

# Progress Report of Cooperative Control Experiment



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## Introduction

- Cooperative Control
  - A distributed control strategy that achieves specified tasks in multi-agent systems
  - It has been motivated by interests in group behavior of animals, formation control of multi-vehicle systems, and so on

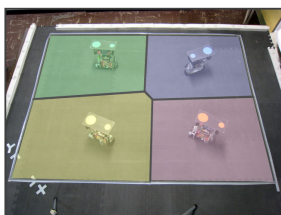


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## Introduction

- Cooperative Control
  - It is hoped to be applied to sensor networks, robot networks and many other multi-agents systems

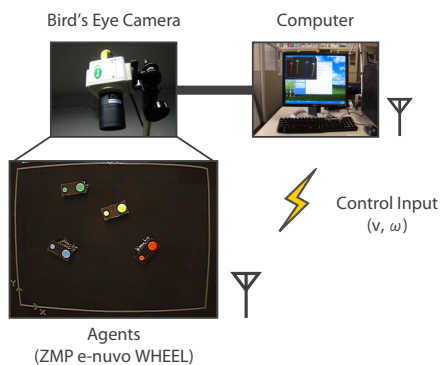


## Outline

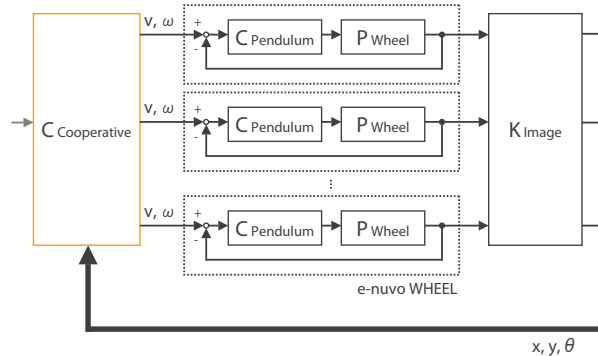
- Improvement of Experiment System
  - System Overview
  - Modification of Communication Protocol
  - Improvement of Image-recognition Algorithm
- Implementation of Cooperative Control Law
  - Attitude Coordination
  - Leader Following
- Summary



## System Overview



## System Overview





## Problems and Solutions

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1. It takes time to transmit the control inputs  
→ Change the communication protocol from TCP/IP to UDP/IP
2. The image-recognition accuracy is low  
→ Change the image-recognition algorithm

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## About TCP/IP

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- Standing for "Transmission Control Protocol"
- One of the core protocols of the Internet protocol suite
- Providing **reliable, in-order delivery of a stream of bytes**  
→ It sometimes incurs long delays
- Managing only the **one-to-one communication**
- The **connection establishment** is needed  
→ It takes long to communicate with many agents

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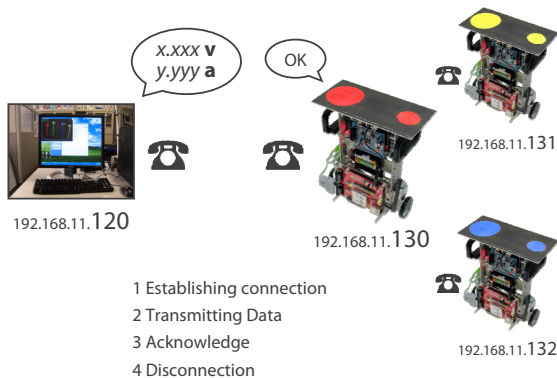
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## Communication Flow of TCP/IP

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## About UDP/IP

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- Standing for "User Datagram Protocol"
- One of the core protocols of the Internet protocol suite
- The connection establishment is **not needed**
- It does **not guarantee** reliability or ordering instead of high-speed transmission
- It is possible to **transmit data to many agents at a time (Broadcast)**

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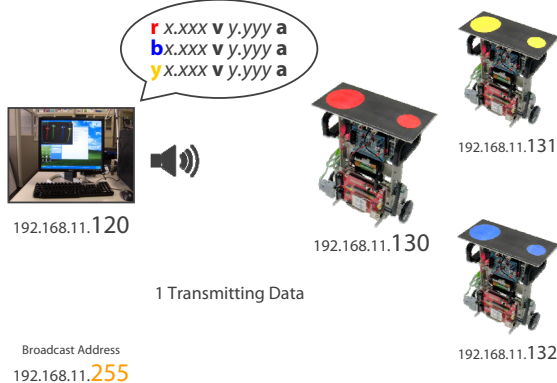
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## Communication Flow of UDP/IP

