Sensible Media Simulation in an Automobile Application and Human Responses to Sensory Effects

Sang-Kyun Kim, Yong-Soo Joo, and YoungMi Lee

A sensible media simulation system for automobiles is introduced to open up new possibilities for an in-car entertainment system. In this paper, the system architecture is presented, which includes a virtuality-to-reality adaptation scheme. Standard data schemes for context and control information from the International Standard MPEG-V (ISO/IEC 23005) are introduced to explain the details of data formats, which are interchangeable in the system. A sensible media simulator and the implementation of a sensory device are presented to prove the effectiveness of the proposed system. Finally, a correlation between learning styles and sensory effects (that is, wind and vibration effects) is statistically analyzed using the proposed system. The experiment results show that the level of satisfaction with the sensory effects is unaffected overall by the learning styles of the test subjects. Stimulations by vibration effects, however, generate more satisfaction in people with a high tactile perception level or a low visual perception level.

Keywords: Sensory effects, 4D media, sensible media, adaptation engine, in-car entertainment, MPEG-V, human factors, style analysis survey.

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I. Introduction

An automobile is an ideal environment in which to adopt sensible media for in-car entertainment, as the automobile is already equipped with many sensory devices and sensors. On the other hand, the safety of drivers and passengers must be the first priority in an automobile. Therefore, an effective sensible media simulator and well-designed quality assessments of sensory effects are required to test the application of sensible media securely, considering many driving situations.

Recently, several studies have examined 4D media and sensory effects applied to a home entertainment system [1]-[14]. A basic system architecture and a simulator of a 4D media system for in-car entertainment appeared in the literature [15], though it described a limited amount of related content. Quality assessments and test datasets pertaining to sensory effects have been reported in several studies [10], [13], [14], [16]. A quality assessment of sensory effects using an MPEG-V compliant authoring tool and an amBX-based sensory effect generation system was reported [10]. The test dataset for the quality assessment of sensory effects and instruction on how to use the dataset was presented [13], and a quality assessment of sensory effects of videos of several genres was also presented [14]. The main consideration in the present study is an investigation of the effects of different genres and the bitrates of test videos on the viewer's degree of satisfaction with the sensory effects. This study, however, does not take into account the personal learning characteristics of the test subjects against the sensory effects presented. Related to this, an electroencephalogram-based analysis of scent effects has been reported [16].

The personal learning styles of humans can be classified as visual, auditory, or haptic, depending on which sensory channels are prominent when the user processes and memorizes new information. The personal learning style plays an important role in determining the final sensory effects displayed in an automobile. In other words, the best sensory effects can be selected or prioritized in accordance with the user's personal learning style.

Before performing a quality assessment of sensory effects by combining all related information (for example, sensor data, user sensory preferences, sensory device capabilities, and the user's learning style), the relationship between personal learning styles and sensory effects should be investigated as a fundamental study. We assume that the satisfaction with sensory effects can be differentiated in accordance with each individual user's personal learning style. Therefore, the relationship between two sensory effects (for example, wind and vibration) presented with video clips and personal learning styles are analyzed in this paper.

The aim of this paper is to comprehensively introduce a sensible media simulation system, the related standards, and its implementation, which includes a virtuality-to-reality (V2R) engine. Also, a quality assessment of sensory effects is presented. Therefore, in this paper, several data formats for user sensory preferences, device capabilities, control commands, and a sensor based on MPEG-V (ISO/IEC 23005) [17], [18] are introduced to enable the realization of sensory effects effectively in an automobile. A sensible media simulation system for an automobile that accepts sensory device commands in real time is presented. Because it is difficult to actually install such a simulation system in an automobile, we provide a set of sensory devices and design an adaptation engine to produce optimal device commands to mimic an in-car situation.

Finally, sensory effects (wind and vibration) generated by the proposed simulation system are evaluated in terms of personal learning styles. Each personal learning style is determined using a style analysis survey (SAS). A quality assessment of wind and vibration effects is performed based on the personal learning styles thus classified.

This paper is organized as follows. The overall system architecture is described in section II. This section also explains how user sensory preferences, sensory device capabilities, sensory device commands, and sensed information for temperature are represented, with definitions from the MPEG-V International Standard (ISO/IEC 23005-5). Furthermore, detailed usage examples of each schema are presented. Section III details the sensible media simulator with descriptions of the system structure and algorithm to adapt to real-life driving situations. The implementation of the sensory device system and the related sensible media simulator are presented in section III as well. Section IV presents experimental settings and human response results against wind and vibration effects based on the personal learning styles. Finally, the conclusion is presented in section V.

