Cooperative Control of a Heterogeneous Mobile Robot Network

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Abstract

Cooperative control of mobile robots has been a rapidly growing area of research and development (R&D) for industry and academia during the past years. Such R&D activities are inspired by cooperative systems found in nature, for example, a flock of birds or a swarm of insects. In this project, the objective is to design and implement cooperative control algorithms on different types of robotic platforms. With the proposed cooperative control structure, several tasks are performed autonomously by a fleet of robot agents, which include point convergence, trajectory following, formation control, and heading alignment. The completion of the tasks is based on the consensus of the heterogeneous robot agents through the exchange of local information. MATLAB is used to conduct simulations of different control structures, and determine how a large number of robot agents can interact with one another. Applications of cooperative control strategies are significant and far reaching. This emerging technology can be used for intelligence, surveillance and reconnaissance (ISR) in military missions and civilian applications as well.

Cooperative Systems in Nature

- School of Fish
- Flock of Birds
- Swarm of Insects

Project Objectives

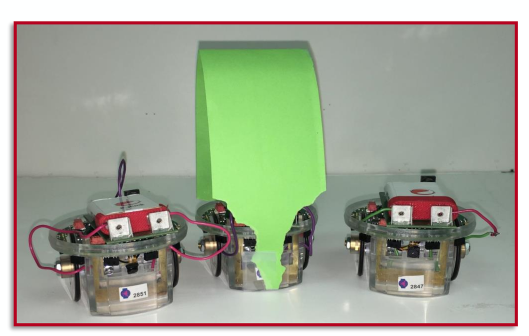
- Design and experimental validation of cooperative control algorithms
- Sensing/communication between robots
- Implementation of local flocking control algorithms
- Implementation of local formation control algorithms

Kilobot

- Diameter of 3.3 cm (Size of a quarter)
- Two differential vibration motors
- IR transmitter and receiver (12 cm range)
- Ambient light sensor

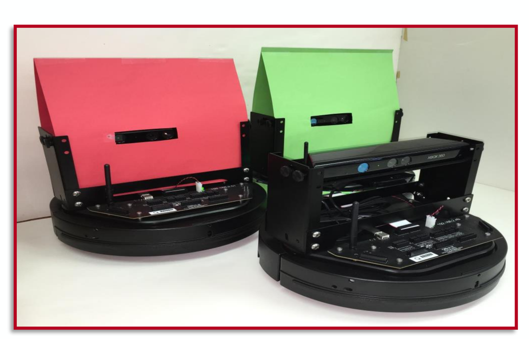
E-puck

- Diameter of 40 cm
- IR transmitter and receiver ring (25 cm range)
- On-board CMOS camera
- Bluetooth 3.0
- dsPIC 30F6014A on-board computer



QBot 2

- Open-architecture autonomous ground robot
- Xbox 360 Kinect
- Kobuki robot base
- Gumstix DouVero Zephr on-board computer

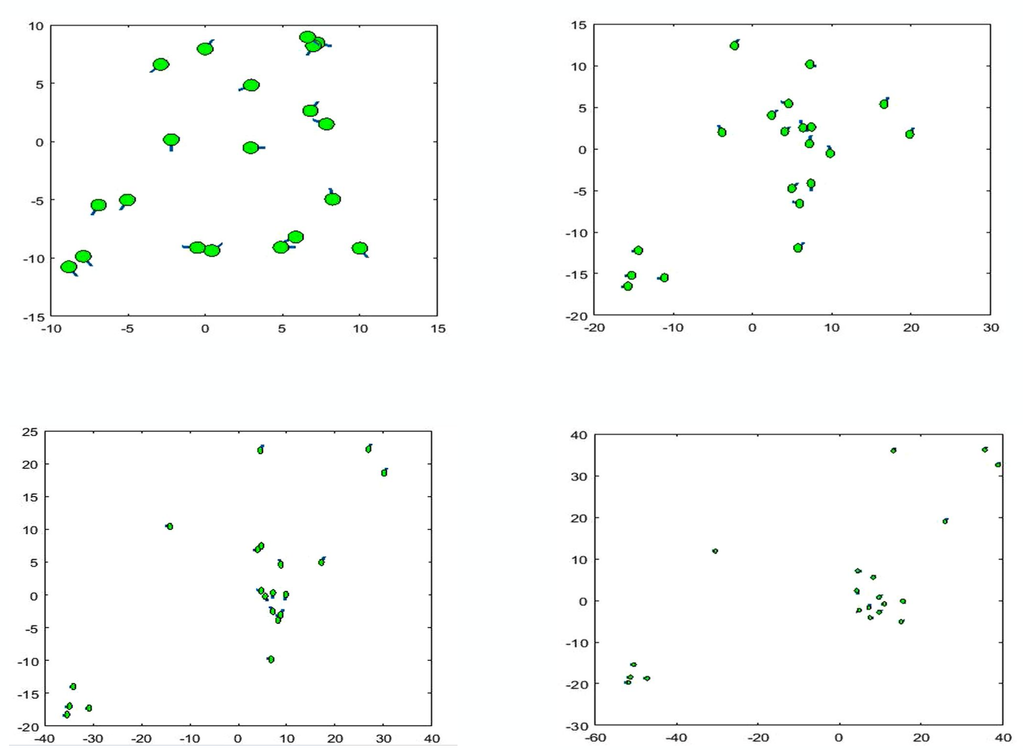


Robot Model

(x_i, y_i) position of the ith robot
θ_i the orientation
v_i driving velocity
ω_i angular velocity

