Wearable Technology for Highway Maintenance and Operation Safety: A Survey of Workers' Perception and Preferences

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Abstract -

Securing the safety of highway work zones is one of the most pressing issues in the highway maintenance and operation community. Recent studies have indicated that highway workers keep suffering f rom f atal i njuries a nd death caused by traffic, long-night shifts, and limited space for maneuvering. In the meantime, recent advances in wearable technology have provided promising potential in the context of safety in different disciplines, especially building construction. However, highway workers have been underrepresented and limited information is available about their perception, preferences and ideas toward wearable technology. With this, in this paper, we document our early results in investigating the perception of highway workers toward wearable technology and their preferences among available devices to be used for safety purposes. Our results highlight a promising potential for the application of wearable technology in highway work zones and an acceptable level of engagement from the body of highway workers. Therefore, we envision this study to energize developers for further research and investment in the application of wearable technology in highway work zone safety.

Keywords -

Wearable Technology; Highway Work Zones; Safety; User Experience; Worker-centered Design

1 Introduction

In 2018, Federal Highway Administration (FHWA) reported that 124 workers lost their lives at highway construction sites. With an average of 135 workers fatality, FHWA also documented that lethal crashes in highway work zones climbed by 3 percent between 2016 and 2017. Fatal injuries on top of death is another substantial threat to the safety of highway workers. A total of 158,000 crashes and 42,000 associated injuries were reported in 2016 alone [1]. Meanwhile, recent investments in highway infrastructure construction would further exacerbate this issue by creating more work zones. Therefore, securing the safety of highway work zones is one of the most pressing issues that the maintenance and operation face in the years to come [2, 3].

The recent boom in wearable technologies has provided significant potential in addressing some of the challenging problems in the engineering world [4]. Latest research trends have demonstrated that researchers and practitioners from different disciplines have rushed toward wearable-enabled systems for enhancing the status-quo, especially in building construction safety [5, 6, 7]. In the meantime, highway maintenance, operation, and construction community is and has been only relying on fairly reactive systems and have not yet departed toward more modern technologies [8, 9]. Meanwhile, building construction researchers have also attempted to increase the usefulness and usability of the newly developed systems by investigating the perception of construction workers toward wearable technology [10]. However, highway workers have been underrepresented in the body of knowledge. The majority of previous studies have targeted vertical building construction safety, and highway maintenance community's perception has not been investigated in comparable detail [11, 8, 12]. Limited space for maneuvering, often long and night shifts, and dealing with drivers with a broader range of behaviors are some of the reasons that make the needs of highway maintenance workers unique. This makes prior information in building construction directly inapplicable to highway work zones and could potentially hinder future developments for highway workers [13, 14].

In this study, we investigated the perception and preferences of highway workers toward wearable technology to be used in safety-related systems. In specific, the contributions of this paper to the body of knowledge are:

- This article is among the first research studies investigating the perception of highway workers toward wearable technology.
- This article specifically compares the highway worker's perception about some of the most common

wearable options in the market.

- The results of this study paves the path toward future interaction and safety system designs for highway workers.

In the following, we will first lay the foundation by explaining the related works of this study. Then, we will move on to explaining our methodology followed by results and discussion.

2 Related Works

2.1 User Perception and Technology Development

It is commonly believed that achieving success in information technology projects requires careful user research. Previous studies have demonstrated that there is usually a gap between what developers think of the system and what users' actual perceptions are [15]. Therefore, investigating whether the intended users would adopt the developed technology or not is of importance [8]. Recent investments in wearable technology have accelerated modernizing the concept of work [16]. However, several researchers have already discussed that there is a potential for the end-users to resist adopting the developed technologies, regardless of their benefits. This fact majorly highlights the importance of early user studies [17]. Therefore, a few researchers in the past performed some studies investigating the reaction of construction workers to new technologies. For example, [18] developed an extended Technology Acceptance Model (TAM) for including the future alterations in the attitude of workers with respect to time [19]. We also identified such studies in other disciplines [20, 21].

