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Perception of safe robot idle time in virtual reality and real industrial environments

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ABSTRACT

The main objective of this study was to investigate human perception of safe idle time of an industrial robot in a virtual reality environment. Studying operators' perception of robot operational characteristics such as safe robot idle time can help develop hazard prevention strategies, and ultimately improve robot safety. Results of data collected from 32 participants showed that robot size and speed had significant effects on the perception of safe robot idle time. This study also examined operators' perceived acceptability level for the robot speed, perceived level of hazard of robot motion, perceived chance of error, and self-reported mental workload. Results of this study were compared to the findings of Rahimi, M., Karwowski, W. [1990. Human perception of robot safe speed and idle time. Behaviour & Information Technology 9(5), 381–389], in which their experiment was conducted in a real industrial environment. This study demonstrated the feasibility of testing human perception of dynamic moving objects in a virtual reality environment. The virtual reality technology is believed to be capable of modeling a complex machinery system such as a robotic system.

Relevance to industry: Human perception of the operational characteristics of industrial robots is an important concern for robot safety since misperception can cause robot operators to err, which in turn can cause injuries and fatalities. Through this study we (1) understand human perception, safety behavior, and decision making in a robotic system and (2) demonstrate the capability of modeling a complex machinery system using virtual reality technology. Our experiments designed to study human perception of safe robot idle time could lead to safety interventions and guidelines or hazard prevention strategy development.

1. Introduction

Accident hazards of industrial robots can arise because robot operators cannot always predict subsequent movements of a robot after programmed stops (e.g., Nicolaisen, 1985). Industrial robots can operate with movements of great variety; they may simply stop and accelerate again with great force and unpredictable movement patterns a moment later. This situation poses considerable danger to the operators because they may be unable to perceive the robot operational characteristics such as the movement characteristics. More specifically, the operators may have difficulty understanding and deciding why a robot stops, whether the cause of the stop is a malfunction, or whether and when the robot is safe to approach (Karwowski and Rahimi, 1991; Sugimoto and Kawaguchi, 1983).

Human perception/misperception of the operational characteristics of robots can cause robot operators to err. This is a significant concern for robot safety because human error is one of the major causes of robot-related injuries and fatalities (Hirschfeld et al., 1993; Nagamachi, 1988; Sanderson et al., 1986; Spettell and Liebert, 1986; Sugimoto and Kawaguchi, 1983). Moreover, the operators' decision-response processes and safety behavior depend on their perception of the robotic system. Robot-related accidents often occurred when operators entered and worked in the operating area (or robot work envelope) of a stationary robot, and were hit by the robot arm when it moved unexpectedly (Beauchamp and Stobbe, 1995; Carlsson, 1984; Karwowski et al., 1991). The operators improperly entered the area because they misperceived the robot's halt, which indeed was a programmed idle, as a malfunction stop (Rahimi and Karwowski, 1990; Sugimoto and Kawaguchi, 1983). When a robot stopped suddenly, in many situations the operators were unable to perceive/understand whether the robot's halt was a programmed stop and failed to wait the appropriate length of

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time before entering the work envelope. Therefore, testing individuals' perception of those dynamic moving objects is important.

Previous studies showed that the characteristics of the robotic systems, such as robot speed and robot size, influenced individuals' safety behavior (Karwowski and Rahimi, 1991; Karwowski et al., 1991; Rahimi and Karwowski, 1990). The experiment of this study was based on Rahimi and Karwowski (1990), in which the perception of safe robot idle time was examined in a laboratory environment. The main objective of this study was to assess the effects of robot speed, robot size, exposure to a simulated accident, and gender on operator perception of a safe robot idle time in a virtual reality industrial environment. In addition, this study tested their effects on perceived acceptability level for the robot speed, perceived level of hazard of robot motion, perceived chance of error, and self-reported mental workload. Virtual reality provides flexibility to simulate various complex industrial workplaces and hazardous scenarios for testing human perception and human–machine interaction (Duffy, 2007; Duffy et al., 2003). It is believed that experiments designed to understand human perception of the performance of dynamic objects, such as robots' operational characteristics in virtual reality industrial environments, could lead to safety interventions and guidelines (Duffy et al., 2003, 2006).