II. Metadata of Sensible Media Simulation for an Automobile Application

1. Overall System Architecture

The overall system architecture for the sensible media simulator discussed herein is displayed in Fig. 1. The architecture is derived from MPEG-V Part 1 (ISO/IEC 23005-1) [19].

The data formats for sensory effects to represent wind, vibration, temperature, and light effects in multimedia content can be described with the syntax and semantics defined in MPEG-V Part 3 (ISO/IEC 23005-3) [20], as depicted in Fig. 1 (ellipse {1}). Because content providers can create sensory effects, we assume that this metadata is delivered and played with multimedia content simultaneously. The initial report about video annotation tools and evaluations of a number of sensory effects were presented in the literature [12].

The metadata introduced in this paper is depicted by means of pink ellipses {2} through {5} in Fig. 1. The capabilities of sensory devices in an automobile can be described with the syntax and semantics of MPEG-V Part 2 (ISO/IEC 23005-2) [17], as depicted in ellipse {2} of Fig. 1. The user sensory preferences can be described with the syntax and semantics of MPEG-V Part 2 (ISO/IEC 23005-2), as depicted in ellipse {3} of Fig. 1. The user sensory preferences indicate the user's personal preference for a specific sensory effect. For example, a pregnant woman would not want to experience any sudden vibrations or movements; therefore, she can exclude vibration effects.

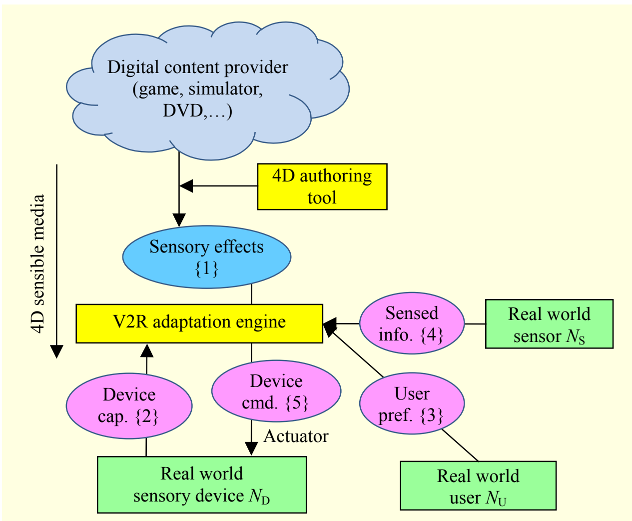

Fig. 1. Sensible media simulator system architecture [19].

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The sensed information from MPEG-V Part 5 (ISO/IEC 23005-5) [18] depicted in ellipse {4} of Fig. 1 can be used to represent the temperature sensor data from inside an automobile. Finally, the data format of device commands from MPEG-V Part 5 (ISO/IEC 23005-5), which control the sensory devices in this automobile, is depicted in ellipse {5} of Fig. 1.

The V2R adaptation engine takes sensory effect metadata from media, sensory effect capabilities from sensory devices, sensed information from sensors, and the sensory effect preferences from users and generates sensory device commands by adapting the sensory effects based on the capabilities, sensed information, and/or preferences.

2. Metadata Syntax and Semantics

The current syntax and semantics of metadata for MPEG-V projects are based on XML schemata. However, in this paper, an overview of the standardized sensory-related information in the EBNF (Extended Backus–Naur Form) style is provided due to the lack of space and the verbosity of XML [5]. Only some of the syntax and semantics are presented due to the lack of space.

A. Schema for Sensory Device Capabilities

HeatingCapabilityType ::=
    SensoryDeviceCapabilityBaseType
    [*unit*] [*maxIntensity*] [*minIntensity*] [*numOfLevels*]

SensoryDeviceCapabilityBaseType provides the topmost base-type hierarchy that each individual sensory device capability can inherit. This type includes *SensoryDeviceCapabilityAttributes*, which describes a group of common attributes for the sensory device capability.

HeatingCapabilityType is a tool for describing the capability of a device to increase the room temperature. The *unit* specifies the unit of the intensity value if a unit other than the default unit is used, as defined by a classification scheme term provided by UnitCS defined in A.2.1 of MPEG-V Part 6 (ISO/IEC 23005-6) [21]. The *unit* attributes from this point on in this paper will share the same meaning. The *maxIntensity* attribute describes the highest temperature that the heating device can provide in Celsius (or Fahrenheit). *CoolingCapabilityType* has the same structure as *HeatingCapabilityType* except that *maxIntensity* describes the lowest temperature provided by the cooling device.