2.2 A Survey of Wearable Devices and Their Applications

Smart wearable devices have a long and rich history [22]. Recent boom in wearable technology has provided industry leaders, researchers and practitioners in different industries with a new source of power for increasing the cognitive capabilities of humans in their daily life and decision making [23, 24]. [25] categorized the state-of-the-art wearable devices under three main categories, accessories, e-textiles, and e-patches. They considered wrist-worn (smart watches and wristbands) , head-mounted (smart eye-wears, hard hats, and ear-buds) and others such as vests as the main subgroups of the accessories wearable devices. Moreover, wearable technology has already been proven as an efficient tool in different disciplines, ranging from healthcare to education [26]. In an interesting study, [4] discussed the historical and current trends in wearable technology and concluded that health related issues are still among the most well-received applications of wearable technology. There have been already multiple review articles that investigated the application of wearable devices in different disciplines [27]. Recent trends show that interest in applying wearables in safety-related contexts are exponentially growing. For example, [28] investigated the application of wearable devices in securing the safety of miners. Another recent trends in wearable technology is using technologies such as Artificial Intelligence (AI) or Internet of Things (IoT) as the backend and wearable technology as the frontend and the means of interaction with users. For instance, the authors in [29] studied how wearable technology can be leveraged in securing the safety of women by sending an emergency notifications to their relatives and adjacent police stations using IoT.

2.3 Wearable Devices and Their Application in Construction

The application of wearable devices in construction industry has been continuously and exponentially growing in recent years for mitigating safety issues. Researchers and practitioners have used wearable technology for monitoring and collecting different information, including kinematic movement, cardiac activity, skin response, and muscle engagement [30, 11]. For this purpose, they have deployed different devices, ranging from smart wristbands, Electroencephalogram (EEG) headsets, and Augmented Reality glasses [31, 32]. These devices were used in order to study safety risks such as falling, engagement to hazardous behaviors, preventing extreme fatigue or other within-site accidents [33, 34]. Some studies also suggested the use of wearable technology for designing active safety systems in construction sites. For instance, [35] proposed a novel system architecture for a safety system that warns construction workers and prevents them from accidents using wearable technology and IoT.

3 Methodology

Given the limited information available about highway workers and wearable technology, our main goal in this study is to investigate the perception of highway workers toward wearable technology to be used in safety-related systems. In specific, we want to investigate:

1. Perception of highway workers toward the practically of wearable technology in highway work zones.
2. Likelihood of highway workers using wearable devices in highway work zones.
3. Preferences of highway workers among the currently available wearable options.
4. Major concerns of highway workers toward using wearable technology.

For this purpose, we designed a two-step methodology, including a semi-structured interview followed by an extensive survey of the body of highway operation and maintenance community. Below, we will explain our methodology in detail.

3.1 Semi-structured Interview

Before designing our questionnaire, we first conducted an in-depth interview with an experienced highway maintenance crew member. The reason behind this was twofold. Firstly, given the unique needs of highway maintenance workers, we wanted to gain an initial impression of their thoughts and beliefs to be reflected in the design of the questionnaire. Secondly, we wanted to run the survey questions by him and ensure the language and general structure of the survey is suitable for highway workers. Our interviewee was a senior and former member of the highway maintenance and operation division of a state Department of Transportation (DOT) with more than 20 years of experience.

Our interview was semi-structured. We first started off with basic demographic questions, including age, experience, and familiarity with this field. Then, we moved on to open discussions about the wearable technology and its application in highway work zones. Our interviewee mentioned that he had no prior experience with wearable technology as a safety mean in highway work zones. Our interviewee believed that wearable technology could be useful in highway work zones. Ultimately, in this step, we selected smart glasses, smart wristbands, smart hard hats, and smart clothes such as smart vests among different available wearable options in the market. We chose these devices after consultation with our interviewee, availability in the market, our literature review, competitive cost, and compatibility with outdoor environment. However, our interviewee at first was concerned about the use of smart glasses for the users who wear prescribed glasses. While this concern is completely valid, some of the currently available options in the market are compatible with prescribed glasses and offer a solution for this problem (see Vuzix Blade [36]).

