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WHICH INFORMATION IS ESSENTIAL FOR AN EXTERNAL HUMAN-MACHINE INTERFACE ON AUTOMATED PERSONAL MOBILITY VEHICLES?

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Abstract. *In the future, just like cars, personal mobility vehicles will be developed into automated personal mobility vehicles (APMVs). An emerging challenge concerns the human-machine collaboration between APMVs and other road users, such as pedestrians and non to low-level automated-driving cars. One approach to making autonomous personal mobility vehicles (APMVs) communicate with other road users is to use an external human-machine interface (eHMI). This study aimed to investigate which type of eHMI is important and clear to understand. We conducted a survey about the importance and clarity of 20 images of eHMI concepts for APMVs to 30 participants. The 20 images consisted of five different types of eHMI concepts from the literature in the color red and green. eHMIs containing text were regarded as clearer than non-textual eHMIs. The allocentric message "WILL STOP" was rated more important and clearer than the egocentric message "WALK". The research findings could be used by companies developing external human-machine interfaces for autonomous personal mobility vehicles and autonomous vehicles in general.*
Keywords: External human-machine interface, Automated personal mobility vehicles, Human-machine collaboration, Information type

1. Introduction.

Personal mobility vehicles (PMVs) are small electric vehicles designed to transport one person. Many types of PMVs, such as e-kickboards, self-balancing devices, and electric wheelchairs, have been developed. In the future, like cars, PMVs will be developed into automated personal mobility vehicles (APMVs). An emerging challenge concerns the human-machine collaboration between APMVs and other road users, such as pedestrians and non to low-level automated-driving cars. Like other modes of transportation, APMV has several drawbacks. These vehicles can easily be involved in accidents. They may yield fatal or severe injury due to higher speed and self-balancing issues, especially when they share walkways or sidewalks with pedestrians. The average walking speed is approximately 5 kph, whereas the speed of the current PMV, like Segway, can achieve up to 30 kph. Besides, APMVs impact pedestrian walkability while operating on a shared walkway or sideway. These devices create discomfort among pedestrians once they approach pedestrians and affect walking behavior.

External human-machine interfaces (eHMIs) have been proposed to compensate for lack of communication between AVs and pedestrians [1]. The communication messages

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of the external HMI can be divided into three types, which are instruction, intention, and base message [2]. Instruction-related messages explicitly inform the other road user how to act and provide confirmation signals when the road user performs the actions. An intention-related message indicates the APMV's intention and decision for the next action. Intention messages like "planning to go" and "slowing down" are believed the most efficient interaction message with the road user [3].

The realization of effective eHMIs also requires multi-modality signals. For instance, the explicit display of intent like "I am about to start driving" and state like "I am in automated mode" can significantly improve the pedestrians' satisfaction and feeling of safety [4]. In contrast, the auditory signals are much easier to be accepted by children and vision-impaired pedestrians [5].

Extensive research has been done to develop eHMI on AVs [1,5-9]; however, no consensus has been achieved on which eHMI concept is best for an AV. Apart from that, there is a difference between APMVs and AVs that has been studied. APMVs are smaller and can share the same space as pedestrians. The approach angle of an APMV is different from general AVs. The design of eHMIs may require standardization and regulation, as it is impractical – and potentially dangerous – to have a variety of eHMIs on future roads. No research has been conducted on eHMI for APMVs. This study aimed to investigate which type of eHMI is important and clear to understand specifically for an APMV. The first two sections present the introduction and methods used in this survey study. The importance and clarity results are presented in the third section. Section 4 discusses the findings in reference to literature and the limitations of the study are presented. Finally, Section 5 concludes the paper.

2. **Methods.** We selected 10 eHMI concepts from the previous eHMI for autonomous vehicle studies [1,6,8] that are suitable for use on an APMV. The purpose of selecting the 10 concepts was to use text-based, anthropomorphic, and non-anthropomorphic concepts from previous research on e-HMI for automated vehicles that lead to varying results on which information is the most important. A survey of 10 concepts kept the average completion time at 20 minutes which yielded a high percentage of complete responses (93%). The 10 eHMI concepts are categorized into various types: 1) 2 concepts were based on circles and light bars; 2) 2 concepts based on arrows and stop icons; 3) 2 concepts based on arrows; 4) 2 concepts based on anthropomorphic gestures and 5) 2 concepts were textual, 1 egocentric perspective for the pedestrian text ("WALK"), 1 allocentric perspective text ("WILL STOP"). Each concept was presented in two colors: green and red. We opted for green and red because these colors are already used in traffic signs, which allows us to investigate whether respondents attach the same 'egocentric' meaning to an eHMI (green meaning freedom to cross and red meaning not crossing) [7]. In total, 20 eHMI images were presented to the participants (Table 1).

