Robotics 311 : How to build robots and make them move

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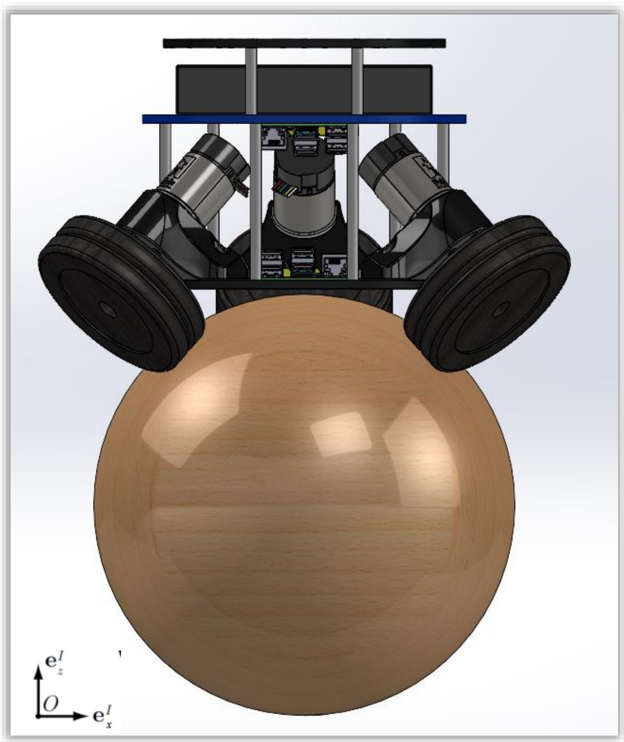
Fall 2022

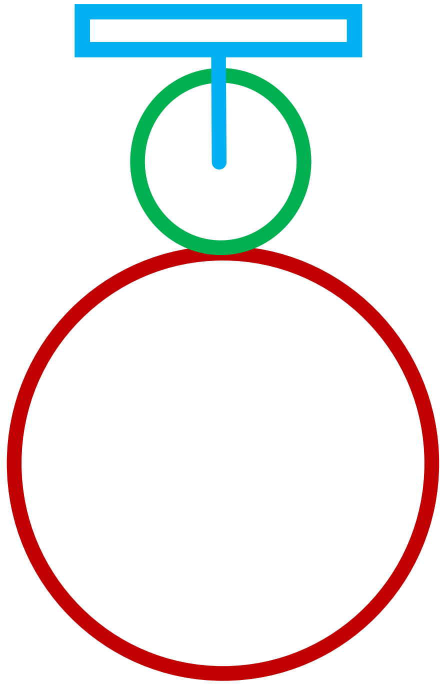
ROB 311 – Lecture 5

- Today:
    - Review planar ball-bot modeling
    - Review motor selection process + Pololu website
    - Review Lab 3
    - Finish in-class example
    - Cover thermal modeling (if we have time)

Mechanical Modeling of a Planar Ball-Bot

- We are learning a planar model of a ball-bot and discussed the simplification
- The required torques will be more than what would be needed in a design with three motors – use as conservative estimate