3.2 The Structure of the Questionnaire

After our initial interview and with the suggestion of our interviewee, we decided to separate our participants into two personas: highway maintenance crew and affiliated participants. The former only includes workers while the latter consists of state DOT members, private consultants, managers, researchers, and other individual who are acquainted with maintenance and operation community and are not a worker. The main reason behind this personification was twofold. Firstly, our target population is all individuals that are physically present in highway work zones and will interact with wearable technology as a safety measurement. However, maintenance crew are more frequently present in work zones than other members. This could lead to these groups having developed a different set of ideas and beliefs about wearable technology to be used as a safety measure. Secondly, we believed that crew members might have different expectations from wearable technology than managers given the differences in the nature of their jobs. For instance, it is logical to assume that workers should not care about the cost of the technology when it could be an important contributor to what managers and supervisors think of the technologies. It should be noted that hereinafter, we will be calling the highway maintenance crew “maintenance crew” and the affiliated participants with highway maintenance and operation community “affiliated members”.

In the next step and based on our feedback from the interview, we designed our questionnaire to survey the body of highway work zone maintenance and operation community. We started off the survey with demographic questions, where we asked participants their age, role, and the frequency of their presence in the highway work zones in general. Next, we asked them about their previous experience with wearable devices, if any. Then, we asked them our major questions, which were:

1. Practicality of the provided wearable devices (Question 1).
2. Likelihood of users utilizing the provided devices (Question 2).

Finally, we asked participants to share with us their concerns in specific about the application of wearable technology in highway work zones (Question 3). We asked them to select from "impractical for operation in highway work zones, unpleasant experience with devices", "influence on the performance such as vision obstruction", "slow and painful adaptation to the technology as a routine", "the unreliability of the devices in identifying potential dangers", "repetitive false alarms and loss of your trust in devices", "none” and "other". They could also have selected multiple options from the provided list. We then reached out to the body of highway maintenance and operation community and asked for their participation. We used Google Form for hosting and conducting this survey.

3.3 Statistical Analysis

After receiving responses from our participants, we statistically analyzed the data to investigate our research objectives. For this purpose, we used chi-square test, both goodness-of-fit and independence versions to investigate whether affiliated members and maintenance crew show

