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Short Communication

Design of a Smart Safety Vest Incorporated With Metal Detector Kits for Enhanced Personal Protection

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ABSTRACT

Background: Personal protective equipment (PPE) has been designed in such a way to reduce accident rates. Unfortunately, existing PPE is rather ineffective as it is not able to provide warning signals when hazard is around. The integration of intelligent systems is envisaged to increase the efficiency of existing PPE.

Methods: This project designed a safety vest incorporated with metal detectors which can provide immediate warning to the field workers when there is metal hazard around. This product has greater freedom of design via smart manufacturing as it involves the assembly of few commercially available parts into a single entity. Briefly, the metal detector is a do it yourself (DIY) kit, and the safety vest is purchasable from any local market. The DIY kit was connected to a copper coil and being sewed into the safety vest.

Results: The metal detector induces beeping sound when there is metal hazard around. A total of 121 engineering students were introduced to the prototype before being requested to answer a survey associated with the design. Respondents have rated >3.00/5.00 for the design simplicity, ease of usage, and light weight. Meanwhile, respondents suggested that the design should be further improved by increasing the metal detection range.

Conclusion: It is envisaged that the introduction of this smart safety vest will allow the workers to carry out their duties securely by reducing the accident rates. Particularly, such design is expected to reduce workplace accident especially during night time at construction sites where the visibility is low.

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1. Introduction

Personal protective equipment (PPE) has been designed in such a way to reduce accident rates [1] to protect the wearers (workers) from any physical impacts and to minimize the workers' direct exposure to any specific hazard [2–4]. Safety vests, safety helmets, goggles, gloves, and safety shoes are some of the common PPE used in various industries [5]. It is generally known that the effectiveness of PPE is an important mechanism to protect the safety and health of the workers [6,7] particularly at construction sites, ports, terminals, warehouses, and so on, where workplace accident always happens. In fact, most employers have enforced their workers to use PPE whenever they enter the working zone.

The statistics by the Department of Occupational Safety and Health revealed that about 1,116 accidents occurred between the year 2011 and 2016 with an average of 37.85–51.50% of it resulting in either death, permanent disability, or nonpermanent disability. In the recent years, accidents at building construction had recorded the highest number of deaths in Malaysia. Unfortunately, the total number of occupational fatal injuries remains immense, despite efforts have been taken to achieve zero accidents. For instance, accident rates kept increasing from 21.72% to 30.30% in the year 2013 to 2016 [8]. Furthermore, in 2016, more than 40% of the accidents happened because workers did not wear PPE properly.

According to Williams et al [9] and Tam and Fung [10], lack of training on safety and health issues caused little awareness on

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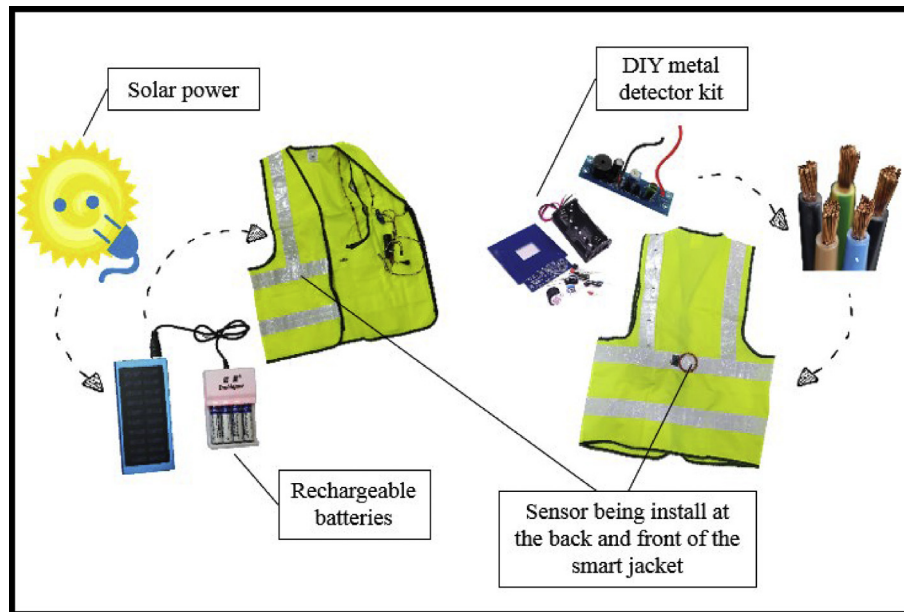


Fig. 1. Overview on the installation of the prototyped smart safety vest.

safety which eventually leads to more accident rates at the workplace. In addition, workplace accidents happened owing to the unique nature of the industry, job condition, management problem, and human element itself [11,12]. Most experienced workers will feel that PPE is not important to them as they are already used to what they are doing. Contrarily, workers who are new to the specific field would think that PPE is important to them as it can protect them from getting injured. This factor can be corrected by enforcement of PPE usage or via the creation of awareness among the workers [7,13,14]. Worthy to highlight is that workplace accidents may also be contributed from the limitation of existing PPE. In specific, the functionality of current PPE is passive in such a way that it only can reduce the impact caused by the accident. It will be good if the PPE can trigger a warning signal when hazard is around so that the wearers can be alerted and get him/herself away from the risk before occurrence of accident.