Mechanical Modeling of a Planar Ball-Bot

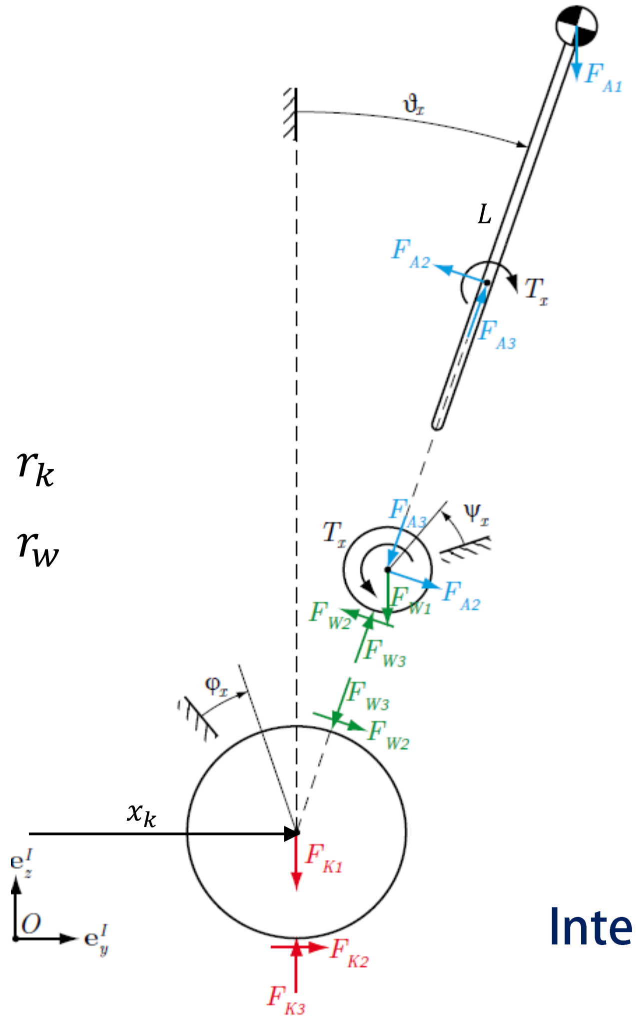
$$F_{K1} = g \cdot m_k$$

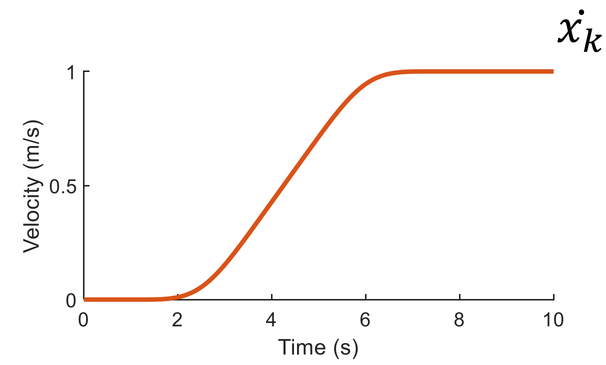
$$F_{W1} = g \cdot m_w$$

$$F_{A1} = g \cdot m_a$$

Ball radius r_k

Wheel radius r_w





Constraints:

$$x_k = r_k \varphi$$

$$\psi = \frac{r_k}{r_w}(\varphi - \vartheta) - \vartheta$$

Ball velocity: $\dot{\varphi} = \frac{\dot{x}_k}{r_k}$

Intermediate var: $\gamma = L \cdot m_a + (r_k + r_w) \cdot m_w$

Tangential contact force : $F_{W2} = (m_a + m_w) \cdot (g \cdot \sin(\vartheta) - r_k \ddot{\varphi} \cos(\vartheta)) - \gamma \ddot{\vartheta}$

Mechanical Modeling of a Planar Ball-Bot

$$\gamma = L \cdot m_a + (r_k + r_w) \cdot m_w$$

$$F_{W2} = (m_a + m_w) \cdot (g \cdot \sin(\vartheta) - r_k \ddot{\varphi} \cos(\vartheta)) - \gamma \ddot{\vartheta}$$