$$\dot{x}_i = v_i \cos\theta_i$$
$$\dot{y}_i = v_i \sin\theta_i$$
$$\dot{\theta}_i = \omega_i$$

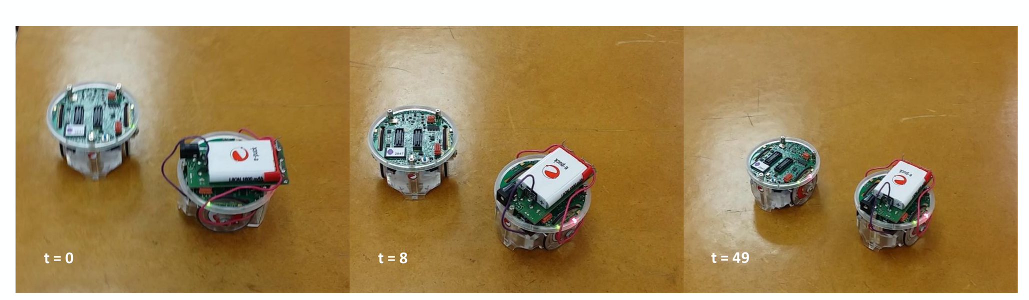
Heading Alignment Simulation



Heading Alignment Algorithm

$$\theta_i(k+1) = \frac{1}{1+n_i(k)}\left(\theta_i(k) + \sum_{j\in N(k)} \theta_j(k)\right)$$

E-puck Experiment

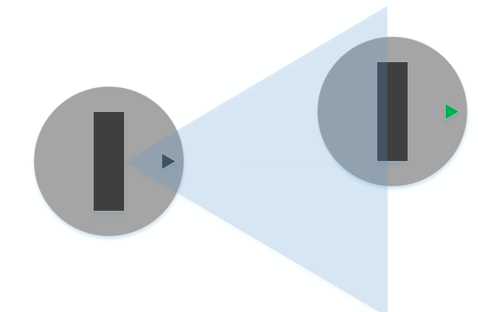


Point Consensus (Rendezvous)

Control objective:
for all robots i,j $\quad x_i = x_j,\ y_i = y_j$

Localization

Utilize Xbox 360 Kinect to determine position of other robot agents.

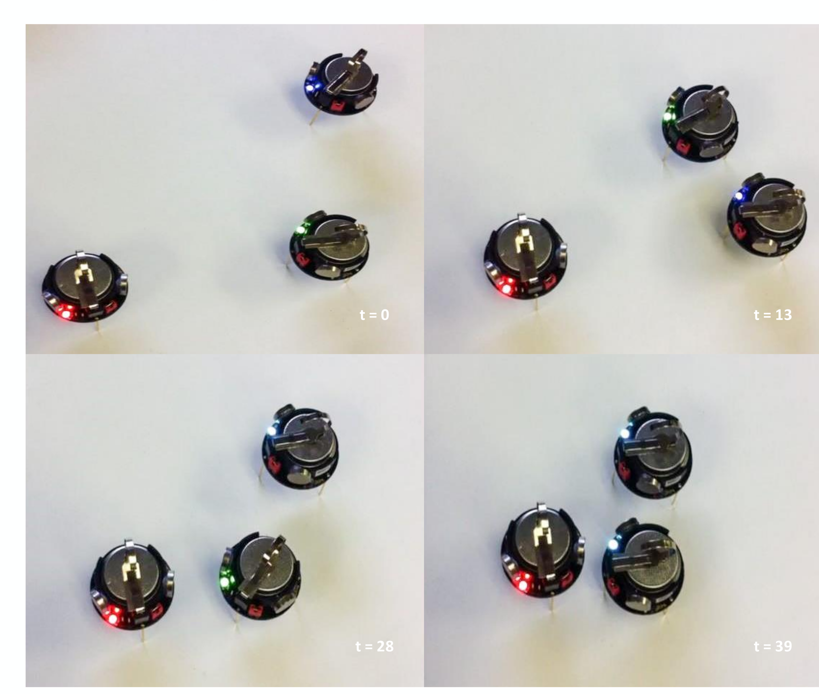


Linearization-based Control

$$u_{i1}(t) = k_i \sum_{j=1}^{n} s_{ij}(t)\left(p_{jx}(t) - p_{ix}(t)\right)$$
$$u_{i2}(t) = k_i \sum_{j=1}^{n} s_{ij}(t)\left(p_{jy}(t) - p_{iy}(t)\right)$$

