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SAFE FLOCKING IN SPITE OF ACTUATOR FAULTS USING DIRECTIONAL FAILURE DETECTORS

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Abstract. The safe flocking problem requires a collection of mobile agents to (a) converge to and maintain an equi-spaced lattice formation, (b) arrive at a destination, and (c) always maintain a minimum safe separation. Safe flocking in Euclidean spaces is a well-studied and difficult coordination problem. In this paper, we study one-dimensional safe flocking in the presence of actuator faults and directional failure detectors (DFDs). Actuator faults cause affected agents to move permanently with arbitrary velocities, and DFDs detect failures only when actuation and required motion are in opposing directions. First, assuming existence of a DFD for actuator faults, we present an algorithm for safe flocking. Next, we show that certain actuator faults cannot be detected with DFDs, while detecting others requires time that grows linearly with the number of participating agents. Finally, we show that our DFD algorithm achieves the latter bound.

Keywords. failure detector, flocking, self-stabilization, switched systems.

1 Introduction

Safe flocking is a distributed coordination problem that requires a collection of mobile agents situated in a Euclidean space to satisfy three properties, namely to: (a) form and maintain an equi-spaced lattice structure called a *flock*, (b) reach a specified destination called the *goal*, and (c) always maintain a minimum *safe* separation. The origins of this problem can be traced to biological studies aimed at understanding the rules that govern flocking of animals in nature (see [1, 2], for example). More recently, recognizing that such understanding could aid the design of autonomous robotic platoons or swarms, this problem and variants have been studied in the robotics, control, and multi-agent systems literature (see, for example, [3, 4, 5, 6, 7, 8, 9, 10]). Most works on flocking assume agents communicate synchronously and that there are no failures [11, 4]. In [11, 4], flocking is studied where agents move at constant velocities and update only their orientations, while in [12, 7], agents have double-integrator dynamics. Even in these settings, to the best of our knowledge, practical safe-flocking in general Euclidean spaces is an open problem, as existing algorithms require unbounded accelerations for guaranteeing safety [7].

In this paper, we study one-dimensional safe-flocking within the realm of synchronous communication, but with a different set of dynamics and failure assumptions. First, we assume rectangular single-integrator dynamics. At the beginning of each synchronous round, the algorithm decides a target point u_i for agent i based on messages received from i's neighbors, and agent i moves with bounded speed $\dot{x}_i \in [v_{min}, v_{max}]$ in the direction of u_i for the duration of that round. That is, our flocking algorithm calculates only the direction in which an agent should move, based on the positions of adjacent agents, and then the speed with which an agent moves is chosen nondeterministically over a range, making the algorithm implementation independent with respect to lower-level motion controllers. Furthermore, the model obtained with rectangular dynamics overapproximates any behavior that can be obtained with double-integrator dynamics with bounded acceleration. Even in this setting with simpler dynamics, it is tricky to develop distributed algorithm that provide collision avoidance, as evidenced by an error that we uncovered in the algorithm proposed in [6]; see Section 4 for details of the error.

Unlike the algorithms in [6, 5, 7, 4] that provide convergence to a flock, we require termination, that is, agents should eventually stop moving. To this end, we use a form of quantization [13, 14]: we assume that there exists a constant $\beta > 0$ such that an agent i moves in a particular round if and only if the computed target u_i is more than β away from the agent's current position x_i. We believe that such quantized control is appropriate for realistic actuators, where power constraints make it is undesirable for the agents to move forever in order to achieve convergence. Quantization affects the type of flock formation that we can achieve and also makes the proof of termination more involved.

Our algorithm combines the corrected algorithm from [6] with Chandy-Lamport's distributed global snapshot algorithm [15]. The targets are computed such that the agents preserve safe separation and eventually form a weak flock, which remains invariant, and progress is

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