From free body diagram

$$\dot{\varphi} = \frac{\dot{x}_k}{r_k}$$

$$\psi = \frac{r_k}{r_w}(\varphi - \vartheta) - \vartheta$$

Constraints

Required current

Output torque to roll ball / mass

Torque to accelerate motor inertia

$$i_w = \frac{\frac{T_x}{N\eta} + JN\ddot{\psi} + bN\dot{\psi}}{k_t}$$

Torque to overcome viscous loss in motor

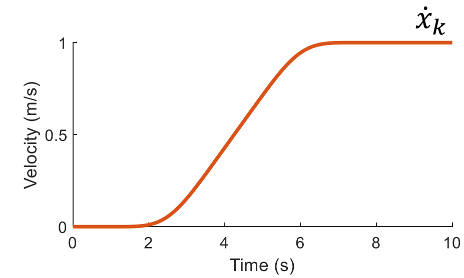
Required voltage

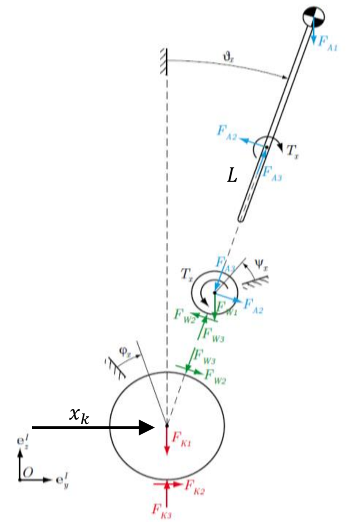
Voltage drop across resistance

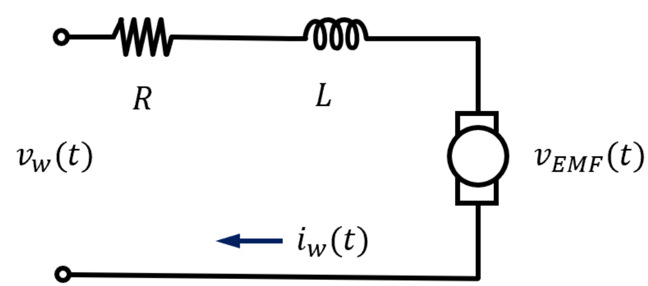
Back EMF voltage

$$v_w = i_w R + k_t N \dot{\psi} + L\frac{di_w}{dt}$$

Voltage drop across inductance



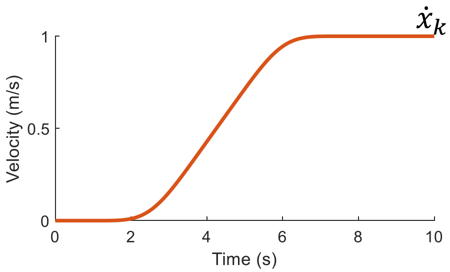




Mechanical Modeling of a Planar Ball-Bot

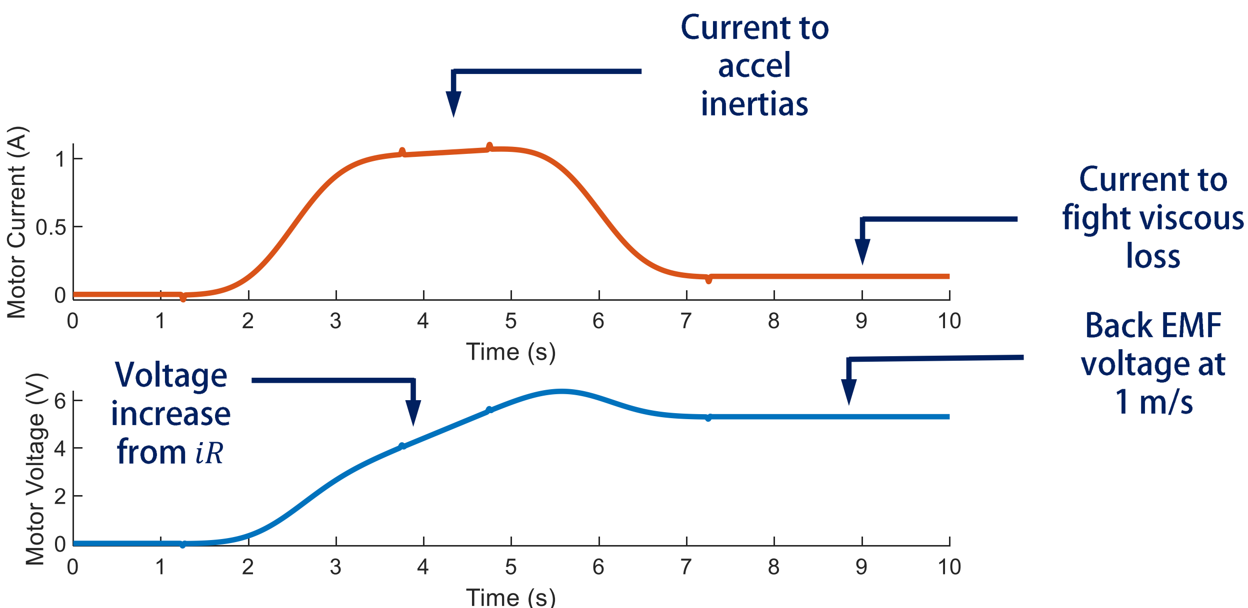
$$\gamma = L \cdot m_a + (r_k + r_w) \cdot m_w$$

$$F_{W2} = (m_a + m_w) \cdot (g \cdot \sin(\vartheta) - r_k \ddot{\varphi} \cos(\vartheta)) - \gamma \ddot{\vartheta}$$



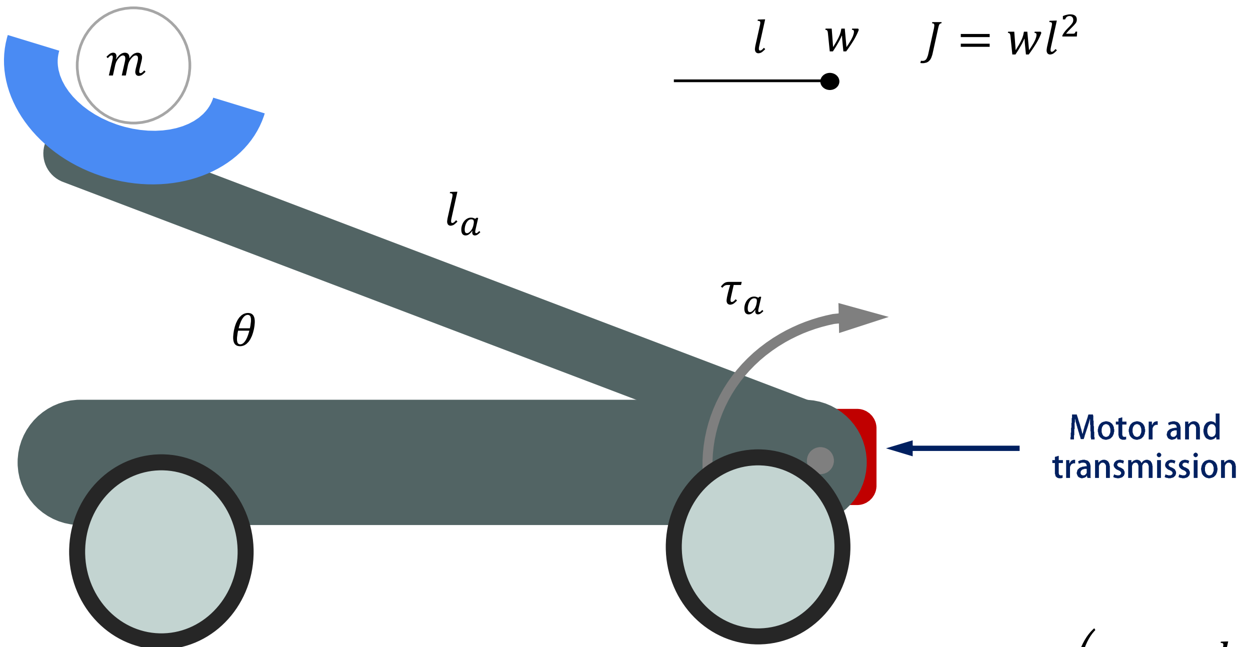
$$\dot{\varphi} = \frac{\dot{x}_k}{r_k} \qquad \psi = \frac{r_k}{r_w}(\varphi - \vartheta) - \vartheta$$

$$i_w = \frac{\frac{T_x}{N\eta} + JN\ddot{\psi} + bN\dot{\psi}}{k_t} \qquad v_w = i_w R + k_t N \dot{\psi} + L\frac{di_w}{dt}$$



