Dynamics of Biomimetic Robotic Self-Assemblages

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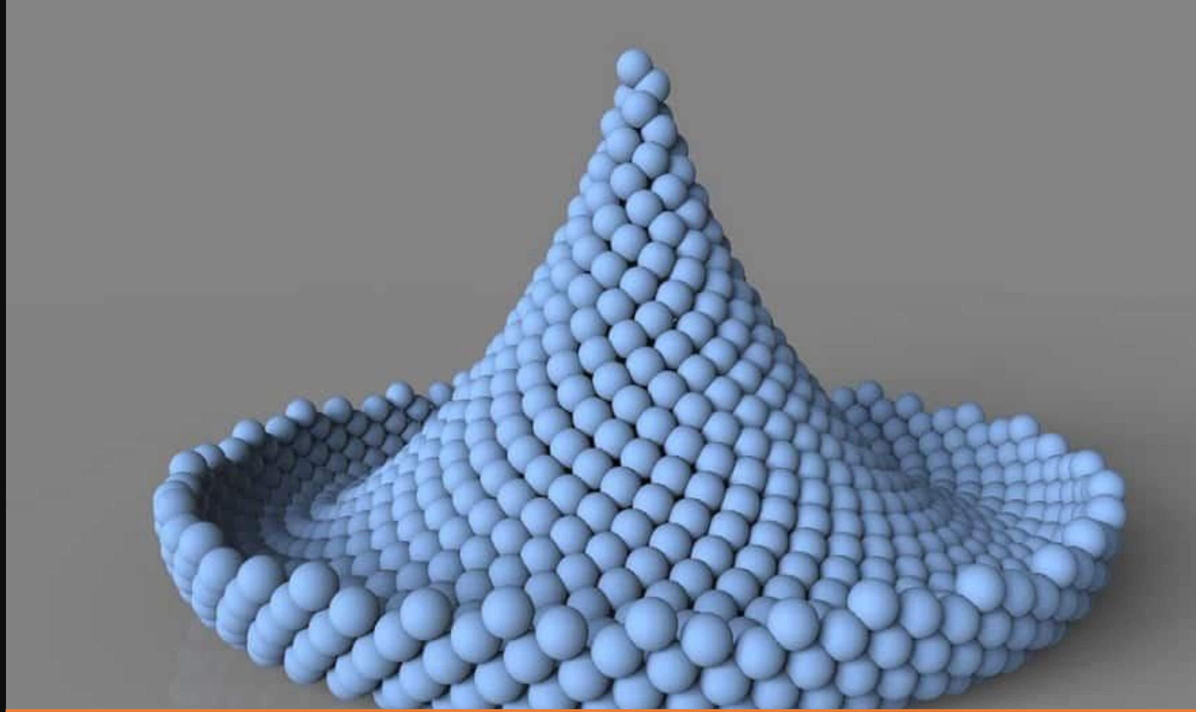
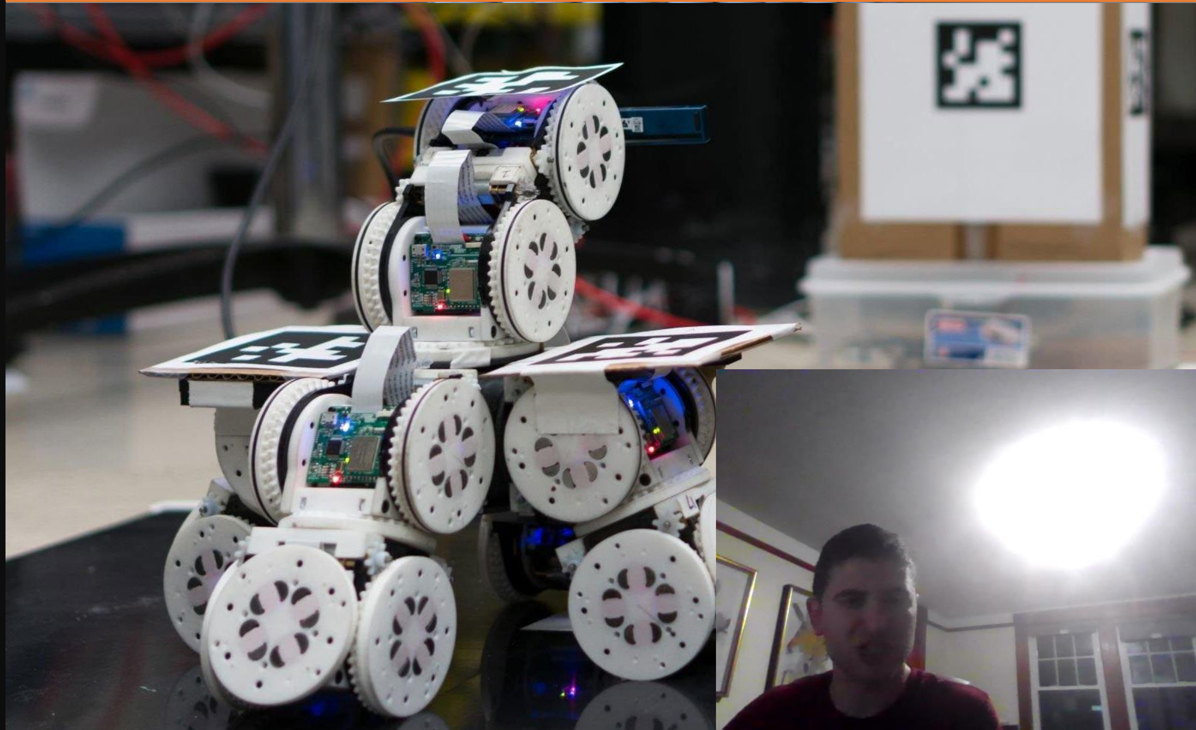
Inspiration from Insect Behavior