Considering the limitation existing in current PPE, the design of smart PPE which is incorporated with hazard detectors appears to be necessary and promising. The term “smart” refers to sense and react to stimuli [15,16]. Through digitization and intelligentization of manufacturing, it is potential to produce highly customized PPE that is incorporated with sensors. In fact, it has been recently highlighted that future PPE should be equipped with sensors to provide alert signals to the wearer [15,17–20]. In the present work, an existing safety vest will be of added value by incorporating a metal detector kit that can provide an immediate warning signal to the field workers when there is metal hazard surrounding him/her. This smart safety vest will be useful for construction workers who are highly exposed to accidents (due to metal impact). More importantly, visibility at the construction site deteriorates during night time and the workers might have work under fatigue and sleepiness condition [21,22]; under this condition, the smart safety vest will appear to be more effective in alerting the workers as compared with the conventional design.

Designing of this improvised version of safety vest is in line with the fourth industrial revolution (IR4.0) objective toward embedding modern technology into the industry. In addition, this design also answers the quest for Sustainable

Development Goal no. 8 (decent work and economic growth) and no. 9 (industry, innovation, and infrastructure). Details of the design, prototype photo, feedback from target respondents, and future modification based on the gathered feedback will be discussed in this article.

2. Materials and methods

Fig. 1 shows the overview of the smart safety vest. Fundamentally, the smart safety vest composes of three parts, namely the do it yourself (DIY) metal detector kit, the rechargeable batteries to power up the metal detector, and the safety vest itself. All the components can be easily purchased from local hardware shop and/or online shop. The DIY metal detector kit comprises simple electronic components such as buzzers, capacitors, resistors, and transistors that are fixable within a small Printed circuit board (PCB) board (6 cm × 6 cm). The whole detector kit is light in weight and thus will not cause extra burden or uncomfortableness to the wearer. Note that this DIY kit was extended to a coil of copper wire. This copper wire coil was installed at the back of the safety vest considering metal hazard located at the back is more critical (as it is out of the wearer’s visible range). Nevertheless, detection of metal hazard from different directions still can be performed by adding a few more detectors at different angles of the safety vest. The metal detector operated using battery which is rechargeable by solar energy, thus, provides a low maintenance cost.

Fig. 2 provides a closer look on the DIY metal detector kit installation and the copper coil structure. The electronic parts are hidden inside the reflector and thus do not affect the outlook and functionality of the reflector. This metal detector uses the simple electromagnetic principle. In brief, electricity that flows through the copper coil creates a magnetic field around the coil. This magnetic field will be disturbed upon approached by a metallic substance (iron in this case). The metal detector transmits this disturbed magnetic field and starts out the audio signal [23].

Noteworthy is that the DIY metal detector kit has been modified by inclusion of an on/off switch (Fig. 2). This on/off switch will allow the wearer to decide whether to on or to off the metal

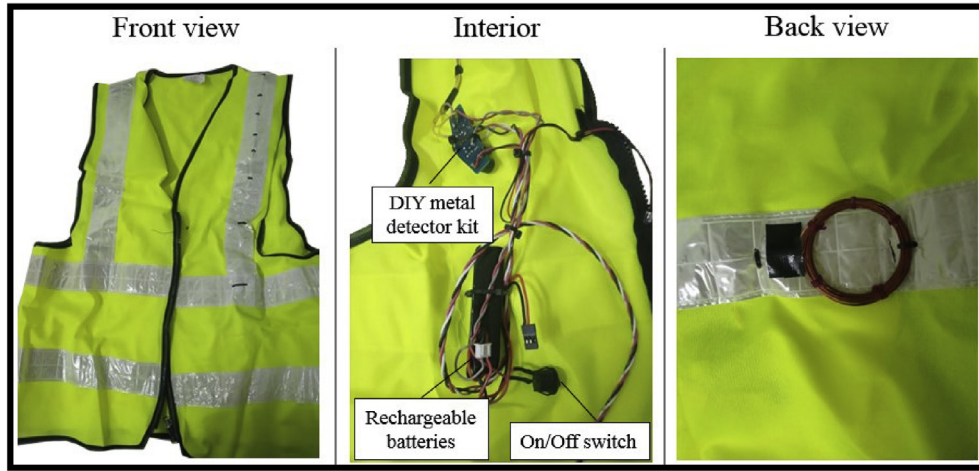


Fig. 2. Front, interior, and back views of the prototyped smart safety vest.

detection function. This gives an alternative option to the wearer whereby he/she can opt to off the metal detection when working with nonhazard metal. In another word, turning off the metal detector will convert the safety vest back to the conventional functionality.

