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CPWR Small Study No. 17-5-PS

Holographic Visual Interaction and Remote Collaboration in Construction Safety and Health

Final Report

Submitted to:

CPWR's Small Study Program

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ABSTRACT

Identifying hazards that may lead to accidents in construction requires effective communication. This study evaluated the feasibility of applying the mixed-reality (MR) technology in enhancing

Timely and accurate communication has been proven to be instrumental to hazard identification and other safety management activities in construction (Abdelhamid and Everett 2000). Studies (Alsamadani et al. 2013; Haslam et al. 2005) have highlighted the importance of communication in safety and health performance improvement of construction. In practices, jobsite safety has been historically communicated on site and in person (e.g., during daily safety inspection). Unfortunately, in the communication process, typical modes involve walking up to someone, encing, which do not facilitate instant access to information, situational awareness, context-based perception, and visual interaction that are essential for effective communication on modern construction sites (Stanton 2013). In specific, walking up to someone to talk and report potential hazards is time-consuming and may hence hinder prompt action to risk control. Phone calls (i.e., audio-only) -.0001 T not fahi5.6(Eric.g., ®n864(a)-d in perlls (ph

OBJECTIVES

The objective of this small study is to evaluate the feasibility of applying an emerging mixed-reality technology in ameliorating safety and health communication at construction jobsites. The research questions the study plans to address include:

1) whether the proposed technology improves the accuracy, efficiency, and ease-of-use on communication of construction jobsite safety and health issues in contrast to the conventional methods;
2) to what extent the proposed technology improves such communication as to the above metrics;
3) to what extent the proposed technology is accepted by the industry.

METHODS

This study answered by the above research questions and by doing so, accomplished the research objective through the following two phases.

The *first phase* was to develop a holographic application that enabled to turn a user's field view into a collaborative environment where others can see and interact with the aid of HoloLens The display of HoloLens allows for superimposition of computer-generated holograms over the user's view of the real world. By presenting additional, contextual information to the user, the real world is enhanced beyond the user's normal experience. In this phase, the Visual Studio 2015, Unity HoloLens Technical Preview, and the device of HoloLens were used for the development of this application. The HoloLens set-up consists of holographic lenses, a depth camera, speakers above the ears, and on-board processing via an Intel 32-bit architecture, an unspecified GPU (graphics processing unit) and HPU (holographic processing unit) that runs the application development. Once initial setup and calibration are complete, the proposed application starts with a hand gesture that invokes the holographic equivalent of the Windows start menu (Furlan 2016). The pointer is controlled by the user's gaze and clicking is done with a finger gesture. Safety information such as a manual can be dragged into the reviewer's space using a pinching gesture. The user enters in search of relevant information using a gaze-activated keyboard. Development of this phase materialized the abilities to move about untethered while communicating and collaborating with remote team members through Skype®, to visualize items that have yet to be real such as to superimpose elements into a 3D space, to annotate spatially and textually in the 3D space by both parties, and to support the subsequent evaluation of the developed technology.

The *second phase* to evaluate the developed holographic application for safety-related issue visualization, communication, and remote collaboration for solutions. To this end, construction sites were identified in Morgantown, WV and its neighboring area. Through collaborating with industry partners such as Contractor Association of West Virginia and AECOM, forty-nine (49) males and four (4) females with work experience -1.195 TD .1596 Tw [eote re u participate in the experiment. They were invited to experience the developed technology in which they were instructed to mimic a scenario on safety risk communication that the research team has designed – one at jobsites and one in office and communication was performed with the aid of the three-dimensional holographic and collaborative environment. This study did not control a specific activity that would be observed on jobsites considering the implementation feasibility of being not interfering with the ongoing work in a construction site. It was the participants' choice to walk about the work environment and observe their area of interest (e.g., foundation pit, wall erection, and scaffolding) that would involve safety issues. The information that was communicated included potential hazards and violations of the current workplace, and spatial annotations and verbalized comments of the hazards, violations, and their suggested preventive and protective measures associated with the video stream. Upon completion, immediate feedback was sought from these participants on the feasibility, benefits and limitations of the developed technology through a questionnaire that has been administered by the research team. The performance metrics were designed to include accuracy, efficiency, ease-of-use, and acceptability of the proposed technology that were benchmarked against the current communication techniques at jobsites. The current communication techniques consisted of phone calls, walking to people and talk, and video conferencing. In addition, the questionnaire provided an option for participants to specify other techniques they employ and seek for their feedback on the performance comparison between the proposed technology and the techniques they specified. Feedback on potential limitations of applying the proposed technology was also collected in the questionnaire, including whether the technology leads to work distraction, whether wearing HoloLens is comfortable, whether barriers to industrial implementation exist, and if any, what those barriers could be.