WindCapabilityType ::=
    SensoryDeviceCapabilityBaseType
    [*unit*] [*maxWindSpeed*] [*numOfLevels*]

WindCapabilityType is a tool for describing the capability of a wind device, such as a fan or an air conditioner. The *maxWindSpeed* attribute describes the maximum wind speed that a fan can provide in meters per second.

VibrationCapabilityType ::=
    SensoryDeviceCapabilityBaseType
    [*unit*] [*maxIntensity*] [*numOfLevels*]

VibrationCapabilityType is a tool for describing the vibration capability. The *maxIntensity* attribute describes the maximum intensity that a vibrator device can provide in terms of the Richter magnitude.

B. Schema for User Sensory Preferences

WindPrefType ::=
    UserSensoryPreferenceBaseType [*maxIntensity*] [*unit*]

UserSensoryPreferenceBaseType provides the topmost base-type hierarchy that each individual user sensory preference can inherit. This type includes *userSensoryPrefBaseAttributes*, which describes a group of common attributes for user sensory preferences.

WindPrefType is a tool for describing user preferences for the wind effect. The *maxIntensity* attribute describes the maximum desirable intensity of the wind effect in terms of strength on the Beaufort scale.

VibrationPrefType ::=
    UserSensoryPreferenceBaseType [*maxIntensity*] [*unit*]

VibrationPrefType is a tool for describing user preferences for the vibration effect. The *maxIntensity* attribute describes the maximum desirable intensity of the vibration effect in terms of strength with respect to the Richter magnitude scale.

C. Schema for Sensed Information

TemperatureSensorType ::=
    SensedInfoBaseType [*unit*] *value*

SensedInfoBaseType provides the topmost base-type hierarchy that each individual's sensed information can inherit. This type includes *sensedInfoBaseAttributes*, which describes a group of common attributes for the sensed information.

TemperatureSensorType is a tool for describing sensed information with respect to a temperature sensor. The *value* describes the sensed value of the temperature in Celsius (°C).

D. Schema for Sensory Device Commands

HeatingType; *CoolingType*; *WindType*; *VibrationType* ::=
    DeviceCommandBaseType [*intensity*]

DeviceCommandBaseType provides the topmost base-type hierarchy that each individual device command can inherit. This type includes *DeviceCmdBaseAttributes*, which describes a group of common attributes for device commands.

Heating, *Cooling*, *Wind*, and *VibrationType* are tools for describing commands for heating, cooling, wind, and vibration devices to follow, respectively. The *intensity* attribute describes the intensity of each effect in percentage with respect to the capable range of the specified device deploying the effect. If the intensity is not specified, this command shall be interpreted as being turned on at maximum intensity.

III. Sensible Media Simulator

1. Structure of Sensible Media Simulation System

The SMURF (Sensible Media aUthoRing Factory) tool [12] is used for describing the sensory effects of a video sequence. It is based on Flex and Java and provides a means for simply creating and editing sensory effects.

Figure 2 demonstrates the structure of the sensible media simulation system. This system is composed of a simulation part based on Flex and a sensible media control system (SMCS) part implemented in Java. While the simulation part simulates the situations in an automobile, the SMCS part controls the sensory effects in accordance with the conditions inside the car. The blazeDS module is used to exchange data.

The core of this system is the SMCS part. The SMCS is composed of the following: an electronic control unit (ECU), which controls every device inside the car; a sensible media rendering engine (SMRE), which controls the rendering of sensory effects; a sensor unit that is used to acquire information inside the car; an XML metadata management unit (XMM) that is used to generate and interpret the standard XML data; and an integrated controller unit that controls the entire control system.

The XMM unit is implemented with reference software provided by ISO/IEC 23005-7 [22]. The SMRE unit generates sensory device commands, which are adapted by combining user sensory preferences, sensory device capabilities, sensed information, and sensory effects embedded in media.

The process inside the system complies with the following steps, as depicted in Fig. 2: {1} a sensory effect event occurs; {2} a service is requested; {3} a sensory device command is generated by combining information from user sensory preferences, sensory device capabilities, sensed information, and the sensory effect event; {4} the sensory device command is returned to the simulation part; and {5} the sensory device command is rendered to the simulator.

