COMS-VR: Mobile Virtual Reality Entertainment System using Electric Car and Head-Mounted Display

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ABSTRACT

We propose a novel virtual reality entertainment system using a car as a motion platform. Motion platforms present a sensation of motion to the user using powerful actuators. Combined with virtual reality content, including surrounding visual, auditory and tactile displays, such systems can provide and immersive experience. However, the space and cost requirements for installation of motion platforms are large. To overcome this issue, we propose to use a car as a motion platform. We developed a prototype system composed of a head mounted display, a one-person electric car and an automatic driving algorithm. We developed and tested immersive content in which users ride on a trolley in a virtual space. All users responded quite positively to the experience.

Keywords: Virtual reality, entertainment, head-mounted display, motion platform, mobile, car.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities.

1 INTRODUCTION

Recent entertainment systems with surrounding visual, auditory, and haptics displays offer an immersive experience, especially with virtual reality (VR) content. One such system is a motion platform (MP) that can present sensations of motion using powerful actuators [1][2].

Although a MP can realize high quality motion feedback, the space and cost required for installation are large, confining them to theme parks or shopping malls. In contrast, the current prevalence of head-mounted displays (HMDs) has enabled inexpensive wide field-of-view VR experiences [3][4][5].

To overcome this issue, we propose a novel VR entertainment system using a car as a MP (Figure 1). Cars they have the power to move forwards and backwards, and induce a yawing motion, making them potential personal MPs. In our proposed system, users wear a HMD in the car, and the visual image and motion are synchronized with the VR environment.

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Figure 1: Conceptual image of the proposed virtual reality system using a car as a potion platform.

2 RELATED WORK

An example type of an inexpensive immersive entertainment system with a small footprint is a television and games console, utilizing whole-body input [6]. Because the users can control the software with body motions, the intuitiveness is high compared with classical handheld controllers. However, the realism of the experience is limited, since the body motions are only for input, and there is no motion feedback.

In a MP, the motions delivered to the user are driven by actuators, providing feedback acceleration in the virtual content. However, MPs typically require massive actuators, hindering widespread use.

One way to address this issue is to induce illusions of motion using galvanic vestibular stimulation [7]. However, this requires electrical nerve stimulation and has different thresholds for different users, requiring further research.

Alternatively, already prevalent products can be used as MPs, such as fitness equipment or elevators [8], or the cooperation of family or friends [9]. As these are commonly available in our daily lives, they can be repurposed as part of a cost-effective entertainment system.

We propose a VR entertainment system using a car as a private MP. Cars are prevalent in modern society, and parking spaces are widely available. Furthermore, since cars are mobile, VR content can be enjoyed not only at home but also in other public area with enough space, such as parking lots or even on the road.

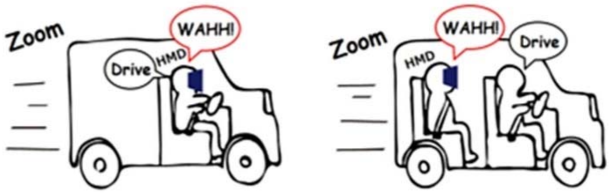
In the present study, we propose COMS-VR, a prototype VR system that uses a one-person electric car and a HMD. After discussing implementation of the minimum necessary hardware and automatic driving algorithm for our concept, we show simple prototype VR content and evaluation results.

3 USING A CAR AS A MOTION PLATFORM

VR systems using a car as a motion platform are classified into two types: virtual drive systems and content player systems.

Figure 2 shows a virtual drive system. The car is driven on real roads, and the driver's experiences are augmented by VR content. These systems are further divided into an active type (Figure 2 a) in which the driver wears a HMD, and a passive type (Figure 2 b) in which the passenger wears a HMD.

Figure 3 shows a content player system. The car is operated by an automatic driving system, and VR content is augmented by the car movements.



(a) Active (b) Passive

Figure 2: Virtual drive systems

Figure 3: Content player system

3.1 Active Virtual Drive System

In the active virtual drive system, the driver wears a HMD and enjoys driving in the virtual space, while the car runs on real roads. This idea has been implemented by Castrol Limited [10] and Japan Automobile Research Institute [11].

In this system the VR content and the user's body motion feedback are highly consistent. However, since the car is driven normally, safety mechanisms and sensors are required to protect the driver and pedestrians. The content is also limited to following the real road that the car is sunning on.

3.2 Passive Virtual Drive System

In the passive virtual drive system, passengers wear HMDs and enjoy VR content. As with the active system, content is limited by the driving route; however, safety is less of an issue compared with the active virtual drive system. This idea has been implemented by Audi Singapore [12]. The system can be used not only for privately owned cars but also for public transportation such as buses, trains, and even airplanes.

