u} \end{bmatrix}(\omega - \omega_0) = \begin{bmatrix} 0 \\ -\frac{m\omega_0^2 rt}{I}\cos\omega_0 t - \frac{2\omega_0 mr}{I}\sin\omega_0 t \end{bmatrix}(\omega - \omega_0)$$

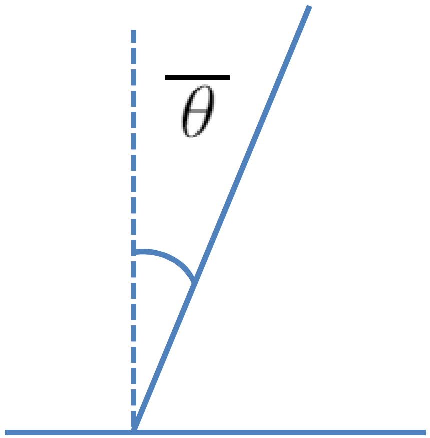
Where

$$a_1 = -\frac{m\omega_0^2 rt}{I}, a_2 = -\frac{2\omega_0 mr}{I}$$

With PD controller

How to Control the Pendulum?





MW Spong - Intelligent Robots and Systems' 94.'Advanced Robotic. " *Partial Feedback Linearization of Underactuated Mechanical System".* 1994. http://www.lirmm.fr/

Can We Design A Controller Which Optimizes Power Consumption?

LQR Objective:
Build a wearable device that can cancel out the tremors.
Energy-efficient

Optimality in terms of a quadratic cost function:

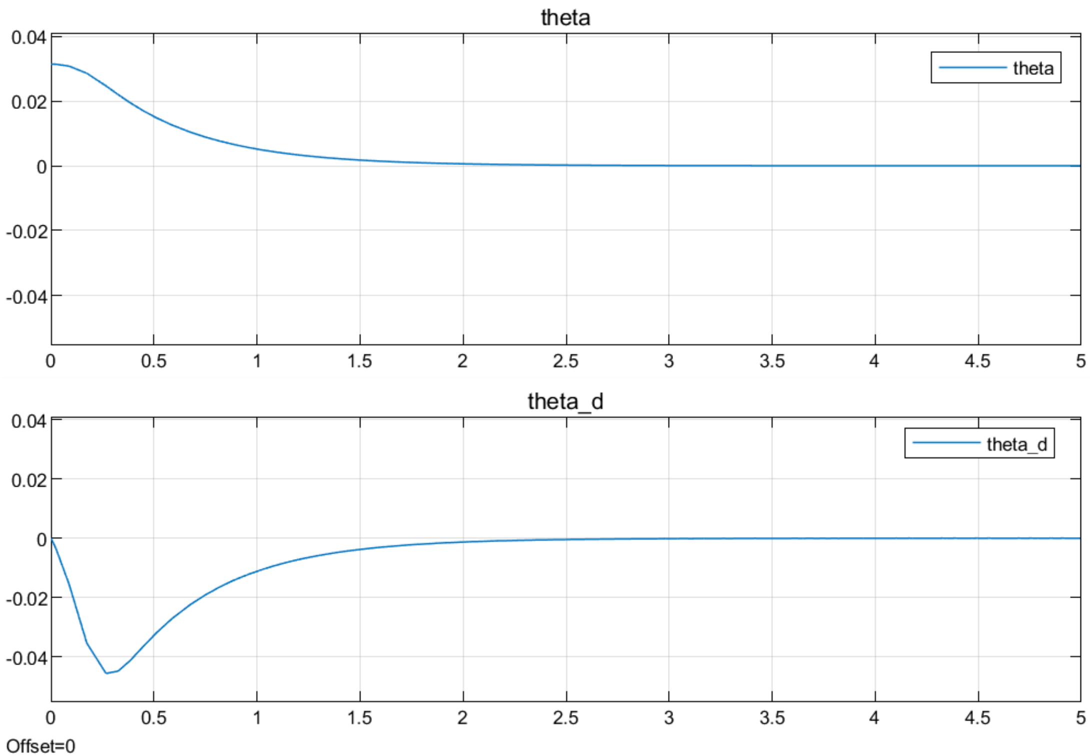
$$\mathbf{J}(\mathbf{x}_0) = \int_0^{\infty} [\mathbf{x}(t)^T \mathbf{Q}\mathbf{x}(t) + \mathbf{u}(t)\mathbf{R}\mathbf{u}(t)]dt),\ \mathbf{x}(0)=\mathbf{X}_0, \mathbf{Q} = \mathbf{Q}^T>0, \mathbf{R} = \mathbf{R}^T>0$$

