PERFORMANCE IMPROVEMENT OF VISUAL ODOMETRY WITH IMU-STEREO CAMERA FOR INDOOR UAV

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ABSTRACT: UAVs used for infrastructure inspections require positioning and ranging to protect against collision accidents with structures in worse GNSS positioning environments such as spaces under a bridge. In this study, we focus on Visual Odometry to achieve positioning without GNSS. Each camera estimates rotation and translation parameters with Visual Odometry processing. In addition, we discuss an adjustment control of accumulation errors in Visual Odometry. First, relocalized positions are detected as a loop closure point in Visual Odometry processing. Second, detected positions are used to estimate an error adjustment value. Finally, the accumulation errors are gradually rectified after the relocalization in a flight. Because the error correction with loop closure causes sudden behavior-changing of UAV, the error correction is processed step by step. Through the accuracy evaluation experiment of Visual Odometry, we confirmed the position estimation accuracy was less than 0.02 [m] in indoor environments. Moreover, we confirmed our methodology can achieve an accumulation error control to improve relocalization processing in Visual Odometry for stable flights of indoor UAVs.

1. INTRODUCTION

Recently, UAVs for infrastructure inspections are equipped with GNSS positioning devices and distance measurement sensors to avoid collisions with objects and structures such as bridges, dams, and towers. However, a poor GNSS environment exists around structures. Thus, indoor-outdoor seamless positioning systems are required for UAVs (Mostafa et al., 2018). Therefore, we will focus on Visual Odometry processing (Davide et al., 2011) as an indoor-outdoor seamless positioning to support the availability of a GNSS positioning environment. Visual Odometry is a part of SLAM processing. SLAM processing can be mainly divided into LiDAR SLAM and Visual SLAM. The Visual SLAM with a single camera, has the advantage of sensor price and light-weight. However, processing cost is required for SLAM. Moreover, processing results depend on environments. Conventional studies of Visual SLAM proposed to use a stereo camera or a combination of a single camera and inertial measurement unit (IMU) to improve the accuracy of estimation of position and orientation in Visual Odometry (Taragay et al., 2007) (Yunliang et al., 2013). Thus, we focus on the performance improvement of Visual Odometry and Visual SLAM with multi-directional image acquisition with multi-stereo cameras equipped with an IMU (IMU stereo camera) (Peidong et al. , 2018). First, we propose a methodology to detect loop closures in Visual Odometry to improve the redundancy of camera position and orientation estimation and with accumulated error adjustment. Next, we explain an overview of our experiment. Then, we summarize and discuss our acquired data and experimental results. Moreover, we verify the performance of Visual Odometry for position and orientation estimation in Visual SLAM to perform stable indoor positioning.

2. METHODOLOGY

We proposed a methodology to improve the redundancy of camera position estimation with combinations of six IMU stereo cameras (front, back, top, bottom, left, and right.). We focused on visual odometry with each camera to cover the flight direction of the UAV, such as horizontal and vertical translation. We also propose a methodology to detect the timing of loop closure processing rectify error adjustment of the accumulation error in the Visual Odometry.

2.1 Visual Odometry

Visual Odometry is camera position and orientation estimation processing as a part of Visual SLAM processing. In conventional studies, a stereo camera or IMU stereo camera is used to improve the position and orientation accuracy of Visual Odometry. In this study, we examine a methodology using IMU stereo cameras in multiple directions.

2.2 Adjustment control of accumulation error

The error accumulation is a part of technical issues of Visual Odometry and SLAM, as shown in Figure 1. Generally, the accumulation errors are rectified with loop closures. First, a re-localized position is detected as a loop closed point. Next, the detected position is used to estimate the error adjustment value. Finally, the accumulation error is gradually corrected after relocalization processing. However, the error correction is not suitable for real-time processing for UAVs, because sudden changes in own position and orientation of UAVs. As a result, a flight operation of a UAV becomes unstable. Therefore, we detect the timing of the loop closing estimated by an IMU stereo camera. We also rectify estimated errors gradually to avoid the sudden changes of own position and orientation in a flight operation of UAVs.

