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Current and Future Applications of Unmanned Surface, Underwater and Ground Vehicles in Construction

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ABSTRACT

For more than a decade, unmanned aerial vehicles (UAVs) have been used on construction job sites for a variety of purposes including structural inspection, and 3D mapping of the site and existing structures. Although the advantages that UAVs have brought to construction are discussed extensively in the literature, applications of other types of unmanned vehicles (UVs) in the construction industry, including unmanned ground vehicles (UGVs), unmanned surface vehicles (USVs) (operating on water surfaces), and unmanned underwater vehicles (UUVs), have received limited attention.

Although UAVs are the most frequently employed type of UVs in the construction industry, UGVs and USVs have also been involved in a few construction-related missions. These include search operations and structural damage assessment in the aftermath of disasters such as the World Trade Center in 2001, Fukushima Daiichi nuclear power plant in 2011, Hurricane Wilma in 2005 and Hurricane Ike in 2008. UGVs and USVs have rarely been used in any other type of construction-related application. Furthermore, there is no available data about construction-related applications of UUVs.

Recent advances in information technology and artificial intelligence have led to the design of autonomous UAVs, UGVs, USVs and UUVs that can operate without, or with little, human intervention in their missions. Advances in UVs and their automated control have resulted in commercially available prototypes of different types of UVs. This, in turn, has created an unexplored potential for the applications of a wide variety of UVs to construction. This paper reviews this potential specifically for USVs, UUVs and UGVs. The details of each mission, including application, UVs type and details of mission are described. The paper concludes with an identification of gaps in the current technology where developments are required before the full potential of USVs, UUVs, and UGVs can be achieved in construction.

INTRODUCTION

Over the last few years, advances in Information Technology (IT), automation control and wireless communication, coupled with the advancement in power storage technology, have led to design and production of durable, resilient and powerful UVs in the commercial market (Manley, 2008). Buying a small-size Unmanned Aerial

Vehicle (UAV), Unmanned Surface Vehicle (USV), Unmanned Underwater Vehicle (UUV) or Unmanned Ground Vehicle (UGV) is just a click away from anyone in the United States and most other parts of the world. The competition between companies in the UV market resulted in significant reduction in prices. These low prices, along with the good quality sensing technologies that UVs provide, allow many construction companies to adopt UVs for a variety of purposes in the construction industry in daily activities on job sites (Ham et al. 2016; ENR 2015; Liu et al., 2014). UAVs were the first type of UVs that has been widely used on construction job sites. UAVs have been used for variety of purposes, including but not limited to, progress monitoring (Ham et al. 2015; Lin et al. 2015), site monitoring (Wen et al. 2014), building and structural inspection and health management (Pratt et al. 2008; Wefelscheid et al. 2011; Kruijff et al. 2012; Eschmann et al. 2012; Roca et al. 2013; Michael et al. 2012; Kerle et al. 2014; Morgenthal and Hallermann 2014), 3D modeling and surveying job sites (Siebert and Teizer 2014), infrastructure asset management (Metni and Hamel 2007; Rathinam et al. 2008; Zhang and Elaksher 2012; Eschmann et al. 2013; Sankarasrinivasan et al. 2015; Ellenberg et al. 2016), urban monitoring (Qin 2014), material tracking (Hubbard et al. 2015), sustainable energy production site management (Matsuoka et al. 2012) and construction safety (Gheisari and Esmaeili, 2016), with structural inspection, health monitoring, and 3D mapping and modelling of the site and existing structures being the most common applications.

Traditionally, UAVs have been the dominant type of UVs used on construction job sites. The foremost uses of UGVs, USVs and UUVs have been in disaster management including search operations and structural health assessment in the aftermath of disasters such as the World Trade Center in 2001, Fukushima Daiichi nuclear power plant in 2011, Hurricane Wilma in 2005 and Hurricane Ike in 2008 (Murphy, 2014; Murphy et al., 2011a; Steimle et al., 2009; Murphy et al., 2008a). However, in the last decade, there has been some interest in the application of UGVs, UUVs, USVs to construction. This paper reviews the state-of-the-art in the application of UGVs, USVs and UUVs in construction. It provides an overview of the predominant applications of UVs within construction. As UGVs, USVs and UUVs have not been widely used in construction, this paper reviews relevant applications in other industries, and identifies their potential for application to construction. in construction. Finally, it concludes with an identification of gaps in the current technology where developments are required to achieve this potential.

METHODOLOGY

This paper presents an overview of the current and future applications of UGVs, USVs and UUVs in construction. Some of the applications are in industries outside construction such as, mechanical engineering, computer science and marine and ocean engineering, but they have the potential to be implemented in the construction industry with minor modification. An example of such an application is structural inspection in water, which might not be undertaken by ocean scientists as a construction application, but can easily be adopted by construction practitioners and researchers.