Show Pololu site and MATLAB code again

Example – Robotic catapult



$J = wl^2$

$$m = 10\ kg$$
$$l_a = 1\ m$$
$$\eta = 0.8$$

$$k_t i_w = \tau = \left(J + \frac{m{l_a}^2}{N^2}\right)\ddot{\varphi} + b\dot{\varphi} + \frac{mgl\cos\theta}{\eta N}$$

$$i_w = \frac{\left(J + \frac{m{l_a}^2}{N^2}\right)N\ddot{\theta} + bN\dot{\theta} + \frac{mgl\cos\theta}{\eta N}}{k_t}$$

$$\varphi = N\theta$$

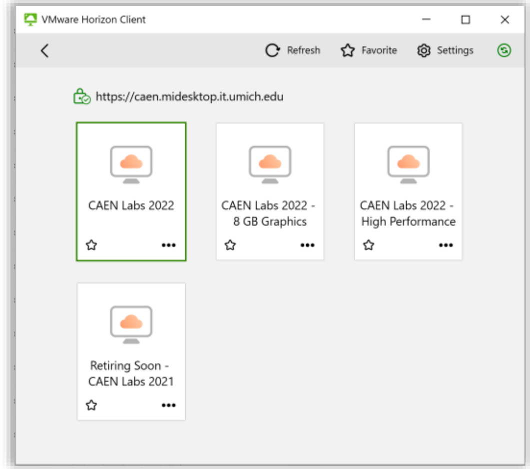
$$v = i_w R + k_t N\dot{\theta} + L\frac{di_w}{dt}$$

Select a motor from the spreadsheet and determine the current and voltage needed

Bonus: Determine i^2R loss (W)

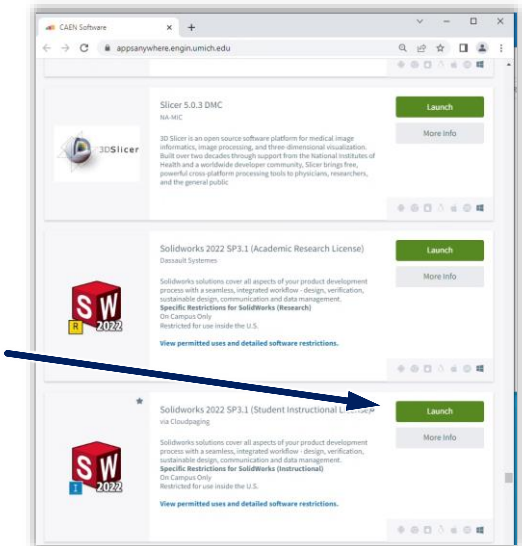
Lab 3 – Setting Up Solidworks

- Tomorrow, we start using Solidworks to design parts of your ball-bot
- If you don't know Solidworks, this class can teach you the basics
- This class won't teach you to be a Solidworks expert—it can do a lot!
- We will provide starting files to assist and can help as much as needed
- You may need to come to office hours
- Plan for solid modeling:
  - Each of you can use Solidworks via a CAEN computer remotely
  - This will let you work on your own laptop but use Solidworks
  - To do this, you need to download the VMware Horizon Client
    - https://caen.midesktop.it.umich.edu/
  - Then connect by adding a new server
    - caen.midesktop.it.umich.edu
  - Then open Solidworks from appsanywhere that auto-launches
  - Double click on application in Cloudpaging when it says 'ready'



VMware Horizon Client – select CAEN Labs 2022

Solidworks Academic License

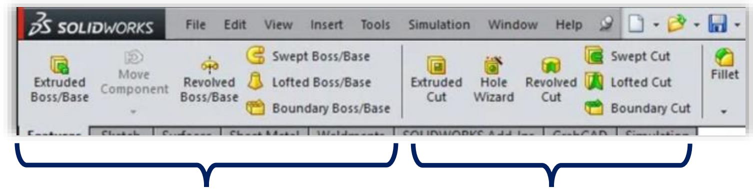


Appsanywhere window

Lab 3 – Solidworks - 3D Operations

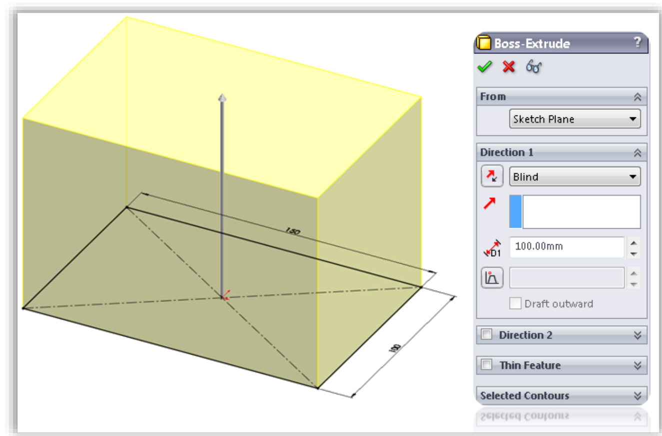
- Solid modeling is a tool used to create representations of 3D parts
- Think of it as virtual clay (with geometry!)
- The parts can be exported for instructions of 3D printers and laser cutters
- Parts are created using geometric operations
- Operations are stacked to create more complex shapes
- Parts can be assembled into Assemblies
- Parts can be created using simple operations (extrude, revolve, loft, etc.)
- Material can be removed with cutting operations (extrude cut, revolve cut, etc.)