3.3 Content Player System

In the content player system, the motion of the car is synchronized with the VR environment, enhancing the content.

The major advantage of the content player system is that the feedback motion of the car is generated by the automatic driving system, even when the car is stationary. The content player system can present full-body motion feedback to the user even within limited spaces such as a parking space. The movement range is small and the maximum speed is low, resulting in a safe and practical system.

In the present study, we employed a content player system to take advantage of these benefits.

4 COMS-VR

4.1 Hardware Configuration

Figure 4 shows the prototyped VR system named "COMS-VR". We adopted the single-seat electric car "COMS" from Toyota Auto Body Co., Ltd as the base platform. A desktop PC (built-in GPU: GTX760; nVIDIA) that controls the system is installed in the trunk. The PC is connected to a HMD (Oculus DK2), a headphone and a joystick. Audio-visual content is rendered using the Unity game engine. This hardware can present the user with immersive image at 75 fps. In addition, the PC is connected to the engine control unit (ECU) via a microcontroller unit (MCU). The MCU is also connected to a rotary encoder installed on the axle of the rear wheel, and the position, speed and acceleration of the car are measured. These data are sampled at 100 Hz, and are used for generating body motion and for the emergency stop function.

The emergency stop function consists of two software triggers and one hardware trigger. One software trigger activates the electric brake to stop the car when communication between the PC and the MCU is interrupted for <50 msec. The other software trigger activates the electric brake when overrunning a specified position. The hardware emergency stop switch activates the electric brake and at the same time shuts down the power supply of the car. The switch is held by the experiment supervisor.

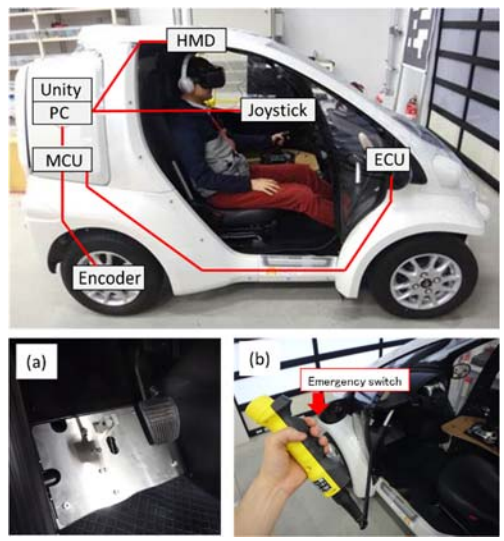


Figure 4: Prototype of the content player system.

In this system, forward or backward acceleration to the user are presented by the position of the shift lever and the depression value of the accelerator pedal. Both are controlled by the MCU.

Figure 5 shows the relationship between the accelerator voltage and the acceleration of the car. In this graph, the positive and negative values of the accelerator voltage correspond to forward and backward directions, respectively. The acceleration increases in proportion to the accelerator voltage and reaches 1.68 m/s^2. Although this maximum acceleration value is relatively low compared with commercial MPs, we decided that this provided sufficient feedback for the experiment. Preliminary experiments showed that this voltage gave a strong feeling of acceleration when combined with VR images.

The minimum acceleration is approximately 0.1 m/s^2, which is perceptible for an average user. This minimum value is caused by simulated creep, which is a function of the ECU that mimics the behavior of a gas-powered car. This function cannot be eliminated without program modification of the ECU, representing a major limitation of our current system, preventing imperceptible positional adjustments. Such adjustments are often employed by MPs, but cannot be achieved with our current system.

The end to end system latency is approximately 200 ms, which is 10 times larger than the perceptible threshold for an average user.

This specification may result in a strange feeling for the user, especially in impulse presentation of motion. This function cannot be eliminated, since this is a function of ECU to protect the car from sudden user inputs.

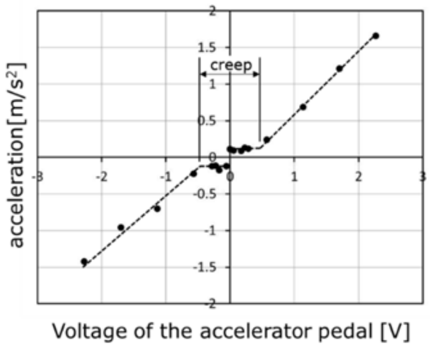


Figure 5: Graph showing acceleration vs accelerator voltage

4.2 Automatic Driving Algorithm

In our proposed virtual drive system, the motion pattern of the car is automatically generated according to the audio-visual content. Figure 6 shows a basic schematic of the automatic driving algorithm.

