BRADLEY
UNIVERSITY

COOPERATIVE CONTROL OF HETEROGENEOUS MOBILE ROBOTS NETWORK

Gregory Bock, Brittany Dhall, Ryan Hendrickson, & Jared Lamkin

Project Advisors: Dr. Jing Wang & Dr. In Soo Ahn

Department of Electrical and Computer Engineering

October 6th, 2015

Outline

I. Background

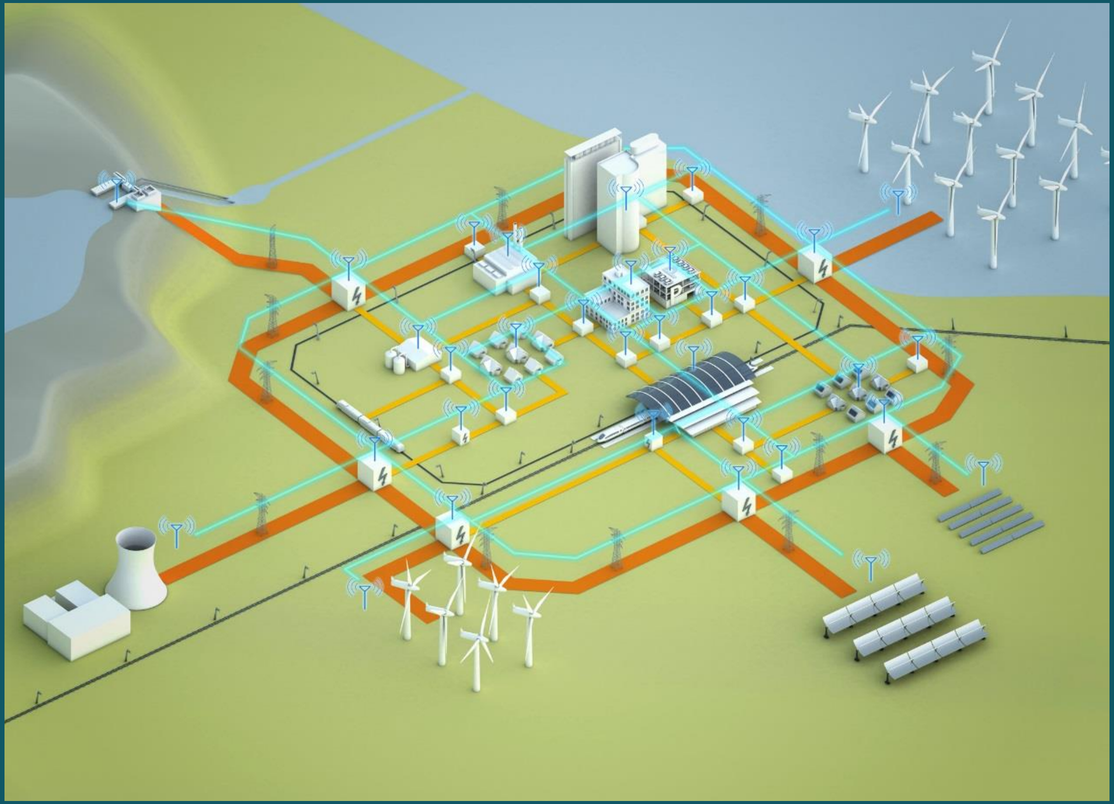
Project Background

- Cooperative systems found in nature
  - School of fish
  - Flock of birds
  - Swarm of insects

http://www.huffingtonpost.com/2013/10/07/plane-hits-bird-ohare_n_4058132.html

Project Background

- Cooperative systems found in engineering
  - Smart Grid
  - Sensor Network
  - Traffic Network



http://www.siemens.com/press/en/events/2012/corporate/2012-06-wildpoldsried.php

Project Background

- Common features
  - Local interactions → group behaviors
- Challenges
  - Manage local information sharing
  - Design local interaction rules
- Potential Applications
  - Military Missions
  - Civilian Tasks: Search & Rescue

Project Objective

- Design and Experimental Validation of Cooperative Control Algorithms
  - Sensing/communication between robots
  - Implementation of local flocking control algorithms
  - Implementation of local formation control algorithms