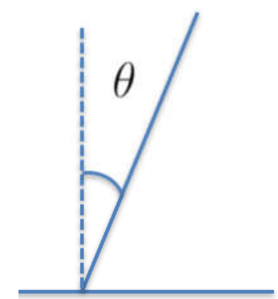
$$\mathbf{u}(t) = -\mathbf{K}\mathbf{x}(t)$$

Where K = lqr(A,B,Q,R)

Russ Tedrake, *Underactuated Robotics: Learning, Planning, and Control for Efficient and Agile Machines*, Massachusetts Institute of Technology, 2009, p.25

Can We Design A Controller Which Optimizes Power Consumption?

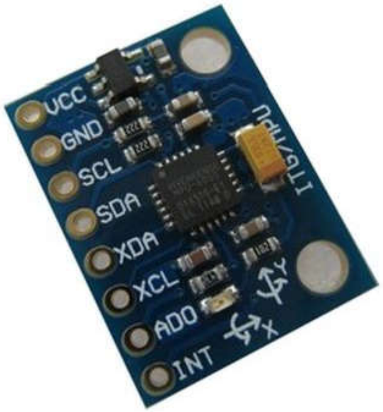




Russ Tedrake, *Underactuated Robotics: Learning, Planning, and Control for Efficient and Agile Machines*, Massachusetts Institute of Technology, 2009, p.25

How to Measure the Position of the Pendulum?

With sensor MPU6050, the control system will know whether the pendulum deflects from the desired position or not.

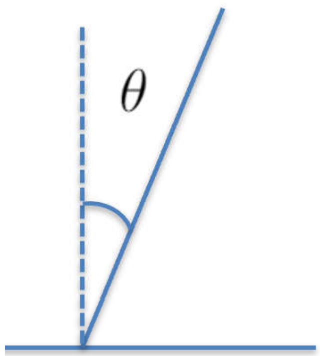


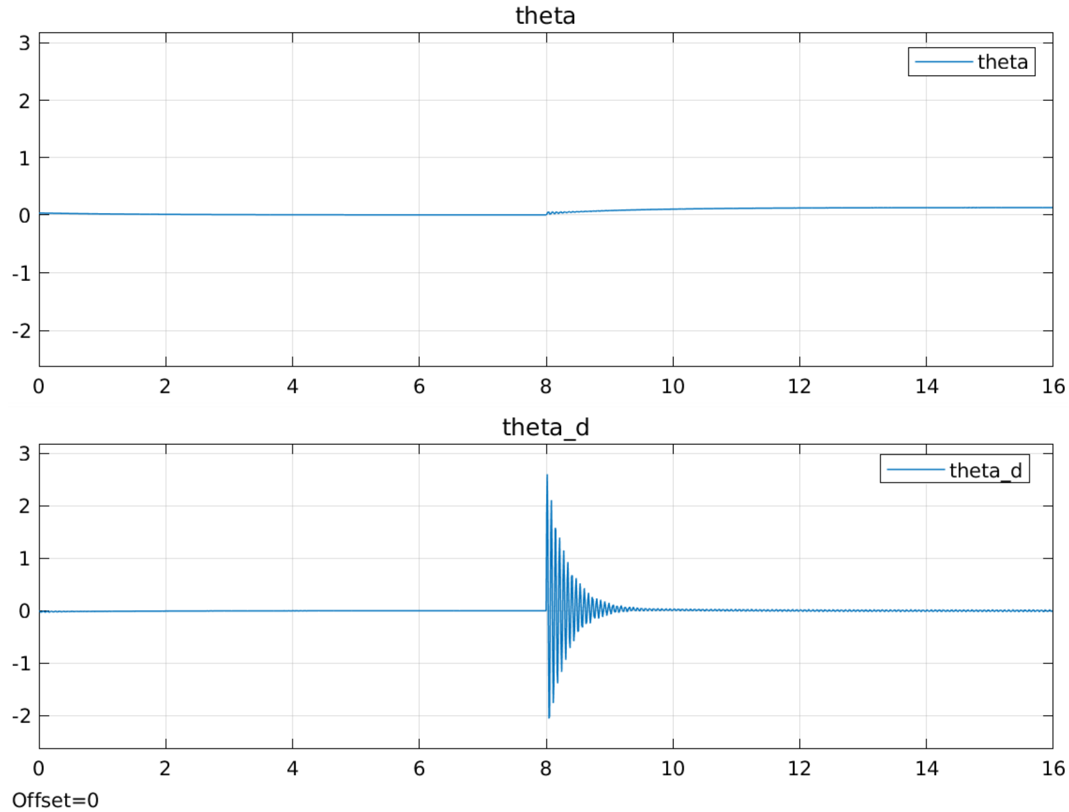
Characteristics:

Zero error
Noise over time
Bit resolution of the sensor
Full physical range of the sensor $\pm 4g$

InvenSense, MPU-6000 and MPU-6050 Product Specification, 2013, p.28

Can We Cancel the Random Disturbance?



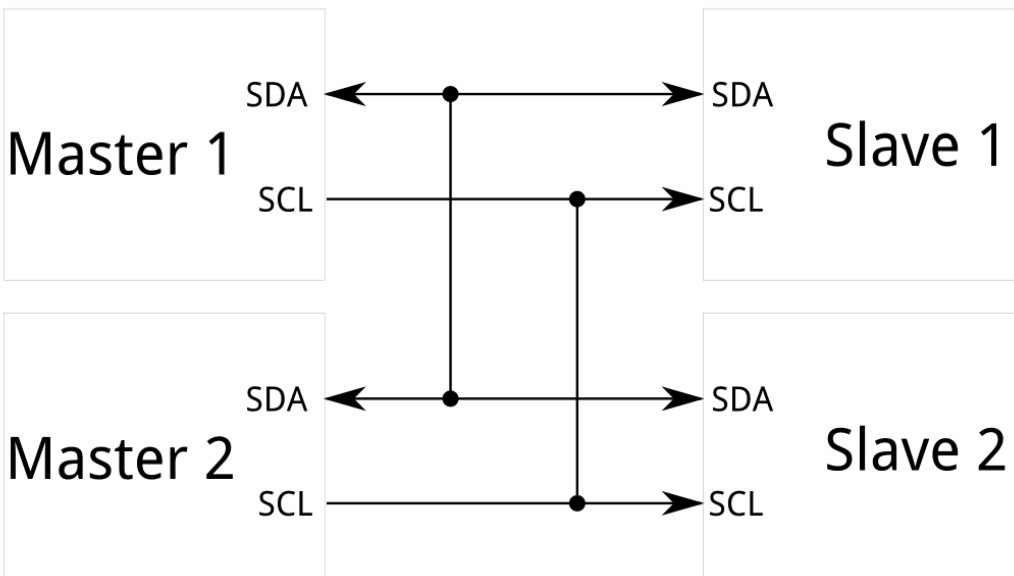


Parkinson's Patients' hand are moving randomly, so it is difficult to model using equations. So we decided to use Linear Quadratic Gaussian (LQG) control to obtain the optimal estimation of actual state of the pendulum.

Tryphon T. Georgiou and Anders Lindquist (2013). "The Separation Principle in Stochastic Control, Redux". *IEEE Transactions on Automatic Control*. 58 (10): 2481–2494

