Vision-based Cooperative Control Experiment

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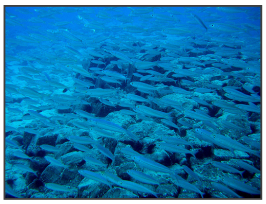
Outline

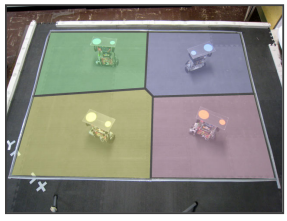
Cooperative Control

- 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



Cooperative Control

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



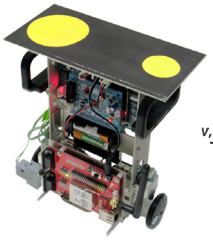
Coverage Control

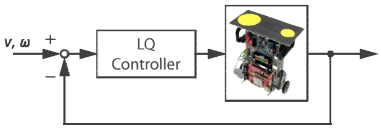
Pose Synchronization

Outline

e-nuvo WHEEL

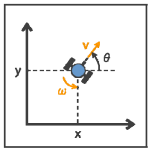
- Mobile Wheeled Inverted Pendulum
- It is internally-stabilized by the LQ controller
- We can send the target values (v, ω) via wireless LAN





e-nuvo WHEEL

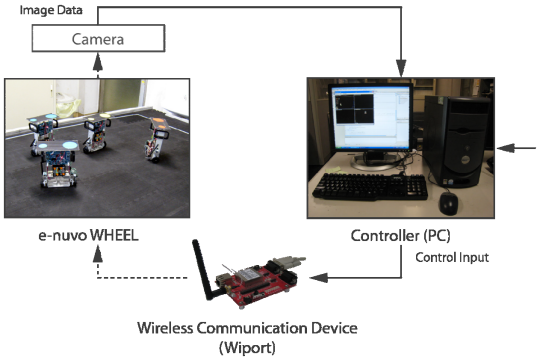
- Kinematic model
  - e-nuvo WHEEL is regarded as a unicycle robot
  - (v, ω) are controllable
  - It has a nonholonomic constraint



$$\begin{aligned} \dot{x} &= v\cos\theta \\ \dot{y} &= v\sin\theta \\ \dot{\theta} &= \omega \end{aligned}$$

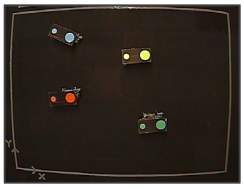
Constraint: $\dot{x}\sin\theta - \dot{y}\cos\theta = 0$

System Configuration

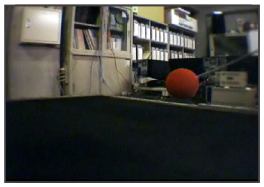


System Configuration

- Controller: Centralized
- Information Acquisition: Centralized or Distributed

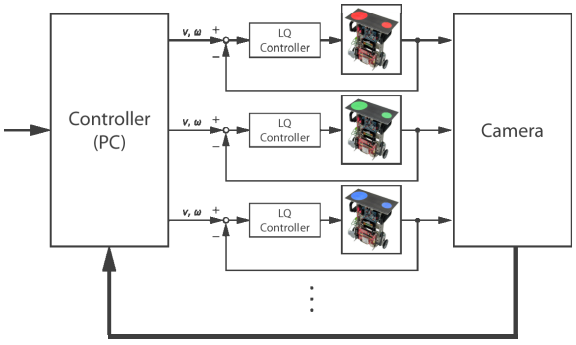


Bird's Eye Camera
Centralized

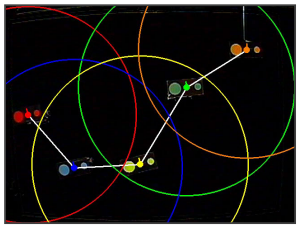


Onboard Camera
Distributed

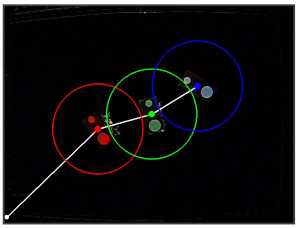
System Configuration



Previous Experiments



Attitude Synchronization



Leader Following

Outline

- Introduction
- System Overview
- Voronoi-based Coverage Control
  - Voronoi Diagram
  - Lloyd's Algorithm
  - Equilibrium Bifurcation
  - Experiments
- Onboard Camera
- Wii Remote Operation
- Summary

