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The Swarm Robotic Game

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Outline

- Introduction
- Hardware
- Software
- Architecture
- Blob Detection
- Initialization, Localization and Heading estimate
- Tracking
- Control
- Swarming
- 1 Vs 1 escape
- Public Demonstration

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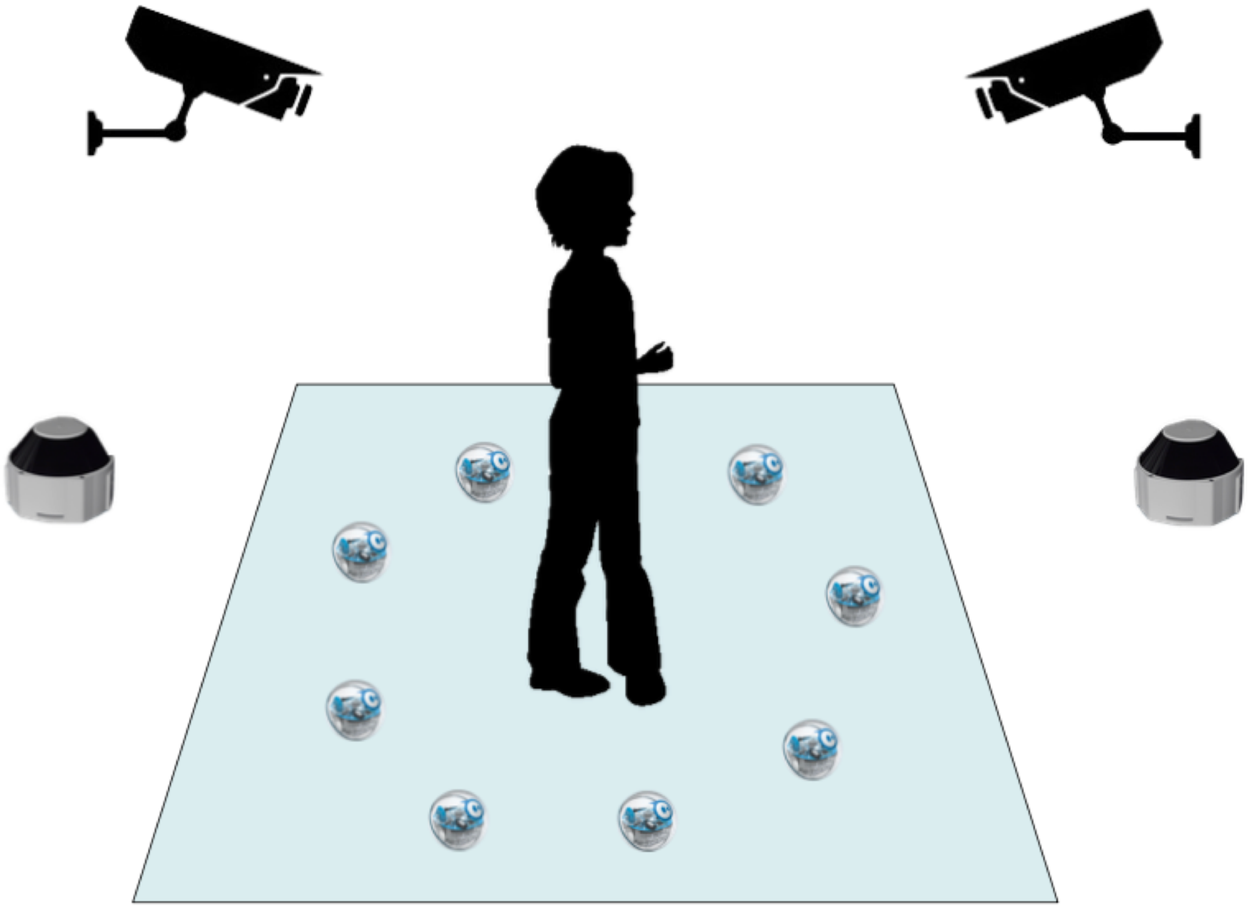
Introduction



- We are building an interactive swarm robotic game where autonomous robots play with humans
- Cameras track robots
- LiDARS track humans

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Gameplay

- After three public demonstrations and feedbacks two gameplay were finalized.
  - Kids - Human chases robots and robots move in formation around the human
  - Adults - Robots try to bump on the human foot while the human tries to dodge them

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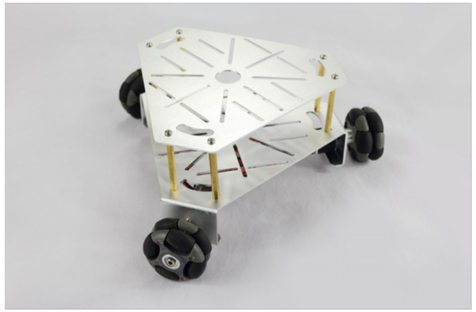
Hardware

- Motion of omni-directional robots are hard to predict and makes them a perfect candidate for the game.
- Some of the considered configurations :



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Hardware

	Cost	Build/Purchase	Time to build	Symmetry	Customizable
Rectangle	$700	Build	2 months	Cuboid 2-axis symmetry	Yes
	$1500	Purchase	10 days		
Triangle	$500	Build	2 months	Delta 2-axis symmetry	Yes
	$1400	Purchase	10 days		
Sphero Sprk+	$100	Purchase	1 day	Sphere 3-axis symmetry	No

