Projection Alignment Correction by Appearance Control for 2-axis movement*

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Abstract
In this paper, we propose to extend the alignment correction method for moving projected objects to correction of 2-axis movement. We also propose a method to deal with afterimages that occur when a projection method using model predictive control is applied to a moving object. In this method, the projected image is generated considering the frame buffer of the camera and the alignment correction is applied. Experimental results show that the proposed method does not generate afterimages and that the intended projection is possible.

Keywords
Spatial Augmented Reality, Appearance Control, Projector-camera system

1. Introduction

Spatial Augmented Reality (SAR) has emerged as a technology that employs projectors to project virtual objects into real world. This key technology, shader ramps, was proposed by Rasker et al[1]. This technology has produced great results, especially in projection mapping, and it demonstrates a valuable lighting effect not only for amusement [2] but also for guidance in the factory [3] . By leveraging observation in SAR, new avenues open up for exploiting our visual perception, enabling the manipulation of visible color and also achieves enhancing our vision [4].

In the realm of SAR research, Amano et al. introduced an innovative approach called as Appearance Control, utilizing feedback processing through MPC(model predictive control) [5]. However, a problem issue arises with Appearance Control when the projection target undergoes movement, leading to the occurrence of after-images due to system delays, consequently impeding the intended control. To address this challenge, Kono et al. proposed an Algorithm to Compensate the Time Delay for the Appearance Control System [6]. This method effectively reduces the afterimage generation time by accounting for processing delays within the system. However, it fails to completely prevent afterimage occurrence, even when the projection target is in motion.

In a different context, Amano et al. proposed the application of appearance control to automobile headlights, providing visual assistance for drivers [7].This study proposes a method to correct alignment errors in projections from moving vehicles. However, the method was limited to movement along a single axis, thus lacking support for motion in other directions. In this study, we take a preliminary step towards supporting rotational motion by extending the projection object's movement to 2-axis. We propose a comprehensive method for scenarios where the projection object can move in any direction.

The previous approach in [7] relied on feedforward control for projection, as opposed to MPC. The rationale behind this choice is that feedforward control merely shifts the projection position, while MPC causes the projection to stretch, akin to an afterimage. Consequently, compensating solely for the projection position was deemed insufficient to solve the problem. Nonetheless, the Appearance Control with feedforward control failed to account for modeling errors, preventing the object's appearance from closely aligning with the intended target.Therefore, in this research, we present a novel method that enables the intended projection even when utilizing Appearance Control with MPC for moving objects.

2. Related Work

In this study, we extend the alignment correction method [7] in 2-axis and aim to resolve the afterimage that occur when using Appearance Control [5] on a moving object. Therefore, this chapter introduces Appearance Control [5] and alignment correction method [7].

2.1. Appearance Control

The appearance control shown in Fig.1 is achieved by the projector-camera feedback processing using MPC[5] . The procedure for apparent control is as follows.

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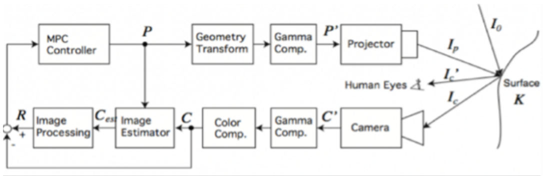

Figure 1: Diagram of Appearance Control using Model Predictive Control

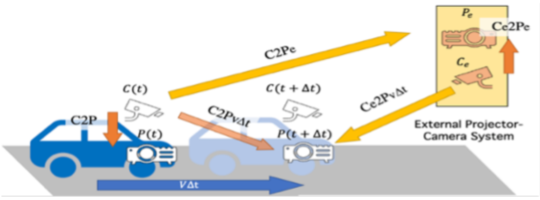

Figure 2: Relation between a captured image C(t) and a projection image P(t) for a moving in-vehicle projector-camera system.[7]

1. Capture image C of the projection target using camera.
2. Estimates reflectance $\hat{K}$ from the relation of projected image P and C with C_{full} (under maximum brightness projection), and C_0 (under minimum brightness projection).
3. Estimate object appearance C_{est} under white light projection using $\hat{K}$ and the image C_{white} captured when projected white light.
4. Apply arbitrary image processing on C_{est} to generate target image R.
5. Adjust P with MPC from the difference between R and C.
6. Convert the shape of P to the projector coordinate system and projected it from the projector.

