Distributed Vision-Based Target Tracking Control Using Multiple Mobile Robots

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Abstract

In this project, a distributed vision-based control system is designed for multiple mobile robots to address the target tracking problem while maintaining the specified formation among robots. The system mainly consists of two modules. One is for target identification and the other is for target tracking control. In the target identification module, the robot is controlled to pivot around its center and perform a survey of the environment using its on-board vision sensor. In the target tracking control module, a leader-follower control strategy is adopted to solve the target tracking and formation control problem of multiple robots. The proposed distributed vision-based control is experimentally tested using three QBot2s from Quanser, Inc.

Motivation

- Distributed control of multiple unmanned autonomous robots (UARs) has been the subject of intensive research in recent years due to the potential applications in search and rescue missions, surveillance and reconnaissance, environmental sensing and monitoring, and intelligent transportation [3].
- In the study of distributed control, efforts have been particularly focused on addressing the formation control problem for UARs, in which the design objective is to make a group of robots maintain certain geometric formation pattern while tracking a target.
- Local sensing information exchange among robots is the key in the design of distributed control.
- Vision sensors have been used in the localization, navigation, and control of the individual robot [1].
- Future study needs to be done in the use of vision sensors for distributed control of multiple robots.

Objective

- The research objective of this project is to design a distributed vision-based target tracking control algorithm for multiple mobile robots.
- To achieve the above objective, the research tasks include:
  - Design a target identification module based on RGB image features obtained from vision sensor
  - Design a target tracking algorithm based on robot model linearization
  - Design a leader-follower formation control algorithm based on depth image features obtained form vision sensor
  - Design a stateflow-driven switching strategy to coordinate target identification module and target control module
  - Validate the proposed distributed control through real experiments

Mobile Robot

Hardware

- Differential drive robot has a maximum speed of 0.7m/s.
- Kinect vision sensor mounted on top of the robot has a horizontal field of view limited to 57^o.
- The RGB image has a minimum resolution of 640×480 pixels and a maximum resolution of 1280×1024 pixels.
- The depth image has a resolution of 640×480 pixels, and has a range of 0.5 to 6 meters.

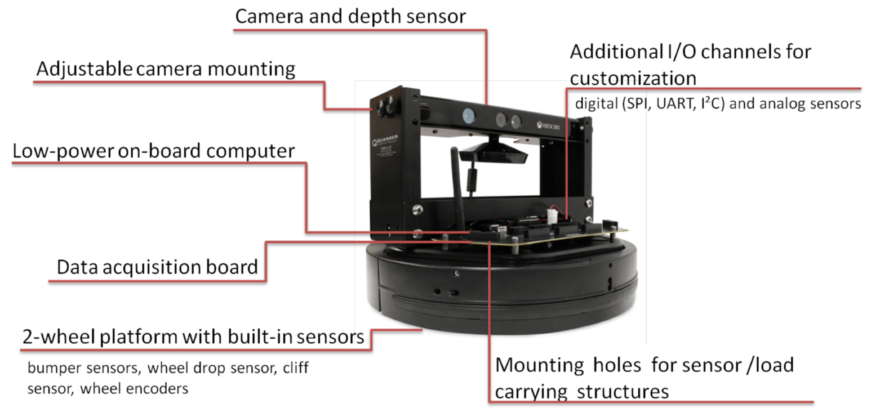

Figure 1: QBot2 Mobile Robot

Software

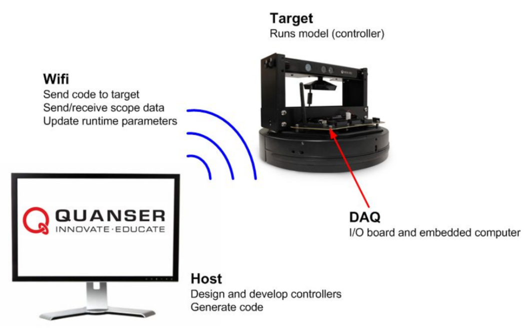

Figure 2: A host-target real-time control system [2]

- The target computer is connected wirelessly with the host computer on which the SIMULINK model is running.
- The control algorithms are developed in MATLAB/SIMULINK with QUARC on the host computer.
- The control models are cross-compiled and downloaded to the target computer in real time.