In the first round of literature review more than 200 papers from a variety of disciplines were collected, analyzed and filtered by searching for key words such as: Unmanned Surface Vehicle, USV, Unmanned Underwater Vehicle, UUV, Unmanned

Ground Vehicle, and UGV. In the second round of the literature review, research papers from different scientific journals and conferences that discuss the use of UGVs, USVs and UUVs in any application that is either applied in the construction industry and/or can be adopted for use in the construction industry were selected. As, there are very few research papers that mainly focus on the use of UGVs, USVs and UUVs in the construction industry, around 50 research papers have been used to map the current state of use of UGVs, USVs and UUVs in different engineering fields. The future applications of UGVs, USVs and UUVs in construction is discussed considering their current applications in other fields related to construction.

UNMANNED SURFACE VEHICLES

Historically, USVs have been the most widely adopted type of UV. They have been used for a variety of applications over the last two decades including, but not limited to, bathymetric surveying (Ferreira et al., 2009; Roberts and Sutton, 2006), environmental monitoring, sampling and assessment (Rasal, 2013; Dunbabin and Grinham, 2010; Caccia et al., 2005), mobile communication relays (Caccia et al., 2008), ocean biological phenomena, and migration and changes in major ecosystems (Goudey et al., 1998), oil, gas and mine explorations (Pastore and Djapic, 2010; Roberts and Sutton, 2006), disaster management (Murphy et al., 2008a) and security and monitoring (Howard et al., 2011). Liu et al. (2016) classified different applications of USVs into the following categories: (1) scientific research, (2) environmental missions, (3) ocean resources exploration, (4) military uses, and (5) other general applications. The advancement of USV research is mainly due to its naval military applications, that led to the development of different prototypes of USVs for different uses. Notably, research on construction applications of USVs is limited to marine and ocean science literature.

Construction-related applications of USVs have been limited to disaster management (Murphy, 2014; Murphy et al., 2008a) and structural health monitoring of marine structures (Han et al., 2015; von Ellenrieder, 2015; Murphy et al., 2011a; Steimle et al., 2009; Murphy et al., 2008a). As noted by von Ellenrieder (2015) and DeVault (2000), in the US only, around 575,000 highway bridges exist, and almost 85% of them span waterways. All highway bridges and infrastructures need to be inspected regularly in order to maintain a safe and reasonable quality of service. This notion highlights the need for the industry to invest in exploring the potential applications of USVs for bridges. UAVs applications in robot-assisted bridge inspection system have been investigated by researchers (Izadi Moud and Gheisari, 2016; Metni and Hamel, 2007) for over a decade but USVs application in bridge health monitoring has not been explored extensively. Bridges are not the only type of structure that USVs can help to monitor. USVs can provide flexibility in access to any other form of marine structure. In the aftermath of hurricane Wilma and Ike, in 2005 and 2008, respectively, USVs were used to help the emergency response teams to inspect different types of marine structures (Murphy, 2014; Murphy et al., 2011a; Steimle et al., 2009; Murphy et al., 2008a). Although these works were not undertaken by construction researchers, it lies in the topic of infrastructure management and structural health monitoring, which are parts of the broader topic of construction engineering and management.

UNMANNED UNDERWATER VEHICLES

UUV refers to an unmanned vehicle that has the capability of exploring underwater. In different cases, a USV is used as a part of a UUV prototype for holding the underwater camera and other sensors. While UUVs are considered a new type of UV in domains like civil engineering, and construction engineering and management, they are one of the most developed technologies due to their advanced military uses, subsurface exploration activities, undersea operations, and oil and gas industry related activities (Gogarty and Robinson, 2011).

UUVs have been developed for a variety of military and civil needs. For a long time, UUVs provided scientists with unprecedented abilities to map undersea, detect wrecks, and rescue submarines (Gogarty and Robinson, 2011). They have also been used for disaster management (Murphy et al., 2011a; Murphy et al., 2011b). In the aftermath of Hurricane Ike, UUVs were used for bridge inspection (Murphy et al., 2011a). In the aftermath of Tohoku Earthquake and Tsunami, UVVs were used in general disaster recovery applications including infrastructure inspection and victim search and retrieval (Murphy et al., 2011b). Other non-military, civilian, uses of UUVs are depth control (Aras et al., 2013), and general robotic research (Caccia et al., 2000). The most publicized use of UUVs occurred in 2010, when a robotic agent was used in the Gulf of Mexico oil spill incident as an emergency response vehicle. Due to the magnitude of this environmental disaster that impacted millions of Americans, the whole mission, including the use of underwater robots caught the limelight for days and was broadcast internationally. It was only due to this media coverage that the vast majority of the public and many researchers became aware of the level of advancement of UUVs and other types of unmanned underwater robots (Zhang et al., 2011).