Design of the survey questionnaire was based on the performance metrics and queries set forth above and guided by a communication evaluation guide by Asibey et al. (2008). The reason that this guide was chosen was because it focuses on communication effectiveness and provides a well-defined evaluation strategy tool. Following this evaluation strategy tool, a communication evaluation scheme was developed and presented in Table 1.

Table 1: Developed Communication Evaluation Scheme for the Proposed Technology

Step 1: Determine what to evaluate	*Applying the mixed-reality technology of HoloLens to enhancing safety risk communication in construction workplaces*
Step 2: Define the goal	*To reduce workplace accidents and injuries*
Step 3: Define the objective	*To improve hazard identification capabilities among the project team; to make more hazards identifiable*
Step 4: Identify the audience	*Construction practitioners who inspect, oversee, record, and report jobsite safety risks*
Step 5: Establish the baseline	*List conventional safety communication channels including phone calls, walking up to people and talk, video conferencing, and others, if any*
Step 6: Pose the	*Ask participants to compare hololens with conventional safety*

evaluation questions	*communications channels for criteria in Step 7* *How do participants respond to the choice of the proposed communication channel (i.e., communication in a collaborative mixed-reality environment)?*
Step 7: Develop the measures	*Accuracy [i.e., participants feel hololens makes it easier to deliver messages; to comprehend messages; to locate the described hazards on sites; participants interested in the unique features of HoloLens (i.e., shared field of view, visual annotation/marking).]* *Efficiency (i.e., participants feel that they may complete their hazard identification and risk discussion faster.)* *Ease-of-use (i.e., participants feel the HoloLens interface is user-friendly and easy to operate .)* *Acceptability (i.e., audience feels comfortable wearing HoloLens; audience feels no distraction wearing HoloLens; audience is willing to use this technology in their future work; audience is willing to invest this technology for their future work; audience feels no barriers to industrial implementation.)*
Step 8: Select the evaluation techniques	*The developed mixed-reality communication tool including HoloLens and a tablet computer with needed software installed; in-person surveys using questionnaire*

Based on the scheme in Table 1, the questionnaire was developed to contain a number of items, which can be categorized into personal/demographic information, occupational information, business information, performance feedback (Likert scale questions) on strengths, weaknesses, and acceptability of the examined communication strategy (i.e., communication with the aid of the proposed technology), barriers to industrial implementation, and comments/suggestions. Improvement of this questionnaire was made with the assistance of one of the PI's collaborators, whose work is associated with jobsite safety supervision. During the phase of implementation, the questionnaire was further piloted with two industrial participants (one project manager and one field worker) to check its adequacy and minor modifications. Suggestions from the two participants were incorporated into the final version of the questionnaire. The study protocol was approved by the West Virginia University's Institutional Review Board (IRB).

Upon completion of the data collection, descriptive statistics and inferential statistics were applied to answer the research questions. It started with the analysis of descriptive characteristics of the data. As this study used the Likert scale for survey and the data does not follow a normal distribution, the non-parametric Kruskal-Wallis test was then applied to determine whether there was a statistically significant difference in application of mixed reality compared to different existing communication methods. Last, t statistic was employed to construct 95% conference interval of item means for each construct. This provided insights about where the average opinion stood based on a scale ranging from strongly disagree (0) to strongly agree (4).

ACCOMPLISHMENTS AND RESULTS

Descriptive Analysis Results

As seen in Fig 2, the medians of different categories increase from left to right indicating that responses with “agree” has a higher median value (11) than responses with “neutral” (6) and “disagree” (0). This implies that most participants agreed that MR has potential to improve risk communication on construction jobsites.