Design Constraints

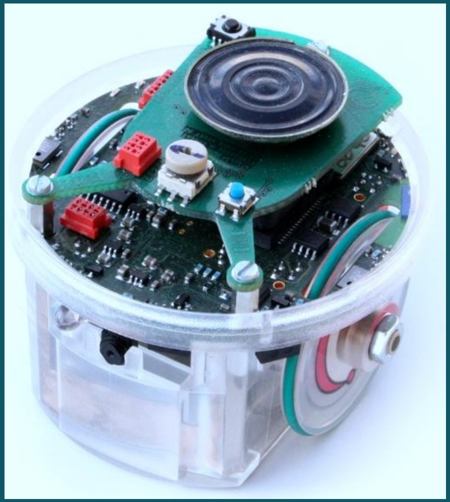
- Must overcome limited communication among networked robots
- Must overcome limited sensing capability of robots
- Must overcome system uncertainties

II. Design Approach

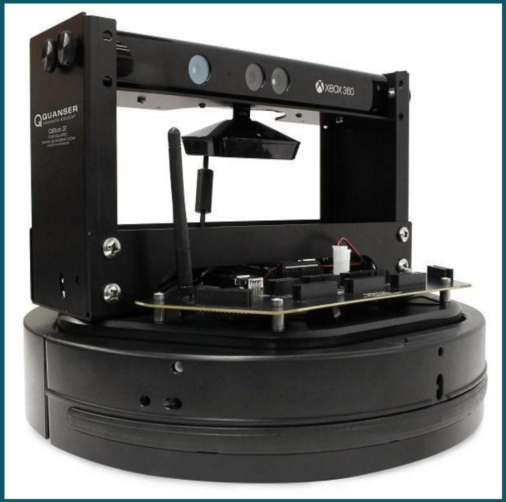
Algorithm Test Platforms

Kilobot

E-Puck

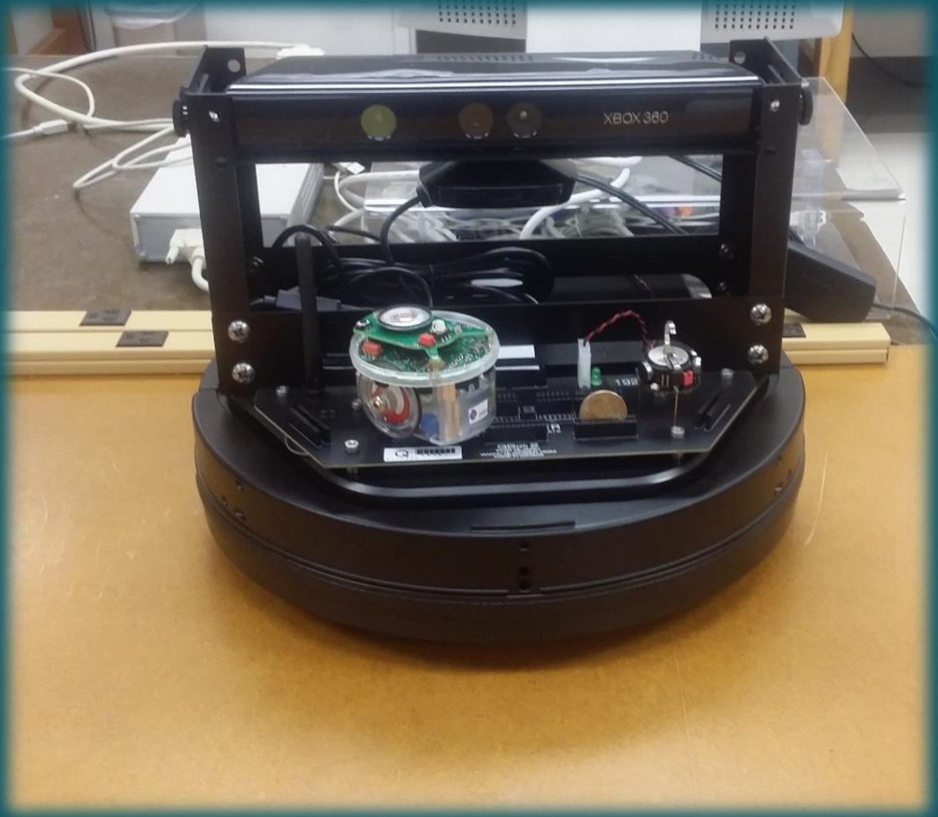


Qbot



http://www.k-team.com/mobile-robotics-products/kilobot
https://en.wikipedia.org/wiki/E-puck_mobile_robot
http://www.mathworks.com/products/connections/product_detail/product_101072.html