A survey with images of the eHMIs was created using www.crowdsignal.com. At the beginning of the survey, the contact information of the researchers was provided, and the purpose of the survey was described as 'for long-term research on external HMI design for automated personal mobility vehicles. Completing the survey more than once from the same ID was not allowed. The content of the survey was provided in both English and Korean through a back-translation process. A payment of $10 was offered for completing the survey.

For each eHMI, respondents answered the statement 'The instructions of the car in concept N above are clear to me' on a 5-point Likert scale from 1) 'disagree strongly' to 5) 'agree strongly', together with a sixth option 'I prefer not to respond'. Additionally, respondents were asked 'What message does the APMV show in concept X above?', for which a textual response was needed. In both cases, X indicates the number of the concepts, as it appeared to the respondent. Additionally, respondents were required to

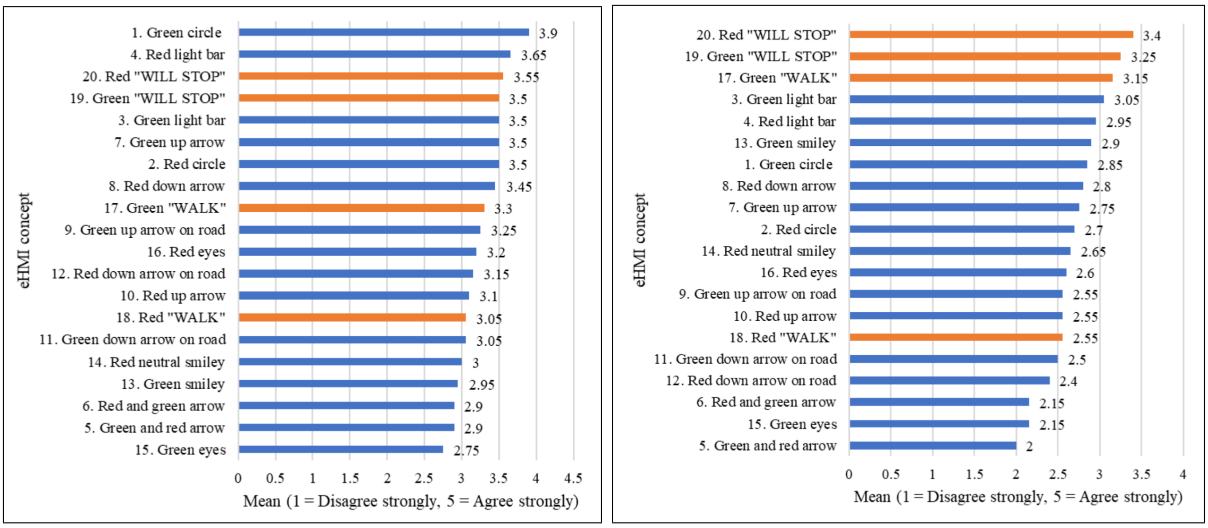
Table 1. eHMI for APMV concepts

1. Green circle 	2. Red circle 	3. Green light bar 	4. Red light bar 
5. Green and red arrow 	6. Red and green arrow 	7. Green up arrow 	8. Red down arrow 
9. Green up arrow on road 	10. Red up arrow on road 	11. Green down arrow on road 	12. Red down arrow on road 
13. Green smiley 	14. Red neutral smiley 	15. Green eyes 	16. Red eyes 
17. Green "WALK" 	18. Red "WALK" 	19. Green "WILL STOP" 	20. Red "WILL STOP" 

answer the question 'What is the color of the text/pixels on the display of the car above?' with options 'Green', 'Red', 'Green and Red', and 'Other'. This test question was added to filter out respondents who answered the questions without paying attention to the question content. The order of the items was randomized.

3. **Results.** Forty respondents participated between 17 June 2022 and 15 July 2022. Respondents who indicated that they had not read the instructions (N = 8) were excluded. Additionally, 2 respondents who made more than 5 mistakes (out of 20 possible) in specifying the color of the display were removed from the analysis. In total, 10 respondents were removed, leaving 30 respondents. The final sample consisted of 16 males and 14 females. The mean age of the respondents was 21.9 years (SD = 5.2). 26 respondents have used a personal mobility vehicle before. None of the participants have color blindness.

Figure 1(a) shows the mean importance ratings of the 20 images with the color of the bars indicating whether the eHMI was textual (orange) or non-textual (blue). Figure 1(b) shows the mean clarity ratings of the 20 images. By analyzing the rating scores for importance and clarity and the textual responses of the participants responses, we obtained the following findings. The green circle was regarded as the most important information to be presented (mean score 3.9); however, the mean clarity score was just 2.85. Following the green circle, the light bars, "WILL STOP", green up arrow, and red circle concepts were rated more than 3.5.