With a higher priority to building the system over building the robots Sphere Sprk+ is selected as the robot platform for this project

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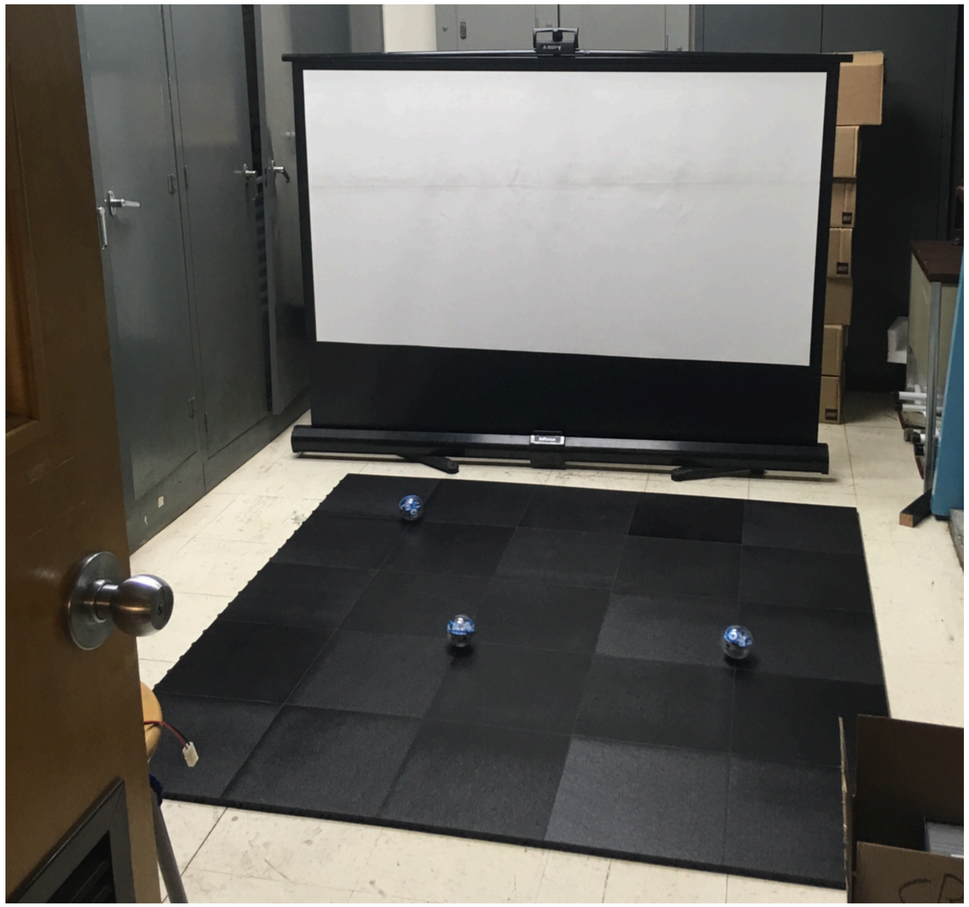
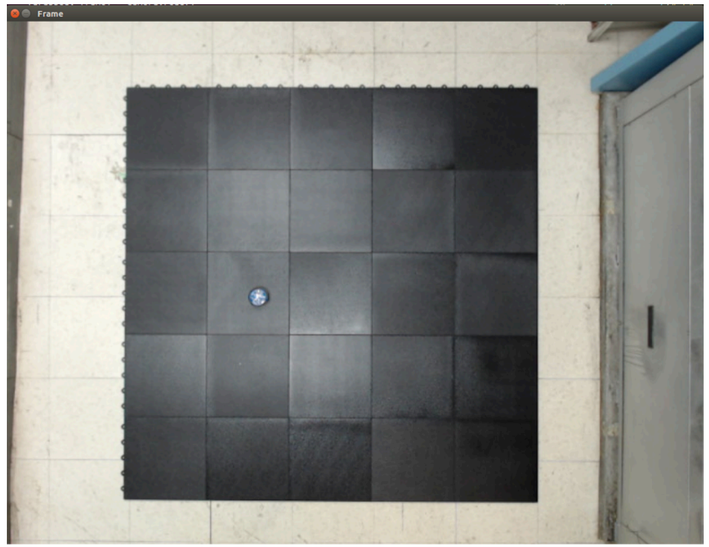
Experimental Setup



Logitech webcam is mounted on the ceiling facing down perpendicular to the black floor



Camera feed

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Software

- We use ROS (Robot Operating System) framework.
    - Our key utility in ROS is the publishing/subscribing plumbing as this eliminated the need to write multithreading in python and handles all the backend in C which is 5 times faster.
- Language: Python 2.7 and 3.14
- Image Processing: OpenCV in Python2.7