Algorithm Test Platforms



Research Problems

- Cooperative Control Algorithm Design Based on Local Information Exchange
  - Robotic platforms' communication protocols
  - Interplatform communications
  - Object recognition
  - Object avoidance

- System Integration

Key Components

- Communication between different platforms
- Local feedback control algorithm for coordination
- Autonomous operations with collision avoidance capability

Project Disciplines

- Electrical Engineering
  - Sensor implementation
  - Interfacing circuit design
- Computer Engineering
  - Algorithm design
  - Programming skills

Project Scope

- Design and test distributed control algorithms using multiple robots (mainly Kilobots and Qbots)
  - Address sensing/communication sharing challenges among robots
  - Study distributed control algorithms
  - Study collision avoidance strategies for robots
  - Design testing scenarios (formation/flocking)

Product Scope

- Establish an integrated testing platform using multiple robots
- Networked robotic system can be used for future demonstration of various multiagent coordination tasks

III. Method of Solution

Solution

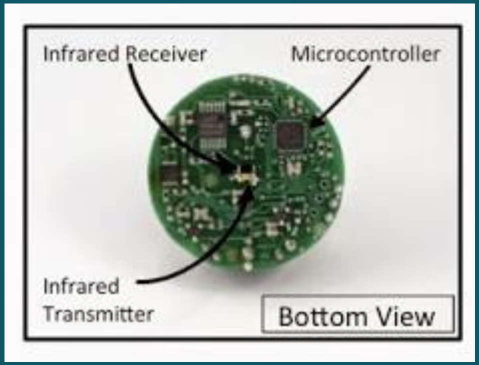
- Cooperative control algorithm design
  - Linear model
  - Non-linear model
- Deployment and validation through experimental testing
  - Modular design
  - System integration

Robot Model

- Linear Model
  - $\dot{x} = U_x$
  - $\dot{y} = U_y$
- Non-linear Model
  - $\dot{x} = v cos(\theta)$
  - $\dot{y} = v sin(\theta)$
  - $\dot{\theta} = \omega$

Sensors Used for Communication

- Infrared Sensors
- Kinect



http://www.eecs.harvard.edu/ssr/projects/progSA/kilobot.html
http://sourcefed.com/holohands-kinect-controlled-lasers/

Solution Testing

- Software Implementation
  - Simulation
  - Algorithm validation
  - Algorithm implementation on platforms
- Hardware Implementation
  - Robot calibration
  - Multiple sensor fusion
- System Integration
  - Software
  - Hardware

Criteria to Determine a Successful Project

- Algorithm can be deployed on multiple robots
- Autonomous robots
- Communication amongst multiple robots