(a) (b)

FIGURE 1. (color online) (a) Mean eHMI importance scores of the instruction or information of the concepts and (b) mean eHMI clarity scores of the instruction or information of the concepts

Overall, eHMIs containing text were regarded as clearer than non-textual eHMIs. Among non-textual eHMIs, the circles and light bars were rated as more important and clearer. The allocentric perspective text "WILL STOP" was rated more important and clearer than the egocentric perspective text "WALK". The anthropomorphic eHMIs were consistently ranked in the bottom 10 out of the 20 concepts in importance and clarity.

The effect of color is evident in egocentric textual eHMIs but not clear in other types of eHMIs. The egocentric text "WALK" in green was rated more important and clearer than if it is designed in red. The concepts with two different direction arrows in green and red were rated low important and meaning unclear, even if it has a line as an indicator to stop.

4. **Discussion.** Extensive research has been conducted on eHMIs for autonomous vehicles, mainly cars [4]. However, no consensus has been achieved as to which eHMI should be recommended to be used on autonomous vehicles. Apart from that, there are many unexplored interactions with road users and vehicle types being studied besides passenger

cars. This is a preliminary study on eHMI for APMVs, which has similarities with autonomous cars but also significant differences. APMVs are smaller, lighter, and maneuver differently to cars, and can share the same space as pedestrians.

The results of this study showed textual eHMI is one of the most important types of eHMI. Text-based eHMI is evaluated as having a clear and unambiguous meaning. This is also consistent with [10] who compared textual and non-textual eHMIs and found that textual eHMIs were regarded as the least ambiguous and required no learning. In [11], pedestrians found egocentric messages (such as "WALK" and "DON'T WALK") clearer than allocentric (such as "BRAKING" and "DRIVING") and ambiguous ("STOP" and "GO") messages. However, this study resulted in the allocentric perspective text "WILL STOP" as both clearer and more important than the egocentric perspective text "WALK". This is in line with [3] which intention messages like "planning to go" and "slowing down" are believed the most efficient interaction message with the surrounding road users.

Another contradicting finding to most studies is that the green circle light has the highest importance rating among other concepts. Although deemed important, half of the participants were not sure what the green circle meant. The mean clarity rating was 2.85 (seventh out of 20 concepts). This shows that color-only eHMI is not informative without prior training, consistent to [7].

This preliminary study compared 10 different concepts that are technically available. The position of the eHMI is located at the bottom of the footstep of the APMV and the colors red and green were compared to understand the effect of color on eHMI importance and clarity. In the future development of eHMI, one of the technical challenges would be incorporating the data from all sensors and cameras of the APMV to correctly decide and present which eHMI to other road users. Specifically for the "eyes" concept (see Table 1, numbers 15 and 16), the technical challenge is to design the eye to be able to move following the pedestrian or other vehicle that is in front of the APMV, providing confirmation that the APMV is "looking".

There are several limitations to this study. Firstly, the eHMI concepts were attributed to only one type or characteristic. In the future, textual and non-textual concepts could be combined and supported with sound to make a multimodal eHMI. Online questionnaire has been used by many eHMIs for autonomous studies before in [2,4,6,7] to acquire meaningful information. However, it is a limitation that the eHMIs were presented in static images. In the future, dynamic scenarios of an APMV with and without eHMI could be studied in virtual reality and on-road. Furthermore, this preliminary study recruited 30 university students as participants. In the future, a higher number of participants and from different age groups is needed.

5. **Conclusions.** In this paper, we studied the importance and clarity of 20 external human-machine interfaces (eHMIs) for autonomous personal mobility vehicles (APMVs). We identified that textual eHMI is important and clear whereas the important non-textual eHMI is the circle light (green and red). The allocentric perspective text "WILL STOP" was rated more important and clearer than the egocentric perspective text "WALK". The anthropomorphic eHMIs were consistently ranked in the bottom 10 out of the 20 concepts in importance and clarity. The effect of color is evident in egocentric textual eHMIs but unclear in other types of eHMIs. Further research in a dynamic scenario presenting the eHMIs on an APMV should be conducted to be able to understand more deeply the effects of each eHMI design. The findings of this research could be used by companies developing external human-machine interfaces for autonomous personal mobility vehicles and autonomous vehicles in general.

In the future, we will conduct an experiment on the different road user point-of-views, APMV approach angles, and eHMI positions on different eHMI concepts. Multimodal eHMI with not only image but sound is also important to look into. Different eHMI sizes is also an important factor as future APMVs could come in very different models, sizes, and speeds which will affect the visibility. The results are noteworthy to be compared with larger automated vehicles.

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