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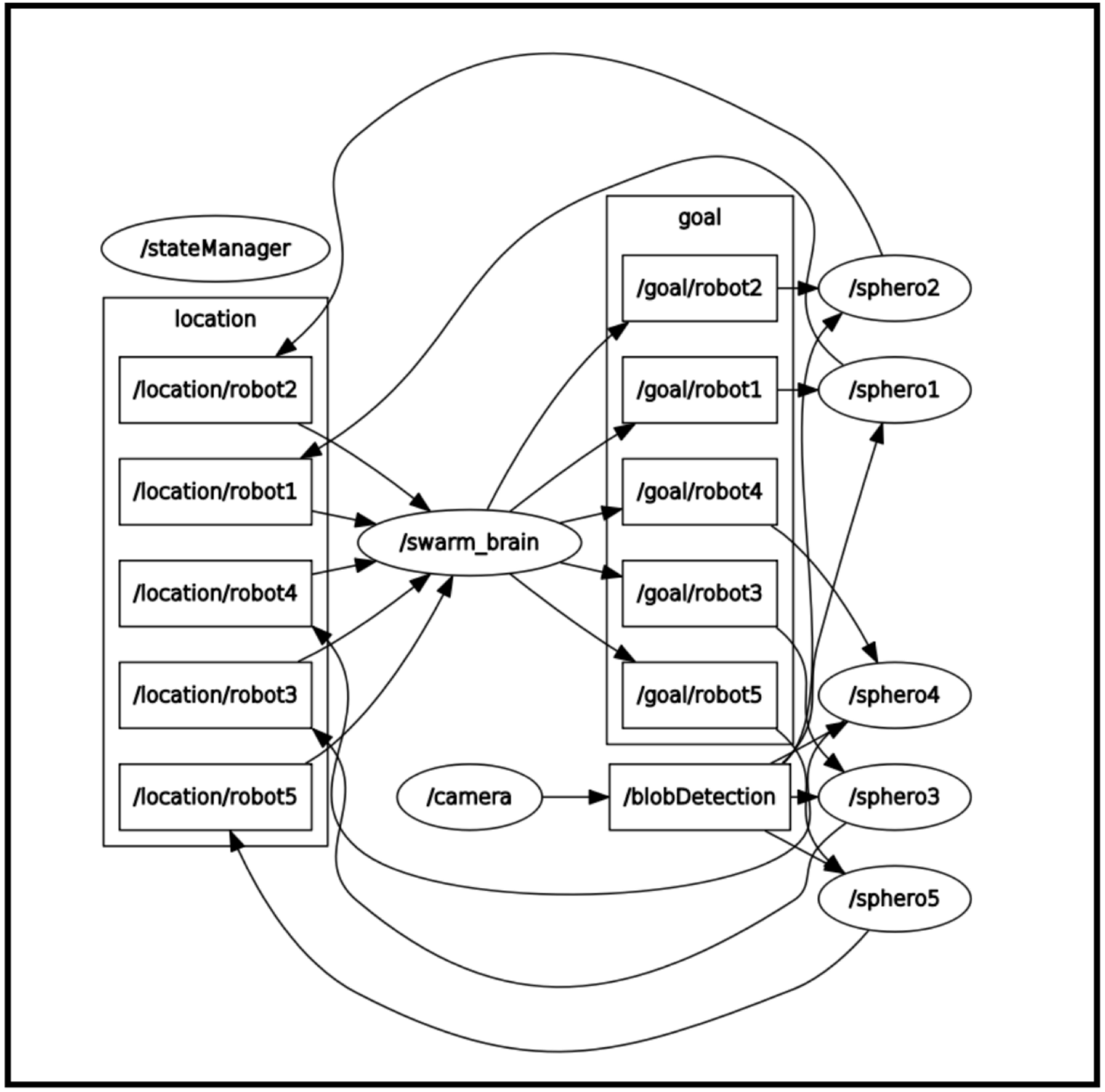
Architecture



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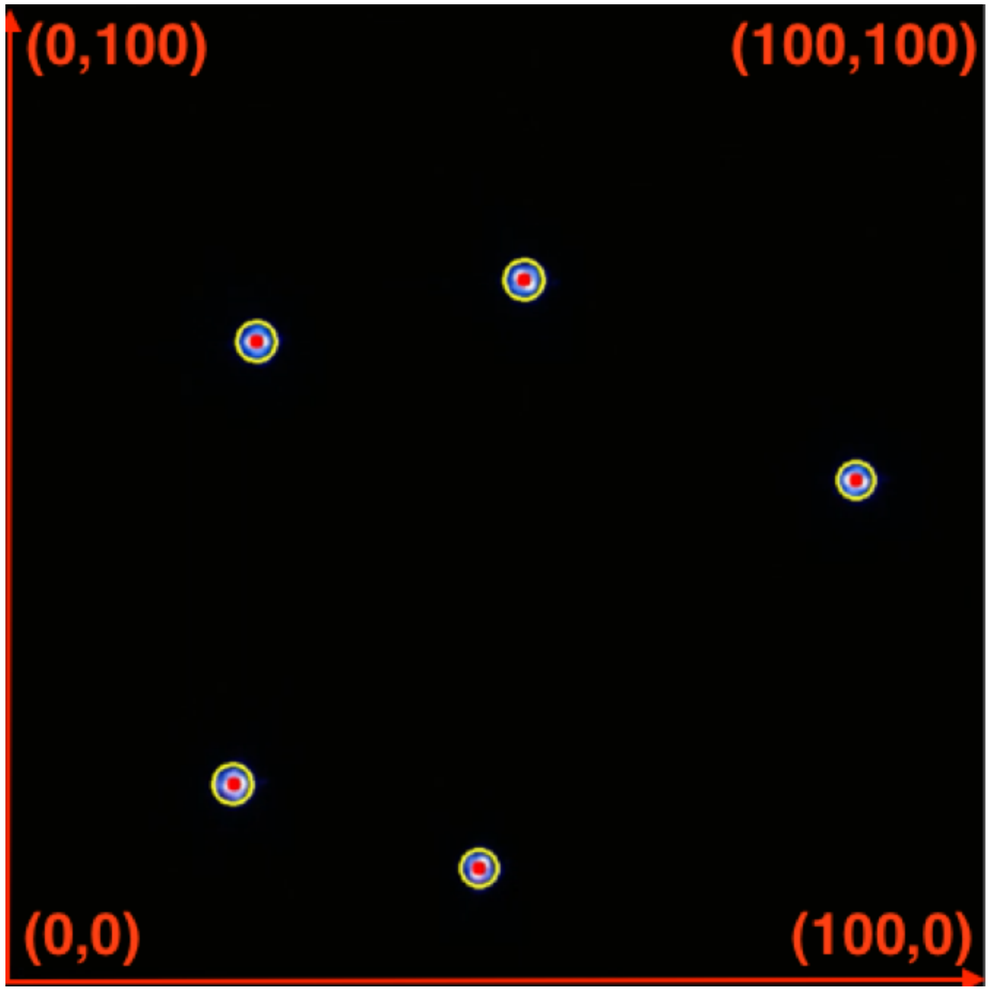
Blob Detection

