

Development of Human Factors Design Guidelines for Haptic Collision Warning Systems

Jaemin Chun¹, Gunhyuk Park², Seunghwan Oh¹, Jongman Seo², In Lee²,
Seungmoon Choi², Sung H. Han¹, Woochul Park³

¹Department of Industrial and Management Engineering, POSTECH, Pohang, South Korea

²Department of Computer Science and Engineering, POSTECH, Pohang, South Korea

³Ergonomics Research Team, Hyundai Motor Company

Abstract

Haptic CWS (Collision Warning Systems) can effectively deliver warning signals, especially when the driver's visual or auditory sensory channel is busy. Warning signals are delivered to the driver through tactile sensation and are free from the interference of any ambient noises. In this study, guidelines for applying haptic feedbacks for collision warning are proposed. The proposed guidelines, based on intensive literature surveys, include: appropriate situations for using haptic feedbacks to provide collision warning, cautions that should be considered while applying the haptic feedbacks for collision warning, and the display type of haptic feedback (vibration on steering wheel, seat and seatback, pedal) most appropriate for a specific warning situation (forward collision warning, lane departure warning, and blind spot warning). General characteristics of tactile sensations were analyzed to identify the situations in which haptic CWS can effectively be used. Also, limitations of haptic displays are discussed to avoid negative side effects of haptic CWS when those displays are implemented in a vehicle. Another literature survey was conducted to collect and summarize the existing works evaluating the effectiveness of different types of haptic displays in various warning situations. Also, important information regarding the driver's behavior, functional requirements, and driving environments were identified to determine the most appropriate type of haptic displays that could be intuitively associated with the warning context. For every combination of the warning situations and display types of haptic feedbacks, this study assessed the appropriateness of each combination in terms of the three categories "Good-Fair-Poor".

Keywords automobile, haptic, collision warning, guideline

1 Introduction

Recently, haptic collision warning systems have gained the interest of the automobile industry. Various types of haptic feedbacks (steering wheel, seat, seat pan, or pedals) have been developed for collision warnings such as forward collision, lane departure, and rear end collision.

Advantages are expected when a collision warning is provided with haptic feedback. As drivers frequently use their visual (by conducting tasks such as concentrating on the road or checking the room and side-mirrors) and auditory (listening to multimedia devices or talking to other passengers) channels while they are driving, transmission of warning signals through those sensory channels could be ineffective [1]. According to the multiple resource theory, humans have independent information processing, which enables parallel processes unless they are inferred by the same modality [2]. By using the tactile modality as a collision warning signal, collision warning signals can be delivered to drivers without adding excessive workloads to the sensory channels (visual and auditory) that are currently in use while driving. Generally, the reaction time was shortest with tactile stimuli compared to visual and auditory stimuli [3, 4]. Through a direct contact between the driver's skin and haptic feedback, a warning signal can be delivered only to the driver who actually needs it.

Integrating results of relevant works, traffic and safety research centers such as NHTSA (National Highway Traffic Safety Administration) developed guidelines for haptic collision warning systems [5]. Though the existing guidelines were informative and well organized, we were able to identify some parts that needed improvement for practical use. In this study, we analyze the existing haptic guidelines and identify some of their weaknesses. Then, complementary works are pursued through intensive literature surveys and in-depth discussions.

2 Methods

2.1 Analysis of Existing Guidelines

A thorough analysis was conducted to identify the limitations of the existing guidelines. Each of the guidelines and their supporting references were examined. From the examination results, the weaknesses of the existing guidelines were sorted into the following three categories:

- Incomplete/outdated; There exist updated or newly published studies related to the existing guidelines.
- Not specific; The comprehensiveness of the guidelines and their rationale are weak. There exist more specific or in-depth researches to support the existing guidelines.
- Not existing; Relevant studies were not carried out, and the guidelines need to be improved with an additional literature survey or experiment.

2.2 Literature Surveys

An intensive literature study was conducted to collect relevant research for the complementary work. In this study, 175 documents (68 documents from proceedings, 49 from journals, 26 from technical report, 5 from books, 12 from patents, and 15 from other sources) were collected and analyzed. For efficient analysis of the literature, we developed a literature summary format (Figure 1).

