COLLABORATIVE AUTONOMY MEETS THE REAL WORLD

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The physical world is being increasingly served by autonomy, including self-driving taxi cabs, autonomous mining vehicles, and robots in warehouses and hospitals. While this is certainly a significant step in technical advancement, these robots and vehicles all operate independently. The ability for robots to work together is a powerful way for them to achieve more than anyone could achieve individually. Working together would allow for achieving high-level, multifaceted goals such as autonomous construction in remote locations, including in space; achieve military mission objectives; find and mitigate forest fires before they spread; and more. What considerations do we need to make for the interoperability of autonomous systems? In this presentation, we will discuss applied research and development work in multirobot autonomous systems that enable robots to know about each other's changing capabilities during the course of a job, manage expectations and exception conditions that can be caused by both intended and unintended consequences of the real world, and provide a way for robots to anticipate other robots' actions when communications are interrupted.

INTRODUCTION

The physical world is being increasingly served by autonomy, including self-driving taxi cabs, autonomous mining vehicles, and robots in warehouses and hospitals. These vehicles operate independently, or if they operate interdependently (such as warehouse robots or drone firework displays), they are part of a specific system that is designed to work in a choreographed manner.

One thing that we are not yet seeing is the ability for autonomous robots and vehicles from multiple manufacturers to have the ability to collaborate with other autonomous vehicles out of the box. However, given the growing presence of independent autonomous vehicles, the ability for such autonomy to have the ability to collaborate in ways defined at deployment time will satisfy several objectives that are currently out of reach but would introduce significant improvements to addressing real-world challenges.

For example, consider autonomy in agriculture. Autonomous farming machines perform regular tasks, saving the farmer time that they can spend on planning their operations and addressing immediate concerns. Autonomous tractors and other machines can collect data on soil moisture and other attributes, or perform weeding tasks. Uncrewed aerial vehicles (UAVs) can spray crops in specific areas. Precision farming enabled by these technologies increases crop production and reduces consumption of pesticides, water, and fuel. However, equipment is expensive, and the most likely use case for autonomous equipment on the farm is that investments into expensive equipment will be made over time. Farmers could purchase vehicles from multiple manufacturers with different capabilities over time, tailoring what they purchase to their specific agricultural operation; in

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essence, they can build an ad hoc swarm of autonomous farming vehicles. There are currently no standards by which those vehicles will operate, and no planning capability for a farmer to design cooperative strategies for the vehicles to work together (e.g., "If the crop scanning tractor finds insect damage at a location, then prepare the UAV to deliver pesticide to this location.").

Or, consider autonomy that could assist in finding incipient forest fires, performing search and rescue, or assisting in disaster zones. In these cases, autonomy from multiple organizations, such as local, state, Federal, and nongovernmental organizations (NGOs), could bring their autonomy together, creating an ad hoc swarm of autonomous emergency response vehicles, but again there are no capabilities for such vehicles to interoperate or for experts to craft behaviors that let the autonomous vehicles build on each other.

CURRENT STATE OF THE ART

We are in the early days of autonomous multivehicle collaboration. Much of the work in this area resides in academic labs, where research into a variety of task allocation and planning techniques (e.g., centralized versus distributed task allocation, optimization approaches) is explored. These explorations are performed on well-known hardware with well-specified network connectivity in laboratory environments. Cooperative warehouse robots benefit from these optimization approaches, but warehouse robots consist of well-known vehicles working in a well-defined space. Drone firework displays are choreographed ahead of time using tools that are more similar to animation software than task planning tools and also use platforms that are known ahead of time.

FUTURE DIRECTIONS

What is absent from today's technology that we need to develop to support a future of interoperability for autonomous systems?

We are essentially seeking the development of an Internet of Things (IoT) but for autonomous, mobile systems that experience real-world challenges in a dynamically changing environment, such as a farm tractor that encounters unexpected mud on its way to a field, or a disaster response vehicle that loses communications with other vehicles.

This sounds like "IoT for swarms," and taking inspiration from existing IoT interoperability standards is a solid first step toward realizing such a capability. Today, IoT enables smart home ecosystems, industrial automation in areas such as predictive maintenance, and electrical grid efficiency and reliability. With IoT, one can establish an ecosystem of devices from multiple manufacturers (e.g., for the home, smart lights, thermostats, and security cameras) and specify how they connect and work together. These devices are often either passive data collectors, or simple actors that may open blinds or turn on lights, and the devices do not leave their home network. IoT for collections of autonomous vehicles will require more considerations. What happens if the vehicle has a problem connecting to its network? How does the collection of vehicles react when it encounters unexpected conditions in the physical world? How do we incorporate safety into autonomy? With vehicles that can move and be assigned to tasks in different locations around the world, how can the swarm's behavior optimize the physical presence (incorporating elements of time, fuel consumption, and safety) and task assignment of vehicles?

We believe that establishing the foundation for how autonomous vehicles, purchased over time and from different manufacturers to account for practical realities of cost and ownership, is an important step in defining the future of smart agriculture, search and rescue, environmental monitoring, space exploration, and military operations, and we welcome opportunities to work with industry and military leaders to continue to make dependable and trustworthy swarm autonomy a reality.

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