- Blob Detection is done using OpenCV
- Maps output form pixels to global frame of reference in 100x100 units
- Output type :
  - Polygon message type
  - geometry_msgs/Point32[]



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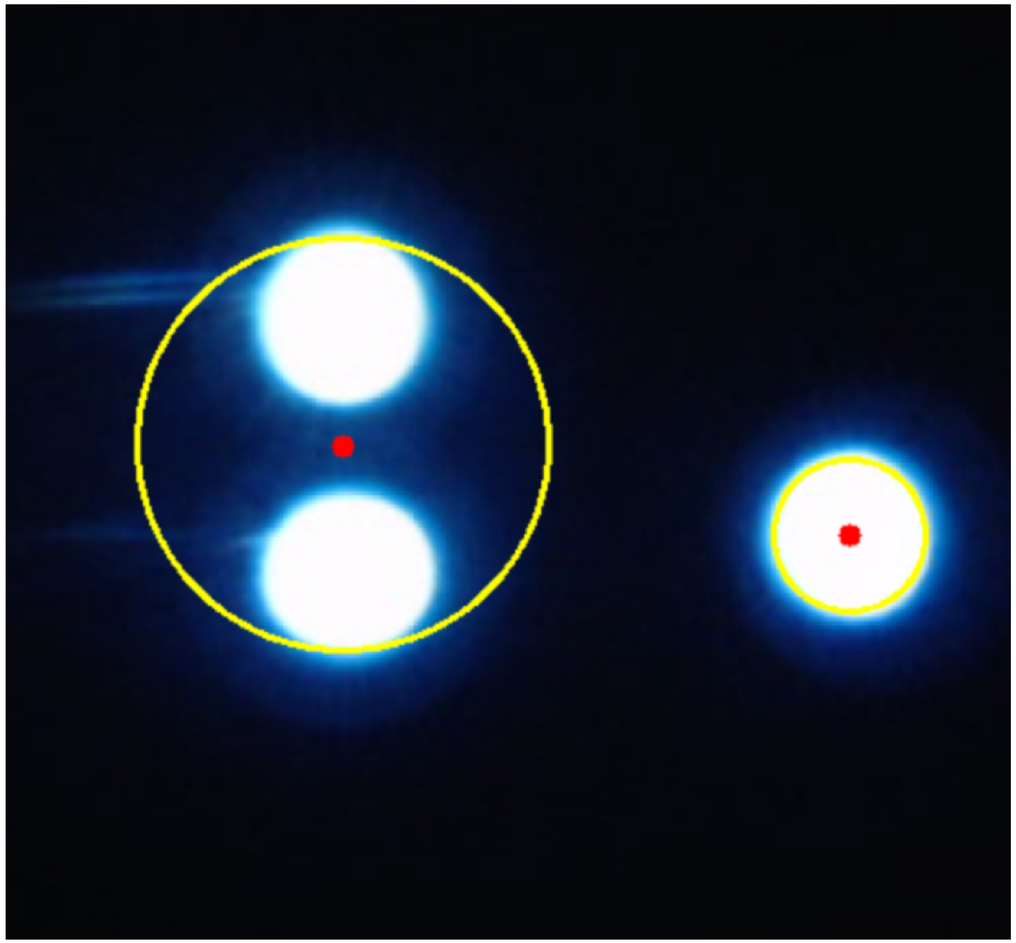
Blob Detection

- Problem :
  - Robots cannot get closer



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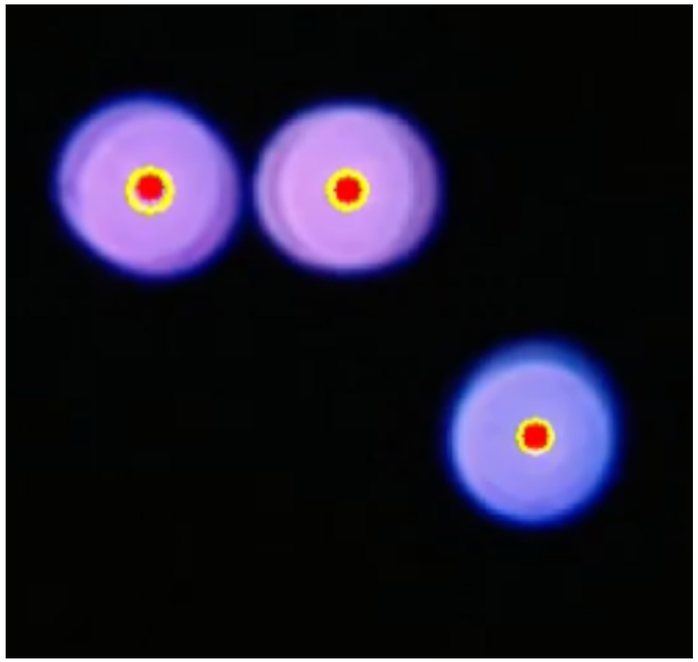
Blob Detection