3. Results

It is generally known that the viability of any newly designed product shall be assessed via survey and product testing [24]. Hence, a total of 121 respondents (who were undergraduate students in the third year engineering programme) were introduced to this prototyped smart vest and allowed to view its functionality from an on-spot demonstration. The respondents' characteristics (such as age, gender, and working experience) are summarized in Table 1. Note that near to half of the respondents have working experience in the actual engineering industry.

The respondents were asked to answer a questionnaire to receive their feedbacks. The questionnaire contains five questions as follows:

- Q1) Do you agree that a safety vest that sense “danger” can provide better protection than the conventional safety vest?
- Q2) How do you rate the design of this metal-sensing vest? (in term of its design simplicity, ease of usage, light weight, level of effectiveness, practicability, and environmental friendliness)
- Q3) In your opinion, what is/are the strength(s) of this metal-sensing vest?

Table 1
Summary of characteristics of the 121 respondents

	Gender	Age range (years old)			Working experience*	
		20-24.9	25-29.9	30-34.9	Yes	No
Male	72	69	3	0	36	36
Female	49	45	3	1	22	27
Total	121					

* Note that the working experience refers to whether the respondents have attended internship in the actual engineering industry before they answered this questionnaire.

- Q4) In your opinion, what is/are the weakness(es) of this metal-sensing vest?
- Q5) How likely will you buy & use this metal-sensing vest if you are working in construction site?

Firstly, 80.2 % of the respondents agreed that a safety vest that is incorporated with a hazard sensor provides a better workplace protection than the conventional safety vest (Fig. 3). Meanwhile, only 19.8 % of respondents disagreed on this statement. This result shows that the current generation is aware of the need to have an improved version of PPE which can provide an instant warning signal to the wearer when it senses the potential hazard. This kind of smart PPE is needed for the safety of people on site [18].

Next, the respondents were requested to give rating on the smart safety vest's design. The ratings were categorized as Rate 1 (poor), Rate 2 (moderate), Rate 3 (good), and Rate 4 (excellent). As shown in Table 2, most respondents rated good to excellent on the design simplicity, ease of use, light weight, and environmental friendliness of the design. These four criteria have obtained a mean rating of above 3. The present prototype is simple in the design as it was formed by incorporating two market available materials (i.e. safety vest and metal detector kit) into a single entity. The metal detector kit is light and thus does not add much weight on the safety vest. In fact, the weight of PPE will affect the compliances of workers to use the PPE [25]. More importantly, the wearer can opt to turn on or turn off the sensor. Here, the wearer can easily turn off the sensor when he/she are to work with metal material that is not a hazard. Nevertheless, only moderate rating was given to the design's level of effectiveness (2.083) and practicability (2.339). Apparently, the respondents have limited satisfaction on the sensing effectiveness. To gain more input from the respondents, they were requested to provide their viewpoints on the strengths and weaknesses of this smart safety vest.

Table 3 lists the summary of comments given by the respondents regarding the strengths and weaknesses of the current prototype version of the smart safety vest. In terms of the strengths, respondents agreed that the concept is creative, easy to install, and robust. More importantly, this smart safety vest can help to reduce accidents when the wearer is working at dark places. The buzzing sound can alert the wearer when he/she was too focused on the work. Nevertheless, respondents also stated that there are certain limitations in the current design. One of the mostly commented is that the current prototype version can only sense metal in a close

