Factors Affecting the Implementation of AI-based Hearing Protection Technology at Construction Workplace

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Abstract –
Standard hearing protection devices (HPDs) that reduce noise by strictly passive means are mandatory at construction sites. However, standard HPDs have been proved weaken the audibility of safety-critical sounds thus worsen construction workers' auditory situational awareness (ASA). Therefore, a wearable hearing protection technology that uses artificial intelligence (AI) to amplify safety-critical sounds while greatly attenuating ambient noise would be in great demand for construction safety monitoring. However, little to no study has provided clear evidence on understanding acceptance of the AI-based Hearing Protection Device (AI-HPD) since it is still in the early stages of development. To bridge the gap, this research sets out to identify important factors that need to be incorporated in the design consideration of AI-HPD and investigate users' intention of use which concerns us. The preliminary factor table is firstly generated from critical literature reviews on existing technology adoption theories. Expert reviews help to refine the factor table. With all summarized factors integrated, the final questionnaire of main survey is developed and given out. Through the returned report, the study discusses overall results and points out further study. This study enables researchers and professionals to better understand critical design and implementation considerations for the success adoption of AI-HPD technology in the future.

Keywords –
Construction Safety Monitoring; AI Application; Hearing Protection; Influence Factor

1 Introduction

Situational awareness is associated with safety-related perceptions at construction sites, notifying field staff critical information, for example, the safe distance of field workers from onsite equipment [1]. Recent developments in the field of Artificial Intelligence (AI) have led to a revolution in Architecture, Engineering, Construction (AEC) and Facilities Management (FM) domain. In order to increase situational awareness at construction sites, a number of studies have been carried out to solve practical problems with the help of AI. Kim et al. developed augmented-reality-applied system "Proximity Warning system (PWS)", which set out to prevent users from collisions with objects [2]. In Mardonova & Choi's literature review paper on wearable devices and sensors that enhance workers' situational awareness during mining operations, four types of sensors have been classified accordingly: environmental sensor, biosensors, location tracking sensors and others. Based on related research so far, it can be concluded that situational awareness enhancement is getting more and more attention in both industry and academia [3].

A construction site is such an unpleasant workplace since it mixes up many kinds of sounds beyond comfort level. According to a report from University of Washington [4], construction workers are exposed to multi-level noises because of the equipment they regularly use on-site, such as bulldozers and impact drivers. The average intensity of the noises is well above the 85 dBA in general. However, any sound featuring intensity at 85 dBA or higher is believed to cause ear damage and is great enough to be defined as hazardous. With that said, denoising is a significant technical issue in terms of protecting field workers' hearing. On the other hand, safety-critical sounds at construction sites, varying from acoustic safety cues to human speeches, make great contributions to generating situational awareness that further directs workers' behaviors. Therefore, auditory situational awareness (ASA), referred to situational awareness resourced from auditory signals, has been introduced. Despite that, traditional hearing protection solutions for field workers such as earplugs fail to balance preventing from ear damage and promising ASA. A practical example of construction can interpret this scene. When a carpenter installs a sub floor by connecting it to wooden-frame joints and uses impact driver to put nails in the joint through the sub-floor, the sound of a successful hitting the joint is different from the missed sound and signals the carpenter a well-done job. However, if the carpenter works with earplugs on, he/she is not able to hear the drilling sound clearly thus fails to give a swift inspection. Additionally, wearable devices are popularly applied to improve situational awareness in industries. As a result, a hearing protection technology in design of wearable device that uses AI to amplify safety-critical sounds while greatly attenuating ambient noise would be in great demand for preserving or augmenting the ASA of construction workers.

Audio signal processing for automated detection guarantees the technology of realizing the AI-based hearing protection device (AI-HPD). A variety of audio signal processing methods employing robust machine learning or deep learning models show prosperous successful potentials to quickly detect auditory safety cues and promise the ASA [5][6][7].These computing advances have been adapted to different contexts, ranging from indoor and public environments [8], medical and health care systems, to working environments [9]. However, when it comes to construction safety, it remains a problem to be addressed. Moreover, little to no study, to the best of our knowledge, has provided evidence on understanding the acceptance of AI-HPD because it stays the early stage of development. In view of the industry's infamous nature of resisting innovation, investigating what controls the successful acceptance of AI-HPD will provide useful information to convince practitioners of its viability.