- Adaptive and Dynamic Structures form from groups of Insects
  - Defensive Structures
  - Pulling Structures
  - Thermoregulation
  - Bridging
  - Rafts
  - Etc.

Potential Applications

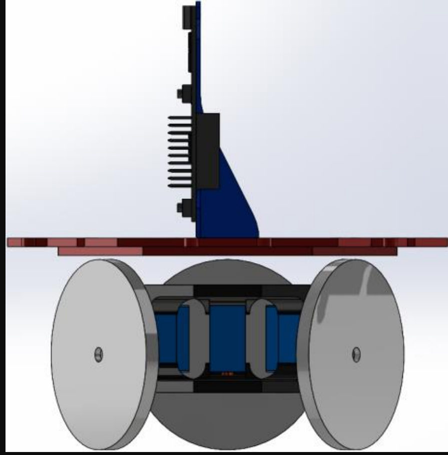
- Claytronics
  - A theoretical form of programmable matter made up of individual millimeter scale robots to form 3d shapes
- Modular Robotics
  - Robots changing their shape to adapt to the environment in different ways

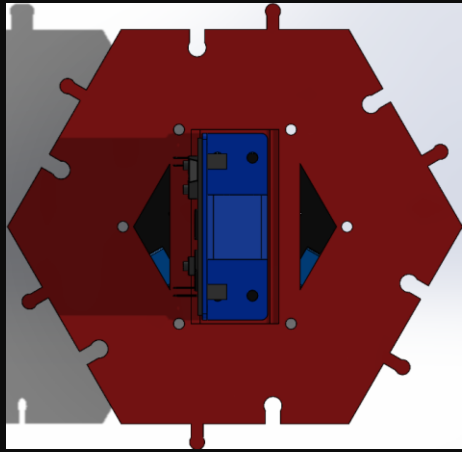


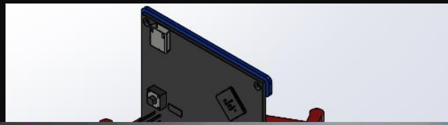


Robot Design

- Modularity
- Omni-directionality
    - Allows for maximum maneuverability in 2D
    - Can follow any desired vector

