Optimization of Shared Autonomy Vehicle Control Architectures for Swarm Operations

Aaron J. Sengstacken, Member, IEEE, Daniel A. DeLaurentis, Member, IEEE, and Mohammad R. Akbarzadeh-T, Senior Member, IEEE

Abstract—The need for greater capacity in automotive transportation (in the midst of constrained resources) and the convergence of key technologies from multiple domains may eventually produce the emergence of a "swarm" concept of operations. The swarm, which is a collection of vehicles traveling at high speeds and in close proximity, will require technology and management techniques to ensure safe, efficient, and reliable vehicle interactions. We propose a shared autonomy control approach, in which the strengths of both human drivers and machines are employed in concert for this management. Building from a fuzzy logic control implementation, optimal architectures for shared autonomy addressing differing classes of drivers (represented by the driver's response time) are developed through a genetic-algorithm-based search for preferred fuzzy rules. Additionally, a form of "phase transition" from a safe to an unsafe swarm architecture as the amount of sensor capability is varied uncovers key insights on the required technology to enable successful shared autonomy for swarm operations.

Index Terms—Fuzzy logic, genetic algorithm (GA), road vehicle control, shared autonomy.

I. INTRODUCTION

The combination of growing demand for mobility and limited capital and real estate for new roads strains the current transportation infrastructure and constrains future options. In this situation, and spurred by the convergence of key technologies in multiple domains, the emergence of a "swarm" concept of operations for automotive transportation is possible, perhaps likely. We define a swarm in this context as a collection of vehicles traveling at high speeds and in close proximity using passive and/or active cues to determine behavior. Potential technologies required for swarm transportation include peer-to-peer networking enabled by WiFi communication, precision

Fig. 1. Vehicle swarm abstraction: interacting agents with their spheres of influence.

Global Positioning System navigation, advanced sensors, and more agile drivetrains.

The suitable combination of technologies, however, will only be apparent when the appropriate architecture for managing dynamics in the swarm is determined. The benefits obtained from a realized swarm-type operation in terms of reduced fuel consumption and pollutants, as well as increased traffic throughput, are expected to be significant. Bose and Ioannou [2], for example, have found that fuel consumption and pollution levels were reduced during rapid acceleration transients by 28.5% and 1.5%–60.6%, respectively, in the presence of only 10% semiautomated vehicles.

A notional depiction of interacting vehicles in a swarm environment is shown in Fig. 1. The present-day architecture for vehicle-to-vehicle interaction emphasizes the human driver, with minimal vehicle autonomy used for detection of problems and collision-avoidance warnings. This driver-centric approach is not sufficient for a safe and efficient swarm environment, where a large number of cars are moving in close proximity and at high rates of speed. Effective techniques for managing the swarm are needed to ensure safe, efficient, and reliable interactions between vehicles. Our overarching research goal is to synthesize control approaches that leverage strengths of human and machine capabilities and that enable effective management and safe participation in a swarm architecture under a wide variety of operational scenarios.

Motivated by this application, our first objective is to develop intelligent control that generates quick decisions and reduces the rate of collisions in the context of the swarm operations. We avoid both extremes of vehicle control—fully autonomous and human driver exclusive operations—seeking instead to