- Fix :
  - Increase erode kernel size
  - Polaroid Filter on camera



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Initialization - Localization

- As all robots look the same an initialization sequence was built to create blob-IP pair
- Sequence:
  - Turn off LEDs in all robots
  - Send command to flash LED on each IP
  - Record blob location on each flash
  - Turn on LEDs on all robots

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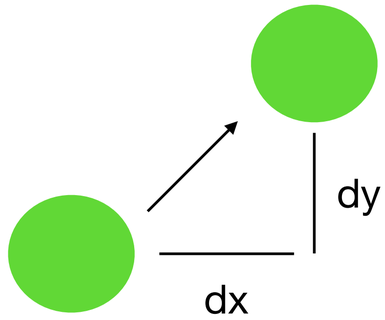
Initialization - Heading

- Sphere considers the heading it faces on power up as its zero reference heading.
- Once the initial heading is captured, we can offset all our controls from the initial heading to map the robot orientation to out global frame.
- Sequence:
  - Check if initial localization is complete
  - Move all robots forward
  - Use minimum cartesian distance between robot and all blobs to estimate new robot position
  - Once robot has moved 5 units from the initial position, calculate arctan2(dy/dx) to capture robot initial heading



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Tracking

Kalman Filter

$$\begin{bmatrix} X\_new \\ Y\_new \\ x\_velocity\_new \\ y\_velocity\_new \end{bmatrix} = \begin{bmatrix} 1 & 0 & dt & 0 \\ 0 & 1 & 0 & dt \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ x\_velocity \\ y\_velocity \end{bmatrix}$$

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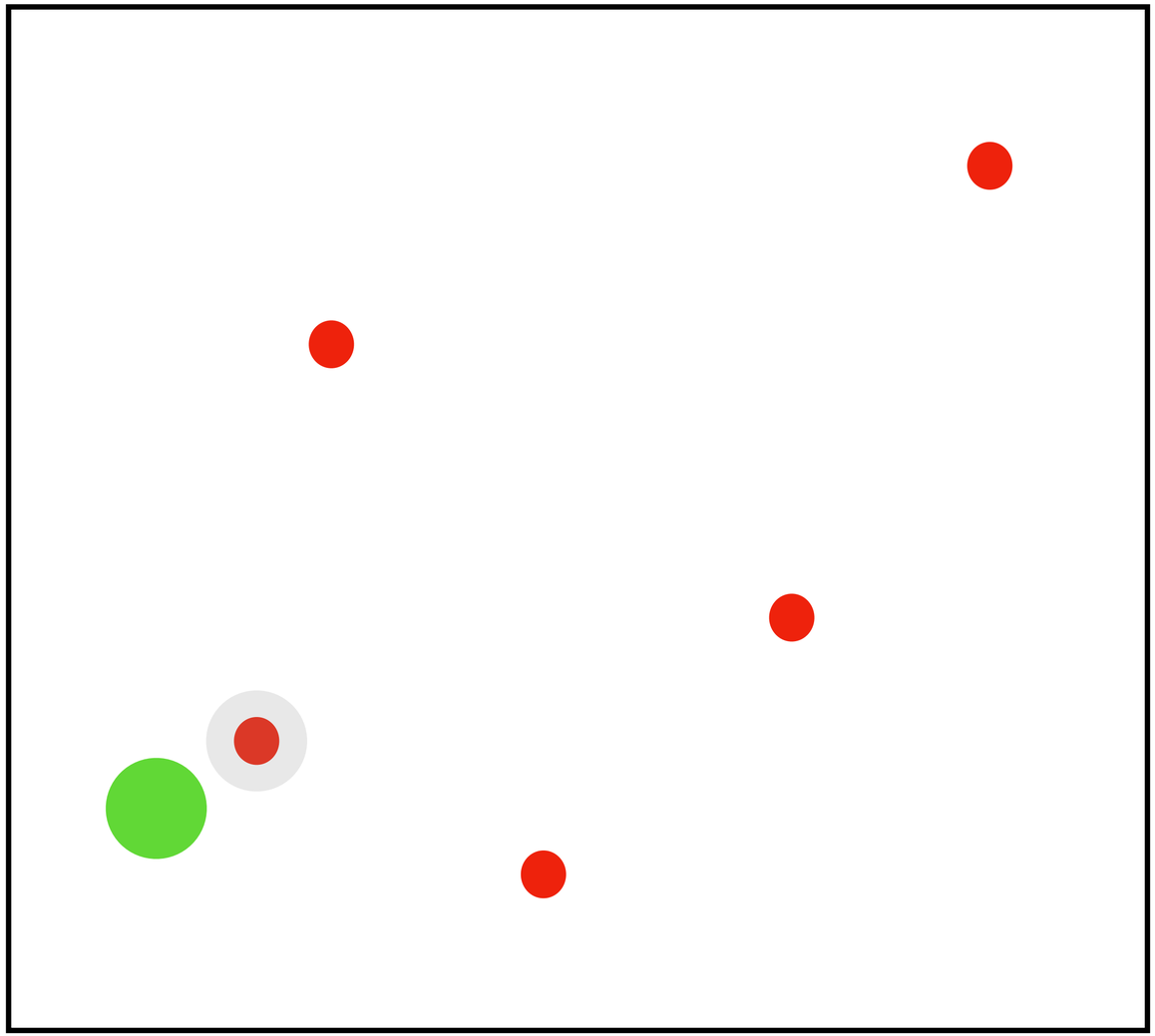
Distance based tracking