2.2. Alignment Correction

Fig.2 shows the relationship between the captured image and the projection image during vehicle movement. In this figure, $C(t)$ and $P(t)$ represent the captured and projected images at time t, respectively; Ce and Pe represent the captured and projected images by the external projector-camera system used for calibration, respectively. When the vehicle is moving at speed V, the annotation is projected to the forward position with a displacement of $V\Delta t$ for its processing latency of Δt. Therefore, we can compensate for the misalignment due to latency of the moving speed V by finding the pixel mapping $C2P_{V\Delta t}$ between $C(t)$ and $P(t+\Delta t)$.

When moving with a given velocity V', we can compute the corresponding pixel mapping by linearly interpolating the pixel mapping $C2P_{V\Delta t}$ at velocity V as follows:

$$C2P_{V'\Delta t} = \frac{V'}{V}\{C2P_{V\Delta t} - C2P\} + C2P \quad (1)$$

3. Proposed method

The alignment correction method proposed by Amano et al [7] was limited to motion in one axis direction and was insufficient to handle motion in other directions. Therefore, in Section 3.1, we propose a method to extend the moving direction of the projection object to 2-axis. In addition, the previous approach in [7] relied on feed-forward control for projection, in contrast to MPC. So, we propose a new method in 3.2 that enables the intended projection even when MPC-based appearance control is applied to a moving object.

3.1. Extension to 2-axis movement

This section describes how to extend the direction of movement of the projection target to two-axis. First, as in Amano et al.'s method [7], calibration is performed in advance to obtain the correspondence before and after the move. In this study, the correspondence $C2C_{V\Delta t}$ between cameras before and after moving is obtained and used.

To extend this correspondence to 2-axis, we obtain the pixel mapping by moving the projector-camera system along the X and Y axes of the Cartesian coordinate system, respectively. We denote the pixel mapping that compensates for the positional deviation when moving in the X-axis direction is $C2C_{V_x\Delta t}$, and the pixel mapping that compensates for the positional deviation in the Y-axis direction is $C2C_{V_y\Delta t}$.

The displacement of movement is calculated from these pixel mappings and extended to 2-axis by combining them. The pixel mapping $C2C_{V'\Delta t}$ which corrects the displacement when moving in 2-axis, can be obtained as follows:

$$C2C_{V'\Delta t} = \frac{V'_x}{V_x}\{C2C_{V_x\Delta t}(x_c, y_c) - (x_c, y_c)^T\} + \frac{V'_y}{V_y}\{C2C_{V_y\Delta t}(x_c, y_c) - (x_c, y_c)^T\} + (x_c, y_c)^T \quad (2)$$

where (x_c, y_c) represent the coordinates of the captured image before movement, V_x, V_y, V'_x and V'_y represent the reference displacement of the X-axis and the Y-axis and the arbitrary velocity in each axis direction, respectively. $C2Ct_x(x_c, y_c)$ and $C2Ct_y(x_c, y_c)$ represent the coordinates of the corresponding captured image at the position where the coordinates (x_c, y_c) of the captured image before the move have moved by the reference displacement V_x ,V_y.

3.2. Alignment correction in appearance control using MPC

When performing alignment correction, it is necessary to project to the position where the projection object has moved within the processing time of the system. In practice, however, there is not only the processing time, but also the delay due to the frame buffer that temporarily stores the images captured by the camera. Therefore, the images processed by the system are the images taken before the number of buffers, so when shifting the projection position, the delay time T_d due to the buffers also had to be considered.