More operations



Create features

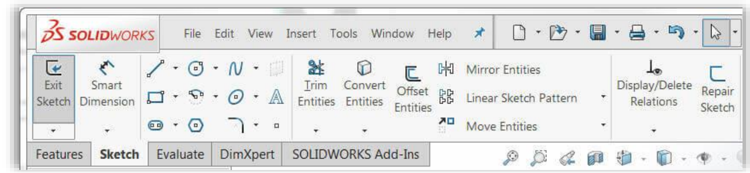
Cut features



Extruding a rectangle from a sketch

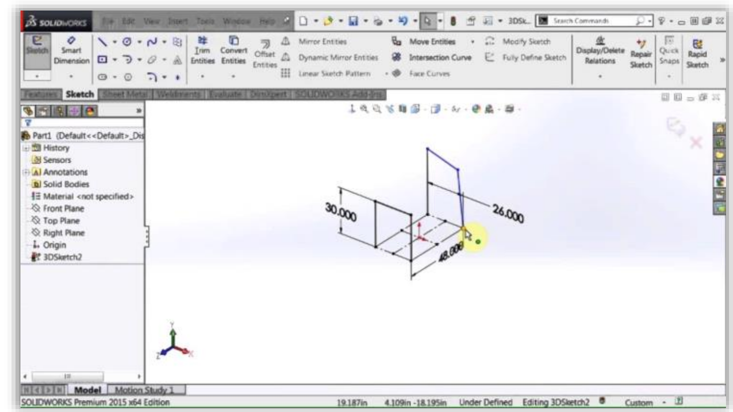
Lab 3 – Solidworks - Sketching

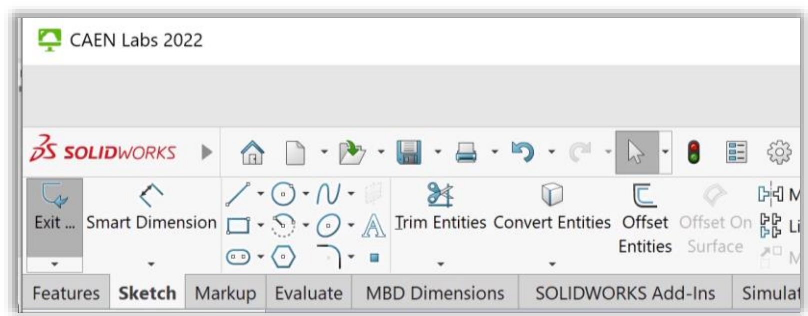
- Each operation begins with a sketch
- Sketches are made on a plane that is selected (shape face, plane, etc.)
- The sketch defines what is being extruded / cut
- Building sketches includes simple operations (lines, circles, fillets, etc.)
- Sketches can be 'trimmed'
- 'Smart Dimension' is used to add dimensions
- Exiting the sketch will bring you back out to the original (3D) operation to select thickness



Create lines /shapes, etc.

Convert, patterns, etc.





Exit Sketch and Smart Dimension buttons

ROBOTICS

Lab 3 – Designing Ball-Bot Structures

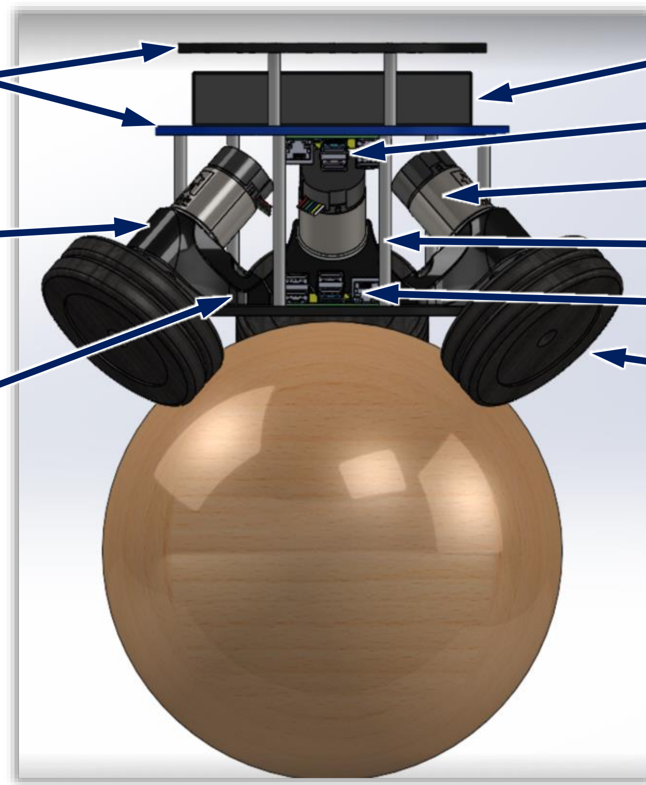
- Over the next few labs, we will build the structures of the ball-bot
- We will begin with the motor mounts then move to the acrylic structures
- You will use these part files to have your designs made

We're going to design and make these

Three different acrylic plate structures
Laser cut

Motor mounts (x3)
3D printed - FDM

RPi isolator plate (acrylic)
Laser cut



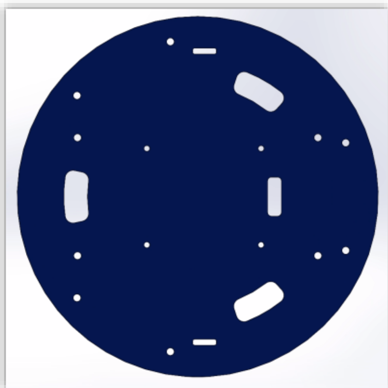
Battery (12 V, 6 AHr)
Raspberry Pi
Brushed motors (x3)
Standoffs (x10)
Raspberry Pi Pico + IMU
Omni-wheels (x3)