Coverage Control

- The goal
  - All mobile agents, placed initially at random, spread out as much as possible (efficiently) over a given area
- Characteristics
  - Large scale of deployment
  - Ability to withstand changes in environment
  - Ability to cope with node failures
- Application
  - Sensor network
  - Environmental monitoring
  - Surveillance robots
  - etc

Voronoi Diagram

- Voronoi Cell *Vi*:

  The set of all points $\boldsymbol{x}$ whose distance from $\boldsymbol{p}_i$ is less then or equal to the distances form all other $\boldsymbol{p}_j$

$$V_i = \{\boldsymbol{x} \in D \mid d(\boldsymbol{x}, \boldsymbol{p}_i) \leq d(\boldsymbol{x}, \boldsymbol{p}_j) \quad \forall j \neq i\}$$

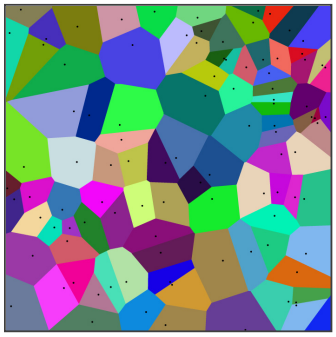
$$P = \{p_1, p_2, \ldots, p_n\} \text{ : Set of Points}$$

$$d \text{ : Distance Function}$$

- Voronoi Diagram *V*:

$$V = \{V_1, V_2, \ldots, V_n\}$$

Voronoi Diagram



Coloured 2D Voronoi diagram

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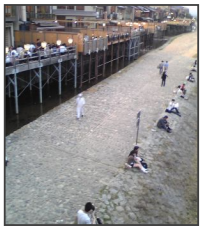
Voronoi Diagram

- Such a diagram is often found as a territory behavior of nearly all major groups of organisms on the planet



Kamogawa, Kyoto

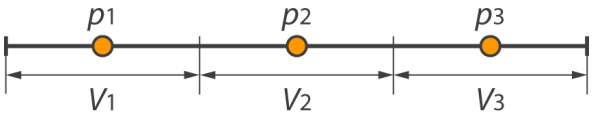
Water Strider

http://www.c-player.com/ac87205/thread/1100069985225

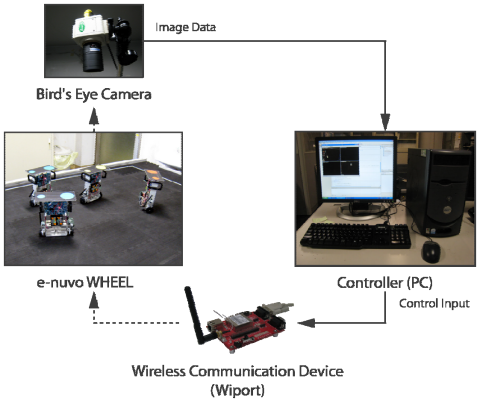
Lloyd's Algorithm

- The method for evenly distributing nodes
  1. Construct Voronoi Partition *Vi*, generated by *pi*
  2. Update *pi* to be the centroid of *Vi*
  3. Return to step 1. until convergence
- Example (1D)