2. Adaptation for Real-Life Driving Situations

The ECU and the integrated controller unit shown in Fig. 2 are designed to override sensory device commands with

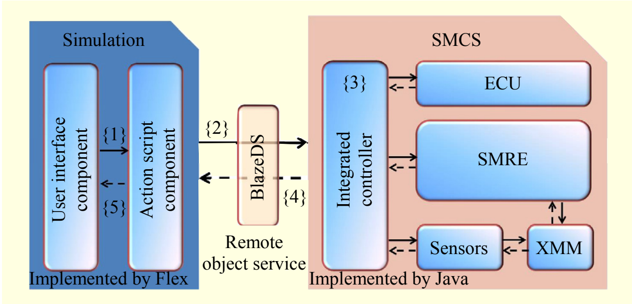

Fig. 2. Sensible media simulation system.

ordinary device controls in accordance with various real-life driving situations. These occasions include those in which the sensory effects interfere with vehicle maneuvering or when a driver needs to acquire driving-related information, all of which should take precedence over in-car entertainment.

For instance, if a car is equipped with an actual collision detection system, an alarm from the system must inform the driver prior to any sensory effects. In other words, any sensory effect (for example, wind, vibration, or sound) shall be canceled or ignored in the case of any alarm. This can cause a serious problem for a driver, who may confuse an alarm with a deployed sensory effect. The SMCS is designed and implemented to resolve this type of conflict.

Another adaptation occurs with temperature effects (that is, heating and cooling). Imagine that a movie contains an arctic scene with a forceful blizzard. The sensory effect corresponding to the scene would be cooling temperature and a wind effect with 5°C at 100% intensity. Assume that the current temperature inside the car is 10°C. It would not be wise to deploy the cooling and wind effect as described in the sensory effect metadata because the current temperature inside the car is already unpleasantly cool. The passenger may feel uncomfortable with the generated sensory effects.

The SMRE and the ECU can automatically control the temperature-related effect in accordance with the temperature information from the temperature sensor(s). For example, the SMRE generates a heating command and sends it to the ECU when the current temperature inside the car is lower than the predefined lower-bound temperature. The SMRE generates a cooling command and sends it to the ECU when the current temperature is higher than the predefined upper-bound temperature. If the current temperature is equal to the temperature designated by the temperature effect, the SMRE does not generate a device control command.

The ECU calculates the difference between the temperature assigned to the device command and the current temperature. The result of the temperature difference can determine the strength of the wind. For example, when the current temperature is 25°C and the device command is 26°C, the

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ECU enacts heating wind with the lowest level.

Therefore, the SMSC is implemented to render the proper temperature effects inside an automobile by generating device control commands considering the current temperature and by controlling the strength of the wind with respect to the difference between the current temperature and the temperature assigned to the device control command.

3. Sensible Media Simulation Rendering

The sensible media simulator depicted in Fig. 3 is a simulation system that plays the sensory effects of media in the automobile. The capabilities of sensory devices in the automobile can be compact, mid-size, or luxury; alternatively, they can be customized. Assuming that the automobile is equipped with sensory devices, such as a wind system with cooling, heating, and ventilating functionality, vibration chairs with a massage function and heating wires, and a LED light system with a color and intensity controller, the sensory device capability information is converted to XML instances and consumed by the SMRE.

Personal user sensory preference information is entered through the simulator UI and converted to XML instances to be consumed by the SMRE. The in-car temperature is initiated by the user through the simulator UI and simulated in accordance with the sensory effects deployed (for example, wind and temperature effects).

When movies with sensory effects are played, the SMRE combines the sensory effect information with capabilities, preferences, and sensed information to generate the appropriate sensory device commands in real time. As shown in Fig. 2, the generated sensory device commands trigger the simulator to illustrate the sensory effects in media in a synchronized manner.

The simulator can simulate driving situations, such as sudden braking, parking in reverse, and collision detection. The temperature of the wind effects is adoptively controlled in accordance with the in-car temperature as calculated by SMRE.