Motor mounts – medium difficulty
Acrylic plates - easy

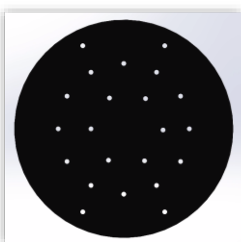
Lab 3 – Designing Ball-Bot Structures (2D)

- Acrylic plates that need to be designed

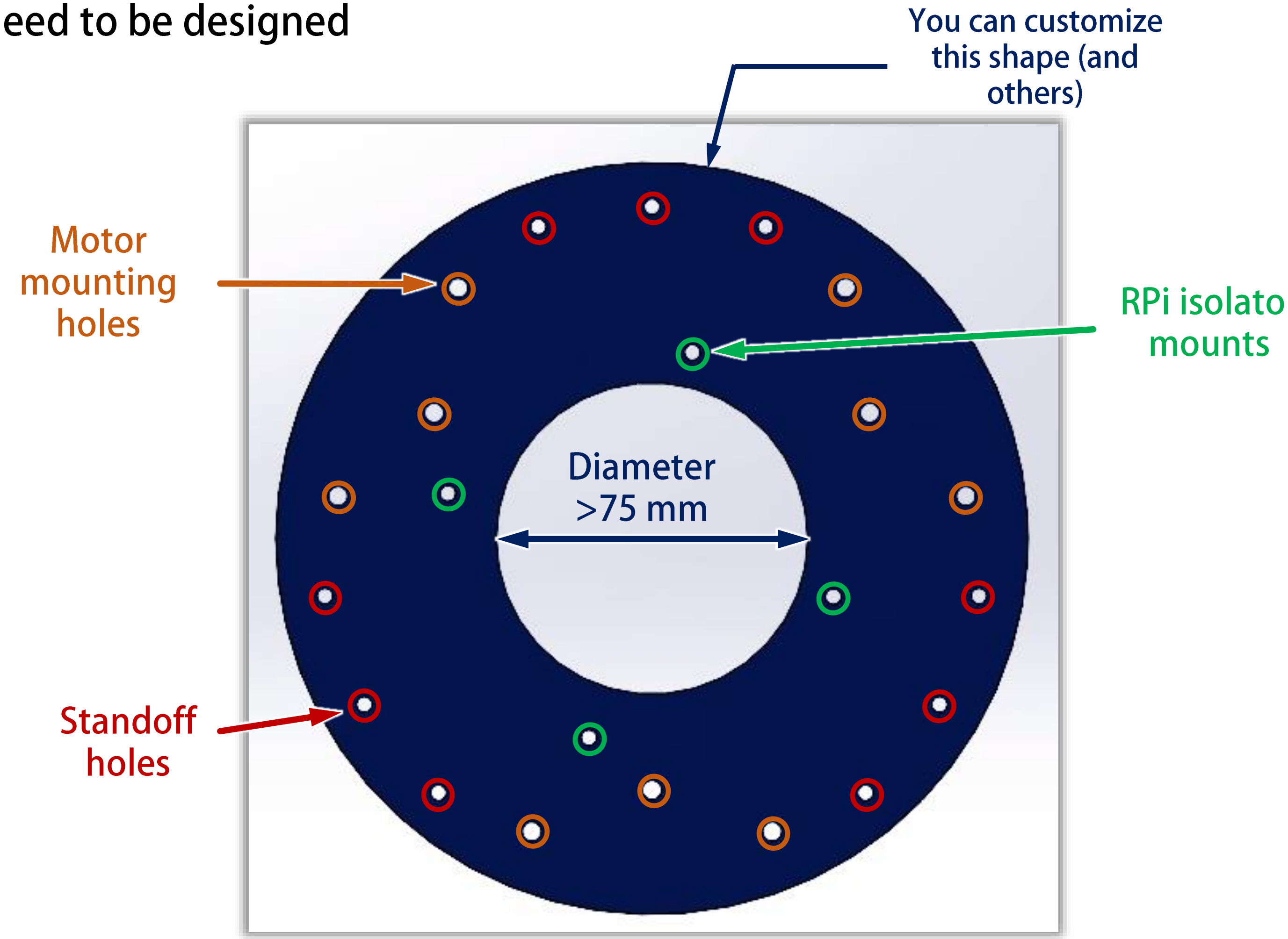
