Toward the Development of a VR Simulator for Speed Sprayers

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***Abstract*—The speed sprayer, an agricultural chemical spraying vehicle, has been used to efficiently control pests and diseases in orchards such as grapes and apples. The use of speed sprayers is also problematic from the perspective of environmental protection, such as the measures to prevent pesticides from drifting outside the field. It also requires a skilled operator to operate the vehicle, as adjustments to travel speed, pressure, and nozzle selection must be considered. To make the speed sprayer easier and safer to operate, improvements to the control panel are required. In this study, we report our effort on the development of a simulator based on Virtual Reality (VR) that can analyze the operator's body movements while driving and operating a speed sprayer. As reference data, we videotaped the operator at the actual site and extracted the characteristics of the body movements during operation using computer vision techniques. The characteristics of the body movements observed while operating the various panels provide useful information for improving the operation panels.**

Keywords-vr-simulator; speed sprayer; virtual reality; head pose; hand gesture.

I. INTRODUCTION

Most of the chemicals sprayed in orchards are liquids. There are several types of sprayers, including pipe sprayers, portable power sprayers, and speed sprayers. The introduction of speed sprayers has a great effect on the efficiency and labor saving of pesticide spraying in orchards. Many studies have been conducted on the prevention of pesticide drift and exposure to pesticides, and the application of small amounts of concentrated pesticides [1].

In Japan, speed sprayers were introduced in 1957. The Japanese Ministry of Health, Labor and Welfare (MHLW) introduced the positive list system for agricultural chemical residues, such as pesticides, feed additives, and veterinary drugs in foods [2]. The use of speed sprayers poses several challenges in terms of occupational safety and environmental protection. In the case of speed sprayers used in orchards, the amount of pesticides sprayed increases due to the large spray area. Therefore, there is an urgent need for measures to prevent drift of pesticides outside the field. A variety of unmanned pest control machines have been developed for more accurate spraying [3], but they have not been widely used.

Speed sprayers require a skilled operator to operate due to the need to consider the relationship between travel speed, pressure, and nozzle selection. Furthermore, the complexity of the operation panel, in addition to the difficulty in seeing the surrounding environment from inside the vehicle, makes the work on this vehicle hard. Driving skills are required,

Figure 1. The electric speed sprayer (SSV1091FSC) manufactured by the YAMABIKO Corporation used in this study.

especially in vineyards, where cars need to pass through the path between the branches.

As the number of agricultural workers in Japan has decreased and the population has aged in recent years, there has been a growing demand for the development of more efficient speed sprayers. Especially, simplifying the operations that require technical skills becomes critical. In the automobile industry, car simulators have been developed as a measure of vehicle performance. However, there are few examples of studies that simulate the operation and driving of tractors in agriculture [4][5].

In this study, we build a simulator using Virtual Reality (VR) to analyze the driving and operation of a speed sprayer. The simulator collects information on the driver's Six-Degree-of-Freedom (6-DoF) head pose, three-dimensional (3D) hand gestures, gas pedal and brake operations, and visualizes the characteristics of driving behavior based on the features of head and hand movements. In the physical environment, we set up two cameras to capture the cockpit and the driver at the same time. Computer vision techniques were used to track the body movements and the rotation of the steering wheel.

This paper is organized as follows. In Section II, we describe the VR simulator of a speed sprayer built for this study. Section III describes experiments using our VR simulator and their results. In Section IV, we present our computer vision techniques used to observe the operator behavior in the physical environment. Finally, Section V summarizes the results of this study and discusses future perspectives.

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Figure 2. The VR simulator of a speed sprayer developed in this study.

II. VR SIMULATOR OF A SPEED SPRAYER

Figure 1 shows the speed sprayer (SSV1091FSC) that can carry 1000L of pesticide which was used in this study. The simulator of the speed sprayer developed in this study has the following conditions. First, the simulator must be able to track the driver's head pose and finger movements in 6-DoF. Next, the driver must be able to operate the vehicle using physical car controls. Finally, the driver should be able to perceive the car control in the virtual space and that in the physical space equally. Considering these constraints, we adopted a set of Logitech G27 Force Feedback Wheel and Pedal as the car control, and the Oculus Quest 2 as the VR device [6].

