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Emergent Behavior through Local Sensing

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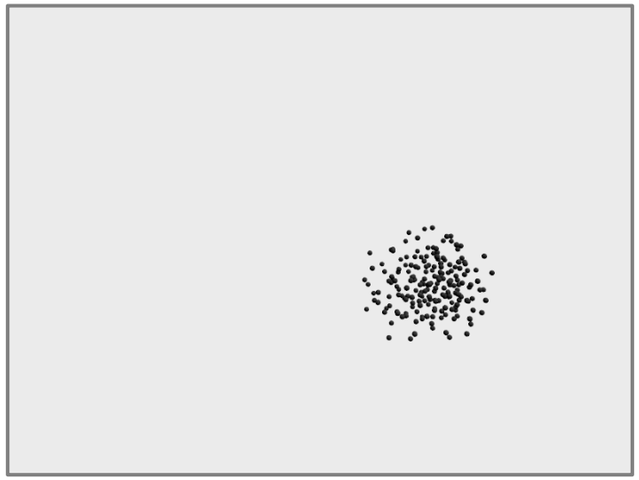
Background

- A common form of swarm control leverages virtual forces generated through proximity to neighbors [cite]
- Often combined with orientation matching. Such agents are referred to as Boids (shown below)
- Easy to implement with global sensing (i.e. Vicon) but this removes the swarm's portability



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Project Goal

- Implement virtual force control using onboard sensing and computing
- Explore emergent behavior resulting from inherent sensor limitations
- Constraints:
  - No agent-to-agent communication that would reduce scalability
  - No specialized sensors
  - Portable anywhere the agents can operate

Simulations

- Used MATLAB to create simulation environments
- Allowed me to quickly iterate through possible onboard sensing configurations as I became familiar with blimp design and control

- Early simulations used single integrator dynamics
- Agents ‘sensed’ closest neighbors and simply moved to their average location

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Simulations

- A few obvious problems
  - Single integrator dynamics are not useful in most cases
  - Agents cannot always sense their closest neighbors, only the closest neighbors within the sensor's 'line of sight'
  - Did not account for seaweed

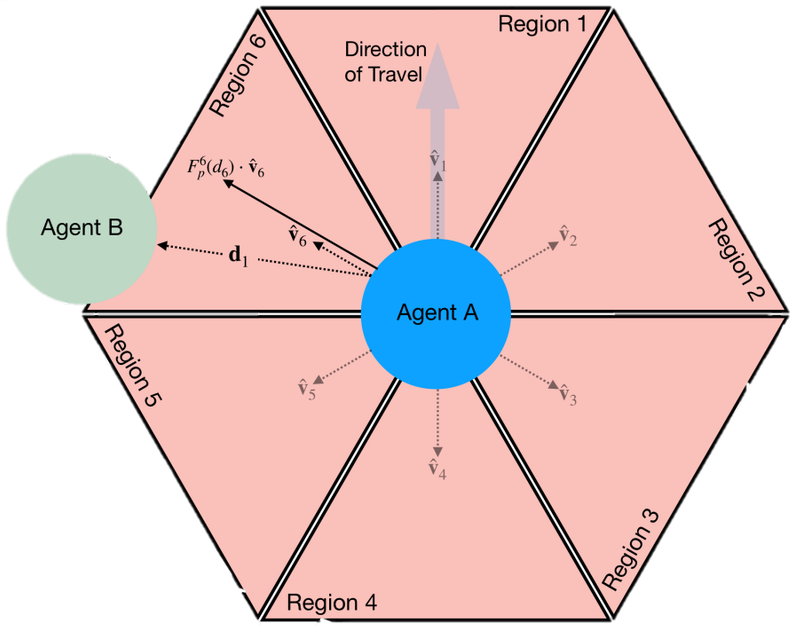
Simulations - Dynamics

- Eventually moved to double integrator dynamics with orientation included as a state
- Dampening values approximated with early blimp designs

