*Journal of Nonlinear Systems and Applications (2011) 1–8*

*http://www.watam.org/JNSA/*

# OBSTACLE AVOIDANCE IN MULTI-VEHICLE COORDINATED MOTION VIA STABILIZATION OF TIME-VARYING SETS

Parham Ghorbanian, Sergey G. Nersesov, and Hashem Ashrafiuon *†

**Abstract.** In this paper, we review the recent results on stability and control for time-varying sets of nonlinear time-varying dynamical systems and utilize them for the problem of multi-vehicle coordinated motion in the context of obstacle avoidance where obstacles are approximated and enclosed by elliptic shapes. Specifically, we design distributed controllers for individual vehicles moving in a specified formation in the presence of such obstacles. The obstacle avoidance algorithm that we propose is based on transitional trajectories which are defined by a set of ordinary differential equations that exhibit a stable elliptical limit cycle. The control framework is implemented on the system of double integrators and is shown to globally exponentially stabilize moving formation of the agents in pursuit of a leader while ensuring obstacle avoidance.

**Keywords.** Obstacle avoidance, stabilization of sets, vector Lyapunov functions, multi-vehicle systems, coordinated motion.

## 1 Introduction

Multi-vehicle systems present a class of interconnected dynamical systems where vehicles are often coupled through the common task that they need to accomplish, but otherwise dynamically decoupled, meaning that the motion of one does not directly affect the others. The complexity of multi-vehicle cooperative manoeuvres as well as environmental conditions often necessitate the design of feedback control algorithms that use information about current position and velocity of each vehicle to steer them while maintaining a specified formation. For example, for mobile agents operating in foggy environment or located far from each other, open-loop visual control for coordinated motion becomes impractical. In this case, feedback control algorithms are required for individual vehicle steering which determine how a given vehicle maneuvers based on positions and velocities of nearby vehicles and/or on those of a formation leader.

Analysis and control design for networks of mobile agents has received considerable attention in the literature. Some of the common manoeuvres that a group of mobile agents may perform are flocking [1], cyclic pursuit [2], (virtual) leader following [3], rendezvous [4], etc. A number of recent papers propose rigorous mathematical techniques for the analysis of networks of agents [5, 6, 7]. Distributed control of robotic networks has been extensively studied in [8, 4] where the authors develop a variety of control algorithms for network consensus. A survey of recent research results in cooperative control of multi-vehicle systems was performed in [9].

It was shown in [10] that a specified formation of multiple vehicles can be characterized by a time-varying set in the state space, and hence, the problem of control design for multi-vehicle coordinated motion is equivalent to design of stabilizing controllers for time-varying sets of nonlinear dynamical systems. Authors in [10] developed stability analysis and control design framework for time-varying sets of nonlinear time-varying dynamical systems using vector Lyapunov functions. Specifically, distributed control algorithms were designed for multi-vehicle coordination and are shown to globally exponentially stabilize multi-vehicle formations.

Some obstacle avoidance strategies for multi-vehicle problems include decentralized control approaches where local control laws are defined for each agent based on local information [11, 12] and behavior-based methods presented in [13, 14]. Perhaps, the most promising approach to obstacle avoidance is the potential field method which has been extensively utilized for mobile robots with static and dynamic obstacles implemented in real time experiments [15, 16, 17, 18] and applied with robust controllers such as sliding mode control law [19].

Another more recent, rarely employed approach to obstacle avoidance is the limit cycle based method. Authors in [20] use limit cycles to generate trajectories for robot manipulators while avoiding obstacles. They define unstable limit cycles as objects of finite size and shape as a way of modeling complex obstacles to be avoided. The use of stable limit cycles as a navigation method has been introduced for obstacle avoidance of mobile robots in [21, 22]. The approach only considers circular limit cycles for mobile robots which are suitable for shapes with approximately the same length and width.

In this paper, we present an obstacle avoidance strategy that involves transitional trajectories defined as solu-

*Parham Ghorbanian, Sergey G. Nersesov, and Hashem Ashrafiuon are with Department of Mechanical Engineering, Villanova University, Villanova, PA, USA. E-mails: parham.ghorbanian@villanova.edu, sergey.nersesov@villanova.edu, and hashem.ashrafiuon@villanova.edu

†Manuscript received October 31, 2010; revised February 8, 2011.