Vision Based Multi-Robot Coordination for Mapping

Samuel Liu[1,2], Liangting Wu[2], Roberto Tron[2]

[1]BASIS Independent Silicon Valley, 1290 Parkmoor Ave, San Jose, CA 95126

[2]Boston University Robotics Laboratory, 750 Commonwealth Ave, Brookline, MA, 02446

Introduction

Background:

- **Multi-robot system**: collaboration algorithms to complete tasks
  - More effective than **singular robots** [1]
- **Mapping**: creating a map
- Multi-robot mapping often use **communication** of positions [2]
  - Synchronization issues, communication delay [3]
  - **Decentralized** solution: coordinate with each other instead of central robot [3]

Goal:

1. Implement vision-based coordination pattern between both robots
2. Use vision-based coordination to simultaneously map environment

Methods

Materials:

- **2 ROSBots**
- **ROS2**: nodes, topics, messages
- **AprilTags**: position and orientation data

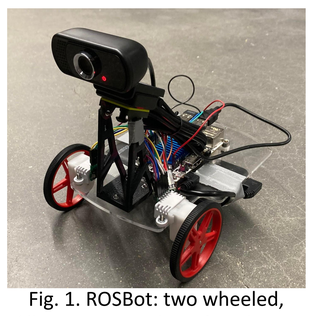

Fig. 1. ROSBot: two wheeled, Libre computer board, webcam

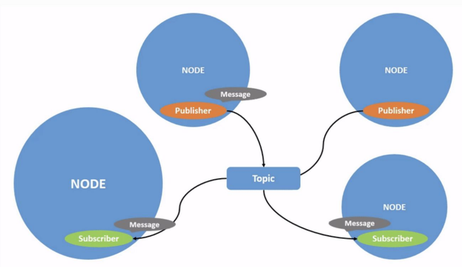

Fig. 2. Flow of ROS2 data between different nodes and topics [4]

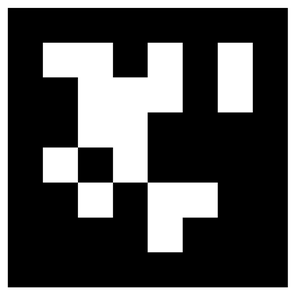

Fig. 3. AprilTag, family 36h11, id=0

Vision-based coordination:

- AprilTag detection => calculate translational and angular **error** => **Proportional Derivative** (PD) controller

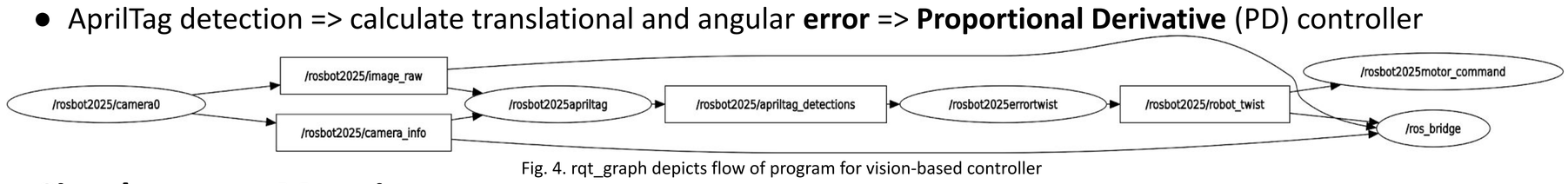

Fig. 4. rqt_graph depicts flow of program for vision-based controller

Simultaneous Mapping:

- Both spin in circle => adjacent tag **transform** => apply **affine transformations** to create map
- **Merge** both maps together: take average coordinate value of each vertex
- Single robot map vs double robot map **RMS** error

$$\vec{x} = \mathbf{R}\vec{x'} + \vec{T}$$

Fig. 6. Affine transformation to find global position of a point

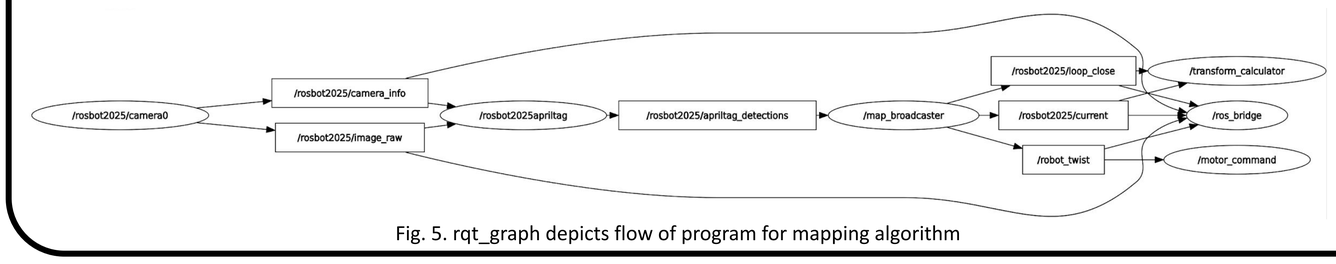

Fig. 5. rqt_graph depicts flow of program for mapping algorithm

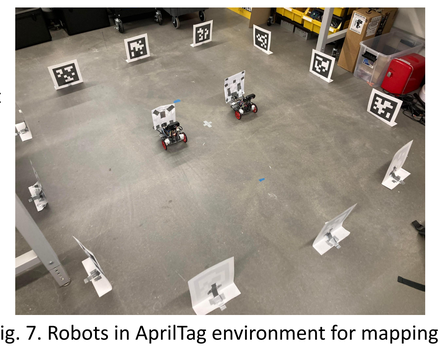

Fig. 7. Robots in AprilTag environment for mapping

Results

Vision-based PD Controller Performance:

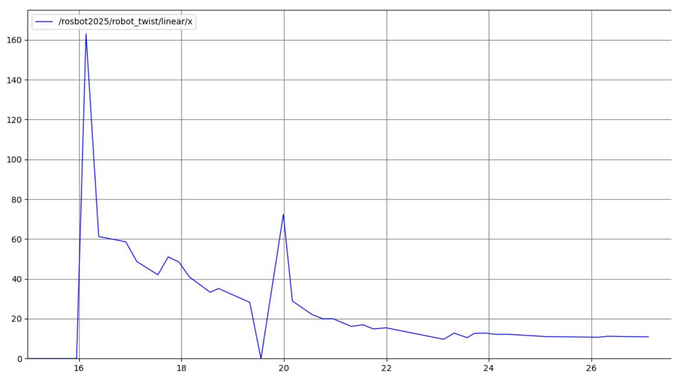

Fig. 8. Plot depicts the vision-based PD controller. x-axis is time, y-axis is control signal.

$$y(t) = K_p \cdot e(t) + K_d \cdot \frac{d}{dt}e(t)$$

Fig. 9. Equation for PD controller output

Graph Details:

- Error quickly converges near 0
- Oscillations from delay between error calculation and motor output

Mapping Performance:

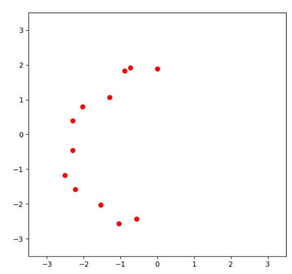

Fig. 10. Robot 1's independent map

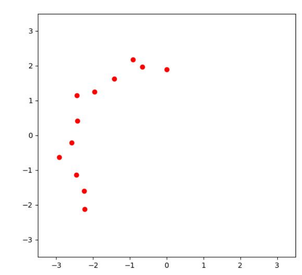

Fig. 11. Robot 2's independent map

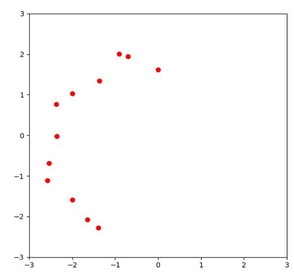

Fig. 12. Merged independent maps

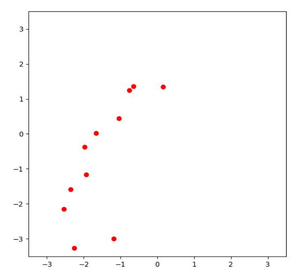

Fig. 13. Robot 1's coordinated map

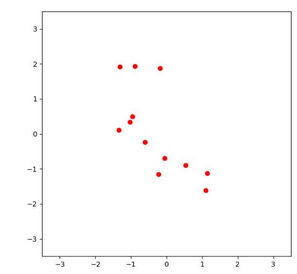

Fig. 14. Robot 2's coordinated map

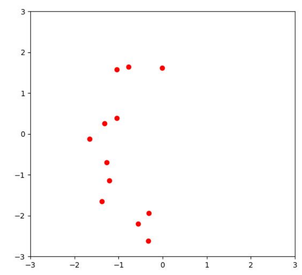

Fig. 15. Merged coordinated maps

Map Details:

- x-axis and y-axes are coordinate plane for environment
- Robot is located at (0,0)
- Red dots are location of tags

	Without coordination	With coordination
Robot 1	2.55m	2.96m
Robot 2	2.92m	1.31m
Merged	2.69m	2.05m

Table 1. Root mean square error of mapping with and without coordination

Conclusions

Vision-Based Coordination:

- Successful: able to execute **follow-the-leader** pattern
  - Didn't need to communicate positional data between each other

Mapping:

- Unsuccessful: mapping algorithm **unable** to accurately depict environment
  - Possible Problems: **error accumulation**, inaccurate positional readings from camera
  - Possible Improvements: **recalibrate** camera, use **GTSAM** [5], adjust adjacent transform calculations
- Partially Successful: coordinated map has **less error** but appearance looks **less accurate**
  - Possible Reasons: flawed merging algorithm, flawed error calculation, inaccurate data from cameras

Future Directions

- Use more **advanced** robots: right now, robots are too simple and struggle to do certain tasks
- Use **more** robots: only two robots right now, having more to make
- **Object detection** model for vision coordination: no need to put clunky AprilTag on robot
- Implement **Simultaneous Localization and Mapping** (SLAM)

References

[1] Darmanin, R. N., & Bugeja, M. K. (2017, July). A review on multi-robot systems categorised by application domain. In 2017 25th mediterranean conference on control and automation (MED) (pp. 701-706). IEEE.
[2] Fox, D., Ko, J., Konolige, K., Limketkai, B., Schulz, D., & Stewart, B. (2006). Distributed multirobot exploration and mapping. Proceedings of the IEEE, 94(7), 1325-1339.
[3] Lajoie, P. Y., & Beltrame, G. (2023). Swarm-slam: Sparse decentralized collaborative simultaneous localization and mapping framework for multi-robot systems. IEEE Robotics and Automation Letters, 9(1), 475-482.
[4] Understanding topics — ROS 2 Documentation: Foxy documentation. (n.d.). https://docs.ros.org/en/foxy/Tutorials/Beginner-CLI-Tools/Understanding-ROS2-Topics/Understanding-ROS2-Topics.html
[5]Dellaert, F. (2012). Factor graphs and GTSAM: A hands-on introduction. Georgia Institute of Technology, Tech. Rep, 2, 4.
[6] Liu, S. (2024). Samuel Liu BU RISE Blog. 2024, https://samuelrise2024.blogspot.com/
[7] Liu, S. (2024). Samuel Liu BU RISE Code. https://bitbucket.org/burobotics/rise_rosbot_following/src/master/

Acknowledgements

I would like to thank Professor Tron for providing me with expert knowledge and a fulfilling experience here at RISE. I would also like to thank Tom Wu for his guidance as I worked on my research. Furthermore, I am grateful for the entire BU Robotics laboratory for supporting me and showing me the many cool opportunities in the field of robotics. Lastly, I am grateful for my parents for making this experience possible and supporting me every step of the way.