Robot Model

$$\dot{x} = v\cos\theta, \quad \dot{y} = v\sin\theta, \quad \dot{\theta} = \omega$$
$$v_R = v + \frac{d}{2}\omega, \quad v_L = v - \frac{d}{2}\omega \qquad (1)$$

Design of Distributed Vision-Based Control

Target Identification

- RGB image and depth image are acquired for target/robot identification. Image thresholding and blob detection algorithms are used in image processing.

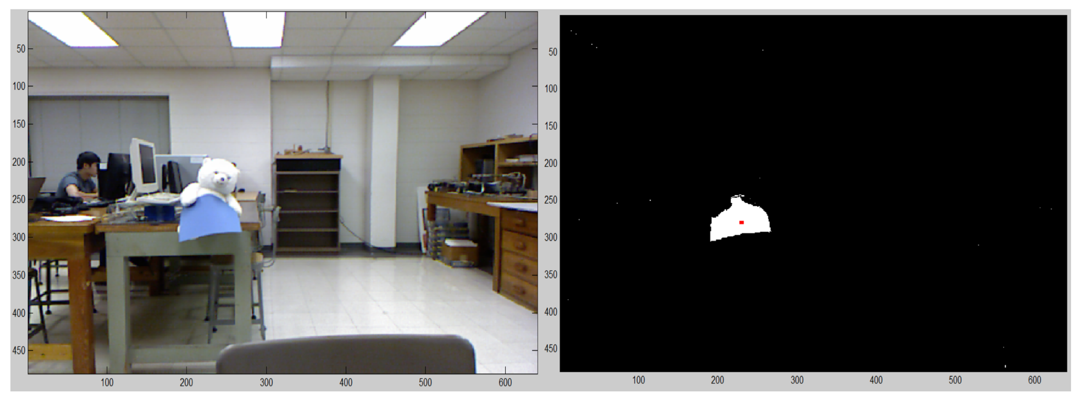

Figure 3: RGB Image Processing

- Thresholds RGB values are obtained from the first image.
- The second image is the one after implementing the thresholding algorithm.
- Blob analysis is done to determine a centroid of the target denoted by the red dot.
- The depth image is performed to obtain the distance to the target and accordingly to compute the coordinate of the target in the local frame.

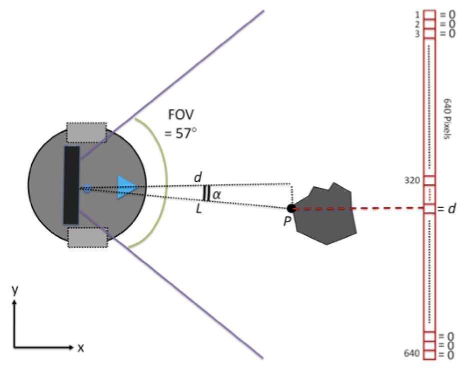

Figure 4: Depth Image Processing [2]

Target Tracking Control

- Target Tracking (encirclement control)
  - Based on linearized model: $\dot{p} = u$
  - $u = J^{-1}\begin{bmatrix} k_\rho(\rho^* - \rho) \\ \omega^* \end{bmatrix}$
- Leader-follower control
  - $v = k_v(\rho^* - \rho)$
  - $\omega = -k_\omega \tan^{-1}(\frac{\Delta y}{\Delta x})$.