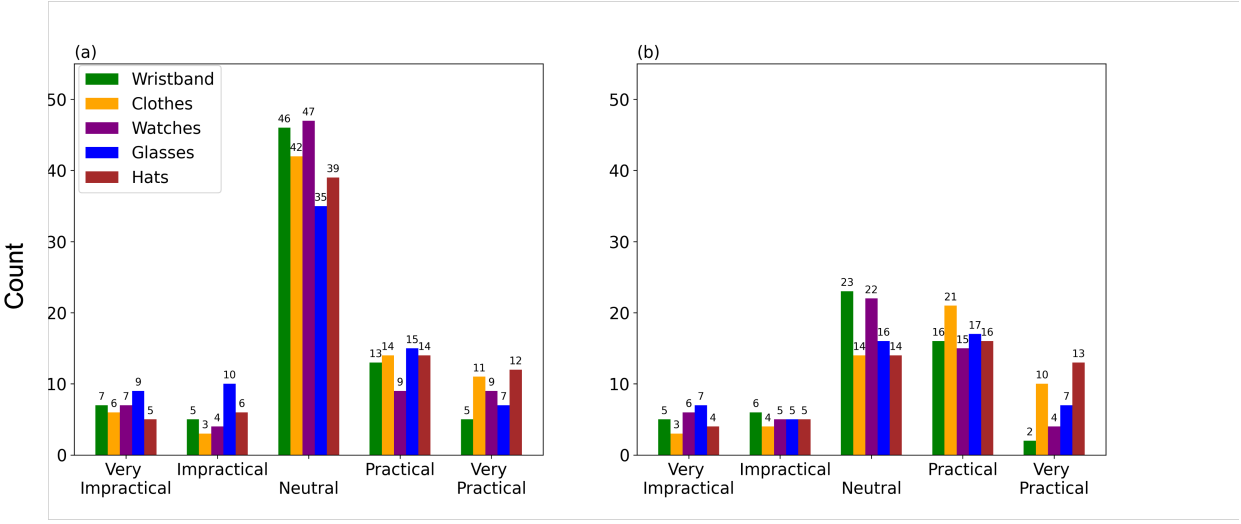

Figure 1. The practicality of the selected wearable options in (a) maintenance crew and (b) affiliated members

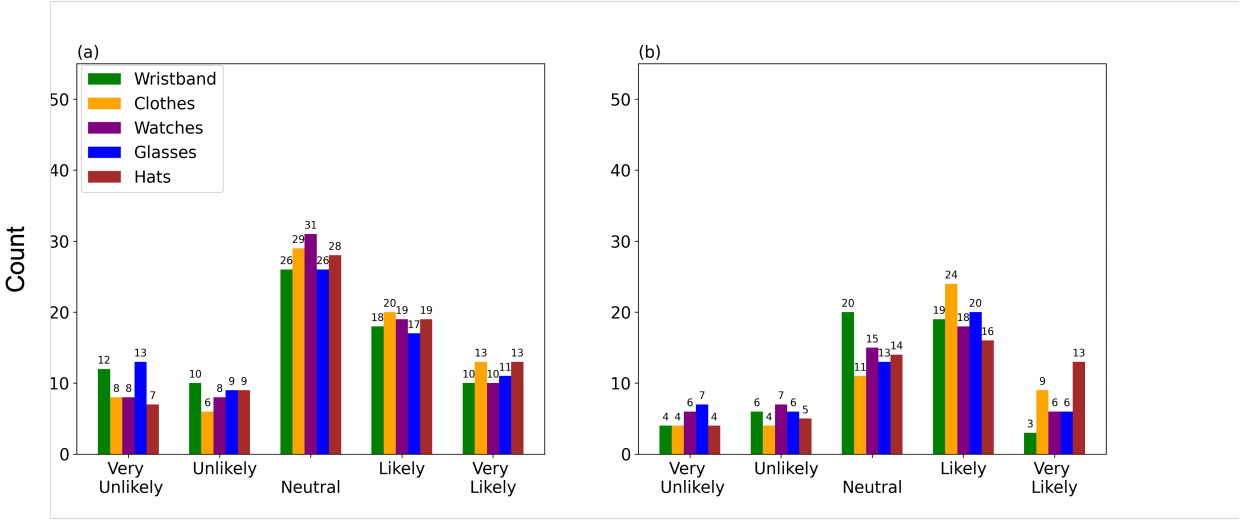

Figure 2. The likelihood of (a) maintenance crew and (b) affiliated members to use the selected wearable options

Table 1. Chi-square goodness-of-fit test on the collected data and the corresponding p-values

Question	Group	Wristband	Clothes	Watch	Glasses	Hats
1	Maintenance Crew	$1.2 * 10^{-16}$	$4.4 * 10^{-13}$	$2.2 * 10^{-17}$	$5.8 * 10^{-13}$	$2.9 * 10^{-10}$
1	Affiliated Members	$5.6 * 10^{-6}$	$2.8 * 10^{-4}$	$9.7 * 10^{-5}$	$1.5 * 10^{-3}$	$2 * 10^{-2}$
2	Maintenance Crew	$1.4 * 10^{-3}$	$1 * 10^{-4}$	$3.2 * 10^{-5}$	$1.8 * 10^{-3}$	$7.8 * 10^{-5}$
2	Affiliated Members	$1.9 * 10^{-5}$	$3.3 * 10^{-5}$	$1.4 * 10^{-3}$	$6.2 * 10^{-4}$	$2 * 10^{-2}$

different behavior toward wearable devices in general and the selected devices in particular.