RPi isolator plate



Middle plate



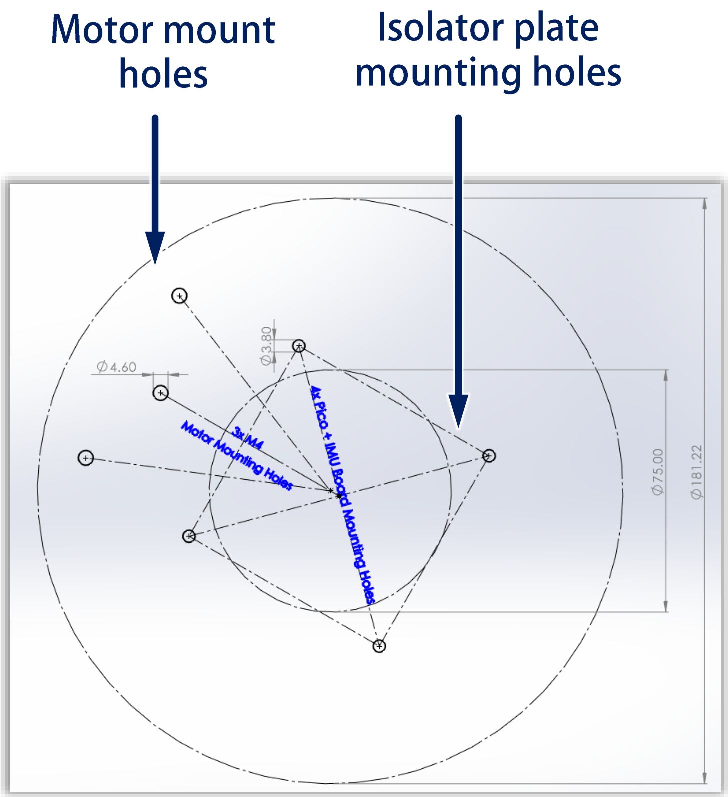
Top plate

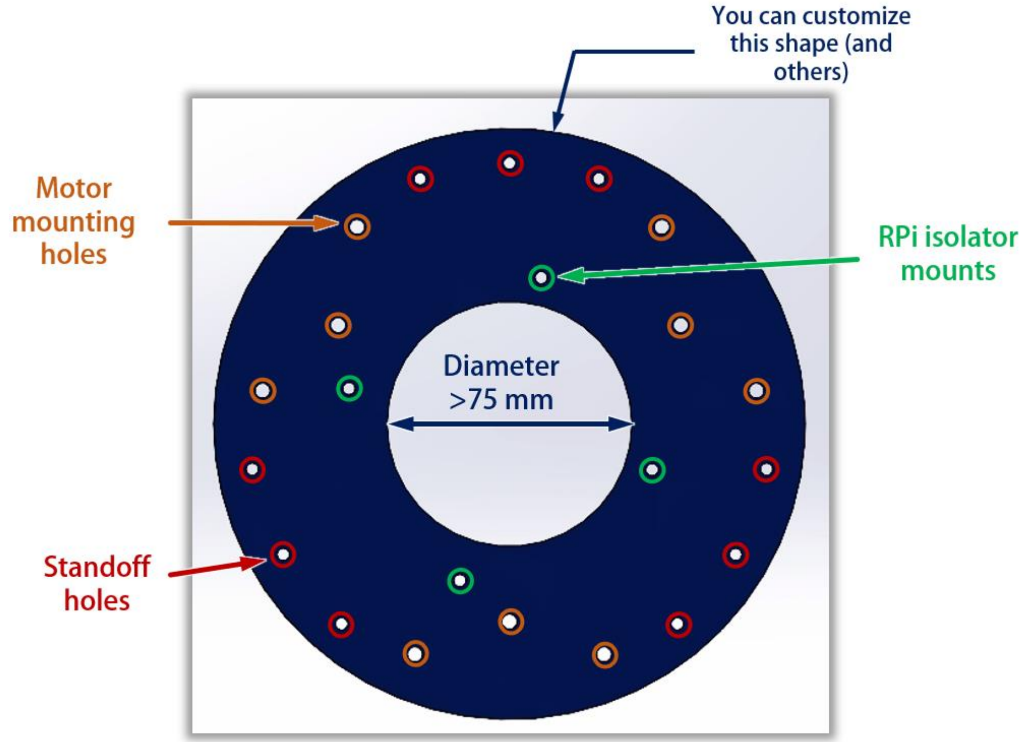


Baseplate

Lab 3 – Designing Ball-Bot Structures (2D)