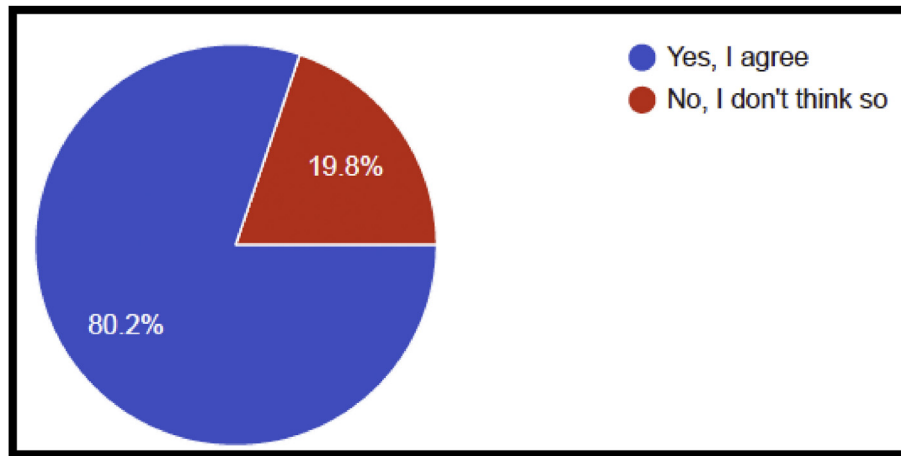


Fig. 3. Respondents' agreement on the better protection provided by a hazard-sensing safety vest as compared with the conventional vest.

distance. Accordingly, the mean rating given to the level of effectiveness is moderate (Table 2). One of the respondents suggested that further improvement shall be carried out by extending the detection range to at least 50–100 cm distance. Meanwhile, few respondents also raised their concerns about the price of this smart safety vest, which is expected to be higher than that of the conventional safety vest.

In the last part of the survey, the respondents were asked to rate the likelihood for them to purchase and use the smart safety vest. As shown in Fig. 4, 15 respondents voted for Rate 5 (very likely), 35 respondents voted for Rate 4 (likely), 49 respondents voted for Rate 3 (neutral), 16 respondents voted for Rate 2 (unlikely), and only 6 respondents voted for Rate 1 (very unlikely). Overall, positive feedbacks were received from the respondents with the mean rating falling at 3.306. Nevertheless, despite aware of the need of smart PPE, about half of the respondents hold a neutral decision on their likelihood to buy and use this smart PPE. Such results may ascribe to the limitations of the current prototype as mentioned in Q4 of the survey form. It is believed that the mean rating scale will shift to the right upon further improvement of the metal-sensing effectiveness.

4. Discussion and implication

Workers of the construction sites, warehouses, ports, and terminals are often exposed to workplace accidents. In particular, heavy impact induced by metal hazard may cause severe injuries. Despite being the common way to protect workers from hazard, the existing PPE is insufficient as it does not give warning signal before the occurrence of accident. The present work designed a smart safety vest by attaching a commercially available metal detector kit

Table 2
Rating on the design of the smart safety vest

Criteria	Mean rating	Rate 1 (poor)	Rate 2 (moderate)	Rate 3 (good)	Rate 4 (excellent)
Design simplicity	3.140	—	19	66	36
Ease of use	3.198	1	17	60	43
Light weight	3.256	1	18	51	51
Level of effectiveness	2.083	30	59	24	8
Practicability	2.339	22	48	39	12
Environmental friendliness	3.017	3	24	62	32

onto an existing safety vest. The prototype version is able to produce beeping sound and light on the light-emitting diode (LED) whenever a metallic object is approaching the copper coil. This warning signal is useful to alert the workers particularly at low visibility locations. Nevertheless, the detection distance is rather limited for this prototype version (~4 cm). Thus, it is envisaged that future modification is carried out so that the detection range can be fine-tuned based on the workers' requirement.

A preliminary survey has been made to gather feedback from target respondents (a group of undergraduate students in their third year engineering programme); the questionnaire was designed in such a way to identify the changes in the current market (Q1), to realize the needs of the potential customers (Q2), and to acquire an understanding of the marketability of this new product (Q5) [24,26]. More importantly, the respondents' viewpoint on the strengths (Q3) and weaknesses (Q4) of this prototyped product was gathered so that further improvement can be carried out before it becomes available in the market. The

Table 3
Summary comments given by the respondents regarding strengths and weaknesses of the current prototype version

Strengths	Weaknesses
1. Can avoid accident at dark places.	1. I think the weakness is that the metal sensor can only sense the danger in a close distance.
2. Ease of use, easy to install, and very good concept.	2. Range of the sensor too short. Not enough time to react.
3. The signal given is very clear.	3. Range to detect should be longer. Minimum of from 1 meter to 50 cm away.
4. Robust and light.	4. Sound produced is not loud. If the working environment is loud, will not be able to hear it.
5. It can help us to detect anything that might cause us dangerous while we are paying attention on our task without noticing the thing behind or come close to us.	5. Will be more expensive than conventional vest
6. Environmentally friendly with solar power recharging.	6. Water or sweat might affect the electronic system.