Construction related applications of UUVs are broader compared to USVs. As mentioned earlier, UUVs have been used for underwater structural inspection including bridges, oil and gas industry structures, and underwater mapping. Many applications of UUVs in disaster management, such as structural health monitoring and inspection, have overlapped with their applications in construction and civil engineering. All of the aforementioned applications of UUVs are not directly performed by construction practitioners and/or researchers but by multi-disciplinary teams or researchers in other fields. However, some of these applications could be easily adopted and integrated into construction processes.

UNMANNED GROUND VEHICLES

UGVs are the most well-known type of UV to the public. UGVs, like its counterparts in the UV family, have been widely used for applications in disaster responses. Murphy (2014) provided a comprehensive list of uses of UGVs in disaster management responses around the world. The commonly publicized use of UGVs was in the aftermath of the World Trade Center in 2001. However, they were commonly used in the aftermath of other disasters like Hurricane Katrina in 2005 and La Conchita, California mudslides in 2005 (Murphy et al., 2008b). On the non-civil side of UGVs applications, they have been used to maneuver on sites that pose immediate risks to humans (Gogarty and Robinson, 2011). Construction related applications of UGVs has been very limited. In a study by Torok et al. (2013), an integrated robotic system of a UAV and a UGV was used for automated crack detection of post-disastrous structures.

UGVs are also used for inspecting coal mines (Subhan and Bhide, 2014). A novel advanced use of UGVs could be transportation and operation of utility logistics equipment (Gogarty and Robinson, 2011). As with USVs and UUVs, UGVs have also been used for structural inspection. UGVs have been used for inspecting bridges (Gucunski et al., 2014; Kurz et al., 2011; Murphy et al., 2011a), tunnels (Yu et al., 2007), and buildings (Michael et al., 2012). Although UGVs have been used in a variety of civilian missions including some that are construction-related, the main area of application of UGVs has been rescue and recovery in the field of disaster management.

DISCUSSION AND CONCLUSION

This paper has briefly reviewed current applications of USVs, UUVs and UGVs across all industries, and elaborates on the current construction-related applications of these devices. By reviewing the non-construction related applications of USVs, UUVs and UGVs, the paper has identified the potential areas for UVs future application in the construction industry. It is worth noting that very few of the reviewed papers were conducted by construction industry practitioners or researchers. However, this does not preclude these applications from being used in the construction industry. The authors consider any application, from any industry that has the potential to be included within the broader domain of construction engineering and management to be a construction-related application.

USVs are the most commonly used type of UVs. They have been used for a range of applications such as mapping the sea, rescue operations, and security. The most common construction related use of USVs is marine structural health inspection. Bathymetric application, undersea mapping, and underwater search are some of the common applications of UUVs. UUVs have also been used in the oil and gas industry for robotic underwater tasks and also for underwater structural health monitoring. Different types of USVs and UUVs prototypes are available for non-military uses. On the other hand, UGVs are not well developed. Their non-military applications are limited to some structural health inspection tasks in small-scale research missions, and more advanced search and rescue missions in post disaster response.

The pattern in use of USVs, UUVs and UGVs shows that the unmanned nature of operation of these devices makes them favorable for disaster management applications and tasks that pose a danger to human operators. Current construction-related applications of USVs, UUVs and UGVs are mainly restricted to structural health monitoring. Use of UVs in disaster management applications and structural health monitoring show the advantages that UVs provide for accessing “difficult to access” places. One of the main conclusions of this paper is to recognize this pattern of use in UV applications. This paper recommends that future UV research focus on developing applications for UVs in “difficult to access” areas, such as mines, tunnels and underground construction.

One issue that appears to be lacking in UVs research is the use of artificial intelligence in UV operation. Development in this area could happen by developing more advanced, and larger size USVs, UUVs and UGVs that can perform more tasks autonomously, with little, or none, human intervention. Autonomy is the future of all UVs. Artificial intelligence provides the ability to develop UVs that can operate autonomously in unstructured and uncertain environments. While research on USVs and UUVs are mature and many medium and large-scale prototypes of USVs and UUVs have been developed, research on UGVs lags far behind and not many non-military applications have been attempted. UGVs are the category of UVs that have the greatest potential to be widely used in the construction industry. In future, UGVs can potentially be used in construction for tasks such as cut and fill the tranches with large-size autonomous and driverless construction machineries. While driverless cars are going to happen in near future, construction industry should focus on the future of driverless heavy construction machineries, as large-scale UGVs, that can perform all tasks autonomously.

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