2. Literature review and background

2.1. Brief overview of the experiment conducted in the real industrial environment

Rahimi and Karwowski (1990) assessed human perception of safe robot idle time of a robot in a real workplace; whereas, this study examined the perception in a virtual reality environment. Perceived safe robot idle time was the minimum length of time operators would wait to consider that the stop of the robotic system was due to a malfunction rather than a programmed idle, and believed that the robot was safe to approach. In Rahimi and Karwowski (1990), the effects of four factors on perceived safe robot idle time were tested: (1) learning effect, (2) robot speed, (3) simulated accident exposure, and (4) gender. Twenty-four university students (20 males and 4 females) participated. To examine human perception of safe robot idle time, their experiment used the General Electric MH33 material handling robot. Their results showed that robot speed, simulated accident exposure, and gender had significant effects on the perception of safe robot idle time.

2.2. Laboratory layout

After visiting the laboratory of the University of Louisville where Rahimi and Karwowski's experiment was conducted, this research developed a virtual reality industrial environment that was intended to replicate the layout of their laboratory. A more detailed schematic diagram illustrating the layout and the placement of the MH33 robot can be seen in Karwowski et al. (1987). In this study, we used the Virtual Reality Modeling Language and JavaScript to develop the virtual reality environment. Fig. 1 shows a screen snapshot of the virtual reality environment.

2.3. A comparison of the real and the virtual reality experiments

In this study, efforts were made to replicate the settings and experimental procedures in Rahimi and Karwowski (1990). The experimental design in our study was similar to that in Rahimi and Karwowski (1990); however, there were some differences. Table 1 illustrates the similarities and differences of the experimental design.

3. Methods

3.1. Variables, data analysis, and participants

Perceived safe robot idle time was the main dependent variable. Perceived safe robot idle time data were analyzed using a four-factor mixed design analysis of variance procedure (ANOVA) with two between-subject factors (simulated accident exposure and gender) and two within-subject factors (robot speed and size). Simulated accident exposure had two levels: (1) the exposure group in which the participants were exposed to the simulated accident and (2) the non-exposure group in which the participants were not shown the simulated accident. Robot size had two levels: the original size and the enlarged size, which was 50% of the original. Robot speed also had two levels: 10% and 90% of the maximum speed of the robot (the robot possessed a rotational speed around the base at a maximum of 100 cm/s). All experimental conditions were randomized for each participant. Four additional outcome variables were also measured: (1) participants' perceived acceptability level for the robot speed, (2) perceived level of hazard of the robot motion, (3) perceived chance of an operator error, and (4) self-reported mental workload. More detailed information about those four measures can be found in Duffy et al.

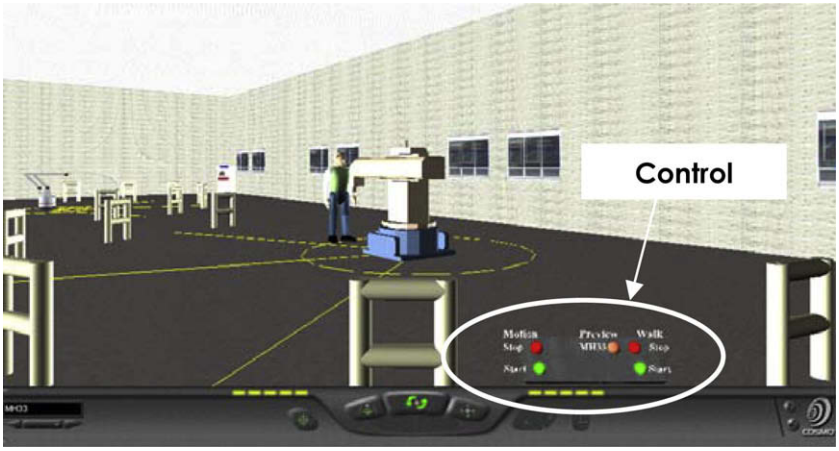

Fig. 1. The virtual reality industrial environment tested in this study.