4. Sensory Device System Implementation

The sensory effects rendered in the simulator are simultaneously displayed through actuators, which include fans, LEDs, and vibrators. Figure 4 shows the actuators for the sensory effect display and their control modules. Figure 4(a) is a fan for a wind effect, Fig. 4(b) is a heating fan for a heating effect, Fig. 4(d) is a LED light for a lighting effect, and Fig. 4(e) is a vibrator for a vibration effect. Figures 4(c) and 4(f) are the actuator control modules. Figure 5 shows a sensory device command transmitter that transmits sensory device commands created by the SMRE to each actuator. Figure 6 presents a simulation system setup that displays sensory effects on both

Fig. 3. Sensible media simulator implementation (rendering of heating, vibration, and lighting effects).

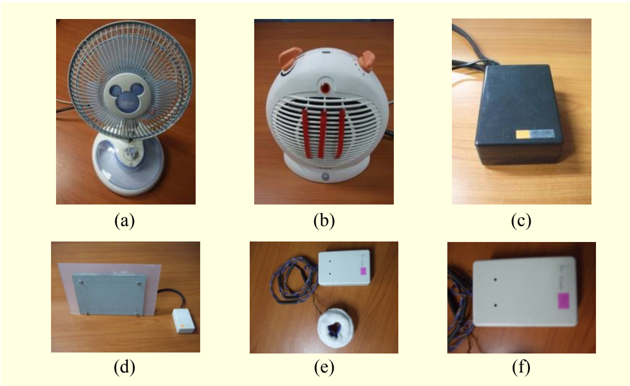

Fig. 4. Actuators for sensory effect display (a), (b), (d), (e) and their control modules (c), (f).

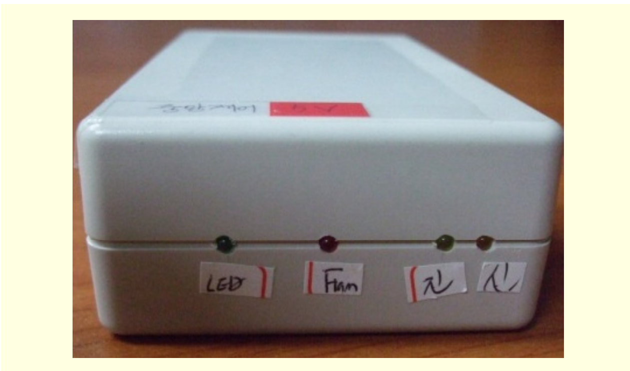

Fig. 5. Sensory device command transmitter.

the sensible media simulator and sensory effect display actuators. In the figure, wind and lighting effects are being displayed on the simulator and by the actuators simultaneously.

In more detail, a sensory effect actuation process proceeds as follows. The sensory effects embedded in the media are

Fig. 6. Simulation system setup.

```
<SEM>
  <!--Fade-In-->
  <Effect xsi:type="sev:WindType" activate="true"
intensity-value="50" fade="3" si:pts="0"/>
  <Effect xsi:type="sev:WindType" activate="true"
intensity-value="50" duration="5" si:pts="3"/>
  <!--Fade-In-->
  <Effect xsi:type="sev:WindType" activate="true"
intensity-value="80" fade="2" si:pts="8"/>
  <Effect xsi:type="sev:WindType" activate="true"
intensity-value="80" duration="5" si:pts="10"/>
  <!--Fade-Out-->
  <Effect xsi:type="sev:WindType" activate="false"
intensity-value="50" fade="3" si:pts="15" />
  <Effect xsi:type="sev:WindType" activate="true"
intensity-value="50" duration="7" si:pts="18" />
  <!--Fade-Out-->
  <Effect xsi:type="sev:WindType" activate="false"
intensity-value="0" fade="3" si:pts="25" />
</SEM>
```

Fig. 7. XML instance of series of wind effects.

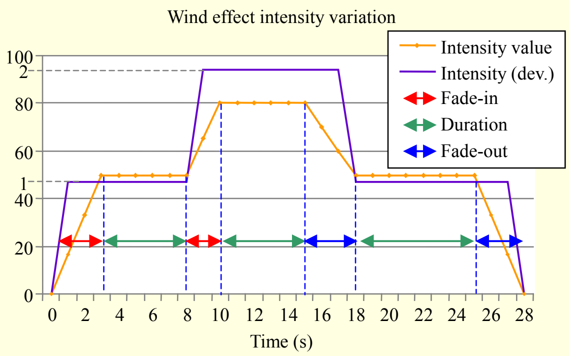

Fig. 8. Graph of sensory effects and their corresponding sensory device commands.

combined with user sensory effect preferences and the actuator capabilities. The SMRE then generates optimal sensory effect commands in real time. The sensory effect commands generated are converted into actuation commands and transmitted to the sensory device command transmitter (Fig. 5) using an RS-232 serial communication. The sensory device command transmitter then transmits the actuation commands to each control module in the actuators by means of ZigBee communication. The control modules control the actuators to display the corresponding actuation commands.

