Chapter 20
Distributed Multi–Robot Localization

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ABSTRACT

In this chapter, the design of a completely decentralized and distributed multi-robot localization algorithm is presented. The issue is approached using an Interlaced Extended Kalman Filter (IEKF) algorithm. The proposed solution allows the dynamic correction of the position computed by any single robot through information shared during the random rendezvous of robots. The agents are supposed to carry short-range antennas to enable data communication when they have a "visual" contact. The information exchange is limited to the pose variables and the associated covariance matrix. The algorithm combines the robustness of a full-state EKF with the effortlessness of its interlaced implementation. The proposed unsupervised method provides great flexibility by using exteroceptive sensors, even if it does not guarantee the same position estimate accuracy for each agent. However, it can be effective in case of connectivity loss among team robots. Moreover, it does not need synchronization between agents.

INTRODUCTION

A fundamental issue in any mobile robot ad-hoc network is related to the ability of each agent to localize itself with respect to both the workspace and the other agents. In mobile robotics, this issue is referred to as localization when the environment is a known priori, while it is called Simultaneous Localization and Mapping (SLAM) when robots concurrently create a map of the environment and locate themselves on that map. Here, only the localization problem is addressed, although the proposed algorithm can be suitably extended to solve SLAM problems.

In the literature, localization is approached using supervised and unsupervised communication paradigms. In the first case, a centralized supervi-

sor (i.e., a base station) collects all the data coming from the robots and provides an estimate for the pose of the whole team. In the second approach, each robot runs a local algorithm to estimate its pose, using only its own sensors and shares data with its neighbors following the Mobile Ad hoc NETwork (MANET) model.

The complexity of a centralized algorithm grows in a nonlinear way with the number of robots. Moreover, this solution forces all mobile robots to communicate continuously with the supervisor: thereafter, robots need either to move closely to the supervisor location, or to set up a hierarchical network (Antonelli, Arricchiello, Chiaverini, & Setola, 2006). In both cases, some constraints over team mobility are imposed to guarantee that, at each moment, at least one communication-path from any robot to the supervisor exists.

According to the decentralized approach, each robot in the team collaborates to solve the localization problem. The easiest solution is achieved by decomposing the localization problem of the team into autonomous and independent localization tasks. Therefore, each robot implements its own localization algorithm, ignoring the presence of the other robots in the workspace. In other words, the localization problem is solved by multiplexing single robot localization, without exploiting additional information extracted from neighbors. Moreover, no relative measures are used, even if this information could be very important (i.e., formation control, collaborative exploration tasks). For these reasons, in the literature, the multi-robot localization problem is referred to as collaborative/cooperative localization, when the team exploits information sharing.

The relevance of information sharing during localization is particularly useful when it faces heterogeneous robot teams. In this case, some robots are equipped with expensive, high accuracy sensors (i.e., GPS, laser rangefinders, smart camera), while the others are equipped with low-cost sensors (i.e., sonar, Web-cam). Hence, information sharing enhances sensor data, since collaborative multi-robot localization exploits high-accuracy sensors across teams.

This chapter proposes an efficient probabilistic algorithm, the Interlaced Extended Kalman Filter (EKF) (Panzieri, Pascucci, & Setola, 2006), for collaborative multi-robot localization. It is based on the well-known prediction-update scheme of Bayesian filter and represents a sub-optimal solution for probabilistic state estimate. According to this approach, robots are able to compute their poses, exploiting the detection of other robots. Indeed, each robot implements an EKF to localize itself, using proprioceptive sensors and measurements retrieved from the environment. When two robots are visible to each other, they exchange information about their estimated poses and their measurements. By doing so, each robot takes advantage of its neighbors, using them as further virtual sensors. To cope with the noise and the ambiguity arising in real-world scenarios, observation models are set up in a probabilistic framework. Indeed, the covariance matrices related to these virtual devices are suitably manipulated to accommodate the different levels of uncertainties typical of pose estimates. The whole team localization problem is split over the robot network decomposing the whole filter into N sub-filters, where N is the cardinality of the team.

IEKF allows cooperative localization under severe communication and computational constraints. In fact, the communications are performed only during rendezvous and only limited data are broadcast. The computational load is reduced by the decomposition of the estimate procedure. Although reducing computational complexity and communication represents a great advantage, the main novelty of the proposed approach is related to the synchronization of the estimate. Several multi-robot localization algorithms based on Extended Kalman Filter decomposition rely on the assumption that the robotic network is completely synchronized. On the contrary, IEKF does not

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