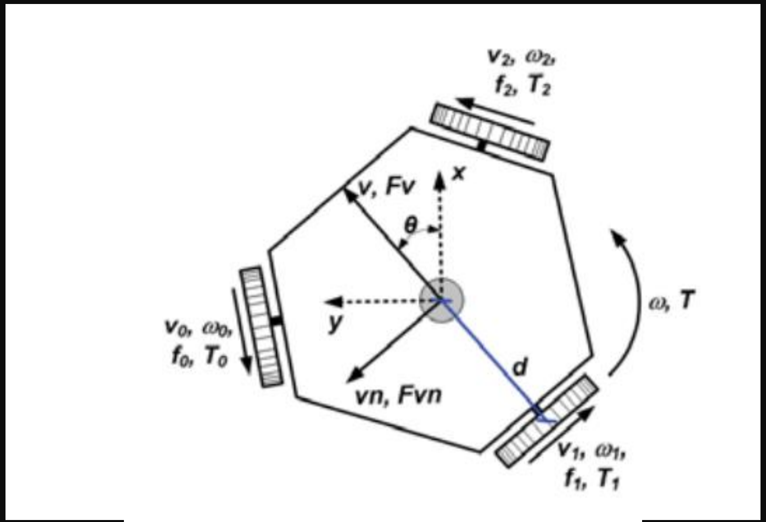






Kinematics

- A 3-wheeled omni-directional robot can be seen
- Transformation from world frame to robot frame is given by a Rotation matrix
- The robot frame velocities can be transformed to wheel velocities



$$\begin{bmatrix} c\theta & s\theta & 0 \\ -s\theta & c\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} v_0(t) \\ v_1(t) \\ v_2(t) \end{bmatrix} = \begin{bmatrix} -\sin(\pi/3) & \cos(\pi/3) & d \\ 0 & -1 & d \\ \sin(\pi/3) & \cos(\pi/3) & d \end{bmatrix} . \begin{bmatrix} v(t) \\ vn(t) \\ \omega(t) \end{bmatrix}$$

Dynamics

- A State-Space Representation of the Dynamic Model is presented
- Representation of terms can be found in the paper and the values can be found in the code
- C++ Implementation

$$\dot{x} = Ax(t) + Bu(t) + K sign(x)$$

$$A = \begin{bmatrix} A_{11} & 0 & 0 \\ 0 & A_{22} & 0 \\ 0 & 0 & A_{33} \end{bmatrix}$$

