Safe Open-Loop Strategies for Handling Intermittent Communications in Multi-Robot Systems

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Communication failures pose a serious threat to the effective functioning of multi-robot systems. In many applications and scenarios such as extra-terrestrial exploration, high precision manufacturing, and multi-robot testbeds, the robots frequently rely on communicating with a central decision maker for their velocity or position commands. This raises the following question: *What should a robot do in case a communication failure prevents it from receiving critical motion commands from a central decision maker?*

To address this issue, we propose a strategy that allows differential-drive robots without sensory or decision-making capabilities, to continue moving safely for a specific amount of time even when velocity commands from a central decision maker are not received. For each robot, the central decision maker computes a time horizon over which collisions with other robots are guaranteed not to occur. This is called the safe time horizon [2].

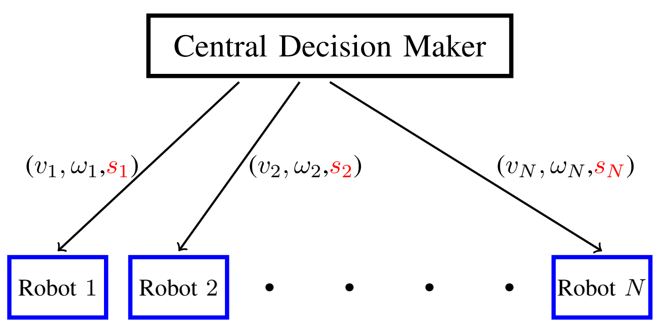

Fig. 1: The safe time horizon algorithm: at each time step, the central decision maker transmits the safe time horizon s_i to each robot along with the velocity commands (v_i, ω_i).

During normal operations, the desired velocity and the safe time horizon are transmitted to the robots periodically (see Figure 1). If a robot stops receiving data due to a communication failure, it executes the last received velocity command for the duration of the last received safe time horizon. This allows the robot to continue moving in an open-loop yet provably collision-free manner despite having no updated information about the environment. Beyond the safe time horizon, it stops moving. In this manner, the safe time horizon algorithm can makes certain types of multi-robot systems resilient to short-duration communication failures.

In order to calculate the safe time horizon, we first compute the set of all possible locations that can be reached by a robot within a given time (i.e., the reachable set [1], depicted in Figure 2). Owing to the computational complexity of performing set-membership tests on the non-convex reachable sets of differential-drive robots, we over-approximate the reachable set by enclosing it within an ellipse whose convex and simple structure allows for simpler set-membership tests. By minimizing the area of the ellipse enclosing the convex hull of the reachable set, we obtain the best ellipsoidal over-approximation of the reachable set in terms of the accuracy and effectiveness of set-membership tests (see Figure 2). Given

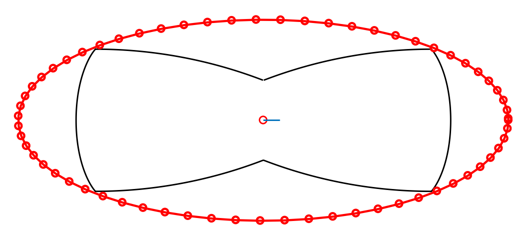

Fig. 2: For a robot, represented by a circle in the center, the reachable set of positions for a given time horizon (shown in black), and the corresponding minimum area ellipse (shown in red) are drawn.

these approximations, the safe time horizon is simply defined as the longest amount of time for which a robot lies outside the reachable sets of its neighboring robots [2].

The safe time horizon algorithm has been implemented on a team of robots operating on a multi-robot testbed. In particular, the safe time horizon algorithm successfully combats issues pertaining to intermittent communications on the Robotarium [3], and enables the seamless execution of coordination algorithms in the face of such failures.

References

[1] A Fedotov, V Patsko, and V Turova. *Reachable Sets for Simple Models of Car Motion*. INTECH Open Access Publisher, 2011.

[2] Siddharth Mayya and Magnus Egerstedt. Safe open-loop strategies for handling intermittent communications in multi-robot systems. *arXiv preprint arXiv:1702.03466*, 2017.

[3] D Pickem, L Wang, P Glotfelter, Y Diaz-Mercado, M Mote, A Ames, E Feron, and M Egerstedt. Safe, remote-access swarm robotics research on the robotarium. *arXiv preprint arXiv:1604.00640*, 2016.