Implementation and Results

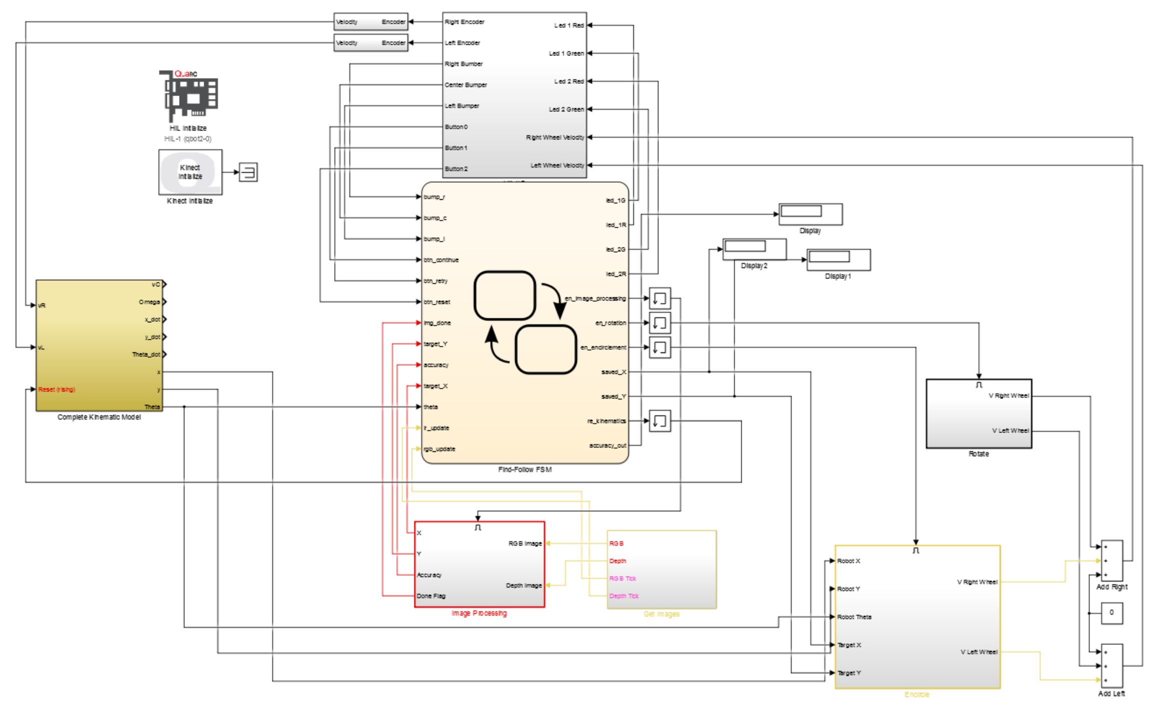

Figure 5: Simulink Implementation of the Overall System

- Stateflow is used to coordinate different task modules including target identification module, target tracking module and leader-follower module.
- In the target identification module, the each robot is controlled to pivot around its center and acquires RGB and depth images every 15 degrees to search for the target or the leader.
- Once the target/leader is found, the target tracking or the leader-follower module is activated for tracking task.
- The switching from control module to target identification module is done once the motion of the target or the leader has been detected.