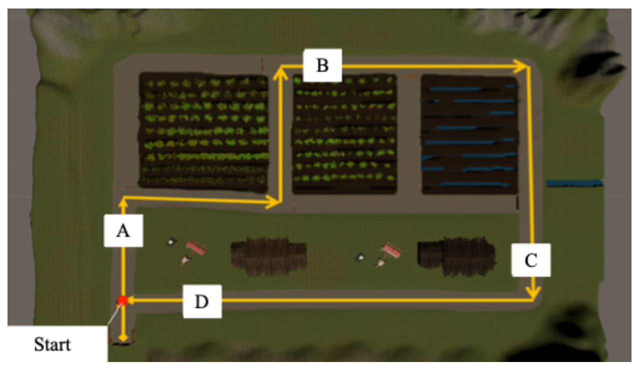
A. Logitech G27 Force Feedback Wheel and Pedal

The Logitech G27 is a gaming racing wheel compatible with PlayStation 2 and 3. It runs on Windows and Mac using the Logitech G27 driver and gaming SDK. The SDK for Windows is also available on the Unity Asset Store. Figure 2 shows the steering wheel and pedals of Logitech's G27 attached to the seat of a racing car fixed with a metal frame.

B. Oculus Quest 2

The Oculus Quest 2 is consumer-oriented Head-Mounted Display (HMD) based VR device developed by Facebook, Inc. featuring a 6-DoF angular and linear tracking system that can measure head pose and hand gestures. This system uses Inertial Measurement Units (IMUs) that assess linear acceleration and rotational velocity with low latency and cameras in the HMD that creates a 3D map of the room space and hand landmarks of the user. Figure 2 shows a user wearing the Oculus Quest operating a panel in a virtual space.

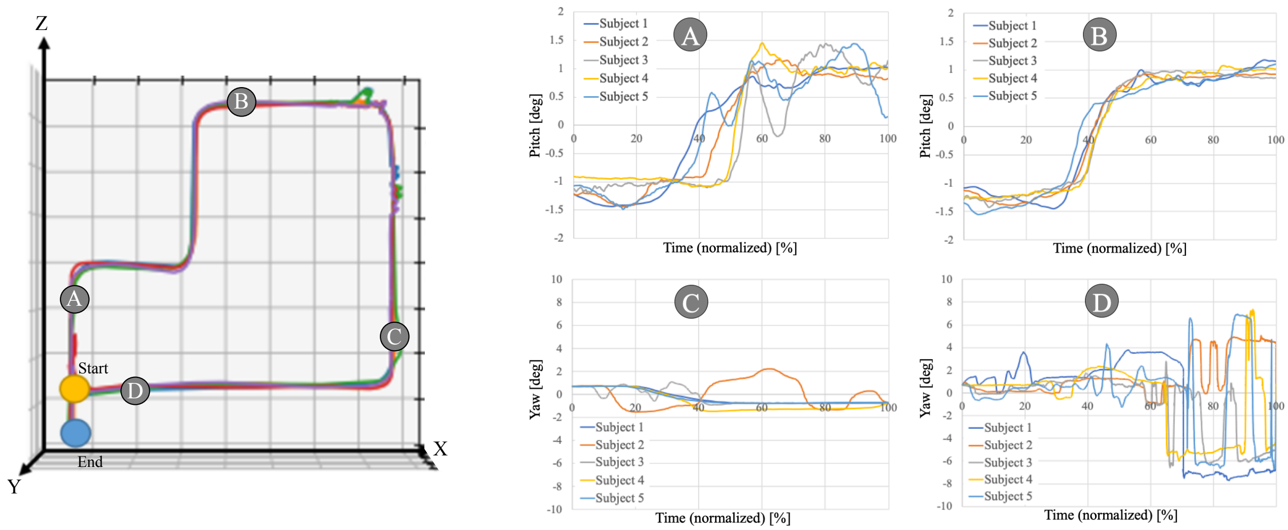
The simulator outputs information on car controls such as steering, gas pedal, and brake, as well as position and rotation information on the user's head pose and finger joints of both hands observed by the Oculus Quest 2. The initial position of the Oculus Quest 2 was calibrated against the position of the car control beforehand, since no auxiliary devices, such as base stations were used to obtain the absolute position of the user. For data recording, the Oculus Quest 2 was registered to the SteamVR Desktop application. By default, the Oculus Quest 2 runs at a frame rate of 72 Hz, however, to accommodate the frame rate drop caused by the program for the experiment, all data was recorded at a sampling rate of 60



(a) The virtual farmland for this study.

(b) A view from the cockpit in a virtual environment

Figure 3. Virtual farmland used in the experiments of this study.



