Chapter 3
Fault Tolerant Control of Nonholonomic Mobile Robot Formations

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ABSTRACT

In this chapter, a fault tolerant kinematic/torque control law is developed using backstepping for leader-follower based formation control in order to accommodate the dynamics of the robots and the formation in contrast with kinematic-based formation controllers. First, nominal control laws are derived for the leader and follower robots under the assumption of normal operation (no faults), and the stability of the individual robots and the formation is verified using Lyapunov methods. Subsequently, in the presence of state faults such as actuator fault, flat-tire etc., which could be incipient or abrupt in nature, an online fault detection and accommodation (FDA) scheme is derived to mitigate the effects of a fault by modifying the nominal controller. In other words, an additional term is introduced to the existing control law to minimize the effects of the fault, and this additional term is a function of the unknown fault dynamics which are recovered using the online learning capabilities of a neural network. Further, mathematical stability results are derived using Lyapunov theory, and both the FDA scheme and the formation errors are guaranteed to render asymptotic stability in the presence of faults. Numerical results are provided to verify the theoretical conjectures.

INTRODUCTION

Over the past decade, the attention has shifted from the control of a single nonholonomic mobile robot to the formation control of mobile robots because of the advantages a team of robots offers in terms of

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increased efficiency for search and rescue operations, mapping unknown or hazardous environments, perimeter security and bomb sniffing (Chen & Wang, 2005). Leader-follower formation control is a popular methodology where followers stay at a specified separation distance and bearing angle from a designated leader. In such tasks, it is essential to consider the dynamics of each robot as well as the dynamics of the formation in order to ensure that the overall group objectives are achieved (Dierks & Jagannathan, 2009a). Additionally, due to the complexities of the mobile robot system and its interactions with the formation, the risk of failure is very high and jeopardizes the performance or success of the entire formation. Hence a robust, fault tolerant mobile robot formation control is needed. The purpose of the scheme is to maintain a reliable mobile robot formation even in the presence of system uncertainty and faults. Thus, in this work, a novel control design is proposed for leader-follower formation control under normal system operation (i.e., formation control without any faults). Then, a fault tolerant formation control scheme using neural networks (NN's) is proposed for robots with incipient faults.

Formation Control of Healthy Mobile Robots

A characteristic that is common in many formation control efforts is the design of a kinematic controller to keep the formation, thus requiring a perfect velocity tracking assumption (Mariottini, Pappas, Prattichizzo, & Daniilidis, 2005; Mastellone, Stipanović, Graunke, Intlekofer, & Spong, 2008). In other words, researchers Mariottini, Pappas, Prattichizzo, and Daniilidis, (2005), Mastellone, Stipanović, Graunke, Intlekofer, and Spong, (2008), calculate the velocity control inputs to ensure that the formation control objectives are met, whereas they do not consider the torque commands required by the dynamic system to guarantee the velocity of the mobile robot approaches the calculated control velocity (Dierks & Jagannathan, 2009a). In all the kinematic control-based approaches, the stability of the formation is entirely dependent on the stringent assumptions such as the robot perfectly tracks the designed control velocity while ignoring the formation dynamics.

In practice, as observed from robot arm control (Tarn, Bejczy, Yun, & Li, 1991), the dynamics must be considered to ensure that the robots track a desired velocity so as to ensure that the formation errors go to zero while avoiding the use of large control gains which would become necessary to dominate the neglected dynamics in order to ensure an acceptable performance. Similarly, experimental studies by DeVon and Bretl (2007) have verified the need of dynamical controllers for wheeled mobile robots with high inertia, high operating speeds, significant unmodeled dynamics, or high system noise. Therefore, the works such as Li and Chen, (2005)Breivik, Subbotin and Fossen, (2006) and Do, (2008) consider the dynamics of the followers alone whereas the effects of the leader's dynamics on the followers (formation dynamics) are still ignored.

Consequently, in our previous work (Dierks & Jagannathan, 2009b; Dierks & Jagannathan, 2009b), it was shown that the dynamics of the leader become an important part of its follower robots. In addition, in a string formation of robots where a robot follows another robot directly in front of it, by considering its leader's dynamics, a robot inherently considers the dynamics of the robots in front of them. The dynamical extension by Dierks and Jagannathan, (2009a) provides a rigorous method of taking into account the specific robot and formation dynamics to convert a steering system command into control inputs via the backstepping approach. However, the theoretical results derived by Dierks and Jagannathan (2009a) and Dierks and Jagannathan (2009b) are drawn under the assumption of no faults within the robot dynamics systems.

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