$$\begin{bmatrix} x \\ y \\ \theta \\ v_x \\ v_y \\ \omega \end{bmatrix}^+ = \begin{bmatrix} 1 & 0 & 0 & \tau & 0 & 0 \\ 0 & 1 & 0 & 0 & \tau & 0 \\ 0 & 0 & 1 & 0 & 0 & \tau \\ 0 & 0 & 0 & \alpha & 0 & 0 \\ 0 & 0 & 0 & 0 & \alpha & 0 \\ 0 & 0 & 0 & 0 & 0 & \beta \end{bmatrix} \begin{bmatrix} x \\ y \\ \theta \\ v_x \\ v_y \\ \omega \end{bmatrix} + \begin{bmatrix} 0.5\tau^2 & 0 & 0 \\ 0 & 0.5\tau^2 & 0 \\ 0 & 0 & 0.5\tau^2 \\ \tau & 0 & 0 \\ 0 & \tau & 0 \\ 0 & 0 & \tau \end{bmatrix} \begin{bmatrix} a_x(f_x, f_y) \\ a_y(f_x, f_y) \\ a_\omega(f_x, f_y) \end{bmatrix}$$

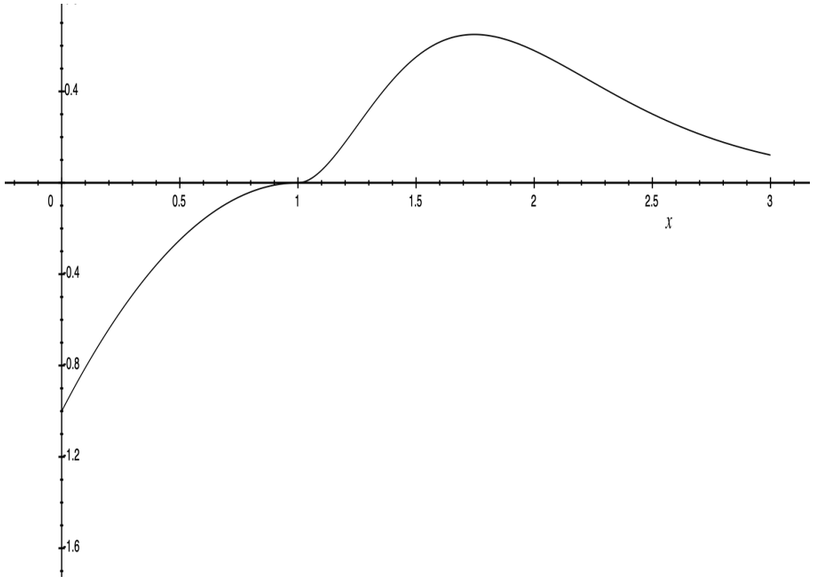
Simulations - Sensing

- Senses the closest neighbors
  - Up to one neighbor sensed per region
  - If a zone had no neighbors within its sensing range, treat as empty
- All agents share an orientation. Allows coordinated movement



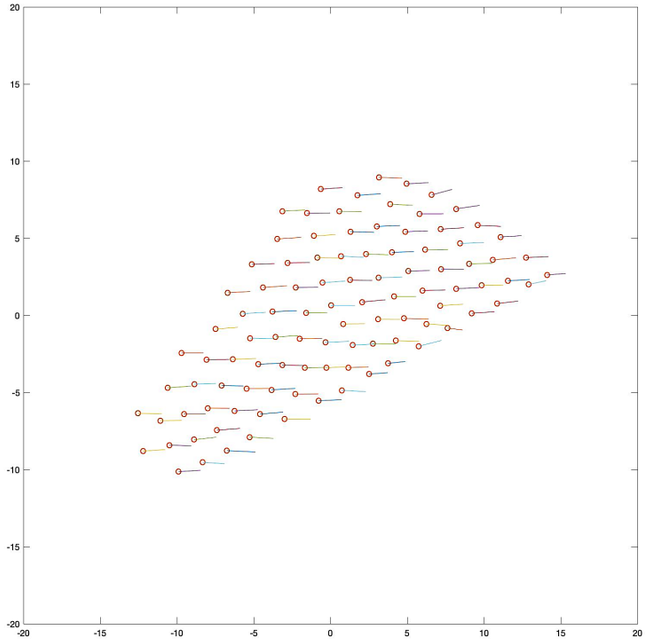
Simulations – Parameter Adjustment

- Parameters where adjusted to reveal hidden emergent behavior
- Only parameters that could be adjusted globally where explored including;
  - Virtual force characteristics
    - Force profile
    - Max force magnitudes
    - Equilibrium distance
    - Max sensing distance
  - Region based weighting
  - Global forces
  - Max number of neighbors sensed



