A Flying Projector Stabilizing Image Fluctuation

Yoshito Hosomizo, Daisuke Iwai, and Kosuke Sato
Graduate School of Engineering Science, Osaka University
Machikaneyama 1-3, Toyonaka, Osaka 560-8531, Japan
Email: {hosomizo, iwai, sato}@sens.sys.es.osaka-u.ac.jp

***Abstract*—This paper proposes an autonomous flying projector (AFP) that projects images from a micro aerial vehicle (MAV) on which a small projector is placed. The AFP works as a public and ubiquitous display, and has a potential for an expansion of projector applications (e.g., a digital signage moving in response to a distribution state of people, and the one following moving targets such as a person and a vehicle). We achieve to reduce fluctuations of projected images using a geometric correction method based on the estimation of the projector's position and orientation.**

I. Introduction

This paper proposes an autonomous flying projector (AFP) that is a micro aerial vehicle (MAV) equipped with a small projector (Fig. 1). The AFP enables to recognize and move to projection targets autonomously, and it can project projection contents with less fluctuations of projected images with hovering in the air. The AFP is expected to work as a public and ubiquitous display, and has a potential for an expansion of projector applications such as advertisements (e.g., a digital signage moving in response to a distribution state of people, and the one following moving targets such as a person and a vehicle).

In general, keeping the MAV completely stable in the air is not achieved even in the case where sophisticated stabilization control is applied. Instead of relying only on such hardware solution, we also apply a software solution that digitally deforms the projection image based on the estimation of the projector's position and orientation so that the projected result is stabilized on the projection surface. Software-based projection stabilization has been studied in the research field of wearable projection. The position and orientation of the projector are estimated based on either dead reckoning [1] or computer vision technique [2]. Dead reckoning technique applies internal sensors such as an accelerometer and a gyro sensor, which measure at a high temporal rate, while it normally faces the accumulation error problem. On the other hand, the computer vision technique, in which a 2D visual marker is used as a reference, does not cause accumulation errors, while it requires computationally expensive processes that cannot be run in real-time on a tiny and low-performance processor installed in most MAVs.

Fig. 1: Concept of autonomous flying projector.

In this study, we apply digital geometric transformation to original images before projection to stabilize the projected results. The parameters required for the transformation are computed by the estimated position and orientation of the projector. For the estimation, we combine dead reckoning and computer vision techniques to reduce accumulation errors while achieving real-time processing.

II. Approach

The overview of the proposed system is shown in Fig. 2. We install a camera, internal sensors, low-performance processor, memory, and a projector on our AFP. Captured images and internal sensor data are transmitted via wireless communication to a server PC on which the position and orientation of the AFP's projector in a 3D coordinate system defined by a user-attached visual marker are computed using image processing and Kalman filter. The computed result represented as the coordinate transformation matrix is sent to the AFP on which the final projection image is computed by digitally deforming the original image using the received matrix. Finally, the deformed image is projected. Note that the original image is either sent from the server PC or stored in the memory of AFP.

We need to estimate the position and orientation of the projector in the marker coordinate system for digital geometric transformation. The position and orientation of the projector estimated by dead reckoning ($\mathbf{\Sigma}_S(t)$) and those estimated by computer vision technique ($\mathbf{\Sigma}_I(t)$) at the current time t are calculated by the following equations,

$$\mathbf{\Sigma}_S(t) = \mathbf{\Sigma}_{pro}\mathbf{\Sigma}_{quad}(t)\mathbf{\Sigma}_{base} \quad (1)$$

$$\mathbf{\Sigma}_I(t) = \mathbf{\Sigma}_{pro}\mathbf{\Sigma}_{img}(t - t_{vis}) \quad (2)$$

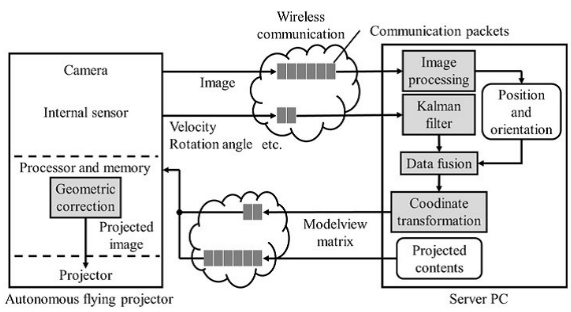
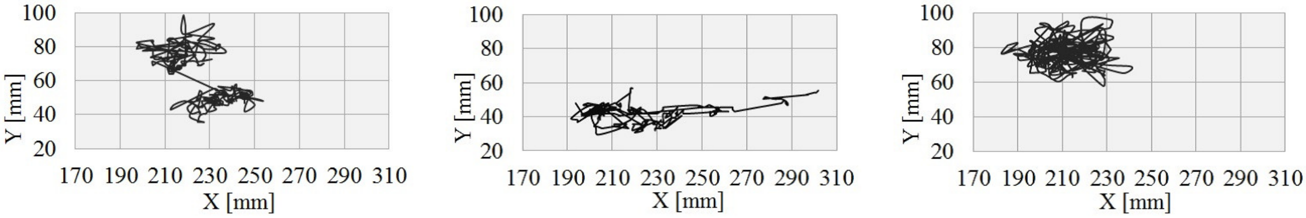


Fig. 2: Overview of the proposed system.