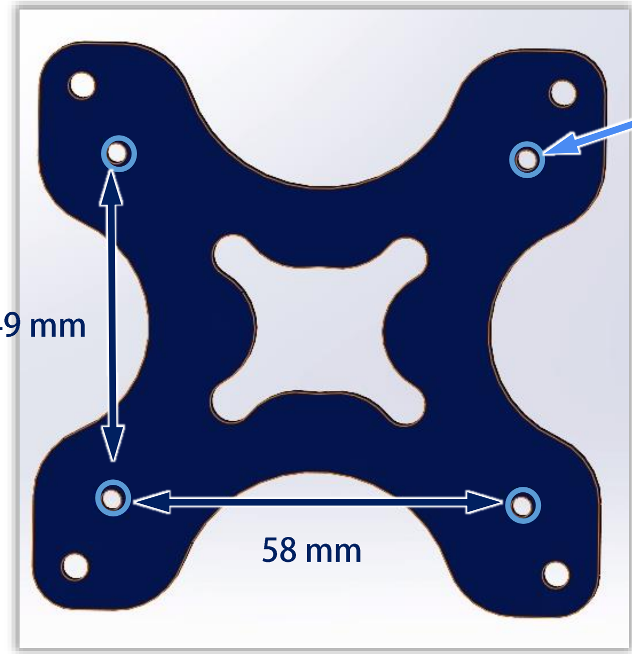
- Baseplate and template



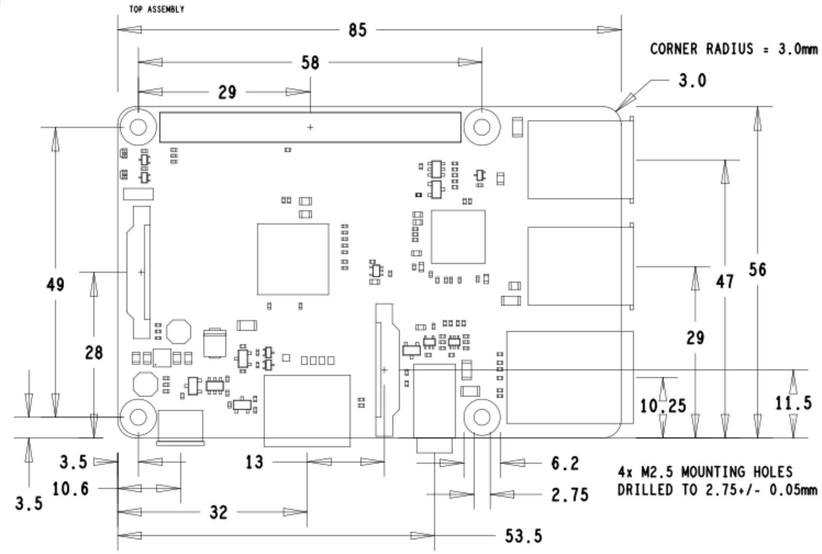


Baseplate

Lab 3 – Designing Ball-Bot Structures (2D)



RPi isolator plate



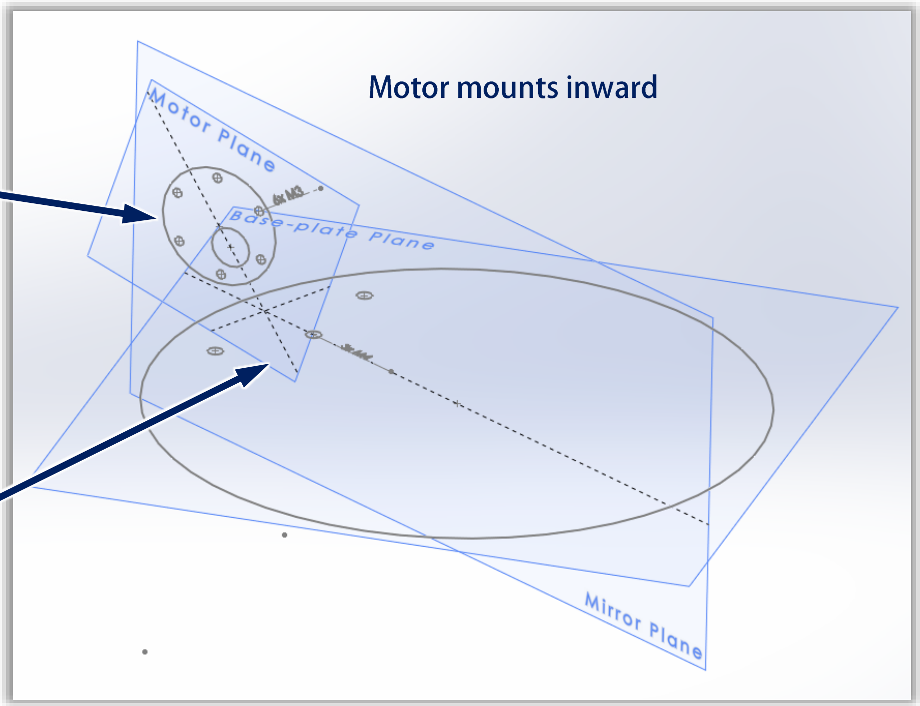
- The isolator plate holds the RPi Pico and IMU off the baseplate, mounted with rubber grommets
- Key idea is to reduce motor vibration impact on the IMU readings
- The RPi mounting holes will need to match the layout on the Raspberry Pi
- The isolator mounting holes can be anywhere, as long as they mount to holes on the baseplate
- The mounting holes for the RPi Pico are the same as the regular RPi

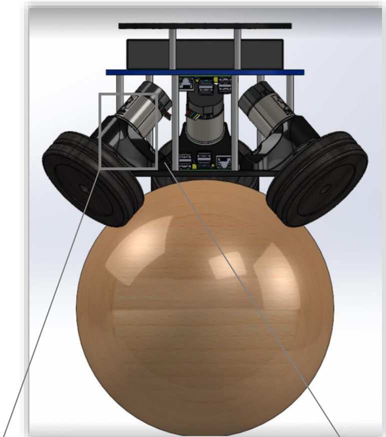
Lab 3 – Designing Ball-Bot Structures (3D)

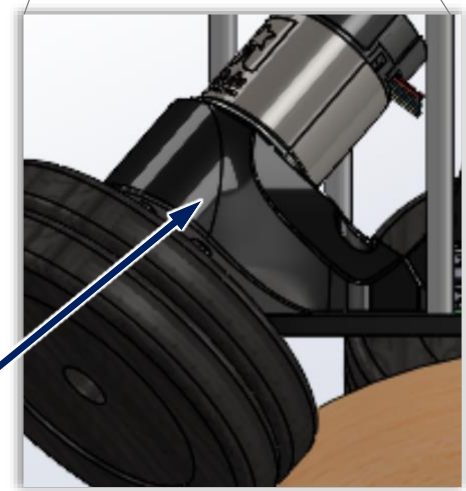
- Provided part file with pre-made sketches:

Motor mount sketch

Sketch w/holes for mounting to baseplate (3x)







Motor mount
leave space for the motor