Figure 7 shows an XML instance of a series of wind effects. The instance contains wind effects with fade-in and fade-out characteristics lasting 28 seconds. Figure 8 depicts the flow of sensory effects in the XML instance shown in Fig. 7 with its corresponding sensory device commands. In Fig. 8, the x axis represents the time in seconds and the y axis represents the intensity values of the sensory effects along with the intensity levels of the sensory device commands. The orange line represents variations of the sensory effect intensity values while the purple line represents the corresponding sensory device commands generated by the SMRE considering the capabilities of the sensory device (for example, the capability of a fan).

IV. Experiments

1. Quality Assessment of Sensory Effects Based on Personal Learning Styles

We assume that the level of satisfaction with sensory effects can be differentiated in accordance with the user's personal learning style. This should be studied before undertaking a quality assessment of sensory effects generated from the adaptation engine described in the previous section.

In this experiment, we undertake a quality assessment of sensory effects (that is, wind and vibration) based on personal learning styles, as classified by a body sensing preference classification method. Because most of the sensory effects are closely related to the tactile senses, a quality assessment of sensory effects can differ in accordance with the personal learning styles of the test subjects based on their body sensing preferences.

To investigate the body sensing preferences of each test subject, we perform an SAS [23]. The SAS is a survey tool that classifies learners' psychological characteristics into five learning patterns: body sensing preferences, interpersonal relationships, coping strategies for possibilities, an assignment approach, and a thinking deployment method.

The body sensing preference classifies a user's learning style into one of the three styles (that is, visual, auditory, or haptic) in accordance with which sensory channel is most active when the user receives and processes new information. The learning style of a test subject is determined via 10 test questions on a five-point scale for each learning style and by assigning the style with the highest score.

2. Experimental Procedure

Two videos approximately one and a half minutes each are

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provided for the quality assessment of the wind and vibration effects. The first video contains scenes of a ski jump. The acceleration of the ski jump is expressed by wind effects. The second video contains scenes of cavalry charges, of which ground tremors are expressed by vibration effects. The actuators in Figs. 6(a) and 6(e) are utilized to render wind and vibration, respectively.

The test subjects are 83 college students, consisting of 68 males and 15 females, aged between 20 years old and 29 years old. Among them, 41 subjects evaluate wind effects and 42 subjects evaluate vibration effects.

The experimental procedure is as follows:

① The learning style of each test subject is classified using the SAS.

② Each test subject experiences the video with sensory effects using the sensible media simulator.

③ After the sensible media simulation, each subject assesses the sensory effect via the evaluation questions.

Because there are no comparable survey questions with which to assess the sensory effects based on personal learning styles in previous studies, an expert in the area of educational psychology (one of the authors of this paper) is invited to design the evaluation questions and experiments. The evaluation questions are provided in Korean. Each evaluation question is scored on a five-point scale by the test subjects. The questions are as follows:

① Before watching a video, I had expectations about the video due to the information provided about sensory effects and their rendering devices.

② The presented sensory effects helped me to enjoy the video more.

③ The presented sensory effects kept me from focusing on the video.

④ The presented sensory effects are well matched with the video content.

⑤ The presented sensory effects lived up to my expectations.

⑥ It was better to experience sensory effects when watching a movie.

⑦ The presented sensory effects gave the actual feelings of the video content.

Question 3 is purely a negative question. This question was deliberately devised to check the consistency of the subjects' answers. The scores for question 3 are reversed when they are counted (for example, 5→1, 2→4).

3. Experiment Results

The quality assessment results for the sensory effects of wind and vibration are statistically analyzed. Table 1 shows statistics used in the quality assessment of each sensory effect. The average score for the wind effect is $\bar{x}_1$ =25.07 out of a total score n of 35. The standard deviation is s_1=2.33. The minimum and maximum scores are 19 and 29, respectively. The average score for the vibration effect is $\bar{x}_2$ =25.05 out of a total score of n of 35. The standard deviation is s_2=2.18. The minimum and maximum scores are 22 and 29, respectively. Both average scores are higher than the midpoint (17.5) of the total score (n=35).

Figure 9 shows graphs of the score distribution of the wind and vibration effects. The x axis represents the scores and the y axis represents the number of test subjects.