In this paper, based on construction workers' hearing protection demands and current technical foundation, we envisioned a new AI-based hearing protection device. In an effort to explore user's input, concerns, requirements that are critical to the development of such technology in the future, we firstly listed possible factors according to a systematical literature review of social, physiological, and cognitive knowledge under the topics, for example, innovation adoption, technology acceptance. Then, we revised the factors in ways of introducing an expert panel review where experts from both the industry and the academia are invited to evaluate each factor. Subsequently, we proposed a questionnaire that integrates all reasonable factors after expert panel review and spread it to targeted group, practitioners who have working experiences at construction sites. After retrieving the returned questionnaires, we summarized and described the data and clarified our findings on it. At last, we concluded our work at this stage and pointed out future work.

2 METHOD

2.1 Influence Factors

In system/technology-related research, quite a few frequently used success models and adoption theories are applied to set up connections among multiple levels of practitioners on understanding the feasibility and benefits when an emerging system/technology is about to implemented [10]. Existing studies to date reveal that these basic models and theories have been extensively used across many fields in knowing the technology adoption and implementation, varying from financial services, Internet to education. Construction industry is not an exception. Son et al. took an interest in figuring out a mobile computing device's acceptance by construction professionals. They extended Technology Acceptance Model (TAM) [11] to explore determinants of user satisfaction with the device and link between user satisfaction and perceived performance. In order to determine the success or failure of EPR (Enterprises Resource Planning) system implementation in construction industry, Chung et al. generated a success model by adapting TAM model with Delone and McLean's information systems [12] and integrating them with key project management principles [13]. In analyzing what affects individuals' intention to utilize new technology for the sake of better leading a construction business, Sargent et al. practiced the Unified Theory of Acceptance and Use of Technology (UTAUT) model to examine IT adoption in construction management [14]. In previous studies, researchers followed a general workflow in preparation for confirming those factors controlling the success of a certain technology adoption: choose an original success model or theory, for example TAM, moderate the TAM based on the original model constructs and context-related variables, collect data and test the moderated model. Considering AI-HPD is part of innovation, confirming the factors can start from previous success models and adoption theories. In our study, we firstly put the basic constructs or variables of models in our factor table, like TAM, UTAUT, Delone and McLean Information System Success Model, Technology Organization Environment (TOE) Model [15], Theory of Planned Behavior (TPB) [16]. Secondly, we widely collected more technology adoption investigation documents in regard to the construction industry and also consider broader aspects of society, economy, and organization. By doing so, we developed a preliminary factor table for AI-HPD, which is supposed to be reviewed by the expert panel review and modified according to their comments.

2.2 Expert Panel Review

After the preliminary conceptional model comes into being, the content review by an expert panel is advised. Referring to previous study and sample size calculation, five experts including three researchers and two professionals in practice, with an average of 16-year experience in construction management, were suggested to review the preliminary factor table with regard to AI-HPD [17]. Out of getting sound and valid result, the candidate list for the expert review were selected from databases such as Google Scholar, ResearchGate, and LinkedIn by their academic or occupational relevance to the topic and academic influence. Three associate professors with key word tag Construction Management at Google Scholar respectively from the United States, Japan, China were invited to check the factor table via emails. Two USA-based civil engineers with approximate 20 years on-site working experience accepted the invitation. As a result, the final factor table was generated, as shown in Table 1.

Table 1. Factor table after expert review

No.	Factor	Definition or Scope
1	Participants Demographic Background	Age, institution or company, gender, race, annual income, education level, job title, hearing status, exposed-to-noise experience, hearing protection history
2	Perceived Usefulness	The degree to which a person believes that the use of AI-HPD would enhance his or her personal or job performance
3	Perceived Ease of Use	The degree to which a person believes that AI-HPD would be easy to use
4	Subjective Norms	Perception of important (or relevant) others' beliefs about my use of AI-HPD
5	Resistance to Innovation	The extent to which an individual resists new technology
6	Openness to Data Utilization	The extent to which an individual is comfortable with his or her data of job conditions being used and shared by a certain group while using AI-HPD
7	Hearing Health and Safety Consciousness	Awareness and care of hearing health conditions, and the degree to which hearing health concerns are integrated into an individual's regular work
8	Perceived Economic Constraints	Perception of the economic constraints or consideration of using AI-HPD
9	Perceived Organizational Impact	Perception of the organizational and societal constraints or influence of using AI-HPD
10	Attitude	User's general attitudes towards AI-HPD
11	Familiarity with the Use of AI Assistant	The degree to which the user is familiar with AI assistant
12	Trust	The extent to which an individual believes that using AI-HPD is secure, reliable, effective, and poses no privacy threats
13	Perceived Risks	A combination of uncertainty and seriousness of an outcome in relation to performance, safety, psychological or social uncertainties