Simulations – Emergent Behavior

- Basic emergent behavior such as clustering observed
- Tuning the virtual force curve parameters allowed ordered ‘crystalline’ formations
- Regional equilibrium distances and a global force resulted in an ‘Arrow Formation’



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Agent Design - Goal

- Build a LTA agent that would reflect the simulations using onboard computing and sensing alone
- Be able to control the swarm's position and properties using a single centralized controller, regardless of scaling

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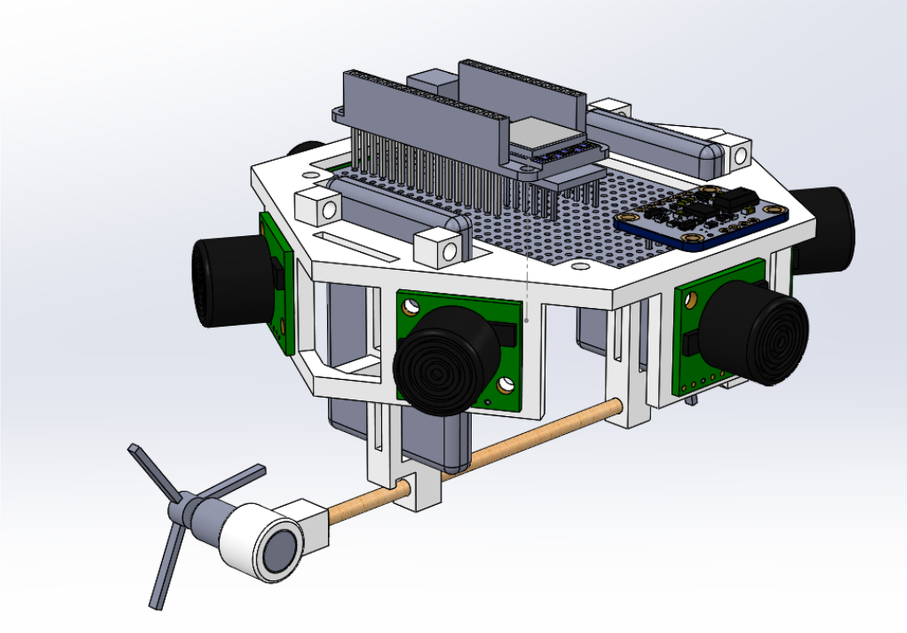
Agent Design

- Control - Adafruit Feather M0
- Communication – Integrated WIFI, UDP Broadcast Client
- Relative Location - MaxBotix ping sensors (6-7 per agent)
- Orientation – Adafruit BNO055 IMU sensor