Implementation on Hardware

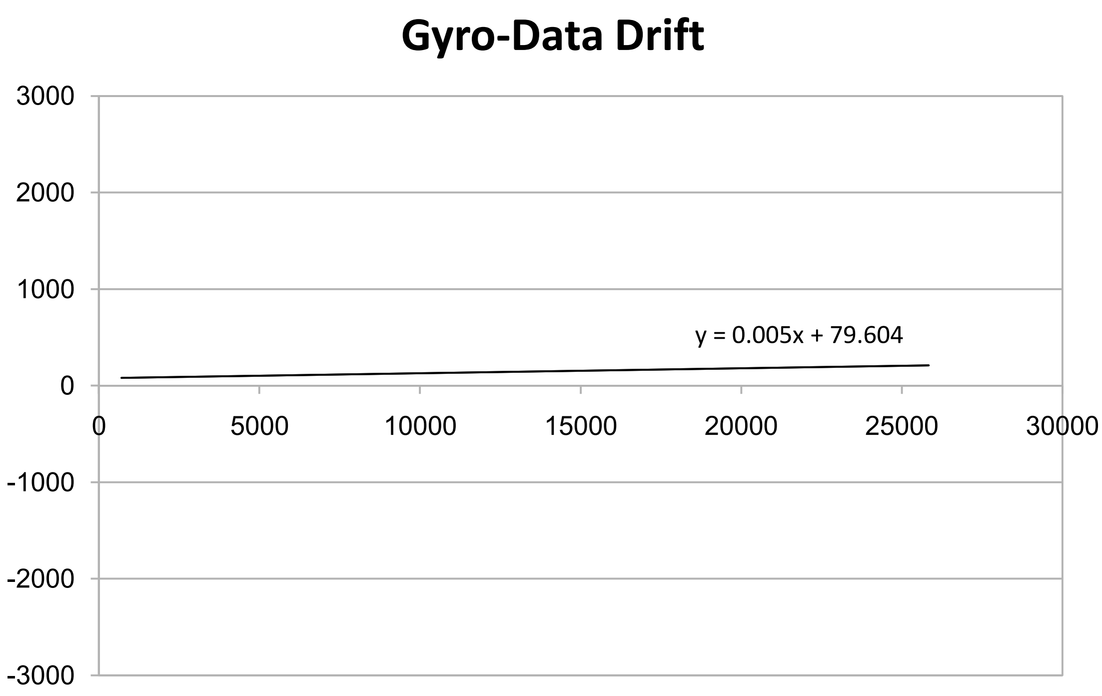
- Sensor (MPU6050)
  - Connect to Arduino (I2C)



Gasperi, Michael; Hurbain, Philippe (2010), "Chapter 13: I²C Bus Communication", *Extreme NXT: Extending the LEGO MINDSTORMS NXT to the Next Level*

Implementation on Hardware

- Sensor (MPU6050)
  - Connect to Arduino (I2C)
  - Filtering (Noise Characteristics)