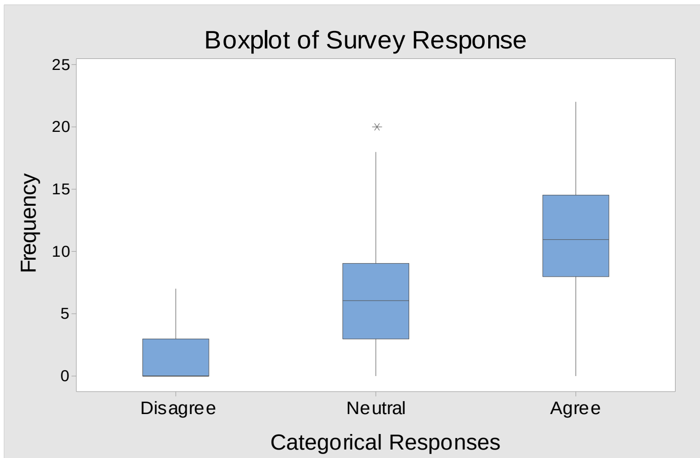

Fig. 2: Total Responses to Each Category by All Participants

Tables 2 to 5 show the frequencies of responses from participants regarding their opinions on accuracy of the mixed reality HoloLens® compared to phone calls, walking up to people and talk, video conferencing, and emails after trials. For the headings of these tables, “Con. MSG” denotes the variable of “ease of conveying messages”, “Und. MSG” denotes “ease of understanding messages”, “Pin. Haz.” denotes “ease of pinpointing a site hazard being described”, “Shr. FOV” denotes “usability of shared field of view to assist in remote communication”, “Vis. Annot.” denotes “usability of visual annotation during communication”, and “Comm. Eff.” denotes “sense of communication efficiency”.

Accuracy compared to phone calls: According to Table 2, eighty (80) percent of responses were in favor of HoloLens®, implying that application of MR has potential to increase accuracy during risk communication on jobsites compared to phone calls. The remaining eighteen (18) percent were undecided while two (2) percent disagreed that MR would improve the accuracy of risk communication. By further observation of the data, users’ ability to pinpoint hazards, to share field of view, and to visually annotate 3D space during remote communication accounts for eighty-eight (88) percent of the responses. This revealed a positive relationship between spatial cue capabilities of HoloLens® and users’ ability to understand each other during communication.

Table 2: Response Counts of Accuracy on HoloLens® vs. Phone Calls

ACCURACY: HOLOLENS® VS. PHONE CALLS					
Response	Con. MSG	Und. MSG	Pin. Haz.	Shr. FOV	Vis. Annot.
0 = Disagree	2	2	1	0	1
1 = Neutral	15	13	5	6	6

2 = Agree	34	36	45	45	44
Total (N)	51	51	51	51	51

Accuracy compared to walking up to people and talk: As indicated in Table 3, an average of sixty-six (66) percent of responses supports that MR performs more accurately during communication while twenty-five (25) percent that were undecided and nine (9) percent that disagreed.

Table 3: Response Counts of Accuracy on HoloLens® vs. Walking Up to People and Talk

Table 9: Response Counts of Efficiency on HoloLens® vs. Emails

EFFICIENCY: HOLOLENS® VS. EMAILS	
Response	Comm. Eff.
0 = Disagree	0
1 = Neutral	13
2 = Agree	17
Total (N)	30

Table 10 shows the frequencies of responses from participants regarding ease-of-use of mixed reality HoloLens®. In its headings, the variables of "Usr. Int." denotes "friendliness of the user interface of HoloLens®", and "Oper." denotes "ease of operation of HoloLens®".

Ease-of-use: In Table 10, forty-six (46) percent of responses agreed that user interface of the mixed reality HoloLens® is easy to navigate. Forty-nine (49) percent were neutral on the ease-of-use of mixed reality during communication. The remaining five (5) percent of responses indicated that the mixed reality interface is not user-friendly.

Table 10: Response Counts of Ease of Use

EASE OF USE OF HOLOLENS®		
Response	Usr. Int.	Oper.
0 = Disagree	4	1
1 = Neutral	24	26
2 = Agree	24	23
Total (N)	52	50

Table 11 shows the frequencies of responses from participants regarding acceptability of mixed reality HoloLens®. In its headings, the variables of "Cmft." denotes "comfortability of wearing HoloLens®", "No Dstr." Denotes "no distraction to work wearing HoloLens®", and "Reuse" denotes "willingness to use HoloLens® for work again".

Acceptability: In Table 11, thirty-two (32) percent of responses were willing to accept mixed reality for risk communication given the technology in its current state while fifty-one (51) percent of responses were neutral and seventeen (17) percent of responses did not agree that it is the best time to adopt the mixed reality for their site risk communication.