Robot(t-1)

Blobs

Best possible location at time t

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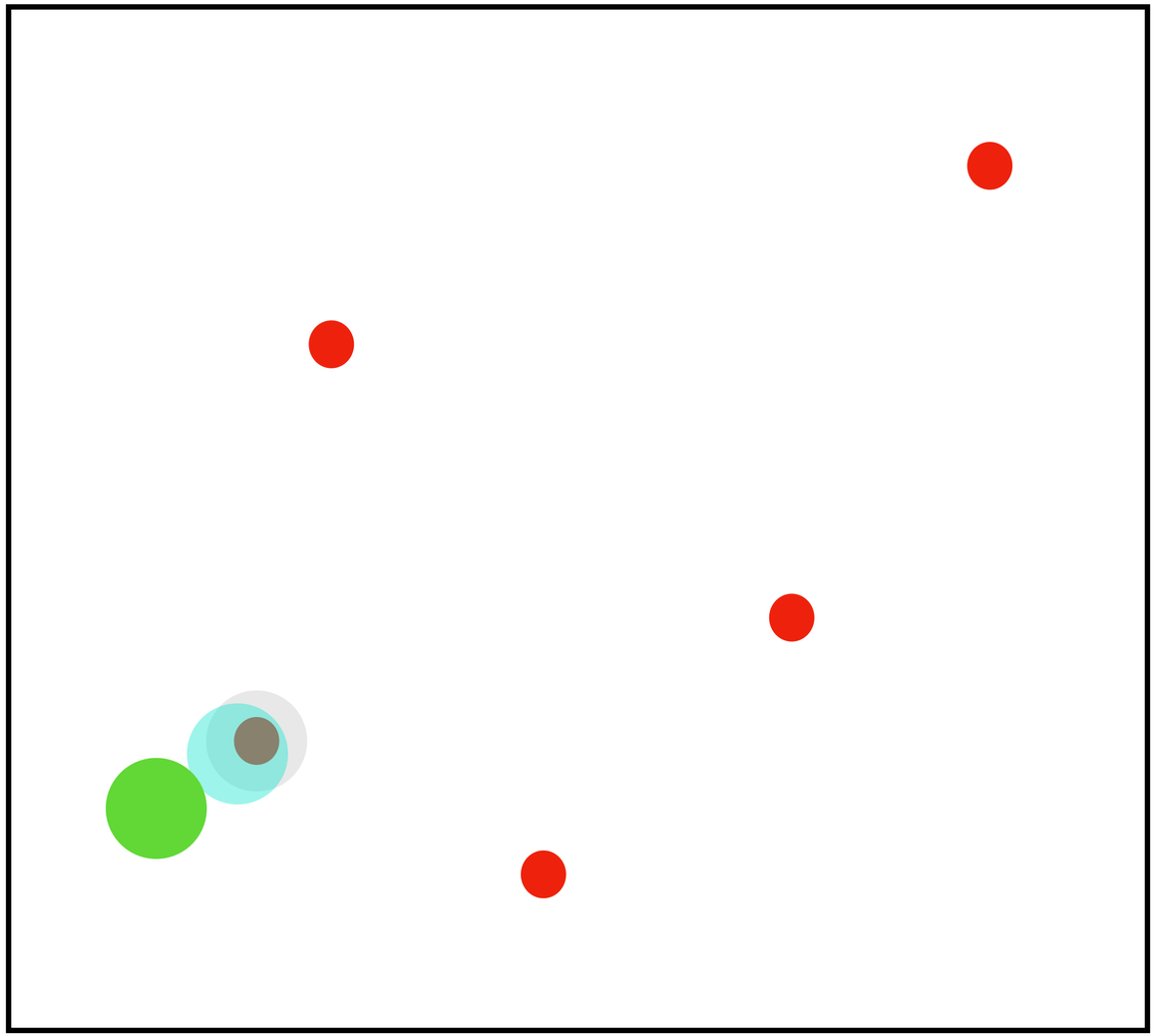
KF based tracking



Robot(t-1)

Blobs

Best possible location at time t

Robot position estimate(t)

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PID Control

- PD control is preferred for similar control situation.
- The reason a PID controller is used is because we might have uncertainty in out initial heading estimate resulting in a constant drift. The Integral term accounts for this drift.