4 Results

In this section, we will provide the results obtained from our survey and analysis.

4.1 Community Engagement

148 individuals responded to our survey, 76 of which identified themselves as maintenance crew and 52 as affiliated participants with the body of highway work zone community. The rest were general participants. Since the general participants did not belong to our target groups, the corresponding results were excluded from our study. The majority of our participants were from the state of North Carolina (62 from the maintenance crew and the

Table 2. Our participants' major concerns about wearable technology in highway work zones

Concern	Maintenance Crew	Affiliated Members
Impractical for operation in highway work zones	13	12
Unpleasant experience with devices	4	5
Influence on the performance such as vision obstruction	16	21
Slow and painful adaptation to the technology as a routine	4	8
Unreliability of the devices in identifying potential dangers	19	24
Repetitive false alarms and loss of your trust in devices	17	29
None	23	7
Other	11	12

Table 3. Chi-square independence test on the collected data and the corresponding p-values

Question	Wristband	Clothes	Watch	Glasses	Hats
1	0.25	0.013	0.07	0.309	0.09
2	0.26	0.15	0.63	0.39	0.64

34 from affiliated participants). This was followed by the state of Virginia with 6 participants from the maintenance crew and 8 from affiliated ones. The states of Florida, Georgia, Indiana, Pennsylvania, and Texas also had some representatives in this survey. Finally, we received one response from a crew member who mentioned to be based in Canada.

4.2 Questionnaire Results

Among our participants, 28 mentioned that they are at least 55 years old. 78 participants also mentioned that their age is between 36 and 55 years (37 in 36-45 and 41 in 45-55). Moreover, only 10 participants mentioned to be less than 25 years old. Therefore, it is safe to conclude that while we have a fairly acceptable diversity from different age groups, the majority of our participants are either middle-aged or seniors. Additionally, 92 out of 128 participants mentioned that they had been working in the field of highway operation and maintenance for at least 10 years. Only 13 participants mentioned that they were novice with having 0-2 years of experience. 13 people also mentioned that they had been actively involved in this field for at least 3 to 5 years. Therefore, we can also conclude that the majority of our participants were experienced-enough with the hazards of highway work zones. Finally, only 22 participants (roughly 17 percent) mentioned that the had previous experience with wearable technology while they were present in a highway work zones.

Figure 1 illustrates the responses from our participants to Question 1. Figure 1 (a) represents the responses from the maintenance crew and Figure 1 (b) demonstrates the responses from affiliated members. Moreover, Figure 2 visualizes the responses that we received from (a) maintenance crew and (b) affiliated members to Question 2. Furthermore, Table 2 summarizes the major concerns of our participants toward using wearable technology in highway work zones as a safety measure.

4.3 Statistical Analysis

In this section, we statistically analyzed the collected data to further investigate our research questions. We first used goodness-of-fit version of chi-square test on all of the collected samples to investigate whether the difference among the number of votes in each category of collected data for both Question 1 and Question 2 in all provided wearable options are statistically significant. That resulted in 20 tests and the results are summarized in Table 1. The obtained p-values are all less than the traditional 0.05 significance cut-off, and therefore mean that the differences among the collected samples in different categories are statistically significant.

Finally, we used the independence version of the chi-square test to statistically compare the responses from both groups and investigate whether groups show a statistically different behavior toward wearable technology. We used this test 5 times in each question (10 times in total), and the results are summarized in Table 3. This table illustrates that with the exception of practicality of clothes, all obtained p-values are larger than the traditional 0.05 level of significance. This denotes that the collected samples are independent from each other, and the null hypotheses of Chi-squared test, which is the samples are independent, is kept.