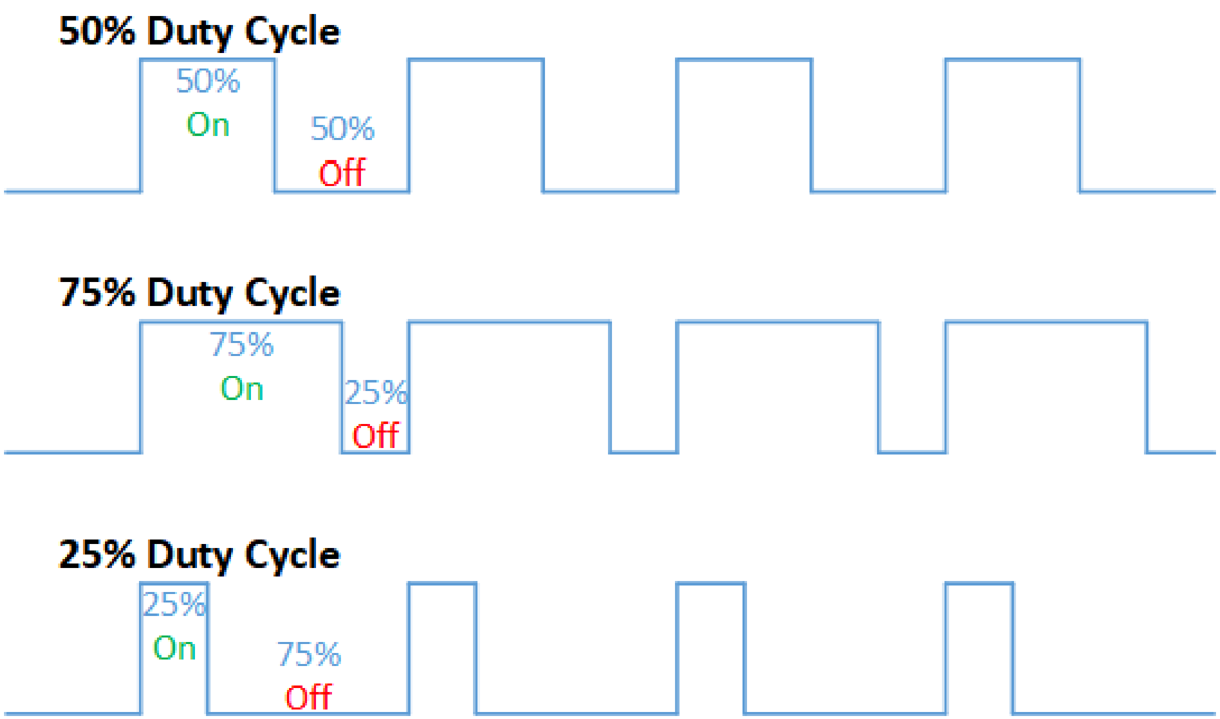
Implementation on Hardware

- Sensor (MPU6050)
  - Connect to Arduino (I2C)
  - Filtering (Noise Characteristics)
  - Calibration Bias and Drift (Average it)

	Acc-X(m)	Acc-Y(m)	Gyro-Z(rad)
Bias	0.967779675	-9.870905209	0.000490287
Std dev	0.088415429	0.060230496	0.028707556

Implementation on Hardware

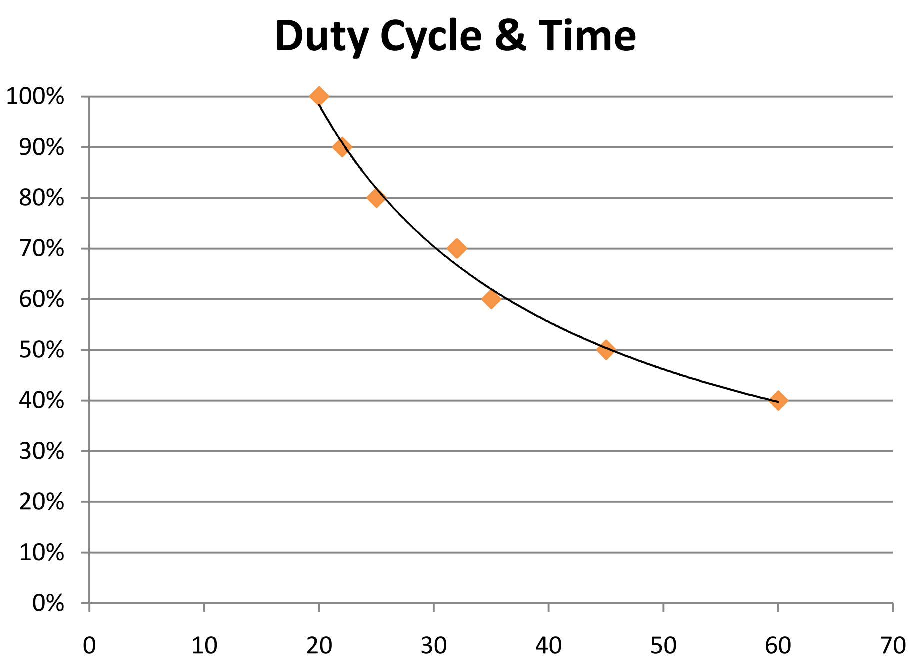
- Motor（DC）and Motor Driver
  - Connect to Arduino (PWM)



Barrett, Steven Frank; Pack, Daniel J. (2006). "Timing subsystem". *Microcontrollers Fundamentals for Engineers and Scientists*. Morgan and Claypool Publishers. pp. 51–64. ISBN 1-598-29058-4.