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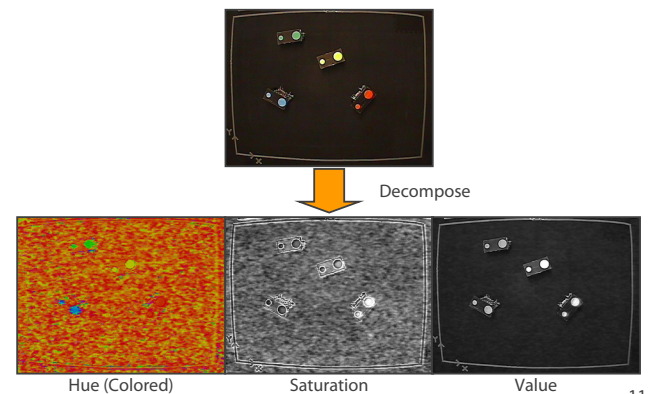
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## Previous Image-recognition Algorithm (1)

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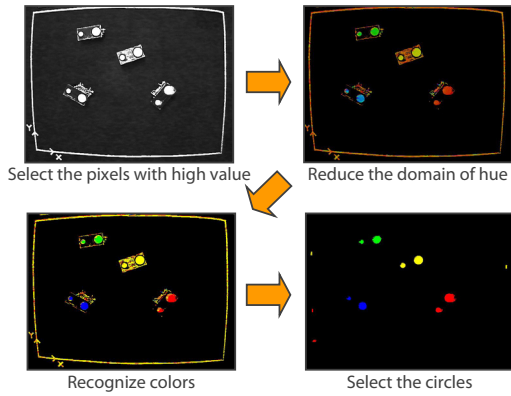
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## Previous Image-recognition Algorithm (2)

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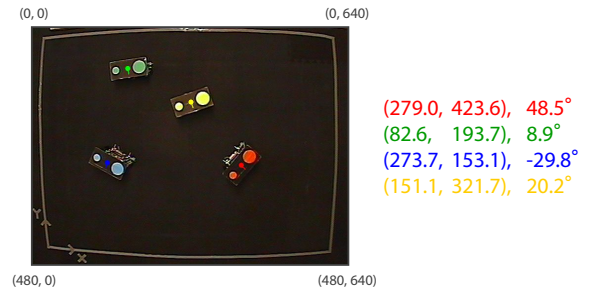
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## Previous Image-recognition Algorithm (3)

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- Calculating the position and the attitude of agents from the position of circles



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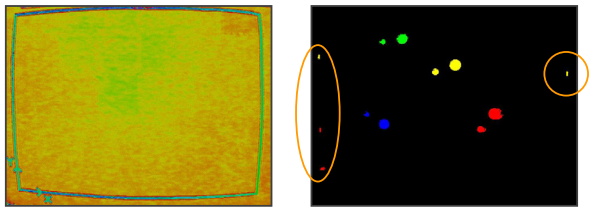
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## The Concrete Problems

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- It is unable to eliminate the effects of the ambient light
- It often mistakes something unconcerned as the agent



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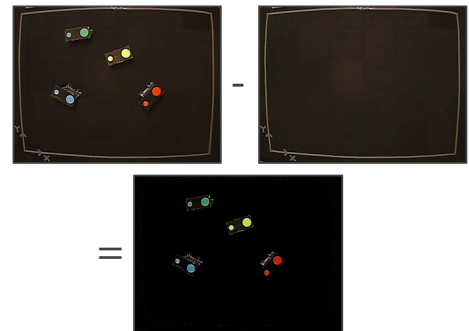
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## Improved Algorithm (1)

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- Preparing the background image in advance, and subtracting it from the current image



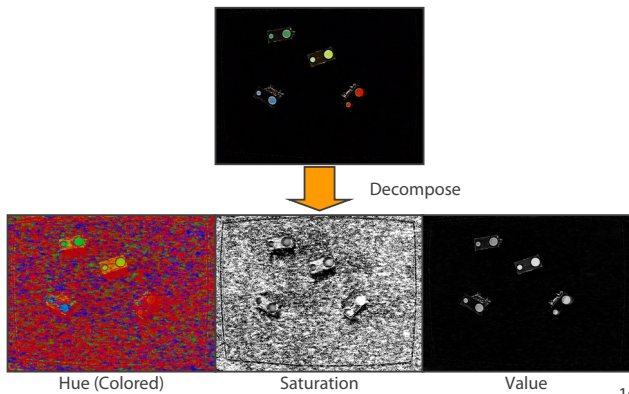
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## Improved Algorithm (2)