1 2 3



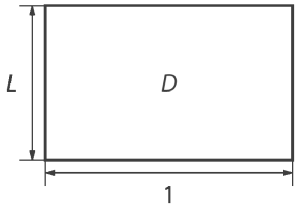
Experiment System



Modeling

- Consider *N* agents in a rectangular domain *D* with sides of length 1 and *L*

$$0 < L \leq 1$$



Modeling

- Voronoi cell for agent *i* at time step *n* is

$$V_i^{(n)} = \{\boldsymbol{x} \in D \,|\, |\boldsymbol{x} - \boldsymbol{p}_i| \leq |\boldsymbol{x} - \boldsymbol{p}_j| \quad \forall j \neq i\}$$

$\boldsymbol{p}_i$: the position of agent *i*

with centroid

$$\boldsymbol{c}_i^{(n)} = \frac{1}{\left|V_i^{(n)}\right|} \int_{V_i^{(n)}} \boldsymbol{x} d\boldsymbol{x}$$

- Agent *i*'s location at time step *n*+1 is

$$\boldsymbol{p}_i^{(n+1)} = \boldsymbol{p}_i^{(n)} + \left(\boldsymbol{c}_i^{(n)} - \boldsymbol{p}_i^{(n)}\right)/M \quad (M \geq 1)$$

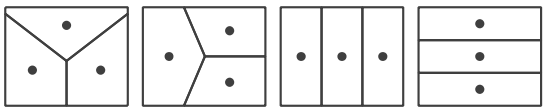
Modeling

- Now we are interested in equilibrium configurations, that is, those for which

$$\boldsymbol{p}_i^{(n+1)} = \boldsymbol{p}_i^{(n)} \quad \forall i$$

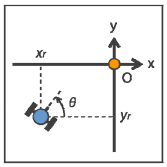
Such equilibria can be stable or unstable

- Example (*N*=3, *L*=0.80)



Unicycle Controller

- e-nuvo WHEEL is used as a agent in experiment
  → We have to design the controller to move it to an arbitrary point
- Astolfi's Controller

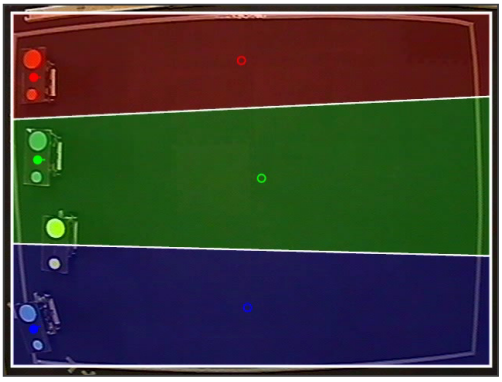


$$v = -k_v \cdot (x_r \cos\theta + y_r \sin\theta)$$

$$\omega = 2k_\omega \cdot \tan^{-1} \frac{-x_r \sin\theta + y_r \cos\theta}{x_r \cos\theta + y_r \sin\theta}$$

k_v, k_ω : Gain

Coverage Control Experiment



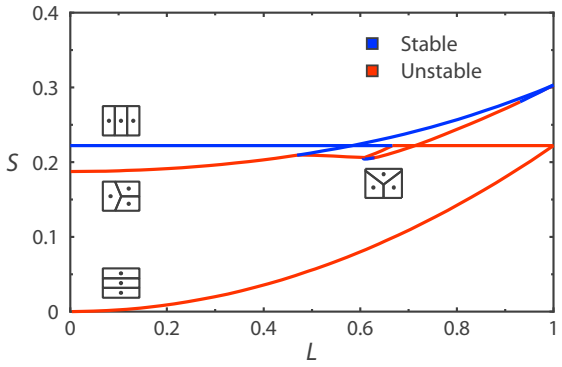
Equilibrium Bifurcation Analysis

- We treat *L* as a bifurcation parameter
- The bifurcation results are independent of *M*
- Bifurcation detection is performed by monitoring the eigenvalues of the linearized equations directly
- As a measure of an equilibrium configuration, we use