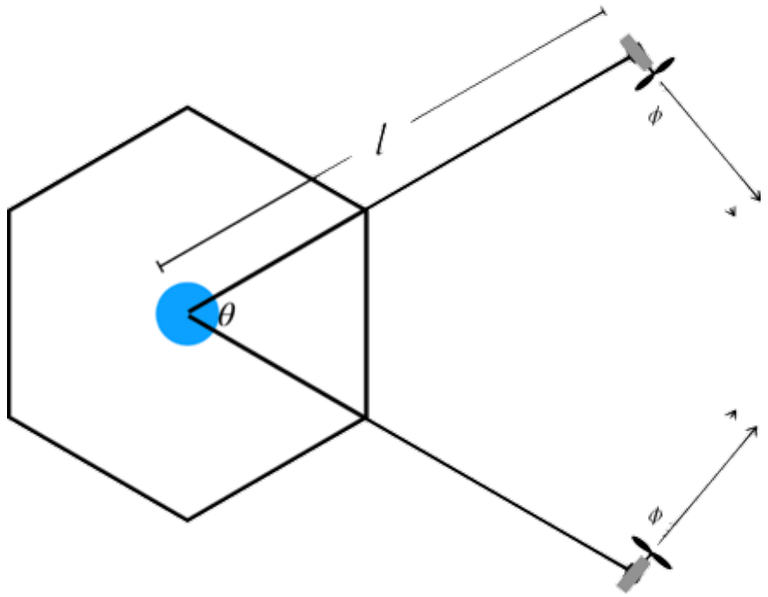
Agent Design – Ver 1

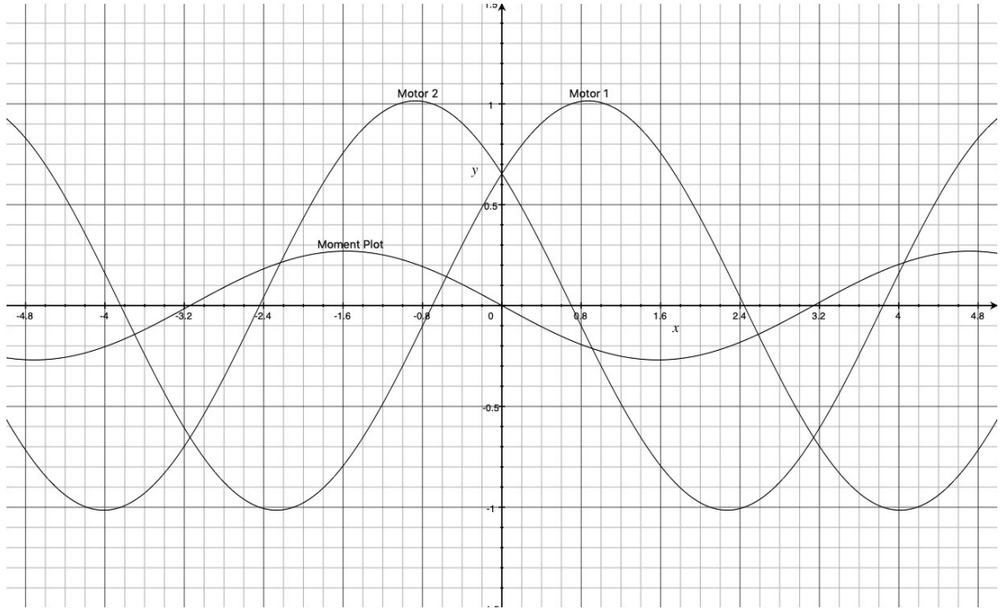
- Two envelopes
- Differential drive system
- Drag sting altitude control



Agent Design – Ver 2

- Offset Holonomic Drive
- Unlike traditional holonomic drives, this drive maintains a forward direction
- Simple to control. By just controlling for heading, a correcting moment is applied as a by product