2.3 Main Survey

The main survey was conducted in the form of a questionnaire, which consists of three primary sections, includes 79 open- and close-form questions. The first section introduces fundamental know-how of AI-HPD such as working principles, working modes. After reading the product introduction, participants are expected to answer the trap questions that help to filter out unqualified responses. The trap questions follow the prompts of "I read and understood the introduction section about AI-HPD", "How many modes would the AI-HPD operate", "When using the device under mode 1, you will hear every ambient sound". The second section requests demographic-based information from the survey participants. The third section asks the participants to rate the perceived level of importance for each factor using a five-point Likert scale where 1 represents "Totally disagree" and 5 represents "Totally agree." In particular, the questionnaire survey was designed on the platform of an online tool Qualtrics and distributed to elicit responses from the participants about the importance of the identified factors. At the same time, Amazon Mechanical Turk assisted to identify and reach the targeted construction personnel [18].

In our study, the AI-HPD would offer the following two operation modes.

- **Under the mode 1**, the intelligent filter blocks every sound to the user's ears and only send an alert when a hazard event is detected. The user would not hear anything except for warning alerts.
- **Under the mode 2**, the intelligent filter reduces every sound to under a safe level, but amplifies any critical sounds detected and attenuating unimportant sounds. The user would hear every ambient sound along with a warning alert if any.

Additionally, Intention of Use functions as a very important indicator in testing the participants' acceptance; whether AI-HPD would be accepted or not, which mode would be accepted, whether users would like to recommend it to others, should be focused. Therefore, our survey design subdivides the final Intention of Use into four parts in order to fully reflect the participants' acceptance on AI-HPD, which is specified by following questions, "I intend to use AI-HPD if it is provided by my organization", "I would prefer to use AI-HPD under the condition the device is on the mode of blocking all sounds to my ears and sending me an alert if a hazard event is detected, considering that system might miss an important sound or send a wrong alert", "I would prefer to use AI-HPD under the condition the device is on the mode of reducing all sounds to a safe level, but bypasses and amplifies any critical sounds detected, considering that the system might fail to amplify a critical sound or amplify an unimportant sound", "I will encourage field workers who are exposed to hazardous noises to use AI-HPD for hearing protection". Besides, when setting up questions for factor Perceived Economic Constraints, a filter question "Do you work, or have you ever worked as a business leader of a project" is designed for stopping unqualified participants.

3 Data Description

There were 332 completed responses. An additional 68 participants began the survey but failed to complete it either quitting halfway or being filtered out by trap questions, resulting in a dropout rate of 17% (68/400). The median survey completion time was 437 seconds.

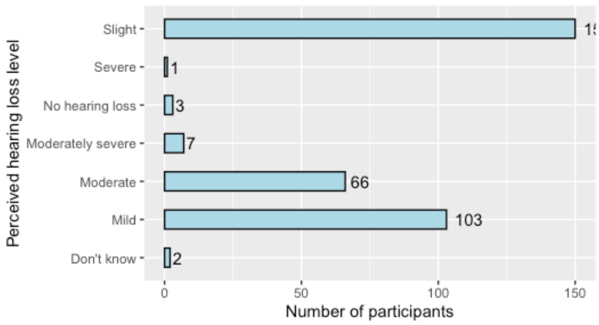

Figure 1. Perceived hearing loss as reported by participants. (N = 332)

3.1 Participant Background Characteristics

Participants ranged from 18 to 69 years old, with median age of 30 (M=32.9, SD=8.9). With all participants positively answering this question, the majority (78.3%) identified as female (N = 260), while 21.7% (N = 72) identified as male. 79.8 % of the participants hold Bachelor or higher degree (N = 265), however, only 1 participant didn't go to high school. Participant' s occupation diverged from business leader to carpenter. Figure 1 shows self-reported level of hearing loss that participants perceived they were suffering, as most participants reported slight or mild hearing loss. Similarly, at least 71.4% (N = 237) of the participants believed they were exposed to noises of different levels during working, as shown in Figure 2. When asked about if they put on hearing protection device whenever there is hazardous noise by Likert scale, the median located at 4 with standard deviation of 1.28, as Figure 3 shows the details. When asked about whether they have heard about any forms of loss caused by the use of hearing protection, the answers were split cleanly between Yes (P = 49.7%, N = 165) and No (P = 50.3%, N = 167), see Figure 4.