(a) (b) (c)

Fig. 3: The path of the projected square in the marker coordinate: the square is stabilized using (a) computer vision technique only, (b) dead reckoning only, and (c) proposed method, respectively.

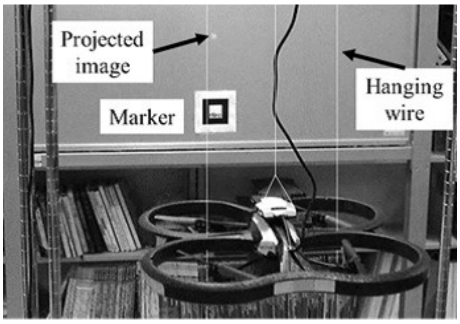


Fig. 4: Overview of the experiment.

TABLE I: Standard deviation of the trajectory.

method	standard deviation [mm]
computer vision only	13.4
dead reckoning only	18.3
proposed method	9.6

where, $\mathbf{\Sigma}_{base}$, $\mathbf{\Sigma}_{quad}(t)$, and $\mathbf{\Sigma}_{pro}$ represent the position and orientation of the AFP in the marker coordinate system at $t = 0$, those of the AFP estimated by dead reckoning in the initial AFP's coordinate system, and those of the projector in the AFP coordinate system. $\mathbf{\Sigma}_{img}(t - t_{vis})$ represents the position and orientation of the AFP measured by computer vision technique in the marker coordinate system with the communication delay of t_{vis} [3].

$\mathbf{\Sigma}_S(t)$ can be estimated with negligibly short communication delay, while it has a accumulation error problem. We correct the error by referring $\mathbf{\Sigma}_I(t)$. Suppose $L_S(t)$ and $L_I(t)$ represent the position parameters of $\mathbf{\Sigma}_S(t)$ and $\mathbf{\Sigma}_I(t)$, respectively, the corrected position parameters $L_P(t)$ is computed by taking into account the communication delay of camera image t_{vis} as follows,

$$L_P(t) = L_I(t) + (L_S(t) - L_S(t - t_{vis})) \quad (3)$$

By replacing the position parameters $L_S(t)$ with $L_P(t)$, we acquire new coordinate transformation matrix $\mathbf{\Sigma}_P(t)$.

The corner positions of the projection image are defined in the marker coordinate system $\boldsymbol{x}_m^i$, $(i = 0, 1, 2, 3)$. Those in the projector screen coordinate system $\boldsymbol{x}_p^i$ are computed by the following equation.

$$\boldsymbol{x}_p^i = \boldsymbol{V}\boldsymbol{P}\mathbf{\Sigma}_P(t)\boldsymbol{x}_m^i \quad (4)$$

where $\boldsymbol{P}$ and $\boldsymbol{V}$ respectively represent the perspective and viewport matrices of the projector.

III. Experiment and Results

We conducted an experiment to verify that how much the proposed method could reduce fluctuations of projected image compared to both dead reckoning only and computer vision technique only. In this experiment, the AFP projected a square (20×20 mm) on a flat surface, on which visual marker is attached. The experiments tried to stabilize the projected square at 200 mm above the marker (80×80 mm) while hovering as shown in Fig. 4. Assuming that the projection image was stored in the memory of AFP, we physically connect the projector on the AFP to a server PC via a video cable, and emulate an on-board processor and memory of the AFP on the server PC. The camera image was transmitted via WiFi with approximately 500 ms delays.

For each method, we recorded the projected results for 20 seconds using a video camera fixed in the environment, and measured the trajectory of the projected square. Figure 3 and Table I show the trajectories of the projected square, and standard deviations of the trajectories, respectively. The proposed method enabled to reduce fluctuations of the projected image (47.5 % less fluctuations than dead reckoning only, and 28.4 % less fluctuations than computer vision technique only).

IV. Conclusion

In this paper, we present the AFP reducing fluctuations of projected images using the geometric correction based on the combination of the measuring results from computer vision and dead reckoning. In the experiment, the proposed method enabled to reduce the variation of the projected image. We believe that the proposed method has a potential to expand AFP's applications.

References

[1] K. Tajimi, K. Uemura, Y. Kaijiwara, N. Sakata, and S. Nishida: "Stabilization Method for Floor Projection with a Hip-mounted Projector", ICAT 2010: Proceedings of 20th international conference on Artificial Reality and Telexistence, vol. 10, pp. 77-83 (2010)

[2] T. Karitsuka, and K. Sato: "A wearable mixed reality with an on-board projector", Proceedings of the 2nd IEEE/ACM International Symposium on Mixed and Augmented Reality, IEEE Computer Society, p. 321 (2003)

[3] H. Kato: "ARToolKit: library for Vision-Based augmented reality", IEICE, PRMU, vol. 101, No. 652, pp. 79-86 (2002)