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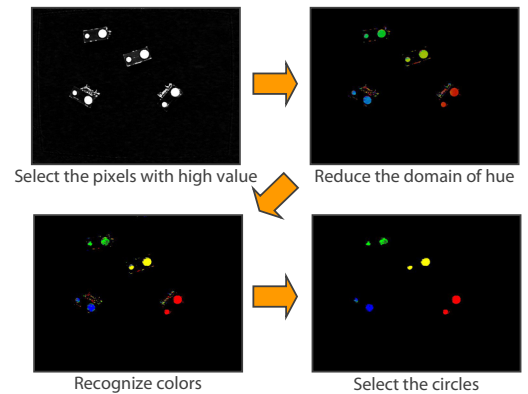
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## Improved Algorithm (3)

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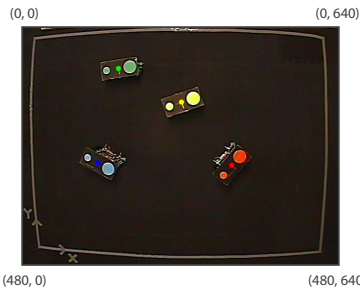
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## Improved Algorithm (4)

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- Calculating the position and the attitude of agents from the position of circles



(279.0, 423.6), 48.5°  
 (82.6, 193.7), 8.9°  
 (273.7, 153.1), -29.8°  
 (151.1, 321.7), 20.2°

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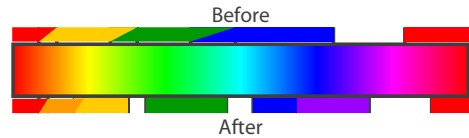
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## Effect of Improvement

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- It is able to eliminate the effects of the ambient light
- It rarely mistakes something unconcerned as the agent (except hands, papers, and so on)
- It is able to recognize more colors than before



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## Outline

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- Improvement of Experiment System
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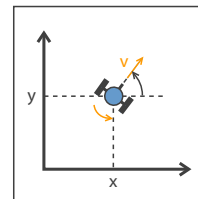
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## Robot Setup

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- Unicycle robot
- It has a nonholonomic constraint
- $(v, \omega)$  are controllable



$$\dot{x} = v \cos \theta$$

$$\dot{y} = v \sin \theta$$

$$\dot{\theta} = \omega$$

$$\text{Constraint: } \dot{x} \sin \theta - \dot{y} \cos \theta = 0$$

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## Attitude Coordination

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- It is to make the attitudes of all the agents be same
- In this experiment, the agents stay on-site, and change their attitudes only



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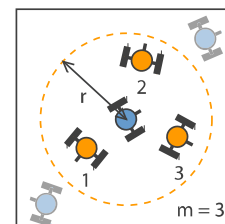
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## Attitude Coordination Setup (1)

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- The agents have **limited visibility**: They can see at most a fixed distance  $r > 0$  away
- Each agent numbers the agents inside its visibility, and defines  $m$  as the number of them



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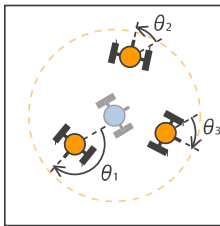
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### Attitude Coordination Setup (2)

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- Each agent can measure the relative attitudes of the neighbor agents



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### Attitude Coordination Control Law

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- The agents stay on-site:  $v = 0$
- The angular velocity input to align the direction with the agents inside the agent's visibility:

$$\omega = K_a \cdot \frac{1}{m} \sum_{i=1}^m \sin \theta_i \quad (K_a > 0)$$

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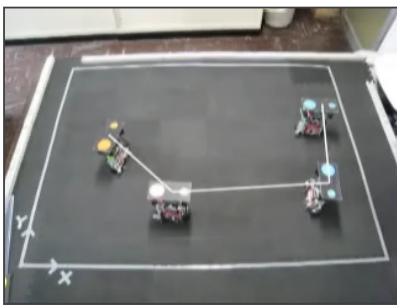
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### Attitude Coordination Experiment (1)

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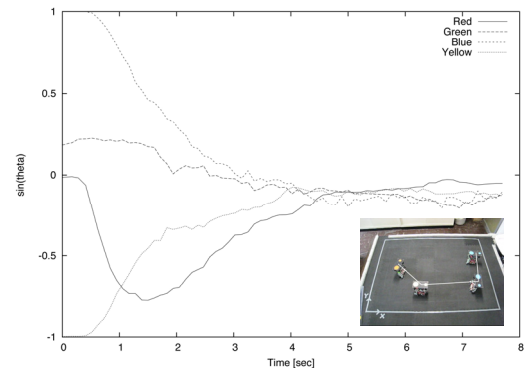
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### Attitude Coordination Experiment (2)