Implementation on Hardware

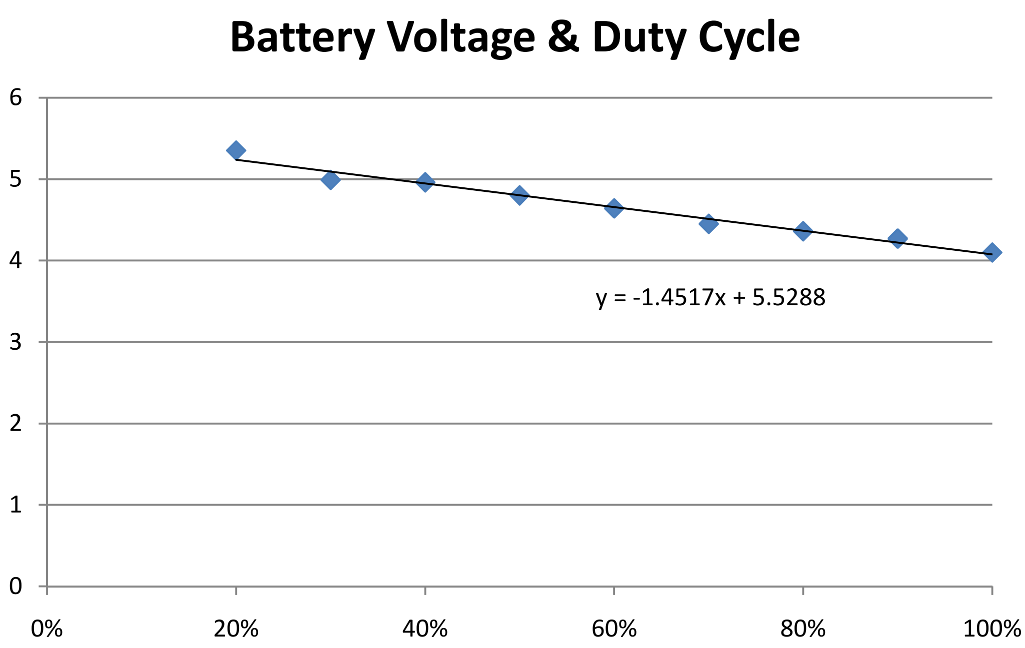
- Motor（DC）and Motor Driver
  - Connect to Arduino (PWM)
  - Duty Cycle Range (Due to the load)



Time(ms)	Duty Circle	Rotation
-	10%	no rotation
-	20%	no rotation
-	30%	no rotation
60	40%	2π
45	50%	2π
35	60%	2π
32	70%	2π
25	80%	2π
22	90%	2π
20	100%	2π