(a) Superimposed travel routes of all subjects

(b) Subjects' head poses as they perform each task in the experiment.

Figure 4. Routes traveled by the subjects and their head poses when performing each task of the experiment.

Hz. Sound feedback was implemented to make it easier to operate buttons and other interfaces in the virtual environment.

III. Experiments and Results

Using the developed simulator, the participants are asked to perform several tasks in a virtual farmland in different locations. The behavior during the tasks and the time required are measured. Figure 3 shows the virtual farmland we set up for the experiment. The field was set up with four points to perform the tasks, and audio instructions were played as the subject passed each point. The tasks are as follows. Following the voice instructions, the subject pressed a virtual button to spray to the left at point A, then another virtual button to spray to the right at point B, then turned off the ventilation fan at point C, and finally parked the car at point D.

In this experiment, we obtain the subject's driving path, head pose, and the time required for each task. The car's position (x, y, z) and the subject's head pose (*pitch*, *yaw*, *roll*) were all measured in the Unity coordinate system. For the head pose, clockwise is positive and counterclockwise is negative. The signal when the brake is pressed is recorded as a binary signal, a digital signal with two distinguishable levels.

For this experiment, five adult males between the ages of 20 and 23 were recruited as subjects. All of the subjects had obtained a car driving license, but had little experience using a driving simulator. Figure 4(a) show the routes traveled by the subjects when performing each task of the experiment. The subjects' routes are almost identical. This means that the subjects can navigate the vehicle along a predetermined route regardless of the virtual environment. Figure 4(b) shows subjects' head poses when performing each task of the experiment. At points A and B, we observed that, in order to press the virtual button, the subjects' heads turned down once to confirm the button's position (negative pitch angle), and then they raised their heads to confirm the direction of travel (positive pitch angle). At point C, the subjects were expected to check the condition of the fan in order to stop the rear

TABLE I. Time taken to accomplish each task for each subject.

Subject	Task 1 (s)	Task 2 (s)	Task 3 (s)	Task 4 (s)
1	1.9	2.9	2.1	57.1
2	3.1	2.4	8.4	106.3
3	9.0	4.2	18.0	111.1
4	3.3	2.9	3.4	79.9
5	2.8	2.8	2.5	59.0
Mean	4.02	3.04	6.88	82.68
Std. Dev.	2.835	0.680	6.710	25.438

ventilation fan, but as they used the rearview mirror to check, the yaw angle did not change significantly. On the contrary, at point D, when the subjects parked the car, they checked the left and right sides of the car, resulting in a significant variation of the yaw angle.

This outcome can be attributed to the fact that the virtual environment can reproduce the relief of the terrain and scenery, so it is likely that subjects who see these scenes will behave in a similar manner. The time taken to accomplish the task for each subject is shown in Table I. The reason that task 4 took longer than the others is that it requires forward, backward, and stop actions to park the vehicle at point D.

These experimental results show that the developed simulator can reproduce the actual task work of pesticides spraying and quantify the operator's behavior in each task, which can be used to improve the interface design in the cockpit for efficient work.

IV. Observation of Operator Behavior in the Physical Environment

We installed two 4K 60fps cameras (GoPro Hero8) in the cockpit of the speed sprayer (SSV1091FSC), one on the dashboard near the door and the other next to the driver's seat. Each camera was used to observe the operator's head and hand movements, steering wheel and button operations.