The correlation between the learning styles of the test subjects and the level of satisfaction with the sensory effects is statistically analyzed as follows. A one-way ANOVA is used to determine whether there are any meaningful differences in the sensory effect satisfaction levels against the different learning styles (that is, visual, auditory, or haptic). The null hypothesis

Table 1. Statistics of quality assessment questions on two sensory effects: wind and vibration.

Sensory effect	No. of subj. (N)	Min. score	Max. score	Mean score	Std. dev.
Wind	41	19	29	25.07	2.33
Vibration	42	22	29	25.05	2.18

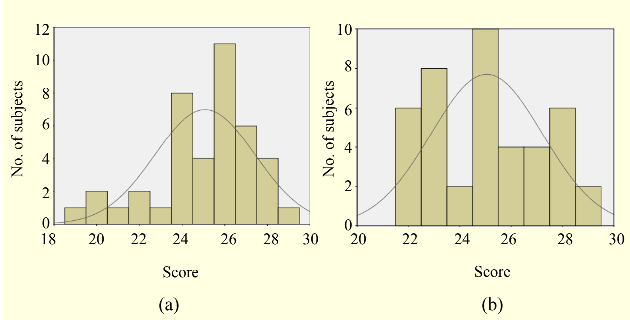

Fig. 9. Score graphs of subject responses pertaining to sensory effects: (a) score distribution for wind effects; (b) score distribution for vibration effects.

Table 2. Results of one-way ANOVA on sensory effect satisfaction levels against three learning styles: visual, auditory, and haptic.

Sensory effect	Degrees of freedom	Mean square	F	F threshold	p-value
Both	2	5.09	1.01	3.11	0.37
Wind	2	6.97	1.29	3.24	0.29
Vibration	2	8.77	1.94	3.24	0.16

(H_0) is as follows: "There are differences in the level of satisfaction in accordance with the learning styles of the test subjects." The level of significance is 95% ($p<0.05$).

Table 2 shows the results of a one-way ANOVA of satisfaction scores in the evaluation of two sensory effects against the three learning styles, that is, visual, auditory, and haptic. The analysis shows that satisfaction with both sensory effects is not related to the learning styles of the test subjects. The null hypothesis (H_0) is rejected because the F ratio becomes 1.01 and the p-value becomes 0.37 (>0.05). Again, the analysis shows that satisfaction with wind or vibration is not related to the learning style of the test subject. The null hypothesis is rejected in both cases (wind: F=1.29, p-value=0.29>0.05; vibration: F=1.94, p-value=0.16>0.05). In other words, satisfaction with sensory effects is unaffected by the learning styles of the test subjects.

The level of satisfaction with sensory effects is analyzed in terms of the haptic style, which is closely related to sensory effects. People with the haptic style recognize information by touching objects or by moving body parts. In other words, people with high tactile perception levels can learn information best when they touch the information source (or object) with their hands or other body parts. A t-test is used to find whether there are any effects on the sensory effect satisfaction level in accordance with the tactile perception levels of the test subjects. The tactile perception levels are divided into a high level and a low level such that the center value is an average value calculated from the total score of haptic style questions on the SAS. The null hypothesis (H_0) becomes, "There are differences in satisfaction levels in accordance with the tactile perception levels of the test subjects." The level of significance is 95% ($p<0.05$).

Table 3 shows the statistics used to examine satisfaction with sensory effects in accordance with the tactile perception levels of the test subjects. The level of satisfaction with both sensory effects is unaffected by the tactile perception level (that is, high versus low) (T=1.14, p-value=0.13>0.05). The level of satisfaction with wind effects is also unaffected by tactile perception levels (T=–0.31, p-value=0.38>0.05). The level of satisfaction with vibration effects, however, is affected by tactile perception levels at a statistically significant level (T=2.06, p-value=0.02<0.05). In other words, a group with a high tactile perception level is more satisfied with the vibration effects than a group with a low tactile perception level. This result demonstrates that stimulations by vibration effects generate more satisfaction in people with a high tactile perception level.

Visual perception levels are divided into a high level and a low level such that the center value is an average value calculated from the total score of the visual style questions on the SAS. The null hypothesis (H_0) becomes, "There are differences in the level of satisfaction in accordance with the visual perception levels of the test subjects." The level of significance is 95% ($p<0.05$).

Table 3. t-test statistics to assess satisfaction with sensory effects in accordance with tactile perception level.