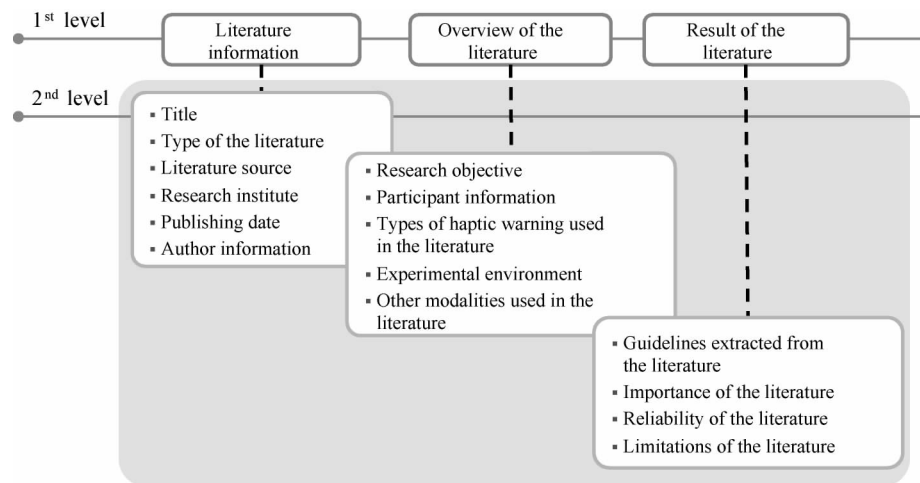


Figure 1 Structure of the literature summary format

The literature summary format comprised sub-categories such as literature information, overview of the literature, types of haptic warning used in the literature, results and limitations of the studies, and ratings of the importance of the literature and the reliability of the developed guideline. The importance of the literature was determined by assessing the relevance of a study's result to its objective. The completeness of the experimental design and the logical flow of the literature were considered while rating the reliability of its guidelines.

2.3 Development of Human Factors Design Guidelines

Based on the NHTSA guidelines, the structure of the proposed human factors design guidelines were composed of two major parts (Figure 2). Summarized information of the literature surveys was selectively used while revising the guidelines. In part 1 of the guidelines, the primary objective was to answer the question "When should haptic warnings be used?"

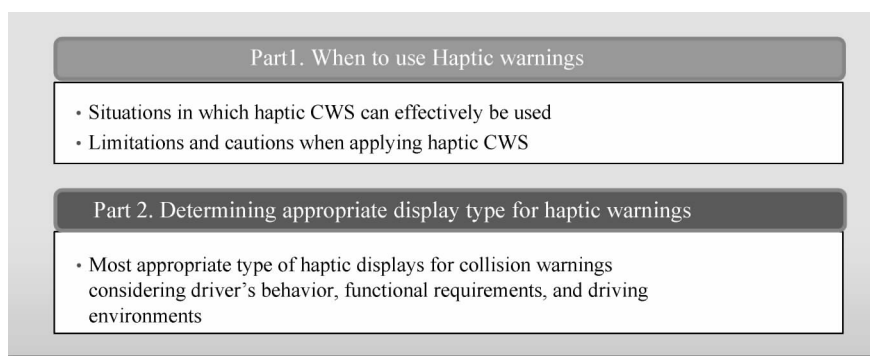


Figure 2 Structure of the human factors design guidelines

To improve the guidelines in part 1, studies concerning general properties of tactile sensory channels and evaluation of haptic warning systems in vehicles were analyzed. For example, an existing guideline suggested that "haptic warnings are good for providing warning information if other modalities are overloaded". However, neither the benefits of using haptic warnings (when other modalities are busy) nor the reasons for those benefits were specified. To complement the target guideline, our first task was to summarize the

relevant literature. That literature was integrated and classified in order to build the supporting rationales for the target guideline (Figure 3). In this way, we were able to develop some new guidelines that existing studies could not cover. In addition, guidelines that describe limitations and cautions when applying haptic CWS were developed in a similar way.

Guideline 7.	Information can be transferred effectively via tactile sensation without placing additional workloads on other sensory channels in use	
Rationales	Title	Reliability
1. Cognitive workload is greater when multiple information is transferred via a single modality compared to a multi-modal interaction	Tactile and Visual Distracters Induce Change Blindnes’s for Tactile Stimuli Presented on the Fingertips	High
	Driver Reaction Time to Tactile and Auditory Rear-End Collision Warnings While Talking on a Cell Phone	High
	BMW: Road Safety that Makes Sense	Medium
2. Masking effect is low among different modalities	Perceiving Ordinal Data Haptically under Workload	Medium
	Cross-modal Change Blindness between Vision and Touch	Medium
	Automotive Collision Avoidance System Field Operational Test	Medium
	Good Vibrations: Tactile Feedback in Support of Attention Allocation and Human-Automation Coordination in Event-Driven Domains	Medium
...