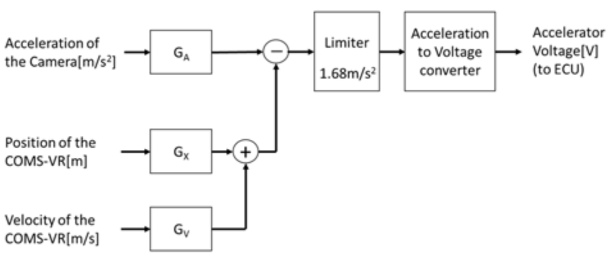


Figure 6: Block diagram of the automatic driving algorithm

In brief, the algorithm attempts to proportionate the acceleration of the car with that presented to the user in the VR environment. The car acceleration is then suppressed, considering the position and velocity of the car, to constrain the car to a limited space such as a parking space. The resulting acceleration is then converted to a command voltage and sent to the ECU. The gain (G_A, G_X and G_V) must be adjusted by the content developer, through preliminary testing, to provide optimum enjoyment and use of space with minimal discomfort.

4.3 Implementation of VR Content

We developed VR content named "Falling Trolley" to evaluate user experiences (Figure 7: Screen image of Falling Trolley). Participants drive a trolley on wooden rails in a VR environment. The direction of the trolley's movement is limited to forwards and backwards (z axis) and up and down (y axis); it never leaves the rails. The joystick in the car is linked to the lever of the trolley, and moves the trolley forwards or backwards. The user receives feedback of acceleration along this axis through acceleration of the car, as shown in Figure 6. No feedback is provided for acceleration along the other axes.

Figure 8 shows the course layout of Falling Trolley. The total length of the course is approximately 350 m, with several runs and falls for the trolley. The velocity of the trolley can reach up to 60 km/h. We included four obstacles so that both acceleration and deceleration can be experienced: (a) a wall of boxes, (b) a jump and (c) a backward downhill slope.

Each gain of the automatic driving algorithm for this content is designed as follows. First, based on the length of standard Japanese parking space, we set the maximum required space to 5.2 m. COMS-VR is 2.4m long, and can therefore move up to 2.8 m under this condition. G_X and G_V were set to 1.0 and 2.0 to maximize movement while minimizing discomfort and also allowing for some control overshoot within the allowed space. To maximize the enjoyment for the user, G_A was set to 0.36.

Figure 9 is a histogram showing the relative position of COMS-VR while playing Falling Trolley with the above specifications. We can see that displacement of the car is within 2.6 m, which means that the car can be confined to the 5.2 m space.

Figure 7: Screen image of Falling Trolley

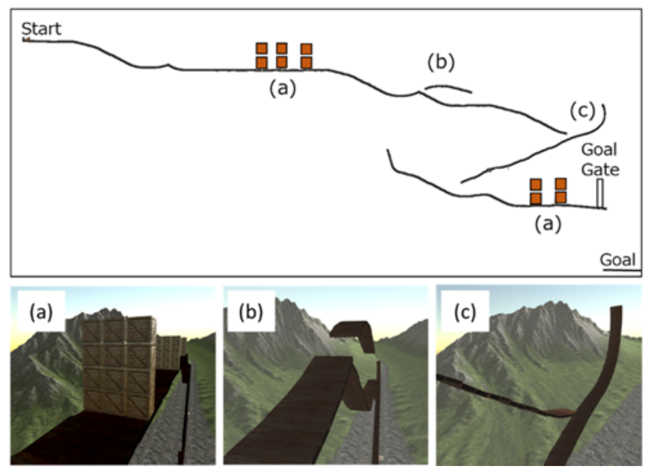


Figure 8: Course layout of Falling Trolley

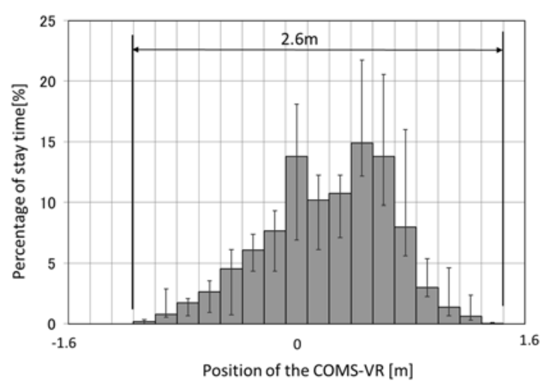


Figure 9: Histogram showing the relative position of COMS-VR while playing Falling Trolley. Bars show mean of 30 runs. Error bars show maximum and minimum percentage of 30runs.