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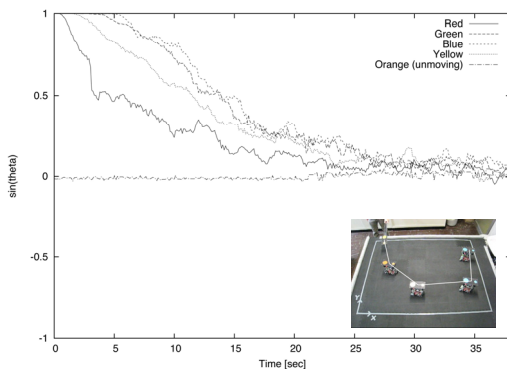
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### Attitude Coordination Experiment (3)

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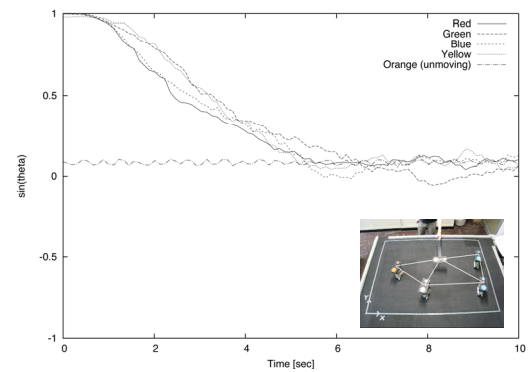
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### Attitude Coordination Experiment (4)

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## Leader Following

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- One of the agents is designated as the leader, with the rest of the agents designated as followers
- The agents are arranged in chains, and the followers keep close to their anterior agent



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## Leader Following Setup (1)

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- Let there be  $n$  agents, and we number them consecutively
- In this experiment, the mouse cursor on screen is designated as the virtual leader



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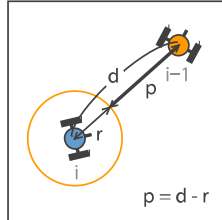
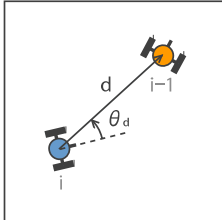
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## Leader Following Setup (2)

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- Each agent can measure the distance and the direction angle of its target
- To avoid a collision with its target, the agent have its own circular territory  
 $r$ : the radius of the territory



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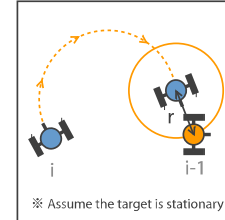
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## Leader Following Control Law

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- The angular velocity input to turn its target:  
 $\omega = K_a \theta_d \quad (K_a > 0)$
- The velocity input to approach its target:  
 $v = K_v p \quad (K_v > 0)$



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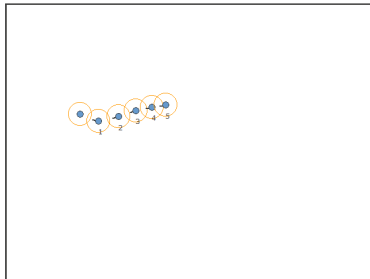
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## Leader Following Simulation

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- The simulation on the web browser using JavaScript
- It works on most web browsers



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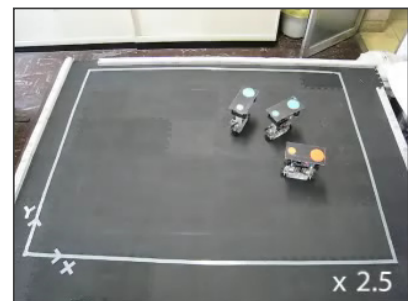
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## Leader Following Experiment (1)

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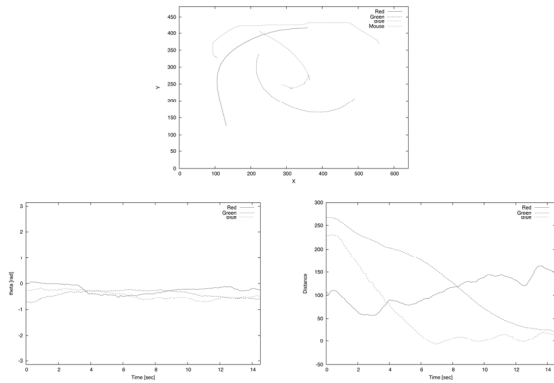
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## Leader Following Experiment (2)

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## Outline

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## Summary

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- I introduced what I did for two months
  - By improvement of experiment system, it is able to experiment using more agents with higher accuracy
  - I implemented the cooperative control laws which would appeal to the general public
- Future Works
  - Mounting the on-board camera
  - Implementation of “true” distributed control

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