However, this camera buffer is the cause and, with appearance control through MPC, simply shifting the projected image cannot eliminate the resulting afterimage. We explain the causes in 3.2.1.

3.2.1. Causes of afterimages

We denote time within the Appearance Control as t. The projection taken in the captured image $C(t)$ is the projected image $P(t - T_d)$ before the number of buffers. This is the correct combination of images to use in the system's calculations. However, since this system does not consider delays caused by buffers, the projection image $P(t - 1)$, which is one step ahead of the captured image $C(t)$, is used in model prediction control. If the projection target is not moving, this combination can still produce the intended projection. However, even if the alignment correction method is applied to the projected image, if the projection target is in motion, the coordinates will no longer match due to the time lag. As a result, the difference image is not added at the intended position in process 5 described in section 2.1. Consequently, the difference image is projected as an afterimage.

3.2.2. considering the frame buffer

To solve such problems, it is necessary to consider the delay caused by buffers. Therefore, we propose a method to realize Appearance Control using MPC without afterimages by considering buffers and applying alignment correction method.

The determination of the next projected image, which considers the buffer, is given by the following equation.

$$P(t+1) \approx P(t - T_d) + \hat{K}^{-1}(t)(1 - \alpha) \{R(t+1) - C(t)./(C_{full} - C_0)\} \quad (3)$$

where, α is a tuning parameter and ./ represents element-wise division. By applying alignment correction method to the calculated projected image $P(t+1)$, the projected image $P'(t+1)$ onto the moving projection target is then determined as follows.

$$P'(t+1) = C2C_{V'\Delta t}(x_p, y_p) \quad (4)$$

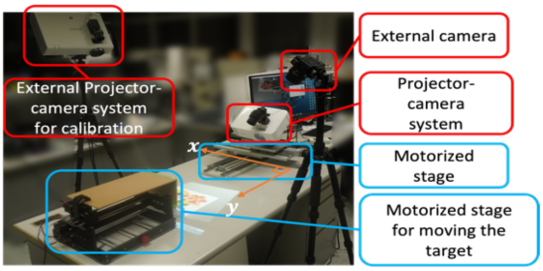

Figure 3: Experimental setup

where (x_p, y_p) are the coordinates of the generated $P(t+1)$. In addition, the apparent estimation under white illumination, shown in processing step 2 of 2.1, uses the following equation presented by Kono et al [6].

$$\hat{K}(t) = diag[C(t)./(C_{full} - C_0) \odot P(t - T_d) + C_0] \quad (5)$$

where $\odot$ is element-wise multiplication.

4. Experimental setup and results

Fig.3 shows our experimental setup. For the projector-camera system, we used a BenQ MH550 with a resolution of 1600 × 900 as projector and a Ximea MQ013CG-E2 with a resolution of 1280 × 900 as camera. was mounted on a motorized linear stage to obtain pixel mapping compensated for displacement due to movement. The external projector for acquiring the pixel mapping was a Sony VPL-EW276 with a resolution of 1280 × 800 and the projector-camera system was positioned so that the range of the image captured by the projector fell within the projector's projection range. The reference displacements for pixel mapping acquisition were set at 10 mm in the x-direction and 50 mm in the y-direction. Also, we determined the value of T_d is 3, which minimizes misalignment, through empirical experience. Decimal values Obtained in calculations (2) were rounded to the nearest whole number.

4.1. Comparative Evaluation

To validate the effectiveness of the proposed method, we compared the appearance control with the proposed method. Fig. 4 shows the projection results when the projection object is moved by a motor stage and at an arbitrary speed. In this evaluation we used color phase control for image processing. The processing time for this projection was approximately 42 fps. The results show that appearance control produces an afterimage. In contrast, the proposed method prevents afterimages from occurring while the projection target is moving and shows overlapping projection results.