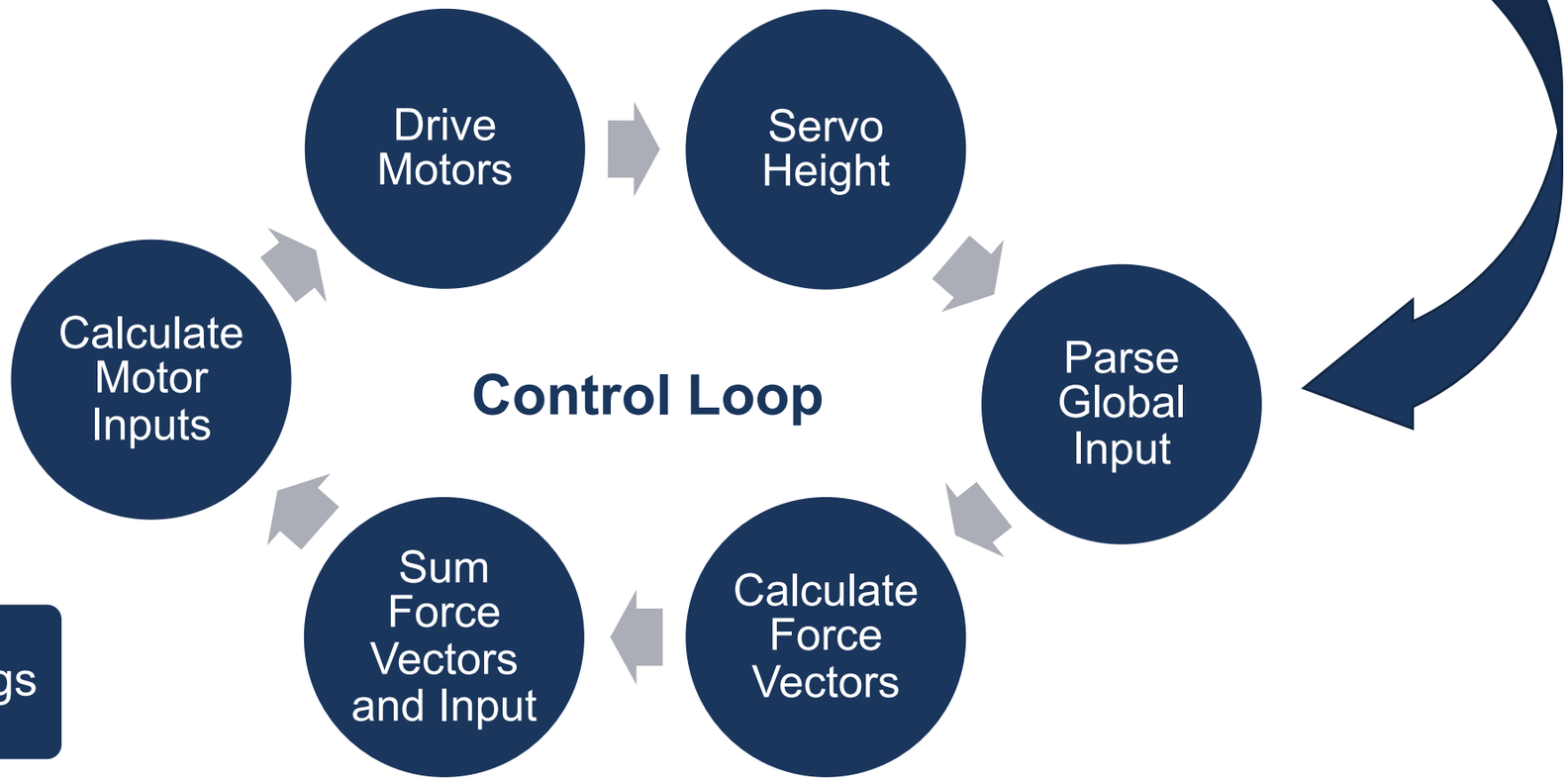


Agent Design – Controller

Setting up…

Configure Motor Driver → Connect to BlimpNet → Calibrate IMU → Begin Firing Pings

Control Loop



Ping Interrupt Service Routine

Read Ping Sensors → Clean Data → Fire Pings

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Testing

- Preliminary tests have been run to assess the qualitative nature of the blimps
- Parameters that need tuning
  - Virtual force curve
  - Ping frequency
  - Ping data filtering
  - Ping positioning
  - Altitude PID parameters
- Once tuned, Vicon will be used to capture the quantitative response to motor inputs
- This data will be used to tune the simulation parameters until the results match

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Future Work

- Move the simulation from MATLAB to a faster platform such as Scrimmage
- Develop a way for the agents to differentiate between a fellow agent and other objects. This would allow the agents to work in tight spaces without ‘sticking’ to the walls
- Expand sensing to a sphere around the agent
- Create a global State Space that includes things such as
  - Average swarm location
  - Swarm radius/density
  - Swarm fanning (column or row formations)
- Implement deployable sensors that would allow a centralized controller to use the global State Space and an advanced control to accomplish a task

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Thank You!