QBot 2 Experiment

Kilobot Experiment



Formation Control

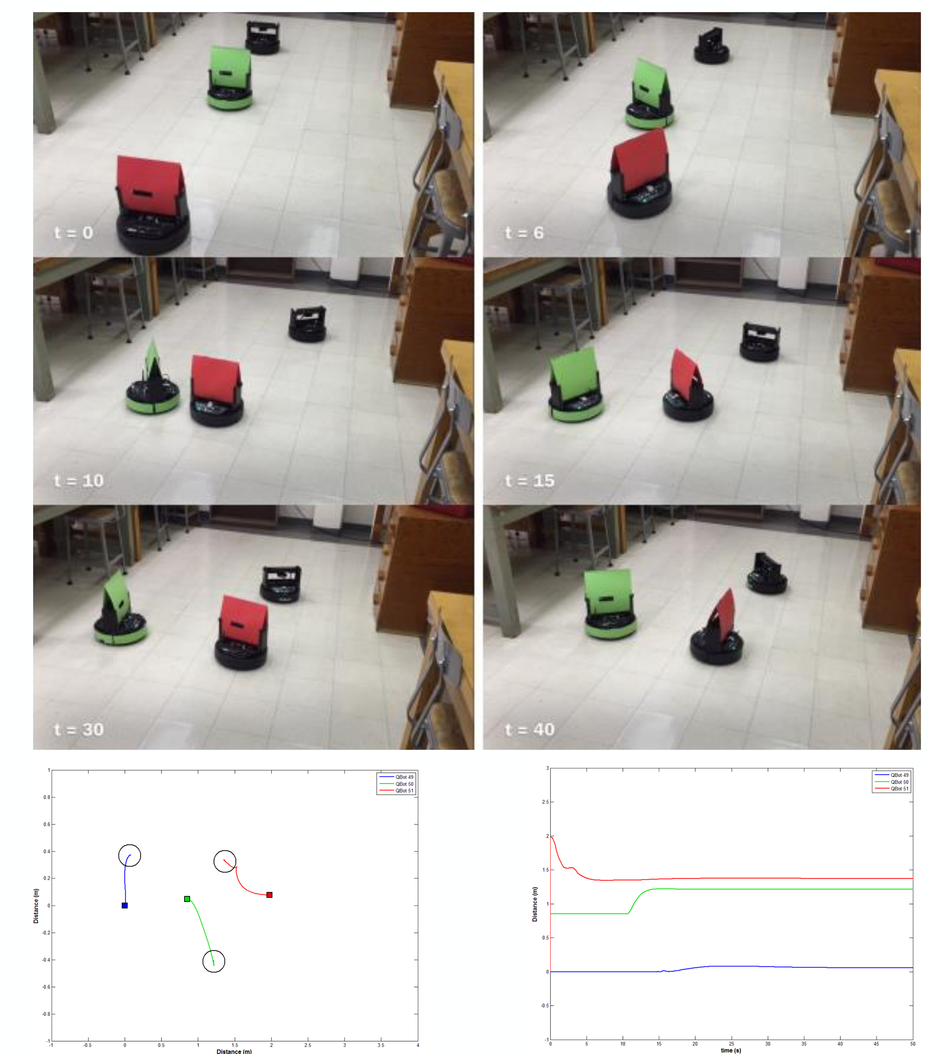
Control objective:
given formation shape parameters $C_{j,x}$, $C_{j,y}$ for all robots i,j

$$x_i - x_j = C_{j,x}$$
$$y_i - y_j = C_{j,y}$$

Linearization-based Control

$$u_{i1}(t) = k_i \sum_{j=1}^{n} s_{ij}(t)\left(p_{jx}(t) - c_{jx} - p_{ix}(t) + c_{ix}\right)$$
$$u_{i2}(t) = k_i \sum_{j=1}^{n} s_{ij}(t)\left(p_{jy}(t) - c_{jy} - p_{iy}(t) + c_{iy}\right)$$

QBot 2 Experiment



Conclusion

In this project, cooperative control algorithms were designed and implemented on a network of mobile robots so that the robots can converge to maintain the same heading, rendezvous in an area, or form maneuvering patterns like filing, toroidal motions, flocking, and swarming. Control algorithms were obtained by linearizing robot models with the assumption of local information exchange through sensing and communication among neighboring robots. Experimental results validated the effectiveness and robustness of the proposed cooperative controls.

Future Work

This is a multi-year project and the work will include the study of target tracking problem by a network of heterogeneous robots, when communication capabilities of some neighboring robots are impaired.