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Analyzing Construction Workers' Recognition of Hazards by Estimating Visual Focus of Attention

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Abstract: High injury and fatality rates remain a serious problem in the construction industry. Many construction injuries and fatalities can be prevented if workers can recognize potential hazards and take actions in time. Many efforts have been devoted in improving workers' ability of hazard recognition through various safety training and education methods. However, a reliable approach for evaluating this ability is missing. Previous studies in the field of human behavior and phycology indicate that the visual focus of attention (VFOA) is a good indicator of worker's actual focus. Towards this direction, this study introduces an automated approach for estimating the VFOA of equipment operators using a head orientation-based VFOA estimation method. The proposed method is validated in a virtual reality scenario using an immersive head mounted display. Results show that the proposed method can effectively estimate the VFOA of test subjects in different test scenarios. The findings in this study broaden the knowledge of detecting the visual focus and distraction of construction workers, and envision the future work in improving work's ability of hazard recognition.

Keywords: Hazard recognition, visual focus of attention, head orientation, virtual reality

I. INTRODUCTION

Construction sites are never hazard-free due to the nature of always being congested and ever-changing. For years, researchers and practitioners have been dedicated to mitigate hazards on construction site by eliminating the presence of hazard from the perspective of designing and planning. The concept of designing for construction worker safety was introduced to the construction industry since 1985 [1]. This concept is so far viewed as a viable intervention to improve worker safety [2]. However, in the construction phase, hazards involve workers and emergent incidents can hardly be prevented and addressed through design and planning. In such cases, the mitigation of the hazards heavily relies on the worker's ability of timely perceiving hazards, correctly recognizing hazards, and safely mitigating hazards. However, Albert et al. (2014) reported that "safety research has not adequately focused on developing specialized strategies to develop construction worker competency in hazard recognition" [3]. As a result, worker's ability to identify hazards heavily depends on the experience and personality of individual workers.

Recently, the introduction of virtual reality technology to the construction industry brought an alternative for educating and training workers' ability of hazard recognition. Lin et al. (2011) developed a 3D video game that provides a virtual safety training environment where students walk through the site to identify potential hazards as a safety inspector [4]. The results from student tests indicate that such system could increase users' learning interests, motivate them to refresh their safety knowledge, and eventually enhance the learning effectiveness. To quantitatively measure the worker's ability of identifying hazards, Li et al. (2012) proposed a safety assessment method using virtual environment [5]. Individual construction workers were presented with virtual risky scenarios and asked to select from a range of possible actions. The system aims to quantify and advance workers knowledge and skill through an iterative process of retraining and testing until a satisfactory level is achieved.

Compared to normal workers, equipment operators' ability of hazard recognition is even more important to the safe execution of construction activities. In a study of 75 crane accidents from 2004 to 2010, King (2011) found 32 of them (43%) were due to the operator failure in their responsibilities [6]. Shapira and Lyachin (2009) with 19 construction equipment and safety experts, operator proficiency has the biggest influence to crane safety [7]. Visser et al. (2012) pointed out that operator distraction is a significant danger to the safe operation of cranes, leading to serious crash-related injuries, work progress delays, and other plant, equipment, and personnel damages on site [8].

Previous studies in the field of human behavior and psychology indicate that the visual focus of attention is a good indicator of worker's actual focus. This paper introduces an automated approach for estimating the VFOA of equipment operators using a head orientation-based VFOA estimation algorithm. Section 2 introduces existing efforts and techniques related to VFOA estimation. Section 3 introduces the VFOA estimation method developed in this study and section 4 shows the validation and test results of the proposed method. Section 5 concludes the findings in this study and envisions the future work.

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II. RELATED WORK

Previous studies in the field of human behavior and psychology indicate that the visual focus of attention (VFOA) is a good indicator of a person's actual focus. The VFOA of a person is defined by his eye gaze, that is, the direction in which the eyes are pointing in the space [9]. Gazing at a target is usually accomplished by rotating both the eyes and the head in the same direction (eye-in-head rotation). The techniques of detecting head and eye direction have been studied and developed for various applications including meeting analysis, advertising, driver assistance, and construction safety. Stiefelhagen (2002) developed a system for tracking the visual focus of attention of meeting participants [9]. This system adopted a panoramic camera and the neural networks to estimate the participants' head orientation from pre-processed face images. The test results showed the visual focus of attention can be correctly identified in 73% of the time in a number of evaluation meetings with for participants. This study also pointed out that the VFOA can be correctly estimated with only head orientation data in 88.7% of the time. Visual focus of attention is also critical for recognizing driver's state and preventing distraction. Liu et al. (2008) proposed a vision-based approach for estimating driver's head pose [10]. The head pose is estimated by accumulating the head rotations between two adjacent frames. To prevent construction accidents related to equipment blind spot, Soumitry and Teizer (2012) introduced an automated approach for estimating the coarse head orientation of equipment operators using a range camera [11]. The estimated head orientation is used to generate a dynamic blind spot map for a mobile crane and a skid steer loader.

