1 Introduction

- Biologists are interested in studying the social behaviour of swarming/schooling/flocking animals,
- Sociologists wish to understand the social networks in human society
- Engineers want to propose methods to control groups of robots in a decentralized fashion without explicitly giving them individual orders

There are two main themes in our endeavour:
1. How to obtain information about the members of the formation
2. How to devise control strategies to make a group of mobile robots cooperate

Graphs are used to model (i) communication, and (ii) sensing among the agents in the formation.

2 A Bit of Notation

There exists another relevant problem called the "pose determination problem" which interests roboticists. The question of interest is how to determine the orientation of a robot in another robot coordinate frame using range measurements only.

3 Formation Localization and Coordination

3.1 Formation Localization and Anchor Selection

The task of estimating positions of the agents in a formation is called "localization". To do so, in many cases, we require:
1. Global rigidity of the formation
2. Existence of at least $N+1$ agents with known position (anchors) in $N$-dimensional space

The selection of these anchors is non-trivial and we addressed using CVX optimization techniques.

3.2 Cooperative Self Localization

Consider three agents without GPS receivers can only measure the distances. The question of interest is: what are their possible locations? Generically, the answer is not unique:

Let $\Sigma_i = \{(x_i, y_i, z_i)\}$ be a reference frame fixed with a moving body. The origin of $\Sigma_i$ is the point $p_i$, denoted by $p_j$ when expressed with respect to $\Sigma_j$. The orientation of $\Sigma_i$ is characterized by the $3\times3$ dimensional rotation matrix $R_{i}$, whose columns are the frame vectors $(x_i, y_i, z_i)$ of $\Sigma_i$ expressed with respect to $\Sigma_j$.

The main problem here is, given a relative sensing network with two agents connected by that edge:

- Frame Localization: the reference frames transformations \( (\tilde{R}_i, \tilde{p}_i) \) for all \( i \in \{1, \ldots, n\} \) are uniquely determined by the relative measurements;
- Orientation Localization: the orientations $\tilde{R}_i$, for all \( i \in \{1, \ldots, n\} \), are uniquely determined by the relative measurements.

4 Formation Control

4.1 Close Target Reconnaissance

The objective in this problem is to move UAVs scattered in an environment in the presence of obstacles towards a target of interest while avoiding collision with other UAVs and the obstacles, and start rotating around the target while forming an equilateral triangle. The problem is depicted in the bottom figure in the left-most column.

4.2 Circumnavigation Via Distance Measurements

The objective in this problem is to first estimate the position of the target using only continuously available range measurements and then try to achieve a rotating maneuver around the target.

5 Future Directions

Future possible research directions include, application of the machinery obtained from algebraic geometry for accomplishing the task of localization using measurements other than distance, formalizing the obstacle avoidance techniques introduced in the earlier works, and extending the frame localization to $\mathbb{R}^3$.

6 Supervision and External Collaborators

Supervised by: Brian D. O. Anderson (ANU/NICTA), and Barış菲尔 (ANU/NICTA), Collaborated with: Hatem Hmam (DSTO), Saurabh Dasgupta (Uni of Iowa), Francesco Bullo (UCSB), Giulia Piovano (UCSB), and Xiaofan Wang.