Implementation on Hardware

- Battery（3V*2）and Wires Force
  - Internal Resistance（ U = U0 – i*R ）

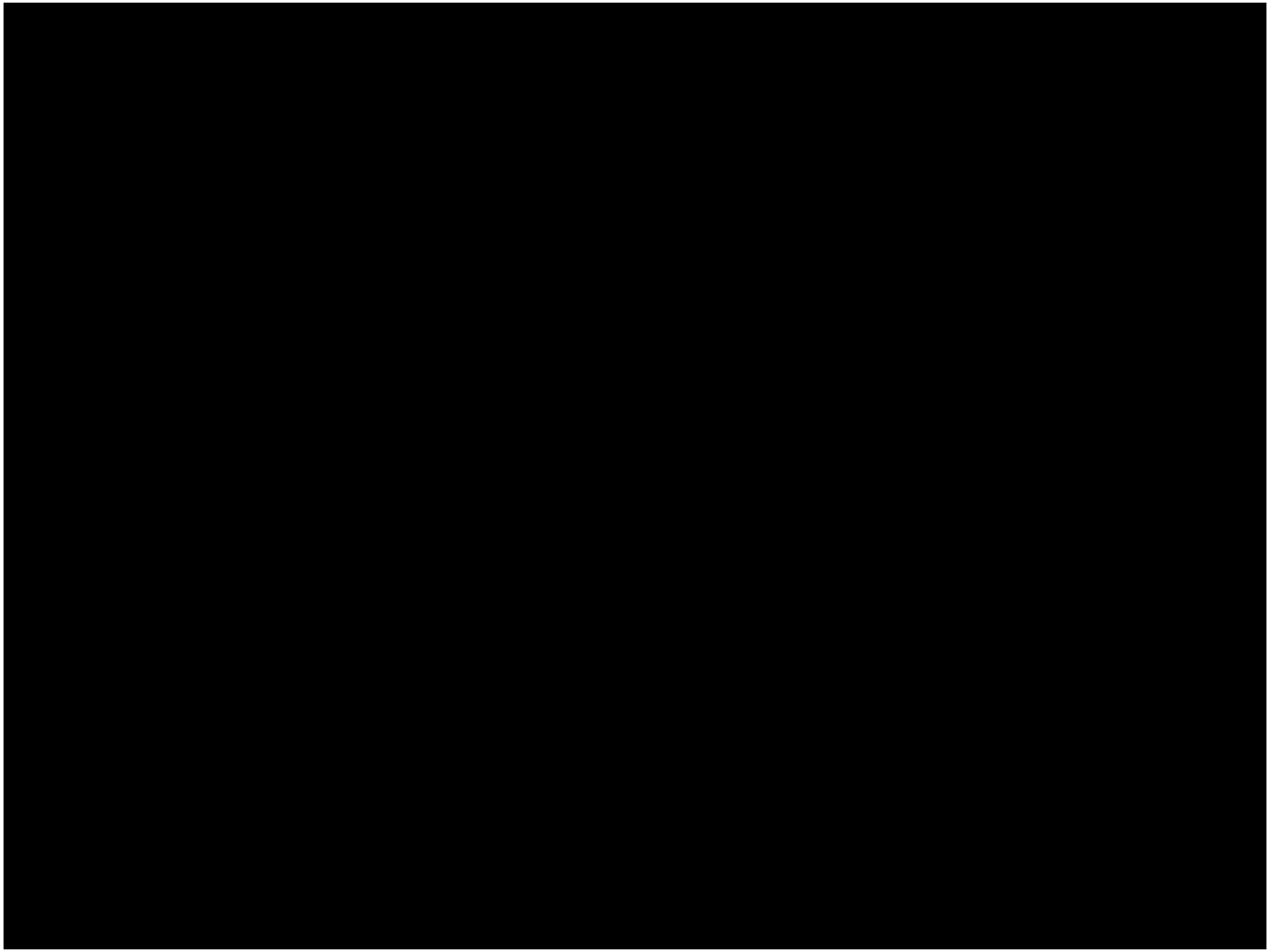


Duty Cycle	Battery Voltage(V)
20%	5.35
30%	4.99
40%	4.96
50%	4.8
60%	4.64
70%	4.45
80%	4.36
90%	4.27
100%	4.1