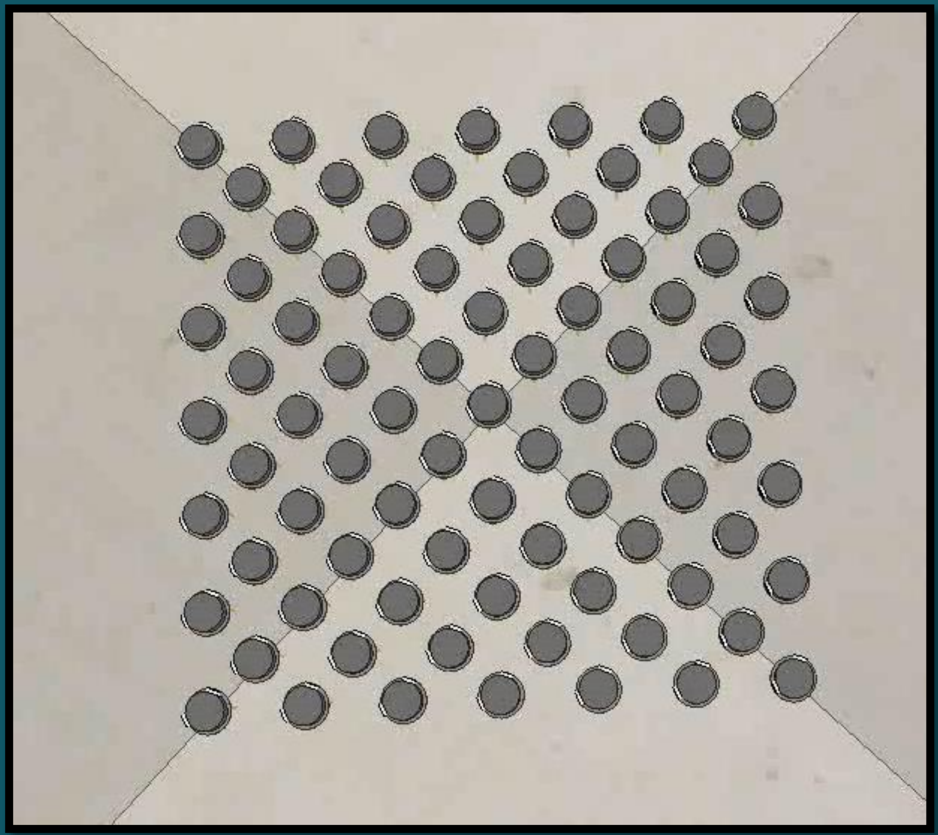
Test Facilities

- Bradley University
  - Projects Lab
  - Senior Lab

Preliminary Work

- Familiarized with Kilobot and Qbot platforms
  - On-board hardware
  - Design environment
  - Software implementation
- Designed and implemented various motion control algorithms for Kilobots and Qbot

Gradient



Orbiting

Asynchronous Consensus

Simple Following

Contingency Plans

- Develop a non-linear cooperative control algorithm
- Develop hierarchy-based sensing/communication protocols

IV. Division of Labor

Division of Labor Overview

Individual Behavior	Kilobots	Jared/Brittany
	Qbots	Ryan/Greg
	E-pucks	Jared/Brittany
Individual Communication	Kilobot - Kilobot	Jared/Brittany
	Qbot - Qbot	Ryan/Greg
	E-puck - E-puck	Jared/Brittany
Integrated Communication	Kilobot - E-puck	Jared/Brittany
	Kilobot - Qbot	Jared/Brittany/Ryan/Greg
	E-puck - Qbot	Jared/Brittany/Ryan/Greg
Algorithm Design	Linearization Based Model	Jared/Brittany/Ryan/Greg
Integrated Behavior	Formation Control Behavior	Jared/Brittany/Ryan/Greg
	Flocking Behavior	Jared/Brittany/Ryan/Greg
Testing	Software Implementation	Jared/Brittany/Ryan/Greg
	Hardware Implementation	Jared/Brittany/Ryan/Greg

Individual Behavior/Communication

Individual Behavior	Kilobots	Jared/Brittany
	Qbots	Ryan/Greg
	E-pucks	Jared/Brittany

Integrated Communication

Integrated Communication	Kilobot - E-puck	Jared/Brittany
	Kilobot - Qbot	Jared/Brittany/Ryan/Greg
	E-puck - Qbot	Jared/Brittany/Ryan/Greg

Algorithm Design

Algorithm Design	Linearization-Based Control Algorithm	Jared/Brittany/Ryan/Greg

Integrated Behavior

Integrated Behavior	Formation Control Behavior	Jared/Brittany/Ryan/Greg
	Flocking Behavior	Jared/Brittany/Ryan/Greg

Testing

Testing	Software Implementation	Jared/Brittany/Ryan/Greg
	Hardware Implementation	Jared/Brittany/Ryan/Greg