$$A_{11} = \frac{-3(K_t)^2 l^2}{2r^2 RM} - \frac{B_v}{M}$$

$$A_{22} = \frac{-3(K_t)^2 l^2}{2r^2 RM} - \frac{B_{vn}}{M}$$

$$A_{33} = \frac{-3d^2(K_t)^2 l^2}{r^2 RJ} - \frac{B_w}{J}$$

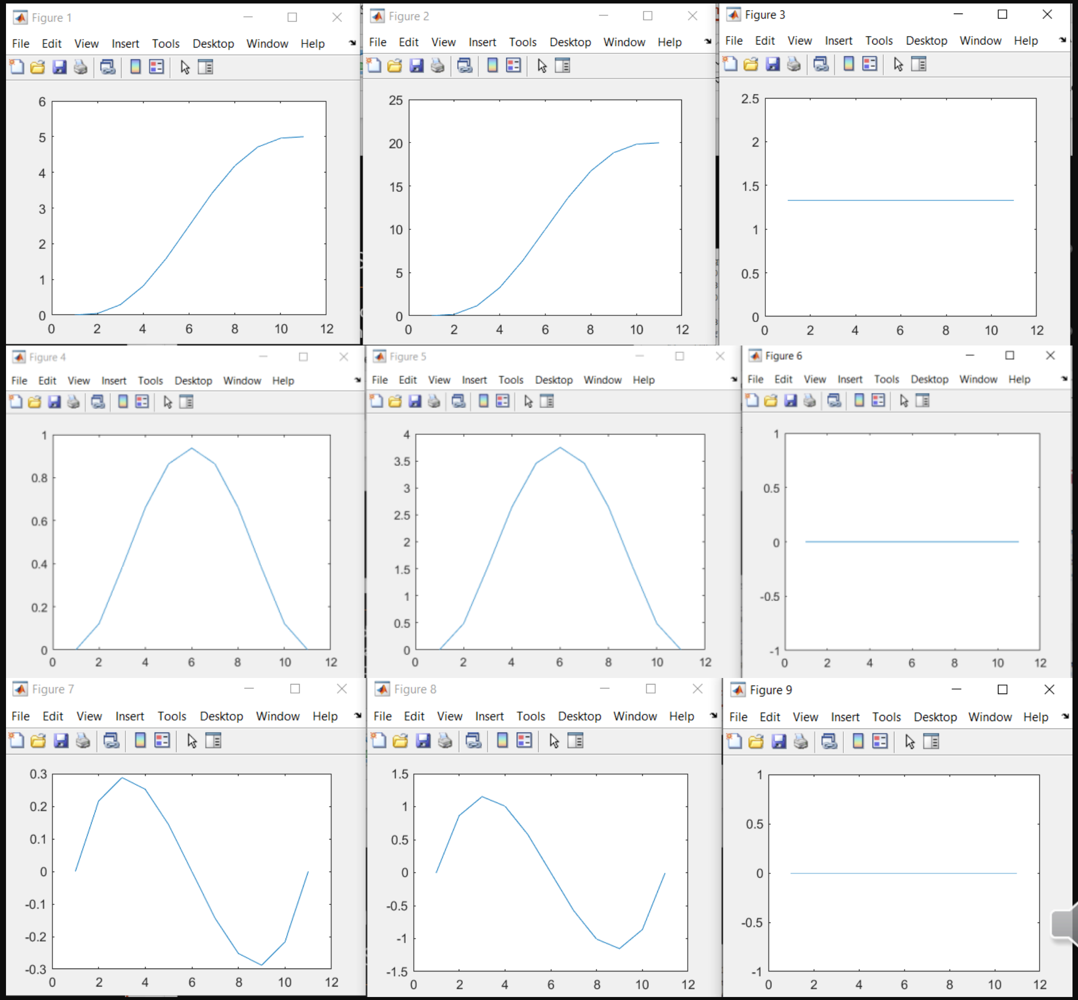
$$B = \frac{lK_t}{rR} \cdot \begin{bmatrix} -\frac{\sqrt{3}}{2M} & 0 & \frac{\sqrt{3}}{2M} \\ \frac{1}{2M} & \frac{1}{M} & \frac{1}{2M} \\ \frac{d}{J} & \frac{d}{J} & \frac{d}{J} \end{bmatrix}$$

$$K = \begin{bmatrix} -\frac{C_v}{M} & 0 & 0 \\ 0 & \frac{C_{vn}}{M} & 0 \\ 0 & 0 & \frac{C_w}{J} \end{bmatrix}$$

Practical Demonstration

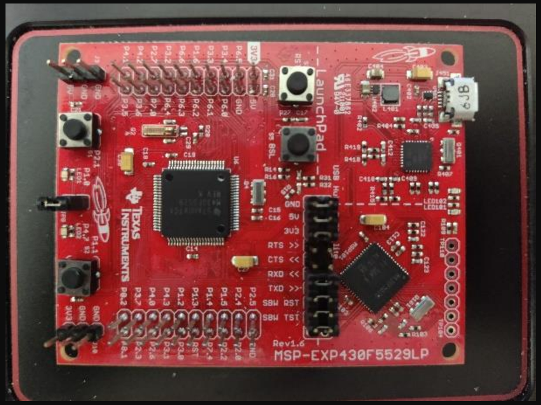
- Quintic (5^{th} order) position, velocity, and acceleration trajectories were generated for the robot in world frame (images in same order)
- A simple implementation of 3 wheels in shown in the video