5 Discussion

In this section, we are discussing our results. Figure 1 shows that while the majority of the maintenance crew seems to feel neutral about the practicality of the selected wearable devices, affiliated members viewed the practicality of wearable technology more positively. In specific, they think that smart clothes and glasses would be a suitable option in highway work zones. This could be attributed to the potential experience with lighting vests and safety glasses, two common "wearable" safety items

in the highway construction industry. Similarly, we can identify a similar pattern in Figure 2 that illustrates the likelihood of using wearable technology in the future. As observed, maintenance crew participants feel more neutral toward using wearable technology in the future and affiliated members are more likely to use werables, especially smart clothes and glasses. Lack of prior experience, age, job description, and technology resistance all could possibly contribute toward this neutral feeling of the maintenance crew.

Moreover, Table 2 summarizes the responses of our participants to Question 3. This table indicates that most affiliated members and maintenance crew feel that wearable technology is not reliable and trustworthy enough to be used in highway work zones. Both personas cited repetitive false alarms and the unreliability of devices as their major concerns. Participants also recognized the lack of prior experience, the additional burden of wearable technology on top of the already existing PPE items, and being a potential source of distractions as their major concerns. The cost was another factor that affiliated members raised. Finally, Table 3 indicates that the maintenance crew and affiliated members showed a different behavior toward both the practicality and the likelihood of using wearable technology in the future across almost all of the provided wearable options. This further corroborates our initial assumption that affiliated members and maintenance crew might have different opinions and beliefs toward wearable technology due to the differences in their job descriptions and other possible contributors, and our personification was on point. As we discussed, this difference was also reflected in their perception toward the practicality and the likelihood of using wearable technology illustrated in Figures 1 and 2. Deep investigation of this difference, identifying major contributors to these persona creation, and studying the unique needs of each persona could be interesting future research directions.

6 Conclusion

In this article, we reported our early efforts in investigating the perception and preferences of highway workers toward wearable technology for safety-related purposes. We involved the community of highway maintenance and operation in the research through a survey and actively pursued their perception, thoughts and ideas toward wearable technology. Our results indicate a notable potential for future development and investment in wearable-enabled for highway work zones. Future studies can analyze the perception of highway workers by developing more intensive Technology Acceptation Models (TAMs), early prototypes and other tools to further investigate what highway workers think of wearable technology,and how such devices can be assimilated into the work zones.

7 Acknowledgments

This research is supported by the National Science Foundation under Award Number 1932524. The authors would like to thank the North Carolina Department of Transportation (NCDOT), Virginia Department of Transportation (VDOT), and DBi services for their support.

References

[1] Facts and statistics—work zone safety. *Federal Highway Administration (FHWA)*, 2018.

[2] John Hourdos. Portable, non-intrusive advance warning devices for work zones with or without flag operators. 2012.

[3] John A Gambatese, Hyun Woo Lee, Chukwuma Aham Nnaji, et al. Work zone intrusion alert technologies: Assessment and practical guidance. Technical report, Oregon. Dept. of Transportation. Research Section, 2017.

[4] Mary Ellen Berglund, Julia Duvall, and Lucy E Dunne. A survey of the historical scope and current trends of wearable technology applications. In *Proceedings of the 2016 ACM international symposium on wearable computers*, pages 40–43, 2016.

[5] Mareike Kritzler, Martin Bäckman, Anders Tenfält, and Florian Michahelles. Wearable technology as a solution for workplace safety. In *Proceedings of the 14th International Conference on Mobile and Ubiquitous Multimedia*, pages 213–217, 2015.