Sensory effect	Tactile perception level	No. of subj. (N)	Mean score	Var.	T	T threshold	p-value
Both	H	40	25.35	5.41	1.14	1.66	0.13
	L	43	24.79	4.65			
Wind	H	18	24.94	7.00	–0.31	1.68	0.38
	L	23	25.17	4.51			
Vibration	H	22	25.68	4.13	2.34*	1.68	0.02
	L	20	24.35	4.66			

Table 4. t-test statistics to assess satisfaction with sensory effects in accordance with visual perception level.

Sensory effect	Tactile perception level	No. of subj. (N)	Mean score	Var.	T	T threshold	p-value
Both	H	42	24.55	4.40	–2.15*	1.66	0.0170
	L	41	25.59	5.25			
Wind	H	23	25.13	3.57	0.10	1.68	0.4600
	L	18	25.06	7.47			
Vibration	H	19	23.84	4.70	3.50*	1.68	0.0006
	L	23	26.00	3.36			

Table 4 shows the statistics used to assess the level of satisfaction with the sensory effects in accordance with the visual perception levels of the test subjects. The level of satisfaction with both sensory effects is affected by the visual perception levels (that is, high versus low) (T=–2.15, p-value=0.017<0.05). This means that stimulations by both effects generate more satisfaction in people with a low visual perception level. The level of satisfaction with wind effects is unaffected by the visual perception levels (T=0.1, p-value=0.46>0.05). The level of satisfaction with vibration effects, however, is affected by the visual perception levels and is statistically significant (T=–3.5, p-value=0.0006<0.05). This result demonstrates that stimulations by vibration effects generate more satisfaction in people with a low visual perception level.

Finally, the auditory perception levels are divided into a high level and a low level such that the center value is an average value calculated from the total score of the auditory style

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Table 5. *t*-test statistics to assess satisfaction with sensory effects in accordance with auditory perception levels.

Sensory effect	Tactile perception level	No. of subj. (N)	Mean score	Var.	T	T threshold	*p*-value
Both	H	41	25.00	4.40	–0.24	1.66	0.41
	L	42	25.12	5.77			
Wind	H	21	24.86	5.73	–0.69	1.68	0.25
	L	20	25.35	4.66			
Vibration	H	20	25.15	3.19	0.34	1.68	0.37
	L	22	24.91	6.94			

questions on the SAS. The null hypothesis (H_0) becomes, "There are differences in the level of satisfaction in accordance with the auditory perception levels of the test subjects." The level of significance is 95% ($p<0.05$).

The results shown in Table 5 demonstrate that the levels of satisfaction with either wind or vibration or both effects are unaffected by the auditory perception levels, that is, all *p*-values are greater than 0.05.

V. Conclusion

In this paper, standard metadata formats that describe user sensory preferences, sensory device capabilities, sensed information, and sensory device commands for an in-car entertainment system that operates sensible media applications were introduced with MPEG-V (ISO/IEC 23005) International Standard specifications. The overall system architecture for in-car entertainment was presented as well. The details of a sensible media simulator and its system structure for an automobile were presented using thoroughly described metadata formats to prove the effectiveness of the proposed system. The simulator effectively generated sensory device commands by adapting user sensory preferences, device capabilities, and temperature sensing information with input sensory effects.

Finally, the correlation between the learning styles of the test subjects and the level of satisfaction with the sensory effects was reported. The results showed that the level of satisfaction with the sensory effects was unaffected overall by the learning styles of the test subjects. Stimulations by vibration effects, however, generated more satisfaction in people with a high tactile perception level at a statistically significant level (T=2.06, *p*-value=0.02<0.05). Stimulations by vibration effects also generated more satisfaction in people with a low visual perception level (T=–3.5, *p*-value=0.0006<0.05). This specifically indicates that vibration effects can be assumed to be a high priority for people with a high tactile perception level and/or a low visual perception level.

In the future, we plan to expand our research to investigate the human factors related to other sensory effects. A correlation between other factors (for example, rendering lengths, strengths, and patterns) of sensory effects and satisfaction levels with sensory effects will be investigated further. The output from the adaptation engine was not evaluated in this paper. The effectiveness of the adaptation engine output will be investigated with careful experimental settings and procedures.

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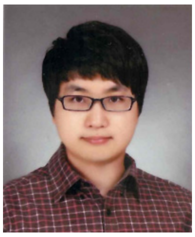

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