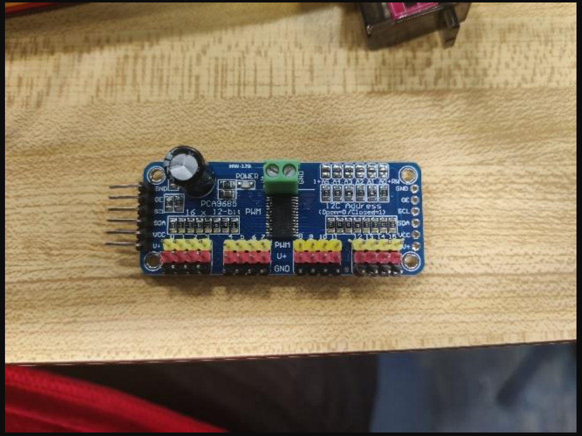
```
function q = quinticpoly(t0,tf,q0,qf,qd0,qdf,qdd0,qddf)
    A1 = [1 t0 t0^2 t0^3 t0^4 t0^5;...
    0 1 2*t0 3*t0^2 4*t0^3 5*t0^4;...
    0 0 2 6*t0 12*t0^2 20*t0^3;...
    1 tf tf^2 tf^3 tf^4 tf^5;...
    0 1 2*tf 3*tf^2 4*tf^3 5*tf^4;...
    0 0 2 6*tf 12*tf^2 20*tf^3];
    b1 = [q0 qd0 qdd0 qf qdf qddf]';

    A = A1\b1;
    syms t;
    q(t) = A(1) + A(2) * t + A(3) * t^2 + A(4) * t^3 + A(5) * t^4 + A(6) * t^5;
end
```