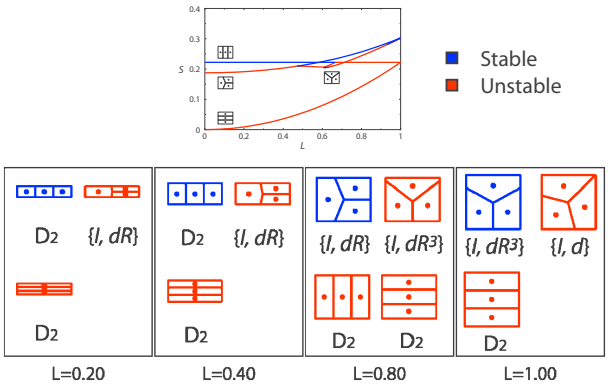
$$S = \sum_{i=1}^{N} |\boldsymbol{p}_i - \bar{\boldsymbol{x}}|^2$$

Where $\bar{\boldsymbol{x}}$ is the center of the domain *D*

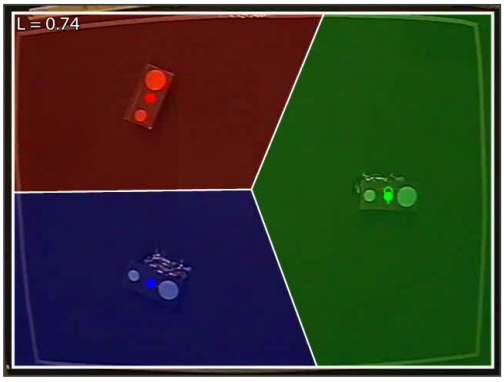
Equilibria Stability on 3 Agents



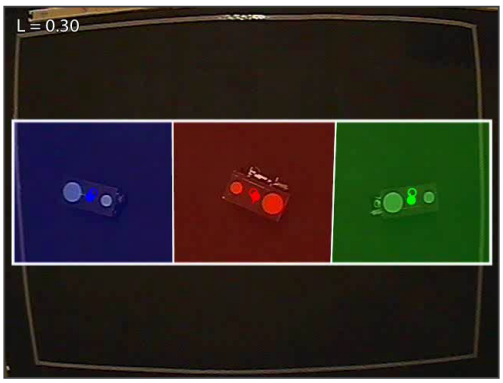
Equilibria Stability on 3 Agents



Bifurcation Experiment (Shrink)

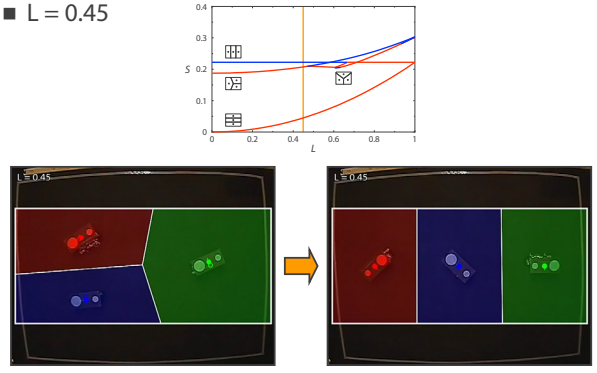


Bifurcation Experiment (Stretch)



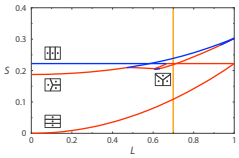
Bifurcation Experiment (Constant L)

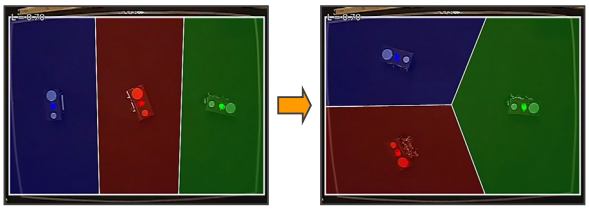
- L = 0.45



Bifurcation Experiment (Constant L)