4.2. Comparative Experiments

The results of 4.1 confirm the effectiveness of the proposed method. In this section, in a similar experimental environment, saturation enhancement was used for image processing, and saturation was compared in three states: with the projection target stationary, moved with the proposed method, and moved without the proposed method. As a projection target, we used a sheet of paper printed with a square of 60 mm in length and width. The projection target was moved at -30 mm/s in the Y-axis direction, and the image taken by the system at the position where the projection target was moved 100 mm was used for evaluation.

Fig.5 shows the experimental results. The results show that when the projection target is moved without using the proposed method, the saturation is reduced in the red square area compared to the state where the projection target is stationary. On the other hand, when the proposed method is used, it can be seen that the saturation has not changed from the stationary state. From this result, we can say that the proposed method is capable of the same projection even when the projection target is moving. However, as can be confirmed by carefully looking at the contour of the projected object in Fig.4, a misalignment in the projected position was observed.

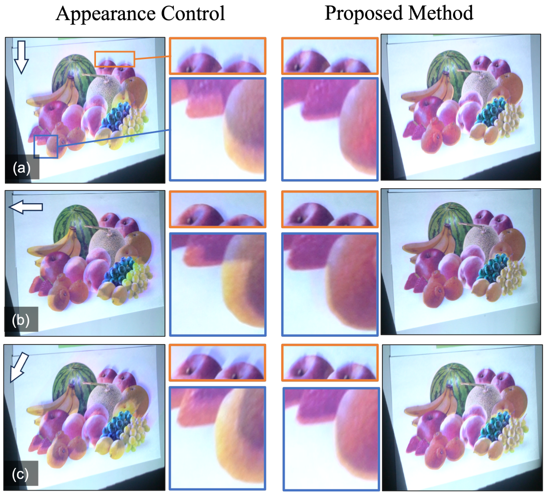

Figure 4: projection result. Result of moving the projection target with (a) -30 mm/s in the Y-axis direction, (b) -30 mm/s in the X-axis direction, (c) -30 mm/s in the X-axis direction and -30 mm/s in the Y-axis direction.

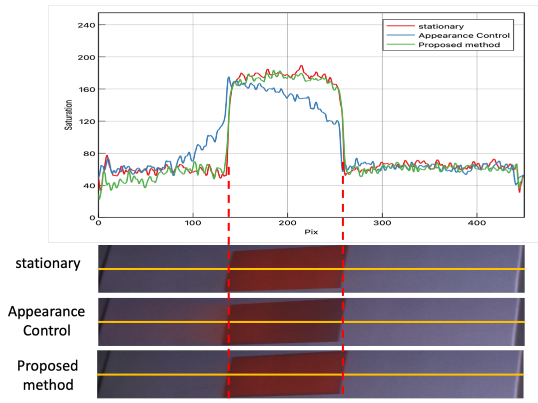

Figure 5: Variation in saturation on the orange line and comparison

5. Discussion

We rounded off the small number of decimal places generated by the calculation in (2) to one decimal place as misalignment compensation. However, truncated and rounded values can accumulate as errors as the steps progress. As a solution to this problem, we are currently considering creating an error map of the decimal part of the result of Eq. (2). Using this map, the decimal portion is accumulated according to the processing steps, and the amount of displacement of pixels whose value exceeds 1 is adjusted. We expect that this method can eliminate the misalignment that occurs.

Also, the proposed method continues to generate afterimages when used in situations where the moving speed of the object is different from the speed given to the system. Therefore, it is necessary to consider methods that do not require providing advance information about the movement of the projection target to the system. We will address this problem in our future work.

6. Conclusion

In this study, a method is proposed to compensate for misalignment of the projection with respect to a moving projection object in any direction. The proposed method extends the compensation for misalignment in two axes to achieve accurate projection alignment. We have also proposed a method for intended projection on moving objects in Appearance Control with MPC. Experimental results showed that the proposed method did not produce afterimages when the object moved in any direction. However, it was also found that the projected positions did not perfectly match due to cumulative errors. In addition, when the proposed method was used in situations where the speed of the moving object was different from the speed given to the system, the proposed method continued to produce afterimages. These problems will be addressed in future studies.

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