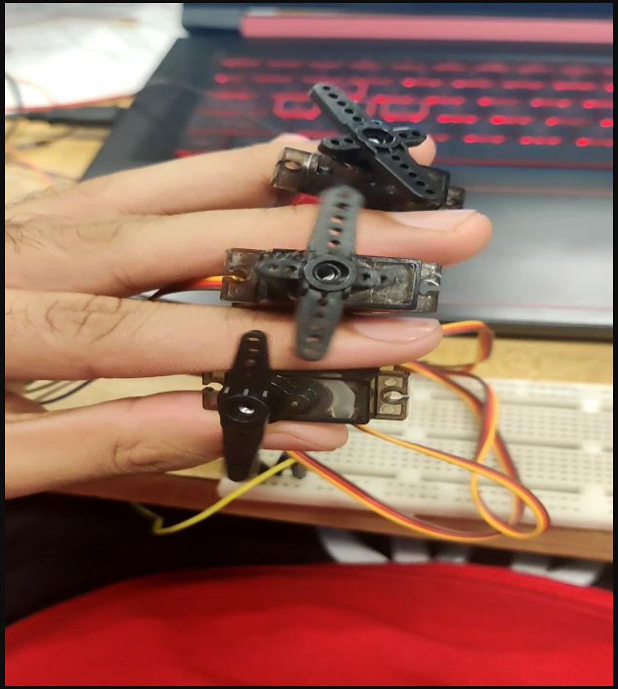
Practical Demonstration

- Components
  - Controllers
  - Servo Driver
  - Motors



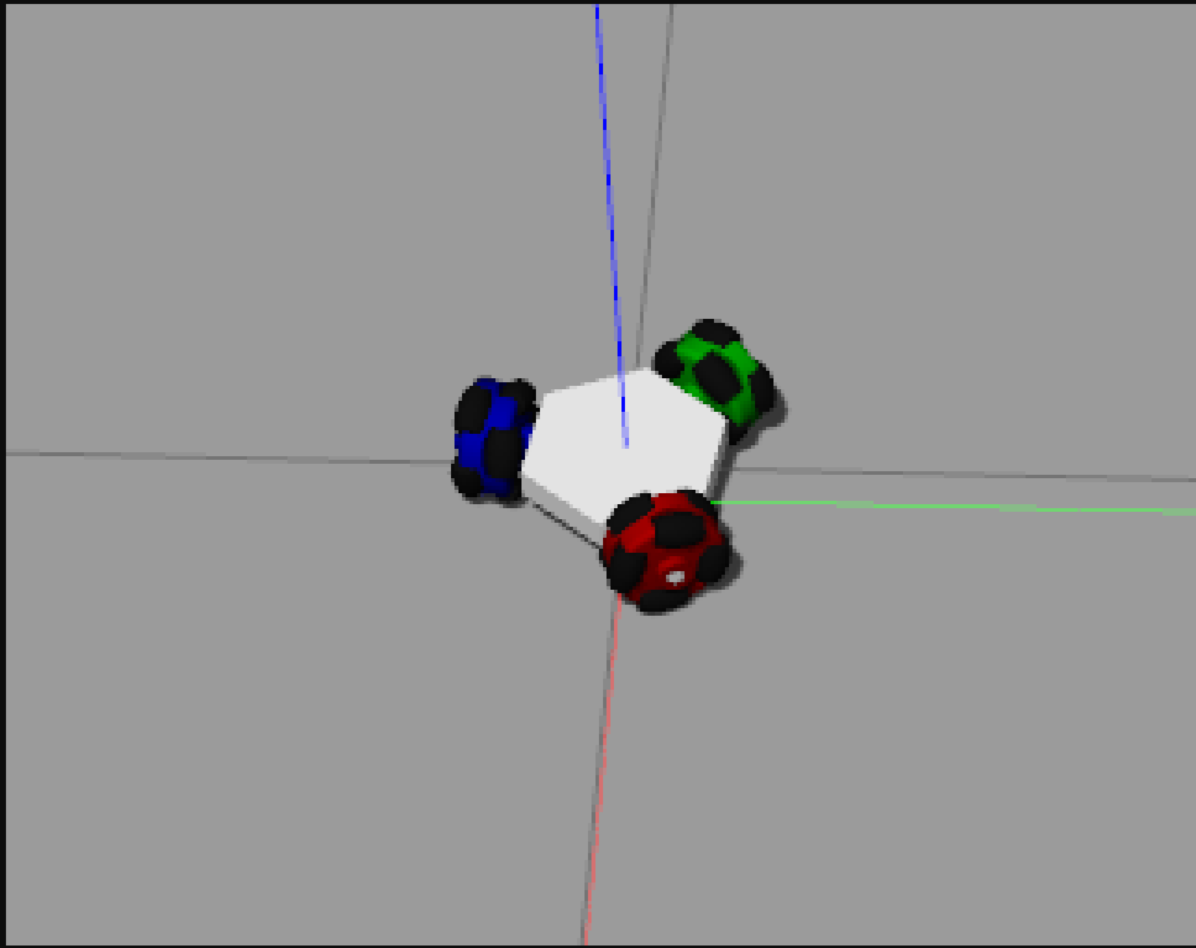


Practical Demonstration



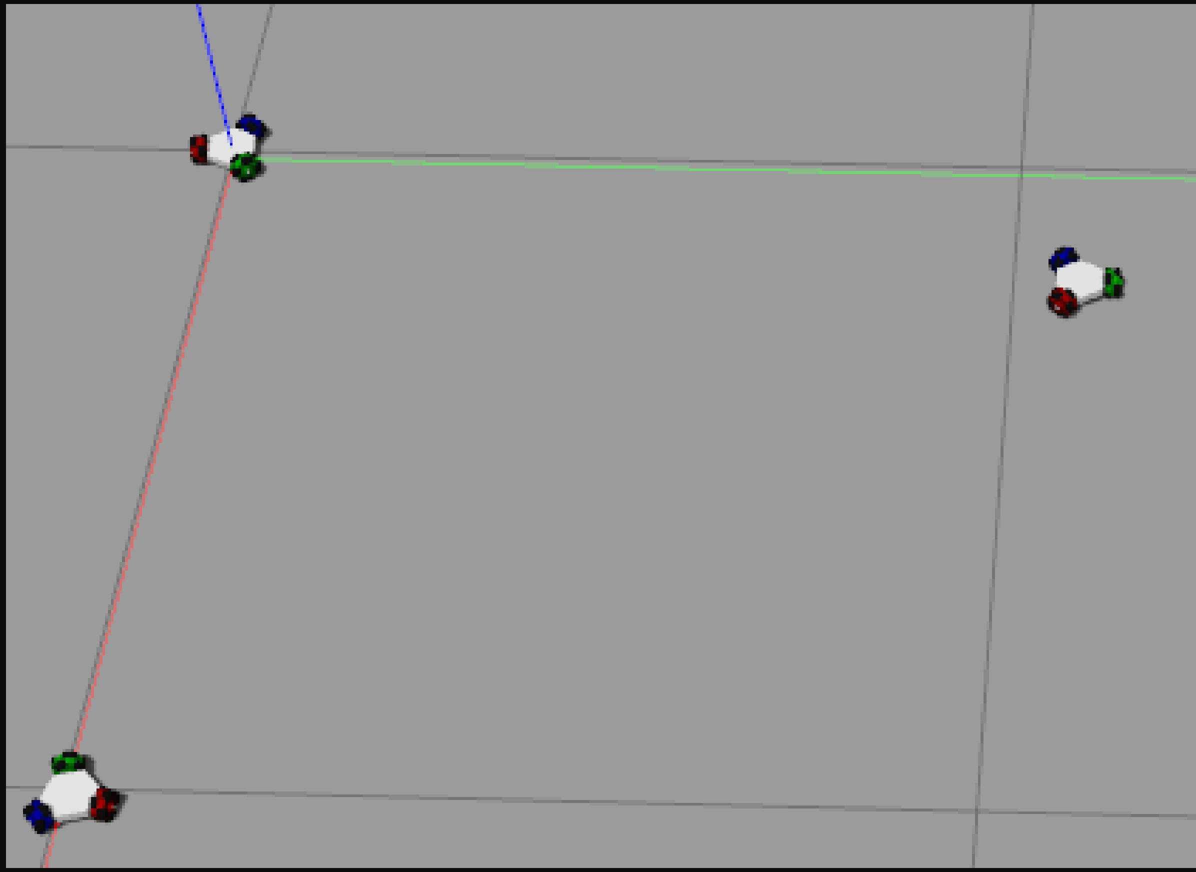
Individual Robot Simulation

- Difficulties creating custom omni wheels in URDF
- OpenBase model
- Trajectory generation



Self-Assemblage Simulation

- Multiple robots
- OpenBase does not support multiple robots
- Possible, but would require a new implementation



Future Steps

- Fabricate and order model body and wheels
- Complete physical implementation
- Run the generated trajectory in simulation
- Modify simulation to allow for three robots at once
- Compare ideal model to simulated characteristics and physical model

References

- Helder P. Oliveira, Armando Jorge Sousa, A. Paulo Moreira, Paulo Jose Cerqueira Gomes da Costa, “Dynamical Models for Omni-directional Robots with 3 and 4 Wheels” 5th International Conference on Informatics in Control, Automation and Robotics, May 2008.
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