- L = 0.70



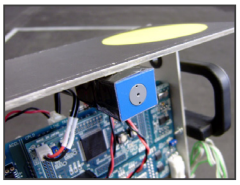


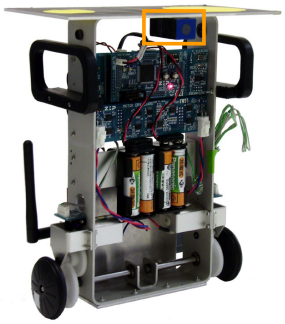
Outline

- Introduction
- System Overview
- Voronoi-based Coverage Control
- Onboard Camera
  - Specification
  - Experiment System
  - Control Law
  - Experiment
- Wii Remote Operation
- Summary

Onboard Camera Specification

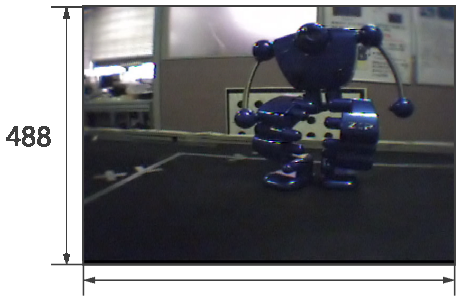
- RF System RC-12
  - Wireless Small Camera (15 × 18 × 35mm)
  - 270,000 pixels



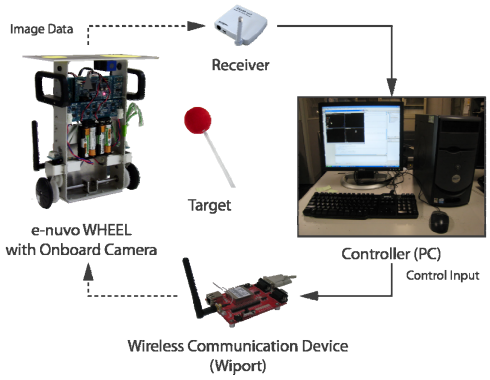


Onboard Camera Specification

- Image example

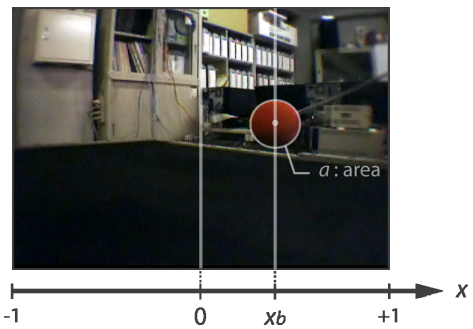


Experiment System



Information Acquisition

- Measuring area and horizontal deviation of the target



Control Law

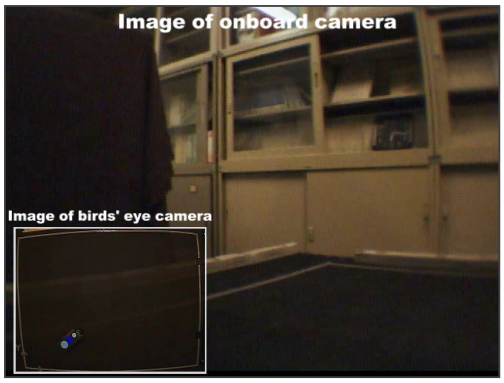
- The control input to follow the target:

$$v = \begin{cases} v_d & (a < a_d) \\ 0 & (a \geq a_d) \end{cases}$$

$$\omega = -K \cdot x_b$$

  - If the area of target is very large, the follower stops to avoid collision
- If the follower loses the target, the control input is maintained at the last value
  - The follower acts like a search behavior
  - This rule also eliminates the effect of fraction

Experiment



Outline

Main Features

- The primary controller for Nintendo's Wii console
- Wireless communication with the console via Bluetooth
- Arrow key and 7 buttons
- Accelerometer to sense acceleration along 3 axes
- Optical sensor to determine where the Wii Remote is pointing

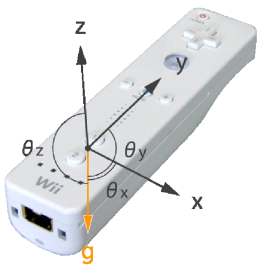
Wii www.nintendo.co.jp

Wii Remote

Why Wii Remote?