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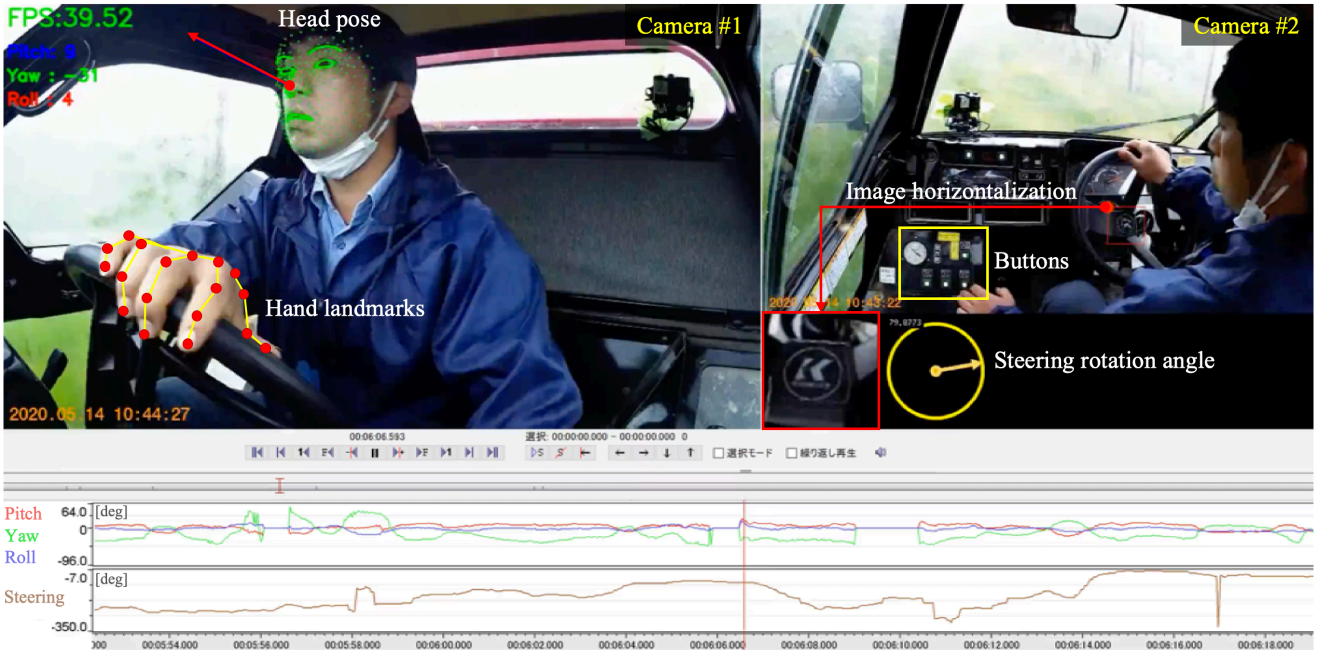

Figure 5. Data of operator behavior integrated into the ELAN.

A. Measuring head and hand movements

MediaPipe [7][8], a framework for building perception pipelines, was used to detect landmarks of faces and hands in real time from images captured by the camera on the dashboard. The head and hand movements can be quantified by obtaining the coordinate values for each landmark. We applied the Perspective-n-Point (PnP) solution to estimate the head pose in 6-DoF from the landmarks that consist of the face [9].

B. Detecting Pressed-Button

In this study, we detected that a button was pressed based on the inclusion of the fingertip coordinates with the range of pre-determined coordinates on the image of the button. This process is done on a frame-by-frame basis, but if a sequence of detected results occurs, these results are counted as a single pressing.

C. Measuring Steering Wheel Rotation

A relatively simple deep feed-forward neural network was constructed to estimate the steering wheel rotation angle. The network takes as input a 64x64 image of the steering wheel and performs convolution, batch normalization, and Rectified Linear Unit (RELU) four times to optimize the results. The network successfully estimated the steering rotation angle from low resolution steering images, where the SIFT features [10] are difficult to extract.

All the data, including video, head and hand movement measurements, steering wheel rotation, and pushed-button detection, is integrated into the ELAN (EUDICO Linguistic Annotator) [11]. ELAN provides a powerful tool for annotating and labeling data with time series characteristics. By statistically analyzing the statistical characteristics of these labels, further analysis can be performed to find out the operations that cause fatigue and how to overcome them. Figure 5 shows the data integrated into ELAN. In this way, ELAN enables us to analyze the data of head pose (*pitch*, *yaw*, *roll*), hand landmarks, and steering wheel rotation angles in a time series. We intend to verify the differences between the two environments by implementing similar tasks in the simulator using labeled tasks that correspond to the behavior of the operator obtained in the physical environment.

V. CONCLUSION

In this study, we have developed a simulator that allows the user to experience driving and operating a speed sprayer in a virtual environment using an HMD-type VR device and a car controller used in games. The simulator enables us to collect a time series of information on the driver's head pose, hand gestures, and gas pedal and brake controls measured by the simulator, and to visualize the characteristics of the driver's behavior during driving.

To achieve a more realistic simulator, data on the behavior of operators in the field was collected so that similar behavioral data could be reproduced in a virtual environment. The MediaPipe framework made it possible to extract data of operator behavior even in a light-sensitive environment such as that inside a cockpit. Next, we will conduct experiments with many tasks using the developed simulator and find valuable data for improving the operation interface of the speed sprayer.

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