Abstract

Robotics research has intensified due to its growing applications (space, surveillance, etc.), as well as reliability, flexibility, and efficiency. One of the most challenging problems has been the trajectory tracking by the robots. Some applications require a single robot, while most vital operations require tracking by formation. The most common problems encountered in trajectory tracking are obstacle avoidance, high formation errors, complex algorithms, and fault-tolerant control. Accordingly, the research addresses these problems through a connected study on trajectory tracking by formation of Multi-Agent Systems (MAS) and Unmanned Aerial Vehicles (UAVs), and on fault-tolerant control of UAVs.

The thesis begins with obstacle avoidance by formation of MAS, which can model real-time systems like UAVs/ Unmanned Ground Vehicles (UGVs). The major issue in obstacle avoidance is local minima, where the attractive force of the goal equals the repulsive force of the obstacle, potentially causing the robot to get stuck, and leading to formation failure or inter-agent collisions. To address this problem, a new Improved Artificial Potential Field (IAPF) has been proposed, which can successfully avoid local minima, thus avoiding obstacles in complex positions. Thus, the first contribution establishes safe trajectory tracking of MAS formation in obstacle-laden environments.

Next, trajectory tracking by formation of second-order nonlinear MAS has been pursued, as most UAVs/UGVs are modeled as second-order nonlinear systems. However, the existing algorithms in the formation problem have high formation errors. These errors have been substantially reduced by utilizing improved kernels in Radial Basis Function Neural Networks (RBFNNs). In this way, the second contribution improves the formation trajectory tracking performance of nonlinear MAS and forms the basis for subsequent extension to UAVs.

The trajectory tracking by the formation of UAVs is next studied. The existing algorithms have been complex in nature, hence difficult for onboard implementation. So, a mathematically simple neuroadaptive sliding mode control algorithm has been proposed for controlling UAV formation while trajectory tracking under external disturbances. Both time-invariant and time-varying formations are addressed. The RBFNNs are utilized for function approximation of external disturbances and the generation of a robust controller signal and formulation of controller gain, which can control the error convergence. Simulation studies confirm superior performance to recent work with validation in a real-time Gazebo simulator. Thus the third contribution advances the work from nonlinear MAS formation control to robust trajectory tracking control of UAV formations.

Finally, developing algorithms in fault-tolerant control (FTC) in trajectory tracking of UAVs is very complex owing to the nonlinear structure of UAVs with external disturbance, model uncertainties, and actuator failures. The existing algorithms are computationally intensive, with communication bandwidths may become exhausted. To address this, an indirect neuroadaptive fault-tolerant control scheme has been developed for quadrotor UAV trajectory tracking. In addition, event-triggered communication mechanisms are developed to reduce communication bandwidth while maintaining satisfactory tracking performance. Simulation studies show better performance than recent works with validation in a real-time Gazebo simulator. Hence, the final contribution completes the progression from safe trajectory tracking of MAS/UAVs to fault-tolerant tracking of UAVs under practical operating conditions.

Keywords: Formation control, Obstacle avoidance, UAV, RBFNN, Sliding mode control, Fault-tolerant control, Neuroadaptive control, parameter estimation, Dynamic Event-Triggered Communication Mechanism (DECM), Lyapunov stability.