V. Financial Analysis

Project Funding

- Air Force Research Lab
- Air Force Proposal - "Multiagent task coordination using a distributed optimization approach”
- Grant Agreement Number – FA8780-13-1-0109

http://www.af.mil/News/Photos/tabid/129/igphoto/2000100887/Default.aspx

Expenses

- Robotic platforms (software included)
- Auxiliary components

Project Platform Costs

Platform	Quantity	Total Price
Qbot2	3	$9,999.00
Kilobot Kit	20	$4,583.00
Epucks	3	$5,093.00

Programming Software Costs

Software	Quantity	Total Price
Kilobot Controller IDE	1	$0.00
E-puck Programming Software	1	$0.00
MATLAB Courseware	1	$0.00

VI. Projected Schedule

Abbreviated Gantt Chart

Task Name	Target Dates	Sep-15					Oct-15				Nov-15				Dec-15					Jan-16				Feb-16				Mar-16				
		1	8	15	22	29	6	13	20	27	3	10	17	24	1	8	15	22	29	5	12	19	26	2	9	16	23	1	8	15	22	29
Individual Behavior	November 10, 2015																															
Individual Communication	December 14, 2015																															
Integrated Communication	December 14, 2015																															
Algorithm Design	December 14, 2015																															
Integrated Behavior	February 1, 2016																															
Testing	March 7, 2016																															

Fall Semester Deliverables

Deliverable	Due Date
Proposal Presentation	October 6, 2015
Proposal Document	October 20, 2015
Webpage Release	October 28, 2015
Progress Presentation	November 19, 2015

Spring Semester Deliverables

Deliverable	Due Date
Progress Presentation	February 18, 2016
Project Demonstration	March 24, 2016
Final Presentation	April 7, 2016
Student Expo	April 14, 2016
Final Report	April 28, 2016
Final Webpage	April 28, 2016
Industrial Advisory Board Poster Presentation	April 29, 2016

VII. Societal and Environmental Impacts

Societal Impacts

- Save lives
- Preserve the environment
- Enhance lifestyle
- Conserve resources

Environmental Impact

- Reduce human endangerment
- Reduce environment endangerment
- Monitor harmful or dangerous conditions

Project Safety

- Kill-switch implementation
- Fault detection
- Collision avoidance algorithms

Our Project Ethics

- Shall not harm people
- Shall not engage in illegal activities
- Shall not damage property

Project Issues

- Collisions
- Hacked system
- Negative emergent behaviors

Preventative Measures

- **Collisions**- avoidance algorithm, safety shutdown
- **Hacking**- out of scope
- **Negative Emergent Behavior**- out of scope

VIII. Summary & Conclusions

Summary & Conclusions

- Design cooperative control algorithms for heterogeneous groups of robots
- Implement algorithms on different robot platforms
- Prevent collisions and implement network security

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Gantt Chart

Task Name	Group Member Responsible for Task	Finish by Date	Sep-15					Oct-15				Nov-15				Dec-15					Jan-16				Feb-16				Mar-16					Apr-16			
			1	8	15	22	29	6	13	20	27	3	10	17	24	1	8	15	22	29	5	12	19	26	2	9	16	23	1	8	15	22	29	5	12	19	26
Individual Behavior																																					
Research Kilobot Sensors	Jared	September 28, 2015																																			
Research Kilobot Communication Protocol	Jared	October 12, 2015																																			
Research Q-bot Image Processing	Ryan/Greg	October 5, 2015																																			
Research Q-bot Sensors	Ryan/Greg	September 28, 2015																																			
Reseach Q-bot Communication Protocol	Ryan/Greg	October 19, 2015																																			
Reseach E-puck Sensors	Brittany	October 26, 2015																																			
Research E-puck Communication Protocol	Brittany																																				
Individual Communication																																					
Research/Test Kilobot - Kilobot	Jared	October 19, 2015																																			
Research/Test E-puck - E-puck	Brittany	December 14, 2015																																			
Research/Test Qbot - Qbot	Ryan/Greg	November 2, 2015																																			
Integrated Communication																																					
Test Kilobot - E-puck	Jared/Brittany	December 14, 2015																																			
Test Kilobot - Qbot	Jared/Ryan/Greg	November 16, 2015																																			
Test E-puck - Qbot	Brittany/Ryan/Greg	December 14, 2015																																			
Algorithm Design																																					
Design Linear Based Model	All	December 14, 2015																																			
Integrated Behavior																																					
Formation Control Behavior																																					
Localization	All	January 25, 2016																																			
Point Convergence	All	January 25, 2016																																			
Leader Follower	All	January 25, 2016																																			
Flocking Behavior																																					
Neighbor Repulsion	All	February 1, 2016																																			
Enpoint Attraction	All	February 1, 2016																																			
Heading	All	February 1, 2016																																			
Testing																																					
Software Implementation	All	March 7, 2016																																			
Hardware Implementation	All	March 7, 2016																																			