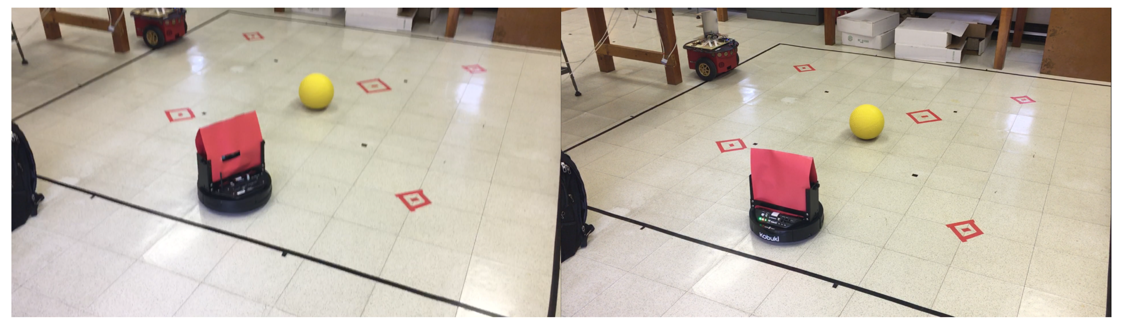

Figure 6: Left: target search; Right: target found

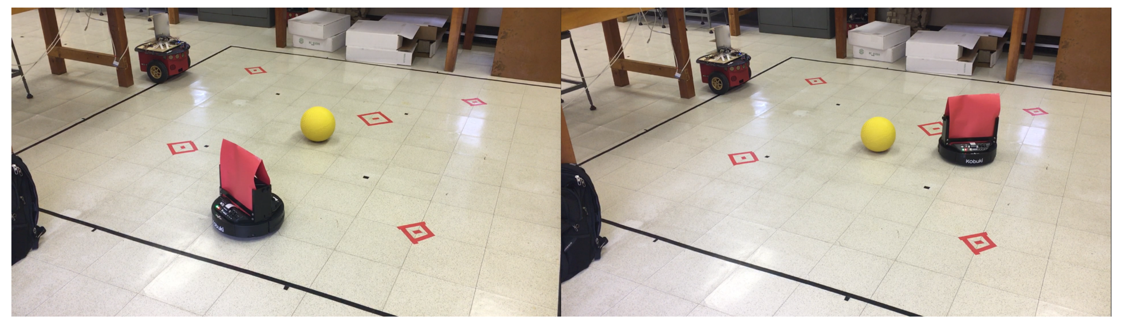

Figure 7: Target Encirclement

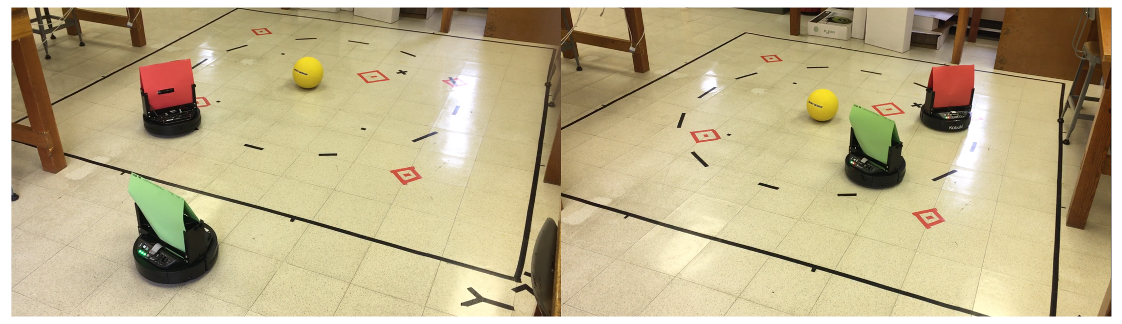

Figure 8: Leader-Follower Control

Conclusions

- A target encirclement control together with the leader-follower control was implemented to show the distributed vision-based control with limited sensing.
- The proposed design was validated with various leader-follower test scenarios.
- Advanced image processing will be further studied to improve the robustness of image thresholding algorithm.
- A vision-based collision avoidance module can be integrated to deal with obstacles in the environment.

References

[1] A. Franchi, P. Stegagno, and G. Oriolo. Decentralized multi-robot encirclement of a 3d target with guaranteed collision avoidance. *Autonomous Robots*, 40:245–265, 2016.

[2] A. Haddadi, P. Martin, and C. Fulford. Qbot2 for quarc workbook. *Quanser, Inc.*, 2014.

[3] R. O. Saber, J. Alex Fax, and R. M. Murray. Consensus and cooperation in networked multi-agent systems. *Proceedings of the IEEE*, 95:215–233, 2007.