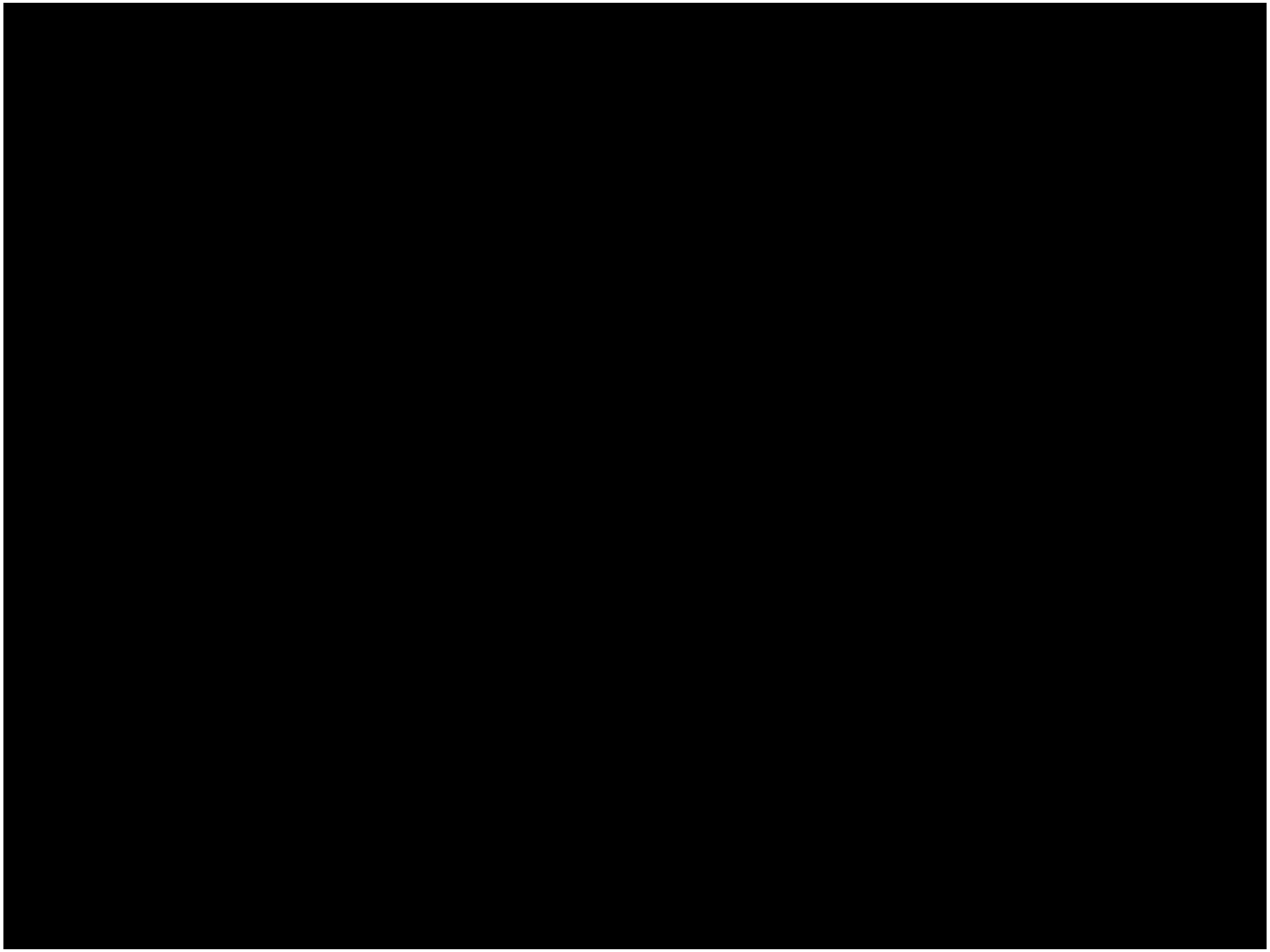
Gaps Between Simulation and Actual Implentation

- Selection of right hardware –motor, motor drivers
  - Saturation of motors at 40% duty cycle
  - Very slow response time to the control commands
  - Control frequency from microcontroller – a lot of tuning effort went into tuning the control frequency for a good enough response.
  - Mechanical design with minimum friction
- Battery internal resistance can limit the output voltage!
  - Need to use a battery output controller
- Sensor bias and sensor noise – makes it difficult to model and use it for measurement. Needs calibration.

Video Demo & Live Demo



Video Demo & Live Demo



Conclusion

- Defined a design process on strong mathematical framework, simulation and experimental validation.
  - Control design: parameters
  - Selection of motors – low inertia motors with high response time.
  - Sensors and their calibration

Future Work

- Simulate by removing assumption which do not exist in real world.
- Improve theoretical framework based on Singular perturbation theory
- Filtering disturbance from hand
- On board electronics and better hardware design
- Raise fund to do it

Reference

1. InvenSense, *MPU-6000 and MPU-6050 Product Specification*, 2013, p.28
2. Russ Tedrake, *Underactuated Robotics: Learning, Planning, and Control for Efficient and Agile Machines,* Massachusetts Institute of Technology, 2009, p.25
3. Tryphon T. Georgiou and Anders Lindquist (2013). "The Separation Principle in Stochastic Control, Redux". *IEEE Transactions on Automatic Control*. 58 (10): 2481–2494
4. MW Spong - Intelligent Robots and Systems' 94.'Advanced Robotic. " *Partial Feedback Linearization of Underactuated Mechanical System".* 1994. http://www.lirmm.fr/
5. Tryphon T. Georgiou and Anders Lindquist (2013). "The Separation Principle in Stochastic Control, Redux". *IEEE Transactions on Automatic Control*. 58 (10): 2481–2494
6. Barrett, Steven Frank; Pack, Daniel J. (2006). "Timing subsystem". *Microcontrollers Fundamentals for Engineers and Scientists*. Morgan and Claypool Publishers. pp. 51–64. ISBN 1-598-29058-4.

Thanks!

Question Time