Gantt Chart – Deliverables

Task Name	Finish by Date/Due Date	Sep-15					Oct-15				Nov-15				Dec-15					Jan-16				Feb-16				Mar-16					Apr-16			
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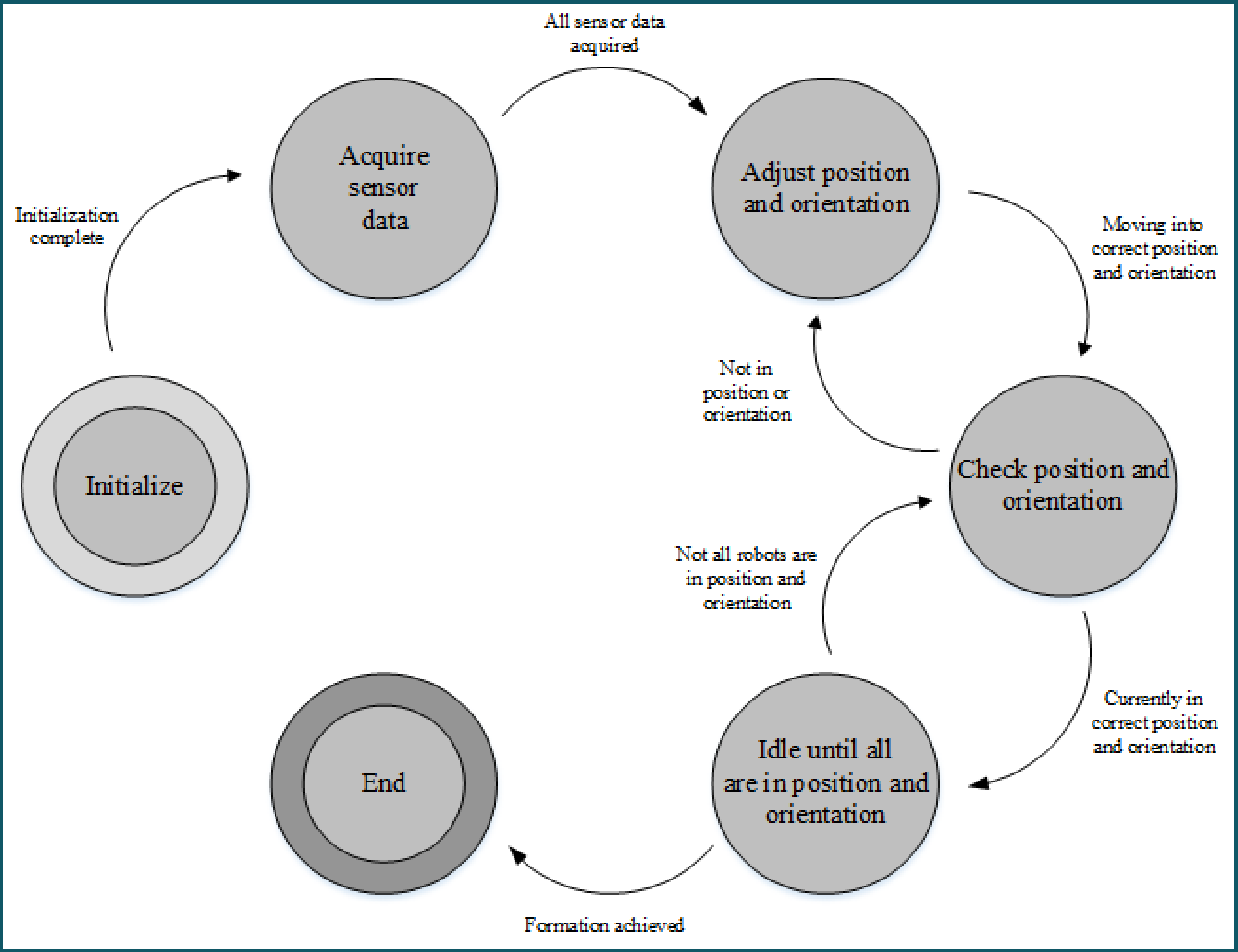
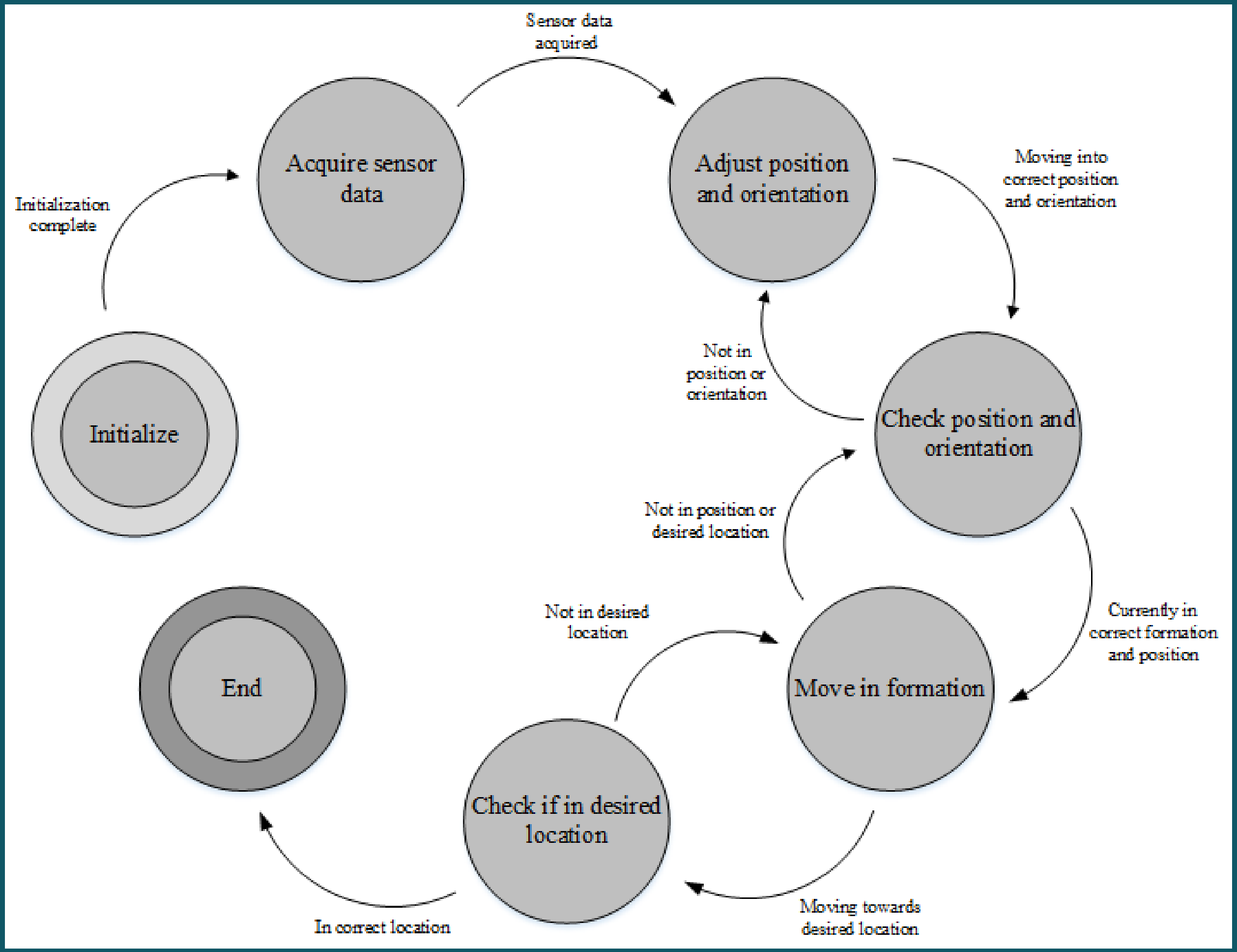
Fall Progress Presentation	November 19, 2015																																			
Fall Performance Evaluation	November 19, 2015																																			
Fall Performance Review	December 3, 2015																																			
Spring Progress Presentation	February 18, 2016																																			
Student Expo Abstract	March 18, 2016																																			
Project Demonstration	March 24, 2016																																			
Final Presentation	April 7, 2016																																			
Student Expo Poster Printing Deadline	April 11, 2016																																			
Student Expo Poster Setup	April 12, 2016																																			
Student Expo	April 14, 2016																																			
Final Report (Draft)	April 14, 2016																																			
Final Report	April 28, 2016																																			
Final Web Page	April 28, 2016																																			
Advisory Board Poster Printing Deadline	April 28, 2016																																			
Advisory Board Poster Presentation	April 29, 2016																																			