[6] Ibukun Awolusi, Eric Marks, and Matthew Hallowell. Wearable technology for personalized construction safety monitoring and trending: Review of applicable devices. *Automation in construction*, 85: 96–106, 2018.

[7] Houtan Jebelli, Byungjoo Choi, and SangHyun Lee. Application of wearable biosensors to construction sites. i: Assessing workers' stress. *Journal of Construction Engineering and Management*, 145(12): 04019079, 2019.

[8] Chukwuma Nnaji, Ali A Karakhan, John Gambatese, and Hyun Woo Lee. Case study to evaluate work-zone safety technologies in highway construction. *Practice Periodical on Structural Design and Construction*, 25(3):05020004, 2020.

[9] Sepehr Sabeti, Omidreza Shoghli, and Hamed Tabkhi. Toward wi-fi-enabled real-time communication for proactive safety systems in highway work zones: A case study. In *Construction Research Congress 2022*, pages 1166–1173, 2022.

[10] Byungjoo Choi, Sungjoo Hwang, and SangHyun Lee. What drives construction workers' acceptance of wearable technologies in the workplace?: Indoor localization and wearable health devices for occupational safety and health. *Automation in Construction*, 84:31–41, 2017.

[11] Sepehr Sabeti, Omidreza Shoghli, Mohammadreza Baharani, and Hamed Tabkhi. Toward ai-enabled augmented reality to enhance the safety of highway work zones: Feasibility, requirements, and challenges. *Advanced Engineering Informatics*, 50: 101429, 2021.

[12] Chukwuma Nnaji, Ali Jafarnejad, and John Gambatese. Effects of wearable light systems on safety of highway construction workers. *Practice Periodical on Structural Design and Construction*, 25(2): 04020003, 2020.

[13] Young Ai Kim, Boong Yeol Ryoo, Yong-Su Kim, and Woon Chan Huh. Major accident factors for effective safety management of highway construction projects. *Journal of construction engineering and management*, 139(6):628–640, 2013.

[14] Aleck Ian Glendon and Debbie K Litherland. Safety climate factors, group differences and safety behaviour in road construction. *Safety science*, 39(3): 157–188, 2001.

[15] Ramanath Subramanyam, Fei Lee Weisstein, and Mayuram S Krishnan. User participation in software development projects. *Communications of the ACM*, 53(3):137–141, 2010.

[16] David Brougham and Jarrod Haar. Employee assessment of their technological redundancy. *Labour & Industry: a journal of the social and economic relations of work*, 27(3):213–231, 2017.

[17] Anjum Naweed and Janette Rose. Assessing technology acceptance for skills development and real-world decision-making in the context of train driving. *Transportation research part F: traffic psychology and behaviour*, 52:86–100, 2018.

[18] Diandian Liu, Weisheng Lu, and Yuhan Niu. Extended technology-acceptance model to make smart construction systems successful. *Journal of Construction Engineering and Management*, 144(6): 04018035, 2018.

[19] Hyojoo Son, Yoora Park, Changwan Kim, and Jui-Sheng Chou. Toward an understanding of construction professionals' acceptance of mobile computing devices in south korea: An extension of the technology acceptance model. *Automation in construction*, 28:82–90, 2012.

[20] Jesse V Jacobs, Lawrence J Hettinger, Yueng-Hsiang Huang, Susan Jeffries, Mary F Lesch, Lucinda A Simmons, Santosh K Verma, and Joanna L Willetts. Employee acceptance of wearable technology in the workplace. *Applied ergonomics*, 78:148–156, 2019.

[21] Baozhen Dai, Ebenezer Larnyo, Ebenezer Ababio Tetteh, Abigail Konadu Aboagye, and Abdul-Aziz Ibn Musah. Factors affecting caregivers' acceptance of the use of wearable devices by patients with dementia: An extension of the unified theory of acceptance and use of technology model. *American Journal of Alzheimer's Disease & Other Dementias®*, 35:1533317519883493, 2020.

