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Systems Engineering Laboratory (LIS – UR7478)
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Title:
Decentralized observer synthesis applied to the cooperative transport of bulky parts

Keywords:
automatic control, nonlinear observers, decentralized estimation, multi agent systems, nonholonomic robots.

Background:

Autonomous mobile robots are increasingly used today for autonomous product transport operations in warehouses and logistics scenarios [1]. Indeed, by their very nature, they enable the expansion of reactive and flexible behaviors in dynamic routing, as they navigate freely in workshops and warehouses. However, the weight of some products requires powerful mobile robots to accomplish the transport task. What's more, some products (wind turbine blades, large trains, aircraft or ship components, engines, etc.) cannot be transported by a single robot. To meet this logistical challenge, one very promising solution is to use several mobile robots capable of performing tasks in cooperation.

This thesis is part of a larger project aimed at developing a solution for transporting heavy and/or bulky products within a warehouse. These products are transported by several robots working together. Although commercial solutions exist for carrying out product transport operations in warehouses, they all have their limitations. For example, some require robots to be mechanically attached to each other, which limits flexibility, or require remote operation (https://www.tii-group.com/fr/tii-scheuerle/notre-solution/spmt/scheuerle-spmt).
Some projects featuring a more flexible approach have emerged recently, for example:
- https://eurecat.org/en/portfolio-items/geomove/
- https://www.mccormick.northwestern.edu/magazine/fall-2022/future-of-human-robot-interaction/
The robots considered in these approaches are omnidirectional with Swedish wheels. Although these robots have the advantage of extremely simple kinematics, they have the disadvantage of poor odometric localization and mechanical complexity, which leads to rapid wear and additional costs.

The aim of this project is to propose a generic scheme that can be applied to the transport of any rigid product, by appropriately selecting the number of robots and the coordinates of the anchor points. In the proposed approach, the product plays an “active” role. It is instrumented (e.g., equipped with an on-board computer) to make decisions, based on its characteristics and the environment, enabling it to be transported from an initial position to a desired position. The mobile robots considered here are non-holonomic, enabling them to generate greater forces and be more durable.

An important aspect of this project is the recovery/reconstruction of the necessary product information. Indeed, transporting a bulky and/or heavy product, which requires complex robotic maneuvers, requires precise, real-time knowledge of the product's movement.

Objective:

The aim of this thesis is to develop observers for reconstructing the signals needed to achieve the objective of transporting the products under consideration.

In order to bring the product safely to its final location, its position, velocity and orientation must be available. Although the position of the product's center can be measured, it's much more complicated to measure its speed and, in particular, its orientation. Estimation of orientation will be carried out using position data from each of the robots, i.e. by first assuming that the position of a fixed number of points attached to the object is measured. Although centralized approaches exist [2], the aim here is to develop a more robust decentralized approach [3]. In addition, data will be assumed to be transmitted asynchronously and aperiodically. We will therefore use continuous-discrete observers [4] which reconstruct the continuous-time state from discrete-time outputs. This approach will also allow us to take into account communication problems (delay, packet loss, etc.). This observer will then be extended to a more complete model, also containing the position and velocity of the object to be moved, in order to fully characterize its dynamics.

The fact that the robots used are non-holonomic limits the possible movement of the robots. It is therefore necessary to allow sufficient deformation at the anchor points between the robots and the product, so that the assembly does not become mechanically locked. The position of the robots does not correspond exactly to the anchoring point on the product, and a stress is therefore exerted on each anchoring point. It will therefore be necessary to have a dynamic model to capture the deformation in the robot/product connection, thus improving understanding of mechanical interactions. By using this complete model and adapting the previously developed observer, we will obtain a distributed observer that estimates both the object pose and the deformation of each link. Finally, the problem of estimating the stresses exerted on each link will be examined [5]. This problem is closely related to reaction force estimation, for example for co-manipulation in robotics [6].

The observation algorithms will first be developed on matlab. Validation of the theoretical results obtained will be carried out first on ROS/Gazebo (simulation platform) and then on the robotics platform at LAMIH (UMR 8201) in Valenciennes.

The thesis will take place at the University of Caen, in the LIS laboratory (UR 7478). It should be noted that one month per year will be spent in Valenciennes to validate theoretical results on the robotics platform.

References :

[1] Yildirim, A., Reefke, H., Aktas, E. (2023). Mobile robot automation in warehouses: a framework for decision making and integration. Springer Nature.

[2] Vertechy, R., & Castelli, V. P. (2007). Accurate and fast body pose estimation by three point position data. *Mechanism and machine theory*, 42(9), 1170-1183.

[3] Arefanjazi, H., Ataei, M., Ekramian, M., Montazeri, A. (2023). A robust distributed observer design for Lipschitz nonlinear systems with time-varying switching topology. *Journal of the Franklin Institute*, 360(14), 10728-10744.

[4] Landicheff, G., Ménard, T., Gehan, O., Pigeon, E. (2022). Continuous-discrete time observer design for multi-output linear continuous systems with aperiodic asynchronous measurements. *IEEE Control Systems Letters*, 6, 3002-3007.

[5] Zheng, Y., Shangguan, W. B., Yin, Z., Li, T., Jiang, J., Rakheja, S. (2023). A hybrid modeling approach for automotive vibration isolation mounts and shock absorbers. *Nonlinear Dynamics*, 111(17), 15911-15932.

[6] Sariyildiz, E., Ohnishi, K. (2014). An adaptive reaction force observer design. *IEEE/ASME Transactions on Mechatronics* 20(2), 750-760.