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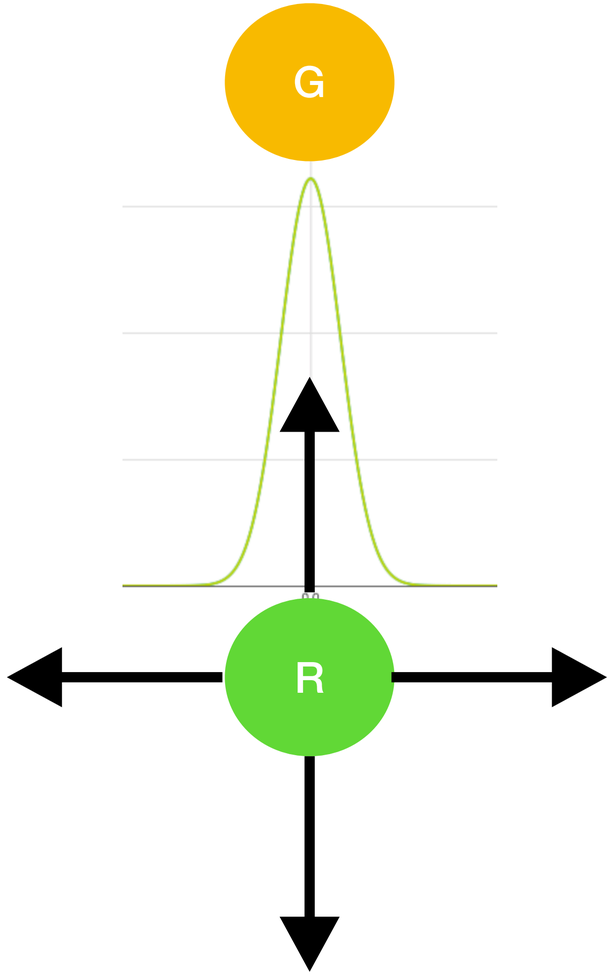
PID Control

- Variables : Steering angle, Velocity
- Steering angle is decided based on angle error
  - Angle error = Δ(current heading - heading to goal)
- Linear velocity is decided based on distance error
  - Distance error = Δ(position_xy - goal_xy)




```
dist = np.linalg.norm(np.array(position)-np.array(goal))
old_dist = np.linalg.norm(np.array(position_old)-np.array(goal))
dist_sum += dist
speed = int(guass(0.0,9.0,(angle_to_goal-steering+heading_error)/100.0) * (15*dist + 190*(old_dist - dist) + 0.00000001*dist_sum))
```

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Swarming

- Each formation is written as a set of constrains.

```
corner_centre   = [[20.0,20.0],[80.0,80.0],[20.0,80.0],[80.0,20.0],[50.0,50.0]]
line_horizontal = [[10.0,50.0],[30.0,50.0],[50.0,50.0],[70.0,50.0],[90.0,50.0]]
```

```
formations = {"corner_centre"   : corner_centre,
              "line_horizontal" : line_horizontal,
```

- Cost matrix is calculated using scipy.distance.cdist between every robot location and all goals.

- Least cost goal is assigned to each robot by using scipy.linear_sum_assignment and is published to the robot nodes

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Swarming

- Swarming node also is programmed with the following functions:

1. Hold a list of formations to cycle through
2. Check of formation consensus is achieved
3. Auto switch formations
4. Scale formations
5. Rotate formation
6. Move formation about any point
7. Camera angle compensation
8. Take user input in the command terminal to switch to any formation

Swarming

- Moving formations
  - Detect human position and convert that to a translation matrix.
  - Add the translation matrix to the goal.
- Rotate formations
  - Multiply goals by rotation matrix
- Move and Rotate formations
  - Multiply goals by a homogeneous transformation matrix

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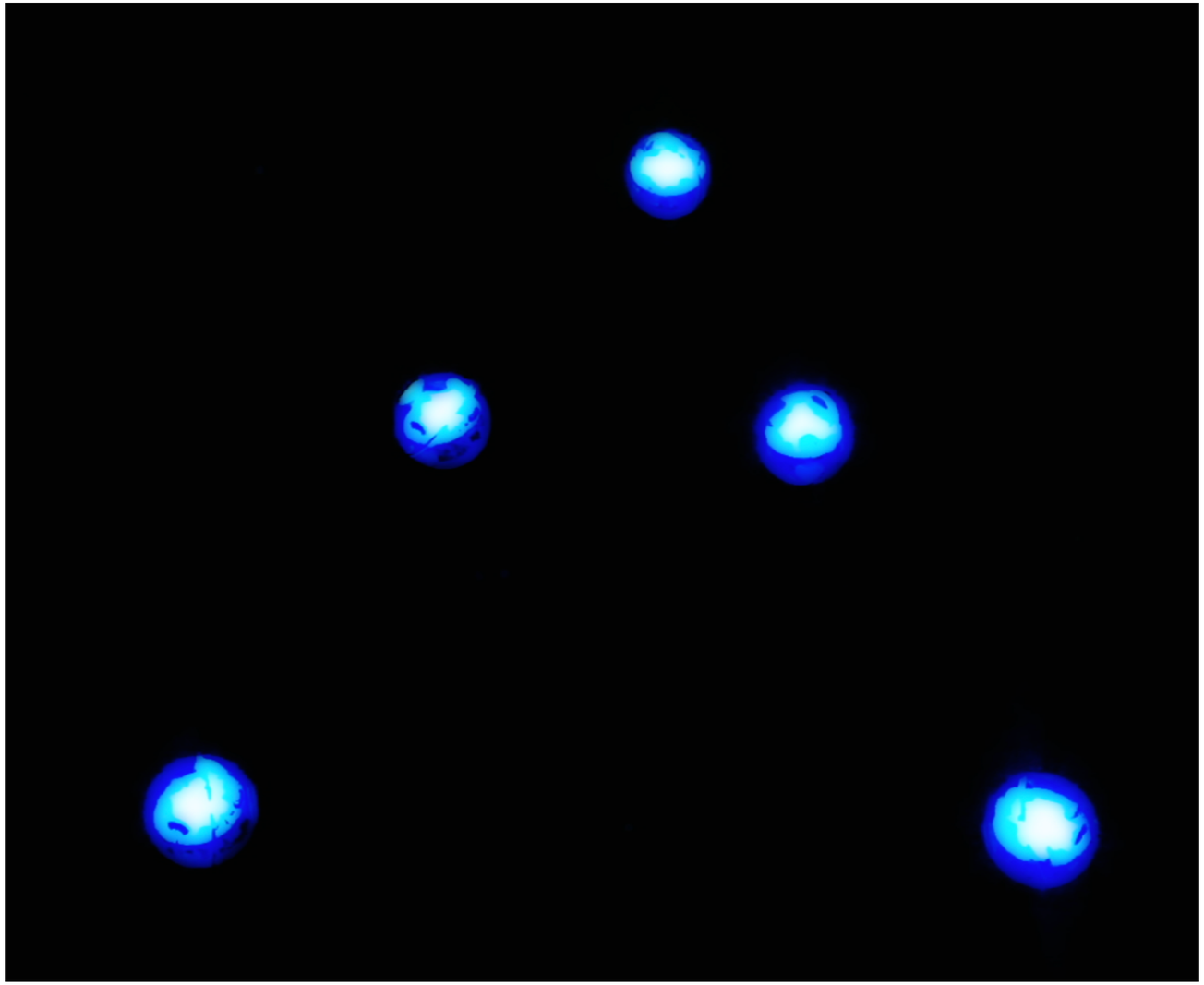
Swarming



