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Evaluation of wearable immersive augmented reality technology in safety-critical systems

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ABSTRACT

New technologies in safety-critical systems offer the promise of next generation system features and capabilities; predictive analytics; enhanced and remote monitoring; and perhaps improved operator performance. At the same time, however, questions arise about the impact of such technologies on system safety, operator performance, and decision processes, in settings where safe and effective performance are of paramount importance. Wearable, immersive augmented reality (WIAR) technology is one such technology whose introduction sparks these questions. Despite the proliferation of WIAR technology in safety-critical settings, few studies have examined its impacts on operator performance, decision processes and situation awareness in these settings. As a result, this paper considers research needs for evaluating WIAR technology in safety-critical systems. To illustrate the research needed, we consider the use case of a WIAR technology in marine navigation, and propose a research framework, summarizing research needs and identifying needed next steps.

1. Introduction

New technologies in safety-critical systems promise improved safety and enhanced operator performance, fewer lives lost and often, mitigated environmental effects. In systems from aviation and space to medicine, battle management, healthcare and transportation, the number of new technology systems and devices being introduced, and the data associated with them, are growing, as are needs for assessments of the impact and contributions of such systems (National Institute of Standards and Technology, 2013). Such assessments are critical, as technologies in these systems have the potential to positively or negatively impact populations, communities, infrastructure, economies, financial markets, and the environment, as well as the safety and security of nations and individuals (U.S. Office of Science and Technology Policy, 2012).

Evaluation of new technologies in safety-critical systems is both important and challenging, as new technologies offer the promise of novel system features and capabilities (Aloini et al., 2016); advance warning of impending harm, risk or diminished safety (Schratter et al., 2017); enhanced remote monitoring, visibility and visualization in hazardous settings (Arcadius et al., 2017); and perhaps improved operator performance (Ehrlich et al., 2016). Evaluating the contributions of new technologies to safety and performance in safety-critical settings thus requires understanding the technologies, and consideration of the relationships between operators and technologies, which occasion a host of important research questions about the impact of new technologies on system safety, individual and system performance, and operator decision-making, in settings where safe and effective performance is of paramount importance.

Wearable, immersive augmented reality (WIAR) technology is an example of new technology being introduced in safety-critical systems from aviation (Dansereau et al., 2015), to military applications (Aaltonen and Laarni, 2017), emergency response and disaster management (Irizarry et al., 2013), marine transportation (Oh et al., 2016), oil and gas operations (Grubert et al., 2017), and medical settings (Muensterer et al., 2014; Chang et al., 2016). WIAR technology provides users with an immersive experience through portable displays that portray information as layers atop views of the physical environment (Monaco, 2013; Willett et al., 2017). The ability of WIAR technology users and operators to 'look out the window' in an operational scenario, unfettered by wired attachments or the need for physical presence in front of or near a display, and aided by information that can be perceived and processed in context, is presumed to improve performance and situation awareness (Hull et al., 1997; Kruijff et al.,

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2010). However, WIAR displays are often reduced in size or miniaturized, leading to questions about the effectiveness of such displays, and about the minimal representations they present (Kim and Sundar, 2016). The impact of these mobile, situated (Willett et al., 2017), context-aware displays (Hong et al., 2009) on operators in safety-critical systems is still an open research question (Viera et al., 2011; McKendrick et al., 2016; Stewart and Billinghurst, 2016).

This paper is motivated by the proliferation of WIAR technology in safety-critical settings, and by needs for research evaluating the impact of this technology in safety-critical systems. Few studies have examined the impact of WIAR technology on operator performance, decision processes and situation awareness. As the use of WIAR technology grows, questions about how wearable, mobile, tetherless augmented reality technology influences decision making, decision processes and situation awareness, including trust in and use of technology, are all salient (Shuhaiber, 2004; Sielhorst et al., 2008; Van Krevelen and Poelman, 2010). Although these are persistent questions that attend new technology introduction, we focus in this paper on questions associated with WIAR technology introduction, and propose a research framework for evaluating WIAR technology in safety-critical systems. We consider research and data needs associated with the framework, motivated by a use case of WIAR technology for ship navigation. We summarize the research needed and identify next steps in the final section.

2. Wearable immersive augmented reality technology

Wearable Immersive Augmented Reality (WIAR) technology utilizes augmented reality to provide degrees of immersion to operators through portable visual systems using sensor input. Augmented reality (AR) systems provide users additional information about the physical world in order to amplify human understanding, performance, information processing and/or decision-making (Sielhorst et al., 2008). Many AR systems employ computer displays for presentation, which by and large lack in immersiveness. Head mounted displays (HMDs), which provide improved immersive experiences, present a small display device in front of each eye, which shows virtual objects superimposed on the user's view of the real world. Head Up Displays (HUDs), adapted from military aviation, are similar, as they present augmented information directly on the user's field of view, or windshield. AR systems may also employ spatial displays, which project AR information onto an object in space, such as a wall, screen or bulkhead, integrating context and environmental information, a capability that is useful for multiple user collaboration and experience.