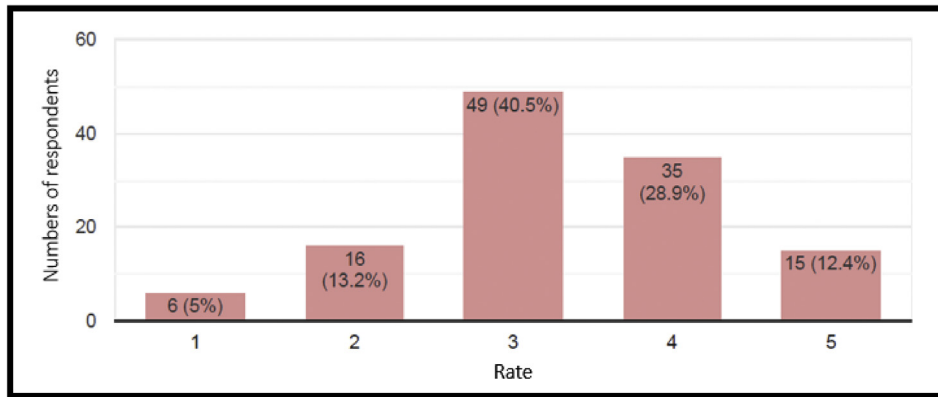


Fig. 4. The respondents' rating on their likelihood to buy and use this newly designed product.

respondents rated above average for the ease of usage, design simplicity, environmental friendliness, and light weight of the smart safety vest. Respondents also quest for further improvement on the detection range. Besides the detection range, other possibilities to upgrade this smart safety vest will be to allocate a tracking system connected to internet so that the employer can identify the location where metal hazard appears. The smart safety vest is appropriate not only for construction workers but also for warehouse or factory workers, road maintenance crews, railway workers, transportation sectors, and accident site inspectors who are normally exposed to metal hazard. With the increase in awareness on occupational safety in workplace, it is believed that the smart safety jacket will find its way in the market in most industries. In fact, 80.2% of the survey respondents agreed that the smart safety vest will provide better protection than the conventional safety vest. The remaining respondents (19.8%) who voted disagreement think that the newly designed vest has limited metal detection range. Accordingly, future tuning on the detection range shall be carried out.

In terms of theoretical implication, this article offers a unique contribution for future researchers to further expand the knowledge base pertaining to smart safety jacket adoption in the construction site toward reducing the accident rates. Moreover, this article is expected to enrich the existing PPE literature and the smart manufacturing application in the construction site in general. Overall, this article is among a few of its kind to adopt metal detector in the smart safety jacket which contributes to the theoretical advancement. This initiative supports the sustainable and innovative industrial environment, parallel with the UN's Sustainable Development Goal. Notably, this article enhances PPE and smart manufacturing literature.

In terms of managerial implications, four groups of stakeholders are expected to be important for successful implementation of this smart safety vest. The stakeholders mentioned here are (i) the government, (ii) the investor, (iii) the employer, and (iv) the employee. The government is also the policy maker responsible to enforce related legislations for better occupational safety and health. In particular, usage of smart safety vests shall be mandatory for those working in the high-risk industry. It is also suggested that more government-sponsored activities (training, workshops) to be conducted to instill the knowledge and awareness of smart safety jacket adoption particularly for the construction site and to other industries as well. Second, the investors play the role to motivate the market; here, it is envisaged that the production of smart safety vests can be upscaled and meets affordable price via proper investment and business plan. Third, the employer shall realize the importance of smart safety vests in protecting their employees and provide sufficient financial

support, despite it is expected that the cost for a smart safety vest is higher than that of the conventional ones. Lastly, the employee, as the person who is directly exposed to metal hazard, needs to ensure that the smart safety vest is being put on and properly used during working time.

5. Conclusion and recommendations

In this study, a conventional safety vest has been successfully modified by adding a simple metal detector kit. This metal detector provides additional function to the safety vest whereby warning signals will be turned on when there is metal hazard nearby the field worker. This newly designed safety vest is useful for workers who are working during night time when the visibility range is low. Feedback from target respondents on the design, the functionality, and the practicability of the smart safety vest has been identified in this study. Based on their feedback, future improvement strategies were proposed. In addition, researchers are highly encouraged to further explore the practicability of the smart safety jacket adoption by extending this study's initiative to broaden the knowledge base. In fact, this smart safety jacket could be further improved by (i) incorporating waterproof property for more extreme field work such as offshoring and underground work, (ii) modifying the metal detection range, and (iii) including an online tracking system for real-time monitoring.

Conflicts of interest

All the authors declare that there is no conflict of interest associated with this manuscript/project.

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