Formation of alphabet A with 5 robots

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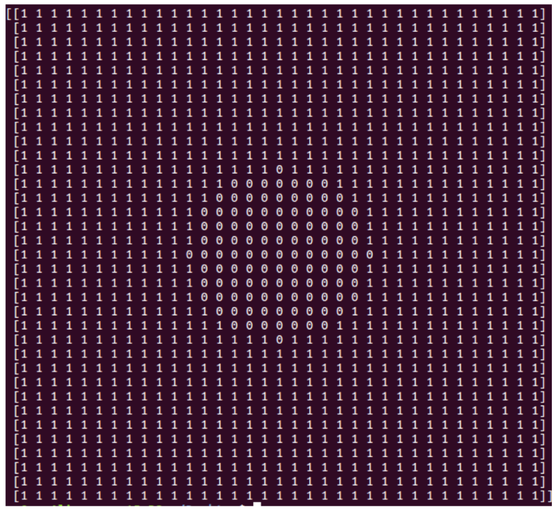
1 vs 1 escape

- An occupancy grid is created for the floor area.
- The human player is simulated by another Sphero that is manually driven with a joystick.
- Few changes made to the sphero script recognizes the human substitute robot and tracks it in realtime.



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1 vs 1 escape

- Gaussian
  - Apply a Multivariate Gaussian around the human substitute with a radius of 1f and also along the walls.
  - The robot picks us the velocity applied of its grid location on the matrix and moves in the direction with minimum cost.
- Kalman Filter + Broder High Weights + Quadrant Escape
  - KF estimate the quadrant to which the human substitute is heading
  - Robots randomly chooses a safe quadrant and moves towards it
  - Corners and edges are given first and second highest priority

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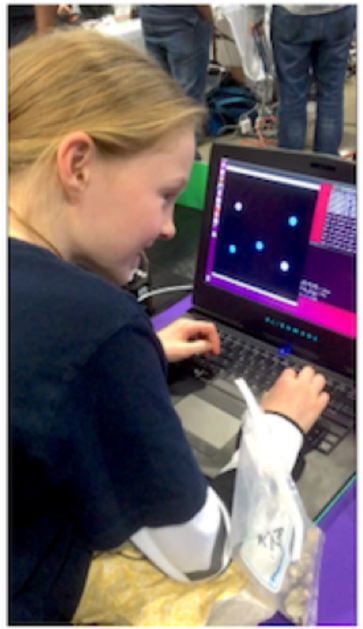
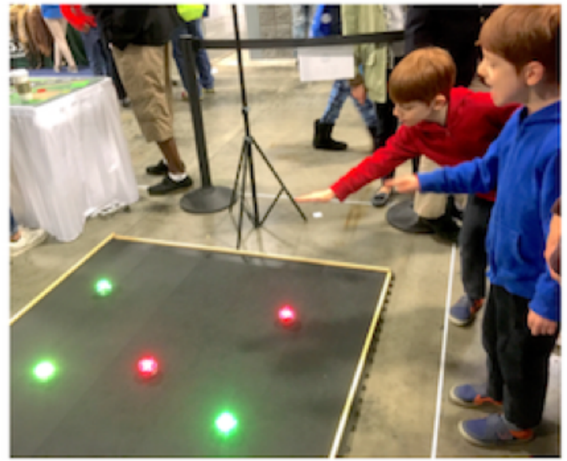
Public Demonstration

- USA Science and Engineering Festival | Non technical audience, mostly kids
- Centre for Advanced Telecommunication Technologies | Technical audience
- NYU Tandon School of Engineering - Research Expo | Mixed audience



Some pictures from the first public demo



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VIDEOS

https://youtu.be/9qRJkepvQ-c

Scripts, Report and All videos are uploaded in the drive