Table 11: Response Counts of Acceptability of HoloLens®

ACCEPTABILITY OF HOLOLENS®			
Response	Cmft.	No Dstr.	Reuse
0 = Disagree	7	12	6
1 = Neutral	20	31	27
2 = Agree	24	8	17
Total (N)	51	51	50

Inferential Analysis Results

Kruskal-Wallis H test of significance: The median differences between participants’ responses for each of the constructs were statistically assessed by applying Kruskal-Wallis H test. The test results indicated that for accuracy, efficiency, ease-of-use, and acceptability, there are significant differences ($p<0.05$) when MR is used for risk communication compared to other methods in terms of phone calls, walking up to people and talk, video conferencing, and emails.

	Disagree vs. Agree	0.001	< 0.05	Significance
	Neutral vs. Agree	0.549	> 0.05	Not significance
Ease-of-Use	Disagree vs. Neutral	0.001	< 0.05	Significance
	Disagree vs. Agree	0.001	< 0.05	Significance
	Neutral vs. Agree	1.000	> 0.05	Not significance
Acceptability	Disagree vs. Neutral	0.001	< 0.05	Significance
	Disagree vs. Agree	0.051	> 0.05	Not significance
	Neutral vs. Agree	0.009	< 0.05	Significance

Pairwise comparisons of the accuracy: In all pairwise comparisons of the accuracy of HoloLens® against other methods, results revealed statistically significant agreements ($p<0.05$) that the mixed reality HoloLens® has potential to increase the accuracy of communication than the other four traditional methods.

Pairwise comparisons of the efficiency: Similar significant results were also obtained in the pairwise comparison of the efficiency of HoloLens® with phone calls and walking up to talk, respectively. The pattern in these comparisons showed that respondents rated the efficiency of HoloLens® to reduce the time spent in delivering concise messages that others can easily understand higher than the other methods. Although we found the pairwise comparisons between the “Neutral” and “Disagree” not significant ($p > 0.05$) for the same constructs, they do not have any significant adverse effect on the overall efficiency rating of the mixed reality. For the pairwise comparisons of efficiency of HoloLens® with video conferencing and emails, there was no significance difference between “Agree” and “Neutral”. This showed that respondents do not believe there was a significant communication time saved between when they used HoloLens® and video conferencing or emails.

Pairwise comparisons of the Ease-of-Use: The comparison between “Neutral” and “Agree” responses showed an evidence of insignificance ($p>0.05$); but the comparison between “Disagree” and “Agree” and “Disagree” and “Neutral” responses were significant.

Pairwise comparisons of the Acceptability: The “Disagree” and “Agree” comparison for acceptability was insignificant based on the result. However, “Disagree” and “Neutral” and “Neutral” and “Agree” comparisons were significant.

The insignificance differences from the ease-of-use and acceptability of HoloLens® may indicate that some amendments to features and adequate training of practitioners for use of the

Table 13: Mean of Responses at 95% CI, $\alpha = 0.05$

Construct	Mean	Standard Deviation	Mean Range @ 95% Confidence Interval
Accuracy			
HoloLens® vs. Phone Calls	3.00	0.70	2.91 - 3.09
HoloLens® vs. Walking Up and Talk	2.72	0.89	2.61 - 2.83
HoloLens® vs. Video Conferencing	2.86	0.65	2.76 - 2.96
HoloLens® vs. Emails	2.86	0.73	2.74 - 2.97
Efficiency			
HoloLens® vs. Phone Calls	2.69	0.91	2.43 - 2.94
HoloLens® vs. Walking Up and Talk	2.53	0.96	2.26 - 2.81
HoloLens® vs. Video Conferencing	2.45	0.72	2.19 - 2.72
HoloLens® vs. Emails	2.73	0.74	2.46 - 3.01
Ease of Use	2.38	0.79	2.22 - 2.53
Acceptability	2.21	0.78	2.09 - 2.34

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injuries avoidance and time saved as a direct result of using the mixed reality intervention during construction risk communication.

CHANGES/PROBLEMS

There are no changes or problems encountered during the study.

FUTURE FUNDING PLANS

Based on the findings of this small study, the re

Conference papers/posters and presentations in construction, transportation, or civil engineering (e.g., CRC, I3CE, TRB, and ICCCBE);

Industry seminars and workshops through WV Construction & Design Exposition.

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