- Intuitive interface of robot operation
- Building the operator into the feedback loop (human-in-the-loop)

Measurement of Tilt

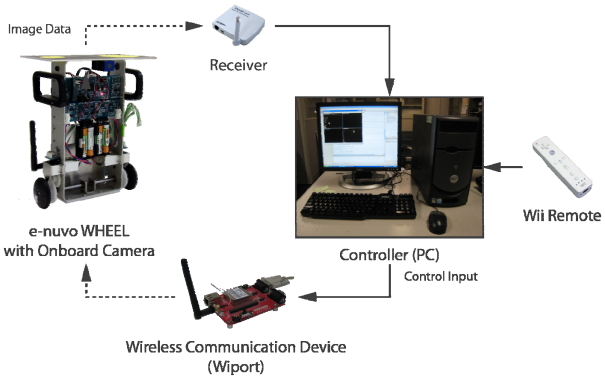


$$\begin{aligned} g_x &= \boldsymbol{g} \cdot \boldsymbol{i} \\ g_y &= \boldsymbol{g} \cdot \boldsymbol{j} \\ g_z &= \boldsymbol{g} \cdot \boldsymbol{k} \end{aligned}$$

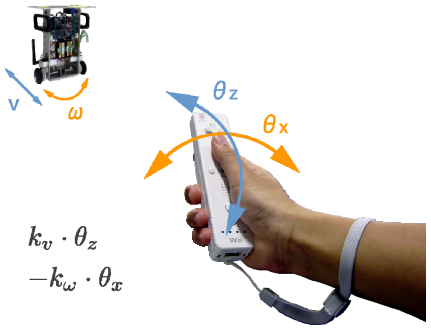
$$\begin{aligned} \theta_x &= \cos^{-1} \frac{g_x}{|\boldsymbol{g}|} \\ \theta_y &= \cos^{-1} \frac{g_y}{|\boldsymbol{g}|} \\ \theta_z &= \cos^{-1} \frac{g_z}{|\boldsymbol{g}|} \end{aligned}$$

$$|\boldsymbol{g}| = \sqrt{g_x^2 + g_y^2 + g_z^2}$$

Robot Operating System

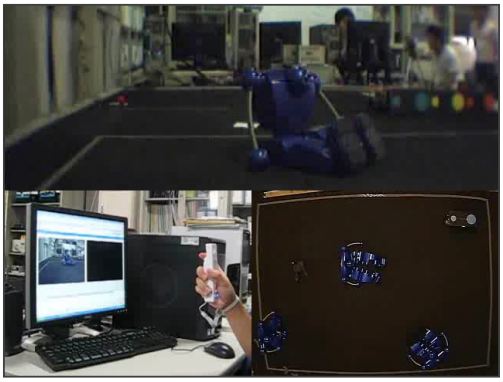


Robot Operating System



$$v = k_v \cdot \theta_z$$
$$\omega = -k_\omega \cdot \theta_x$$

Robot Operating Experiment



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Summary

- Voronoi-based Coverage Control
  - Coverage Algorithm
  - Equilibrium Bifurcation Analysis
  - Experiments
- Onboard Camera
  - Information Acquisition
  - Control Law of Following the ball
  - Experiment
- Wii Remote Operation
  - Measurement of Tilt
  - Robot Operating Experiment

Future Works

- Visual Observer
- Distributed Controller
- Human-in-the-loop