Figure 3 Example of the human factors design guidelines for haptic collision warning systems (part 1)

In part 2, we aimed to evaluate the appropriateness of the types of haptic display (seat, wheel, and pedal) to specific collision warning situations (forward collision warning, lane departure warning, and blind spot warning). Relevant literature was gathered and analyzed for all combinations of haptic display types and collision warning situations (Figure 4). Based on the integrated results of related studies, we rated the appropriateness of each combination as “Good-Fair-Poor”. Tips and cautions for successive implementation of each combination were provided in guidelines.

		FCW	LDW	BSW
	Rating	GOOD	FAIR	FAIR
Seat	Guideline	1. Effectiveness of warning was greater when the haptic feedback was provided simultaneously on seat and seat pan 2. ...	1. Haptic warning on seat pan was effective when provided in LDW situation. But it could be ambiguous when used with CVW 2. ...	1. Warning was most effective when provided on seatback only 2. ...
	Rationales	Effectiveness of warning was better when a warning is provided simultaneously rather than sequentially (seat → seat pan)	CVW should not be used with LDW and FCW. It can be confusing when drivers are on a curved road	More than one vibration actuator on each side of seatback can cause a confusion to the drivers
...

Figure 4 Example of the human factors design guidelines for haptic collision warning systems (part 2)

3 Results & Discussion

Based on NHTSA’s haptic collision warning system guidelines, we revised and improved the existing guidelines through intensive literature surveys and discussions. Out of 175 studies, 44 guidelines and 169 supporting statements were extracted (Figure 5). Of the supporting statements, 56 were rated as “highly reliable,” 86 as “medium,” and 27 as “low”.

The newly developed guidelines delivered enriched and comprehensive information with wider coverage. The guidelines were supported by specified rationales from related studies. For example, there was an existing guideline stating that “haptic warnings are not good for providing complex or potentially ambiguous information”. We determined that the suggested guideline was too implicit and decided to separate it into more specific and explicit guidelines. The revised guidelines are:

- Ambiguity in the warning situation (such as curve warning vs. lane departure or forward collision warning) can decrease the driver’s understanding of haptic warnings.
- Directional information of a haptic warning should be provided in a simplified way for intuitive understanding (Figure 6).
- Redundant information should be eliminated to prevent any misunderstanding of drivers.

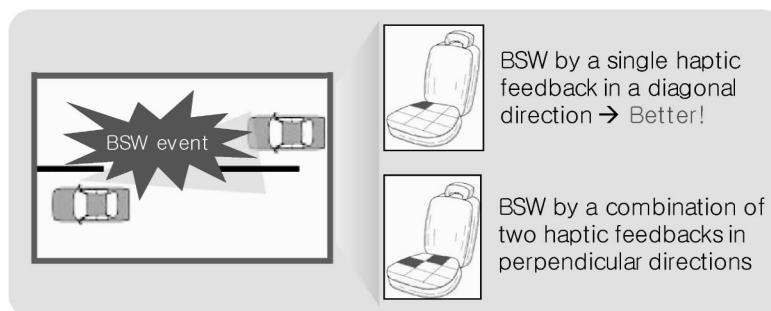


Figure 6 Illustrative explanation of a revised guideline

4 Conclusion

In this paper, we developed human factors design guidelines for haptic collision warning systems based on a study of the relevant literature. Relevant studies were summarized in the specified format developed in this study. Existing guidelines with weak points were

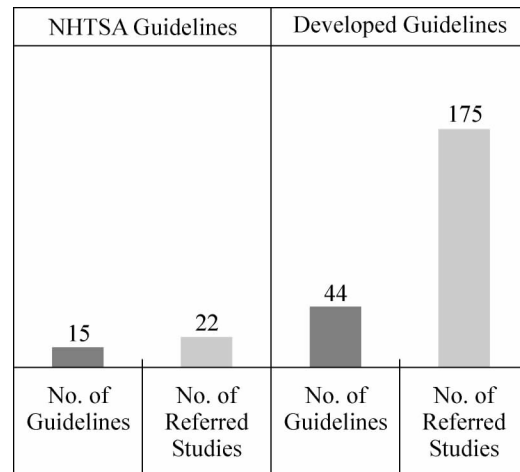


Figure 5 Numerical comparison of existing guidelines (NHTSA) and proposed guidelines

revised, and new guidelines were proposed with accompanying rationales. In this way, the comprehensiveness and reliability of the guidelines were greatly improved.

We hope the results of our research can be used in the process of designing haptic warning systems. Our next project is to find optimal specifications for haptic warnings depending on their display types (steering wheel, seat, or pedals). Additional literature studies are underway.

5 Acknowledgments

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