5 USER STUDY

We surveyed 16 participants (age 25–58 years, 3 women, 13 men) using a paper questionnaire and a supplementary interview. Participants experienced the Falling Trolley content twice before answering the questions. One experience was approximately 40–80 s, depending on the user's control inputs. Figure 10 shows the experiment environment, was approved by the Health and Safety Committee in TOYOTA Central R&D Labs Inc. The safety system of COMS-VR was fully explained before the experience, to allow participants to start the experiment with a feeling of trust, and to concentrate on the content.

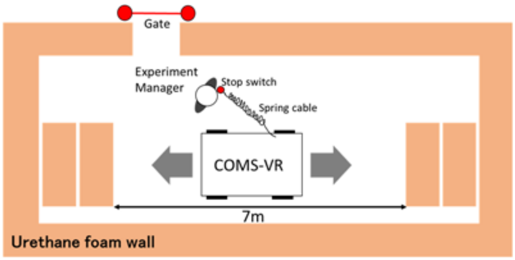


Figure 10: The experiment environment

The questionnaire is as follows:

Q1. How do you rate this experience in terms of enjoyment?
(1: Not enjoyable – 7: Very enjoyable)
Q2. How do you rate this experience in terms scariness?
(1: Not scary – 7: Very scary)
Q3. Did you feel a mismatch between the images and the movements?
(1: Strongly felt – 7: Not felt)
Q4. Did you feel that you were moving?
(1: Strongly disagree – 7: Strongly agree)
Q5. Did you feel that you were falling?
(1: Strongly disagree – 7: Strongly agree)
Q6. Did you feel that you were shaken?
(1: Strongly disagree – 7: Strongly agree)
Q7. How much would you pay for this experience?
(Answer freely)

Figure 11 shows the results of the questionnaires. All respondents felt that the experience was very enjoyable; many felt that is was a little scary. These results suggest that respondents found this immersive content entertaining.

Although not strongly noticeable, there was some mismatch between visual and the movement sensation, owing to the suppression of the acceleration by the automatic driving program. The subjective cyber sickness was reported by 4 respondents (25%) in the interview.

Movement was felt strongly, suggesting that the car is sufficiently powerful as a MP for forwards and backwards acceleration. The feeling of falling was also felt strongly, despite users being presented only forwards and backwards acceleration. This feeling might have been induced by vection, or by an illusion of vertical motion from forward and backward motion; however, falling was not handled in the algorithm. Feeling of being shaken were felt only weakly. We suppose that this is due to the slow response of the car, which cannot express vibrations over 2 Hz.

Regarding the expected price, the median was 500 yen (about 4.4 US dollars) for one experience. From this value, we can say that the value of the experience of this system is about the same level as the high-end gaming system, considering that one experience of a Japanese game arcade is from 100 to 500 yen.

6 Conclusions

In this study we proposed a VR entertainment system using a car as a MP. We developed a prototype using a one-person electric car and an automatic driving algorism. An experiment with Falling Trolley showed that the content can generate a strong feeling of motion for the user, while the motion of the car is limited to a single parking space.

Our proposed system has several limitations. First, it presently provides feedback in limited degrees of freedom. We plan to update the automatic driving algorism to treat multi-axis movement. For example, presentation of acceleration along vertical axis (in VR environment) by forwards or backwards acceleration of the car can simulate impact or landing. Left and right motion can be simulated by using the steering and active suspension. We also plan to incorporate a tactile display that can present vibrations of < 2 Hz, to compensate for the unsatisfactory shake feedback revealed by this study.

Furthermore, we will develop a mechanism to assure safety in public locations. We also intend to update the user interface to utilize car human machine interface (handle, pedals, etc) in VR content, in order to diversify content.

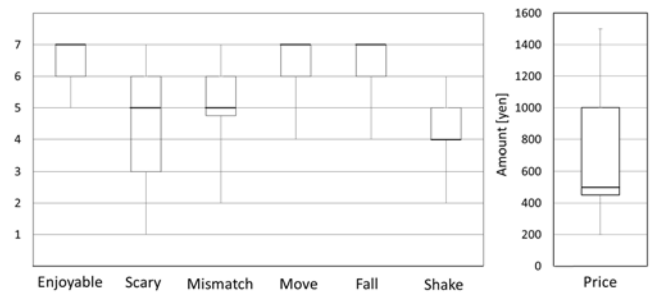


Figure 11: The results of the questionnaire

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