WIAR systems are by definition wearable, meaning that the immersive AR technology is portable and able to be worn on the body, providing freedom of movement; tetherless information access; and levels of interaction more difficult with fixed display technologies. Because WIAR technology is portable and wearable, usually on the head, users receive augmented reality information in context, within the physical environment within which decision-making must occur. WIAR systems therefore integrate immersive augmented reality systems with wearable technology in order to provide users an experience in a virtual world (Von Lukas, 2006).

Early WIAR technology systems were cumbersome and difficult to wear, and problems with usability, wearability and battery life were reported (Behringer et al., 2000). Current WIAR technologies are lighter, less obtrusive and are being evaluated within behavioural simulators and in medical and other safety-critical settings (Baus and Bouchard, 2014; Garcia et al., 2014; Stevens and Eifert, 2014; von Lukas et al., 2013; Scudellari, 2016).

In 2013, Google introduced a wearable, immersive technology called Google Glass (Glass) that mounts a memory chip, a battery, a speaker, two microphones, a video camera, a Wi-Fi antenna, Bluetooth capability, an accelerometer, a gyroscope, and a compass on a pair of glasses (Ackerman, 2012; Fig. 1). Glass understands voice commands,

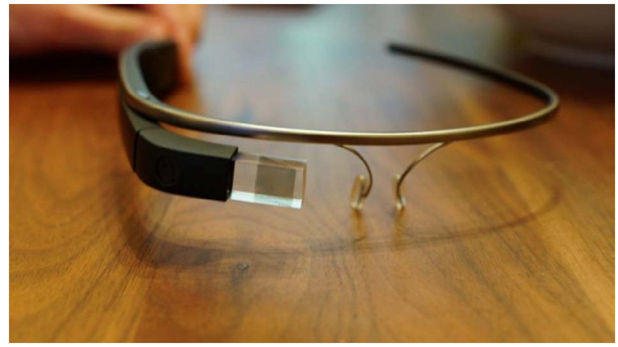

Fig. 1. Google Glass.

and can respond to finger taps and swipes on an earpiece, which acts as a touch pad; it displays results on a small screen that is located above the right eye of the user. Glass is able to record sound and take pictures, which are stored in the cloud. It connects to the Internet through Wi-Fi or Bluetooth and a smartphone and runs the Android operating system (Sterling, 2013). The Glass camera can take five megapixel images or shoot 720-pixel video; it has 16 GB of storage with 12 GB available to the wearer. In addition to having web content displayed on the Glass display, users can also take pictures and video, make phone calls, send texts, and send/receive directions through Glass (Google, 2014). Although Google Glass was discontinued as a commercial product in 2015, developer and research projects, such as the use case described in this paper, continued.

Other immersive, wearable technologies have been introduced, including those developed by Samsung, Epson, Sony, Circlet and Apple (Pachal, 2014; PocketNow, 2014; Ulanoff, 2014; Johnson, 2015), pressure for which was reportedly increased after Facebook's purchase of Oculus Rift, a virtual reality technology, in March 2014 (Meola, 2016). WIAR technology continues to unfold, with more developers and manufacturers entering the market. In 2017, Google announced Glass 2.0, an enterprise edition of the wearable technology for logistics, manufacturing, field support and supply chain applications (Levy, 2017). Although the form factor has not changed significantly, the battery life is reportedly greater and a recording notification light has been added to signify when video is being captured by the device. Thus, WIAR technology continues to evolve, at the same time that the market for and interest in wearable, immersive technology are increasing and are expected to accelerate in the coming decade (Marks et al., 2014; Meeker, 2017; Figueroa, 2016; Meola, 2016).

3. Evaluating WIAR technology

WIAR technology is often envisioned or deployed in a decision support role, providing information, analysis and/or recommendations to operators in safety-critical systems (McTear et al., 2016; Aaltonen and Laarni, 2017). Evaluations of WIAR technology, designed to examine the contributions of the technology to operator performance, safety and decision processes in safety-critical systems, must consider the particular characteristics of WIAR technology that could encourage or inhibit its effectiveness, use, acceptance or performance: its mobility, context-aware capabilities, freedom of movement and tetherless-ness, and its presentation of augmented reality information. Understanding the decision support needs of operators using WIAR technology thus calls for examination of operator performance with minimal displays, tetherless technology, and in perceiving and processing information layers in context, the particular characteristics of WIAR technology that are hypothesized to impact operator performance, decision processes and situation awareness. In the following sections, we explore earlier work examining facets of new and WIAR technology introduction, en route to a description of a research framework for WIAR technology evaluation in safety-critical systems.