Although in many applications head orientation is sufficient for detecting the VFOA, some scientific research fields require much more accurate VFOA estimation. As head is only partially orientated towards the gaze in most cases, it is necessary to detect both the head and eye orientations for accurate VFOA estimation. In the field of neurophysiology and cognitive science, sensing head and eye orientation is usually considered an effective method for determining the VFOA [12] [13]. Other domains in scientific research such as neuroscience, experimental psychology or human factor science can also benefit from eye-tracking methodology to investigate visual processes. However, the major disadvantages of eye-tracking techniques lie in their high cost and usually invasive setup in front of the subject's head.

III. METHODOLOGY

Given the fact that in most cases head orientation is an effective indicator of a person's VFOA, this study introduces an automated approach for estimating the VFOA of construction equipment operators. Inertial Measurement Unit (IMU) is an electronic device that measures velocity, orientation, and gravitational forces by integrating the data from different sensors including accelerometers, gyroscopes, and magnetometers. In this particular study, the IMU sensor is used to measure the absolute head orientation and the head rotation velocity of the subjects. To simplify the VFOA estimation, we assume the subject's body remains still and subject's head only conducts rotations on two axes, namely pitch (nose up and down) and yaw (nose left and right) motions. Figure 1 illustrates the schematic view of head orientation (θh), eye orientation (θe), and gaze orientation (θe) of a subject in yaw motion. The schematic view of head, eye, and gaze orientations in pitch motion is similar.

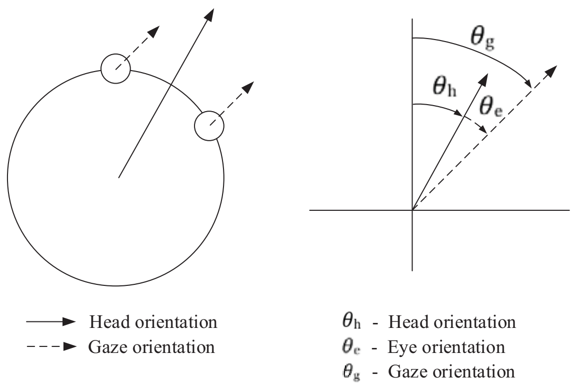

Figure 1: Schematic view of head orientation, eye orientation, and gaze direction of a subject

As illustrated in Figure 1, gaze orientation θg consists of Head orientation (θh) and Eye orientation (θe). The head orientation (θh) is obtained from an IMU sensor measurement directly. Gazing at a target is usually accomplished by rotating both the eyes and the head in the same direction; and the magnitude of eye rotation to some extent is associated with the velocity of head rotation. For instance, the further you want to look from the center of your field of view (FOV), the faster you will turn your head to assist this motion. As such, the eye orientation (θe) is derived from the velocity of head rotation (θh') and multiplied by a coefficient μ. Therefore, the estimated gaze orientation (θg) which is considered the actual VFOA can be obtained by the equation as follows:

$$\theta g = \theta h + \mu * \theta h'$$

The velocity and magnitude of head rotation is different when a person change the point of view in different directions (e.g., you need to quickly raise the head when look up but barely need to lower the head when look down). Hence, μ is determined by the direction of the head rotation.

IV. TEST AND VALIDATION

The validation of the proposed VFOA estimation algorithm consists of four steps: 1) present a virtual test scenario with VFOA targets to the test subject, 2) ask the subject to change the point of focus from the center to each target and measure the subject's head orientation, 3) apply the VFOA estimation algorithm and estimate the VFOA in real-time, and 4) compare the estimated VFOA and the actual VFOA. In this validation test, a state-of-the-art head-mounted display is adopted with the capability of immersively presenting the virtual content to the subject and in the meantime continuously tracking the head orientation using an embedded IMU sensor. Unity game engine is used to build the virtual test scenario and estimate the VFOA based on the head orientation and rotation velocity measured by the Oculus Rift. Figure 2 shows VFOA target placement in virtual test scenario. The subject's point of focus starts from the target in the center of the screen. The eight targets placed along the inner circle are 30 degree deviated from the center target and the eight targets placed along the outer circle are 60 degree deviated from the center target.

