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Review

Automating humanitarian missions with a heterogeneous fleet of vehicles

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ABSTRACT

The use of technology for disaster response and relief in the aftermath of natural disasters is growing. To explore the opportunity afforded by emerging technologies, this work developed an experimental automated emergency response system. Given a set of requests from the field and infrastructure information, a high-level optimization method generates a mission plan for a fleet of autonomous vehicles, including ground vehicles, fixed-wing aircraft, and delivery rotorcraft. The mission plan assigns vehicles to a list of functions and locations to be visited. Internet technology integrates the various system elements and provides a unifying environment for the physical and the modeled world in cyberspace. Guidance and control enable the vehicles to autonomously execute their plans. The movements of the fleet vehicles including their dynamic behavior are illustrated in a virtual reality interface. Preliminary experiments with a small fleet of simulated vehicles show the feasibility of such an approach.

Contents

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1. Introduction

A recent report by the United Nations (IPCC Panel, 2013) found substantial evidence of climate change not only affecting humans but also humans affecting this change. While much attention has been devoted to climate change itself, few humanitarian nongovernmental organizations or international governmental organizations have made much of the unequal impact that climate change will have on society. In particular, the intensifying effects of natural disasters call for improved emergency management, which requires resources often beyond the availability of poor and developing countries (Arizona State University, 2005). The presented paper studies whether technology, with an emphasis on automated response, can serve as an equalizer of emergency management quality following a natural disaster. The response system enables serving each human help request from the field in a time-optimal manner by automatically deploying a fleet of unmanned aerial and ground vehicles to assist victims and emergency responders.

1.1. The case for emergency management

With the change in climate, decreases in regional availability of water and rising sea levels have led people to migrate to areas that oftentimes are more vulnerable to natural calamities such as floods, earthquakes, heat waves, and wildfires (Arizona State University, 2005). Disasters that occur more frequently and with more intensity affect the lives of people at a larger scale. More extensive humanitarian missions are thus increasingly called for, but these are costly and challenging. Much has been made of global warming and its potential costs and effects yet the same does not hold for emergency management. Says Sarewitz (Arizona State University, 2005): "We know how to prepare for disasters, but the world has not made this a high enough priority," "reducing emissions is important, it will not reduce vulnerability to disasters," and "if disaster preparation received the same political attention as global warming, significant progress could be made."

Technological advances hold great promise for more efficient and less costly emergency response and relief. For example, with an annual cost of fires in the United States of about $329 billion (in 2011) (Hall, 2014) the economics of improved fire disaster management are quite compelling. Moreover, technology enables a quality of emergency management in less developed and poor countries that would be otherwise unattainable.

Recent advances in autonomous vehicles, ubiquitous communication networks, and advanced optimization can be leveraged and developed to provide the foundation for improved emergency management. Some of the challenges in this field recognized formerly by Microsoft (2009) research activities, include situational and real-time location awareness, sharing data among organizations, different levels of operation (e.g., strategic, tactical, and operational levels), specific requirements for information types (reports, maps, images, videos, etc.), and unreliable network connections, to name a few. The character of emergency management determines where and how to effectively introduce technology. Not sure what this last sentence means or if it is needed. What is the "Character of emergency management"?

1.2. Technology in emergency management

Management of emergencies can be classified into four activities: (i) mitigation, (ii) preparedness, (iii) response, and (iv) recovery (Rekik, Renaud, & Berkoune, 2012). The first two activities are performed prior to the emergency. The work presented here addresses the latter two, which are performed following an emergency, with a focus on the emergency response activity. Emergency response is of critical importance in saving lives and providing medical aid. Timely response must: (i) ensure public safety, (ii) aid routing of emergency vehicle traffic, and (iii) re-establish critical lifeline routes.

In the wake of a natural disaster, assessment of damage is crucial (Oaks, 1990) and "fundamental to relief and reconstruction as it triggers the beginning of formalized disaster relief and recovery aid, beginning with governmental disaster declarations." Post-disaster assessment can be categorized as Federal Emergency Management Agency (2010): (i) rapid needs assessment (RNA) and (ii) preliminary disaster assessment (PDA). Compared to PDA, RNA is narrower in scope and spans a shorter time line. The RNA evaluation should be executed immediately upon the occurrence of a disaster to obtain an understanding of the scope and impact of the event, including casualties, injuries, and humanitarian needs (McEntire, 2005). An important goal of the RNA is to allocate and marshal resources such as aid and additional damage evaluators to the recovery mission (McEntire, 2005).

Given the time-critical nature of emergency response, automation holds much promise in improving response effectiveness. Any attempt at introducing technology into disaster response must account for the idiosyncratic nature of emergencies, which can differ substantially from the nature of similar activity in everyday life. Differences in needs include levels of availability, responsiveness, agility, transparency, and interactivity. As such, for emergency response solutions availability is more important than utilization, while fast response times are critically important, even in the face of changing infrastructure for transportation and medical care (e.g., hospitals may close down when electrical power goes out and it can be difficult to predict when emergency medical centers will be set up and ready for operation (Careem, De Silva, De Silva, Raschid, & Weerawarana, 2006)) as well as highly dynamic traffic conditions and frequent aid requests. Moreover, the human component calls for broad information dissemination and clarity about the response. Technology can help emergency responders in the field to operate more safely and effectively. It can provide control room operators quick access to precise situational information extracted from reams of streaming data so as to enable insight and rapid decision making. Quickly providing precise, detailed, and up-to-date information improves the effectiveness of emergency response (Federal Emergency Management Agency, 2010).

Recent developments in the area of *cyber-physical systems* (Steering Committee for Foundations in Innovation for Cyber-Physical Systems, 2013) (CPS) are now making an automated emergency response system a realistic vision (Mosterman, Escobar Sanabria, Bilgin, Zhang, & Zander, 2014). Fundamentally, cyber-physical systems are *open*, which provides key qualities for emergency response solutions. With the ability to engage machines in a concerted effort, cyber-physical systems provide the level of flexibility and robustness necessary in disaster scenarios. Moreover, cyber-physical systems are able to deal with