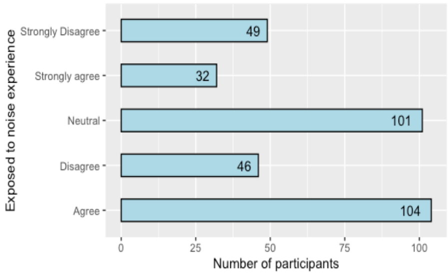

Figure 2. Exposed to noise experience as reported by participants. (N = 332)

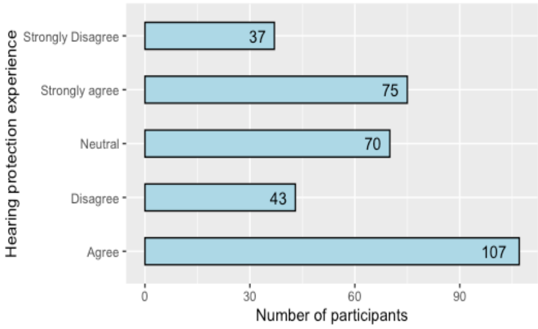

Figure 3. Hearing protection experience as reported by participants. (N = 332)

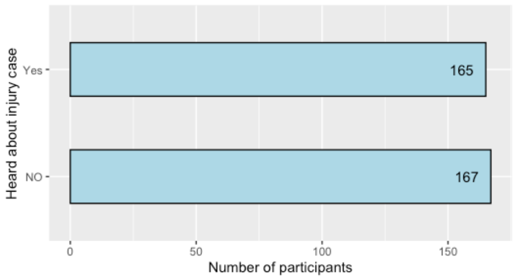

Figure 4. Heard about any injury case caused by using hearing protection as reported by participants. (N = 332)

3.2 Non-demographic factors and Intention of Use

Responses to non-demographic factors represent participants' attitudes towards AI-HPD under the premise they have understood this technology by browsing the introduction section. On the other hand, these factors, to certain degree, reflect the results of how society, economics, organization shape the way that participants treat such an innovation. Based on this, the data description of non-demographic factors is discussed.

Of Perceived Usefulness, approximate three quarters ("agree" or "strongly agree") of the respondents (P=72.5%, N=241) indicated that AI-HPD would be useful in improving the status-quo of construction sites. Just over 78.2% (N=261) of those who responded agreed that AI-HPD was supposed to be easy to use, concluded from the data of Perceived Ease of Use. In terms of Subjective Norms, 263 of 332 participants believed that people who were meant important to them would suggest them to practice AI-HPD if they got to know about it. As for Resistance to Innovation, different from the whole construction industry which posited a negative attitude towards innovation, almost 72.3% (N=240) of the participants were willing to try new technology. According to the result of Openness to Data Utilization, it's noteworthy that the population (P=61.4%, N=204) of those who positively agreed that job-related data could be used and shared was relatively less, in comparison to other factors. Specifically, only 80 of 332 participants chose "strongly agree" in this case, as shown in Table 2. In regard to Hearing Health and Safety Consciousness, the majority (P=81.3%, N=270) of the questionnaire takers concerned about their health and safety during job. Well under 7% of the participants didn't regard it as a big issue. Three questions were designed to observe Perceived Organizational Impact among the participants. When asked about "the regulations, policies, and procedures on safety in my organization is very strict", at least 241 of 332 believed that safety management was strictly performed in his/her organization. When asked about the hearing protection usage of collogues, by the question "most of my peers working in the field are currently using earplugs or earmuffs whenever required", 205 participants agreed that using earplugs or earmuff for hearing protection normally existed. At this time, the population of those who held neutral attitude rose up to 81 as shown in Table 3, which shows that a certain number of participants didn't have any knowledge about the hearing protection usage of their collogues. In the third question, when asked about "My peers who use earplugs or earmuffs for hearing protection have shown their demand in improving hearing capability", the statistics was very similar to that of the second question, explained by 210 responses of "agree" or "strongly agree" and 75 neutral responses. As for the factor Attitude, over 85.6% (N=284) of participants showed that they liked the idea of AI-HPD. In addition, 237 (P=71.4%) of the participants agreed that AI-HPD would be secure, reliable and efficient in terms of the factor Trust. Moreover, the result of Familiarity with the Use of AI Assistant indicated that most of the participants (P=85.2%, N=283) knew AI assistant well. However, when it came to Perceived Risks, 180 participants perceived that the risks such as misusing personal information, missing important sounds or sending wrong alerts were high. 83 of participants held neutral attitudes, explained by Table 4. This finding revealed that user information management and qualified technology are what concerned users and what we should pay special attention on. Additionally, there were 162 participants recognized as business leaders. More than 80% of them agreed that their organizations had the funding to afford AI-HPD and 66.7% of them reckoned that the expense of AI-HPD would be high.