[22] Ivan E. Sutherland. A head-mounted three dimensional display. In *Proceedings of the December 9-11, 1968, Fall Joint Computer Conference, Part I*, AFIPS '68 (Fall, part I), pages 757–764, New York, NY, USA, 1968. ACM. doi:10.1145/1476589.1476686. URL `http://doi.acm.org/10.1145/1476589.1476686`.

[23] M. Satyanarayanan. From the editor in chief: Augmenting cognition. *IEEE Pervasive Computing*, 3(2):4–5, April 2004. ISSN 1536-1268. doi:10.1109/MPRV.2004.1316809.

[24] M. Satyanarayanan, P. Bahl, R. Caceres, and N. Davies. The case for vm-based cloudlets in mobile computing. *IEEE Pervasive Computing*, 8(4):14–23, Oct 2009. ISSN 1536-1268. doi:10.1109/MPRV.2009.82.

[25] Suranga Seneviratne, Yining Hu, Tham Nguyen, Guohao Lan, Sara Khalifa, Kanchana Thilakarathna, Mahbub Hassan, and Aruna Seneviratne. A survey of wearable devices and challenges. *IEEE Communications Surveys & Tutorials*, 19(4):2573–2620, 2017.

[26] Rua M Williams and Juan E Gilbert. Perseverations of the academy: A survey of wearable technologies applied to autism intervention. *International Journal of Human-Computer Studies*, page 102485, 2020.

[27] Ruxandra Tapu, Bogdan Mocanu, and Ermina Tapu. A survey on wearable devices used to assist the visual impaired user navigation in outdoor environments. In *2014 11th international symposium on electronics and telecommunications (ISETC)*, pages 1–4. IEEE, 2014.

[28] Mokhinabonu Mardonova and Yosoon Choi. Review of wearable device technology and its applications to the mining industry. *Energies*, 11(3):547, 2018.

[29] V Hyndavi, N Sai Nikhita, and S Rakesh. Smart wearable device for women safety using iot. In *2020 5th International Conference on Communication and Electronics Systems (ICCES)*, pages 459–463. IEEE, 2020.

[30] Changbum R Ahn, SangHyun Lee, Cenfei Sun, Houtan Jebelli, Kanghyeok Yang, and Byungjoo Choi. Wearable sensing technology applications in construction safety and health. *Journal of Construction Engineering and Management*, 145(11): 03119007, 2019.

[31] Yizhi Liu, Mahmoud Habibnezhad, Houtan Jebelli, Somayeh Asadi, and SangHyun Lee. Ocular artifacts reduction in eeg signals acquired at construction sites by applying a dependent component analysis (dca). In *Construction Research Congress 2020: Computer Applications*, pages 1281–1289. American Society of Civil Engineers Reston, VA, 2020.

[32] Xiao Li, Wen Yi, Hung-Lin Chi, Xiangyu Wang, and Albert PC Chan. A critical review of virtual and augmented reality (vr/ar) applications in construction safety. *Automation in Construction*, 86: 150–162, 2018.

[33] Carlos M Zuluaga, Alex Albert, and Munir A Winkel. Improving safety, efficiency, and productivity: Evaluation of fall protection systems for bridge work using wearable technology and utility analysis. *Journal of Construction Engineering and Management*, 146 (2):04019107, 2020.

[34] Maxwell Fordjour Antwi-Afari and Heng Li. Fall risk assessment of construction workers based on biomechanical gait stability parameters using wearable insole pressure system. *Advanced Engineering Informatics*, 38:683–694, 2018.

[35] Riad Kanan, Obaidallah Elhassan, and Rofaida Bensalem. An iot-based autonomous system for workers' safety in construction sites with real-time alarming, monitoring, and positioning strategies. *Automation in Construction*, 88:73–86, 2018.

[36] Vuzix. https://www.vuzix.com/products/blade-smart-glasses-upgraded. 2020.