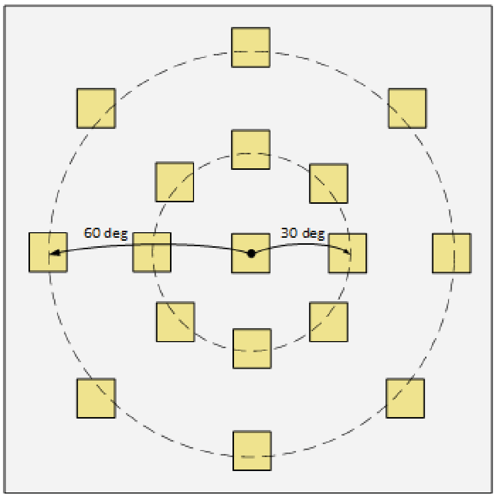

Figure 2: VFOA target placement in virtual test scenario

During the test, the subject is required to first look at the center target and then change the point of focus to the targets along the inner circle and outer circle. The program built by Unity game engine automatically detects if the estimated VFOA locates in any target and which particular target it locates at. Figure 3 shows the subject test and Figure 4 shows the virtual test scenario presented by Oculus Rift. The blue dot indicates head direction and the red dot indicates the estimated gaze direction, namely the estimated VFOA.


Figure 3: Subject test with Oculus Rift

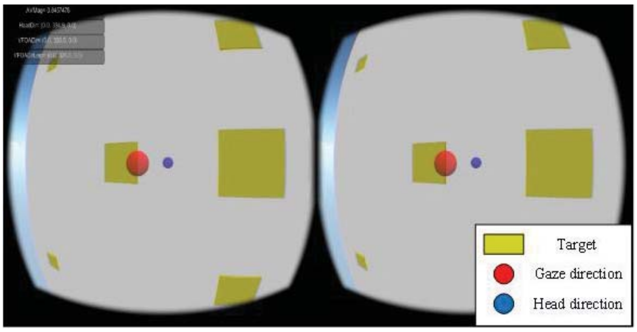

Figure 4: Virtual test scenario in Unity game engine

The estimated VFOA detected by the program is compared with the ground truth of actual sequence of targets the subject looks at. Table 1 presents the results of accuracy performance of the proposed VFOA estimation algorithm. During the test, the subject looked at in total 232 targets (center target excluded), in which 130 targets are along the inner circle (target angle = 30 degree), and 102 targets are along the outer circle (target angle = 60 degree). True positive (TP) cases are defined as that the subject actually looked at a particular target and the program also detects he looked at the same target. False negative (FN) cases are defined as that the subject looked at a particular target but the program detects he did not look at that target. The test results show that the proposed VFOA algorithm can achieve an average precision rate of 82.3%. Specifically, for the 130 targets placed 30 degree deviated from the center target, 89.3% are successfully detected by the algorithm. For the 102 targets placed 60 degree deviated from the center target, 73.6% are successfully detected by the algorithm. The results indicate that the proposed VFOA estimation algorithm can effectively estimate the VFOA of human subjects in the virtual test scenario and the estimation precision will decrease as the deviation angle of the targets increase.

Table 1: Results of accuracy performance of the proposed VFOA estimation algorithm

	True positive (TP)	False negative (FN)	Precision (TP/TP+FN)
Targets at 30 deg	116	14	89.3%
Targets at 60 deg	75	27	73.6%
All targets	191	41	82.3%

V. CONCLUSIONS

Hazard recognition is an essential skill for construction workers to ensure the safety of themselves and others. However, weaknesses in education, training, and evaluation of worker's ability of hazard recognition is identified. One of the main obstacle is the lack of an accurate and reliable approach for tracking the worker's focus of attention. Previous studies in the field of human behavior and psychology indicate that the visual focus of attention (VFOA) is a good indicator of worker's actual focus. Towards this direction, this study introduces an automated approach for estimating VFOA of equipment operators using a head orientation-based VFOA estimation method. Validated in a virtual reality scenario using an immersive head mounted display, the test results show that the proposed method can effectively estimate the VFOA of test subjects in different test scenarios. One of the limitations in this study is that the proposed method only applies to the situation where the operators only move their head and does not move their body during the operation. Future research will include a body motion sensor to comprehensively capture the head orientation and improve the accuracy of VFOA estimation. Integrated with other sensor systems such as real time location sensing (RTLS) and equipment motion capturing system, the proposed VFOA estimation method can provide real-time field assistant to improve operation efficiency and safety.

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