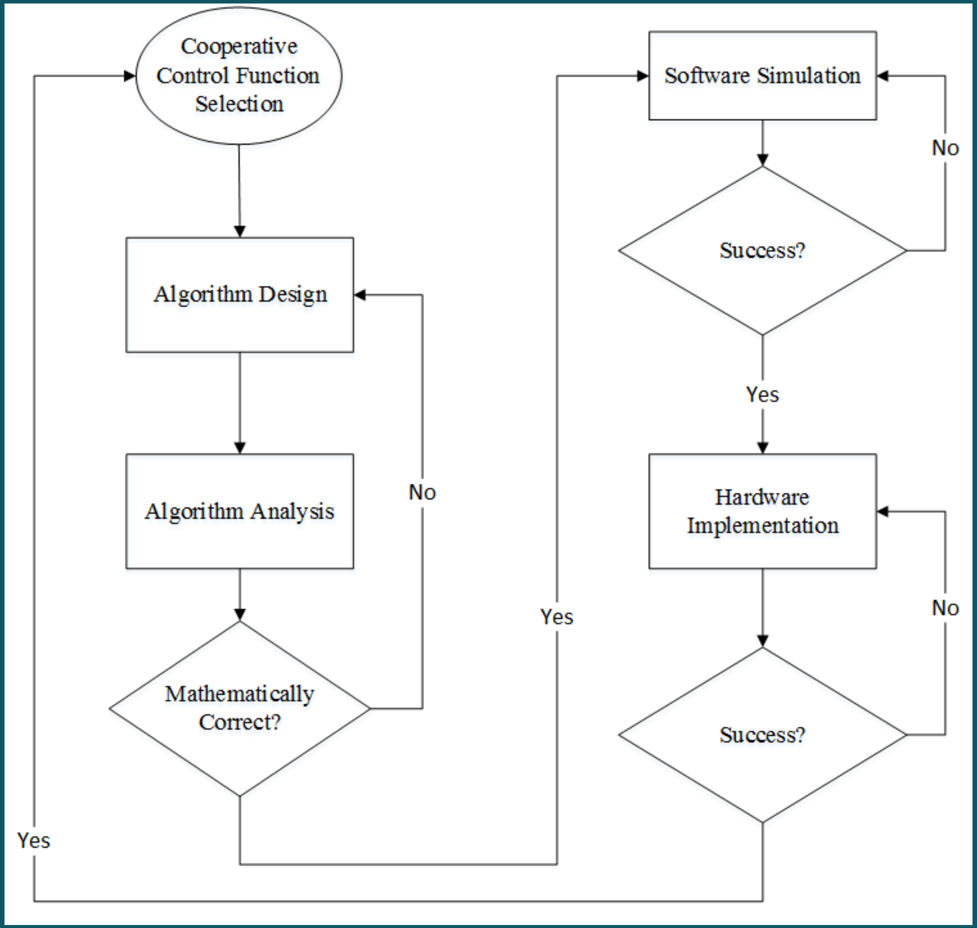
State Diagram: Formation Control Behavior



State Diagram: Flocking Formation



Solution Testing



Objectives

- Mobile robot network should be applicable to different robot platforms
- Mobile robot network should be robust
- Mobile robot network should be autonomous