Table 2. Openness to Data Utilization as reported by participants. (N = 332)

Openness to Data Utilization	Number of participants	Percent of participants
Strongly disagree	29	8.7%
Disagree	44	13.2%
Neither agree nor disagree	55	16.6%
Agree	124	37.3%
Strongly agree	80	24.1%

Table 3. Perceived peers' hearing protection usage as reported by participants. (N = 332)

Perceived peers' hearing protection usage	Number of participants	Percent of participants
Strongly disagree	15	4.5%
Disagree	30	9.0%
Neither agree nor disagree	81	24.4%
Agree	120	36.1%
Strongly agree	86	25.9%

Table 4. Perceived Risks as reported by participants. (N = 332)

Perceived Risks	Number of participants	Percent of participants
Strongly disagree	14	4.2%
Disagree	55	16.6%
Neither agree nor disagree	83	25.0%
Agree	121	36.4%
Strongly agree	59	17.8%

We examined overall intention of using AI-HPD, and the degree of interest of two modes, and intention of recommending it. Overall intention of use was high, with 79.5% of the participants (N=264) "agree" (scale=4) or "strongly agree" (scale=5) to use AI-HPD. Around 56.6% (scale=4 or 5) of the participants with at least "agree" degree to use mode 1 (users would not hear anything except for warning alerts), while 75% participants show great interest in mode 2 (users would hear every ambient sound along with a warning alert if any), as shown in Figure 5. It was worth noting that participants who rate one mode with high interest may agree or disagree the other mode. However, as far as the acceptance of two modes is concerned, mode 2 seemed to be more popular. The result of intention of recommendation indicated over 83% (N=276, scale=4 or 5) of participants had a strong passion on letting more people know about it.

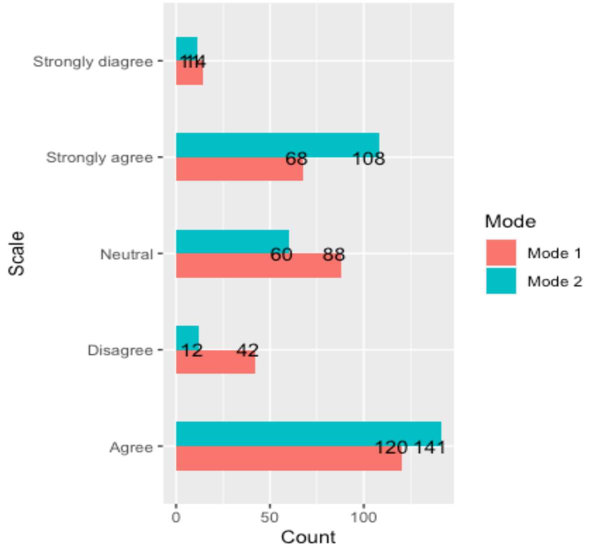

Figure 5. Intention of using Mode 1 and Mode 2

4 Conclusions and Future Work

This paper presents an effort to derive influence factors which control the successful acceptance and implementation of envisioned AI-HPD, a feasible hearing protection technology aiming to improve field worker's operating environments. Significant factors in the realm from social, physiological, economical and construction practice, were confirmed through a review of related literature and expert panel review. In order to further investigate the factors and pre-test workers' intention of using AI-HPD, a survey in the form of a questionnaire was generated, given out and returned with responses. Through describing and discussing the data retrieved, the authors expect this paper to help understand user's input, concerns, requirements that are critical to the development of such technology in the future.

As a result, it can be seen that noises have been an issue to most of the field workers and most of them tried or have been trying to avoid it by taking steps. As for findings from the statistics of non-demographic factors, user information management and qualified technology are what concerned users and where we should pay special attention in post product R&D stage. Quite a few participants believed that organizations they belong to were able to afford the expense of AI-HPD if it was considered; though the expense of AI-HPD was not perceived cheap. This signals us that the economic factors don't need to take up too much consideration when making decisions in the future work. The results of

Intention of Use showed that most people would like to use it; The working mode that enables users hear every ambient sound along with a warning alert if any was more popular, which directs us to focus on amplifying a certain sound in the background of noise in terms of auditory signal processing; large population of them would like to recommend this envisioned technology to their peers.

In future work, there are at least three aspects we should clarify. First, more specific discussions on each identified factor should be practiced. Second, different models or methods are suggested to be applied in analyzing how these factors affect the successful acceptance of AI-HPD and the coefficients of the distinguished factors. Third, the intention of use is made up of three parts, intention of using the technology, intention of choosing mode 1 or 2, intention of recommending the technology. Further data analysis of the subdivisions of intention of use is necessary.

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