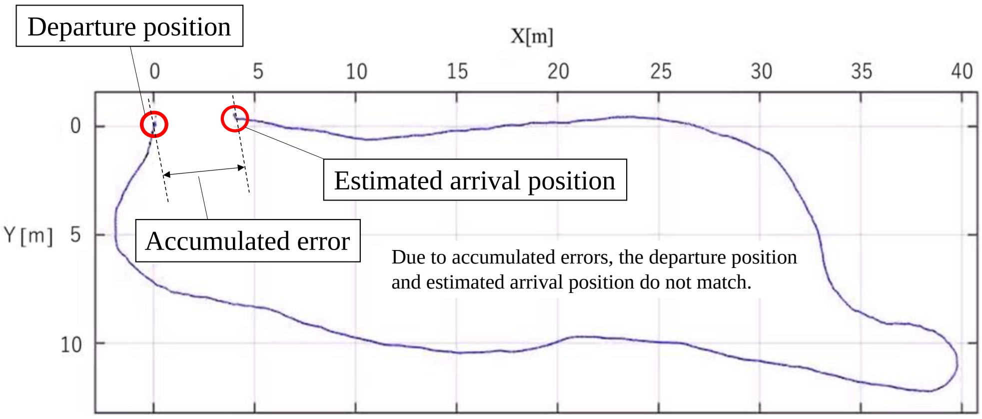

Figure 1. Example of error accumulation

Figure 2 shows the error adjustment control methodology proposed in this study. First, camera position and orientation are estimated by Visual Odometry using an IMU stereo camera. When camera position and orientation are estimated without relocalization, translation values have small changes. On the other hand, when camera position and orientation are estimated with relocalization, translation values have large changes. Based on this difference, the relocalized position is detected. When a loop closing is detected with local camera translation values among scenes, the error value of camera position and orientation is determined with the difference between a start and goal position, and camera position and orientation is relocalized as a landmark update processing. Next, we divide control sections using relocalized positions and determine readjusted error values with linear interpolation. Moreover, the above-mentioned processing is applied for all cameras aligned to the same relative coordinate axes. The final position data are determined using rectified position and orientation data estimated from all cameras.

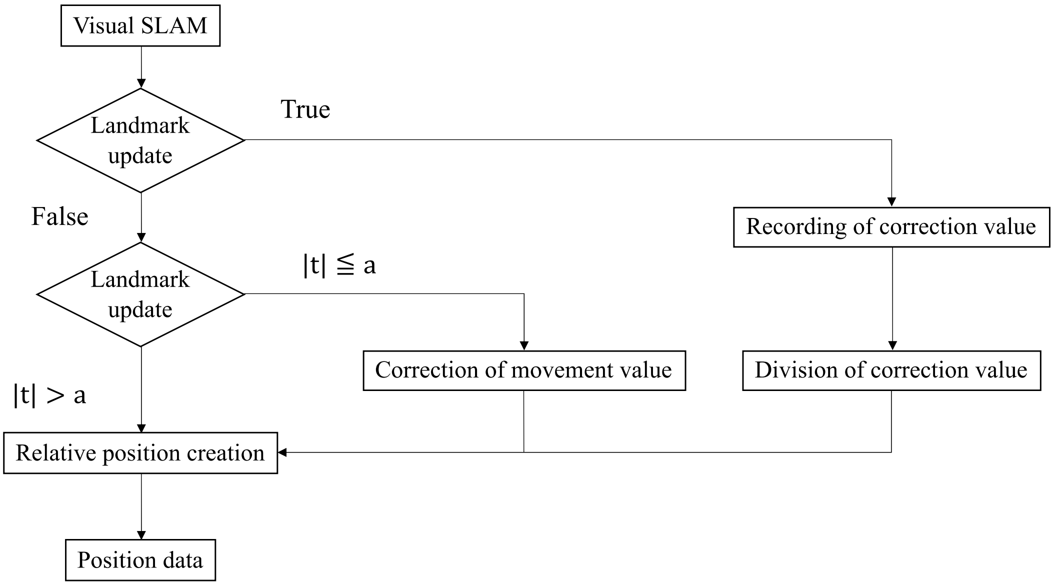

Figure 2. Proposed methodology

3. EXPERIMENTS

Although we will use six cameras, such as front, back, left, right, top, and bottom, to cover all flight directions in our future works, we used three IMU stereo cameras (front, left, and top) to cover three directions in this experiment, as shown in Figure 3. We selected RealSense T265 (Intel) (Table 1) as an IMU stereo camera. All cameras were synchronized with 0.005 [sec] accuracy.

Table 1. RealSense T265 (Intel)

Image size		848×800(px)
Sampling rate	Posture estimation	200(fps)
	Camera	30(fps)

Figure 3. IMU stereo cameras

Figure 4 shows the study area. We prepared a rectangular path with 18 [m] by 6 [m] around an escalator in an indoor environment. The path included lighting and dark areas. The path also included height changes such as stairwells. Moreover, the path included simple textures with fewer feature points for image matching.

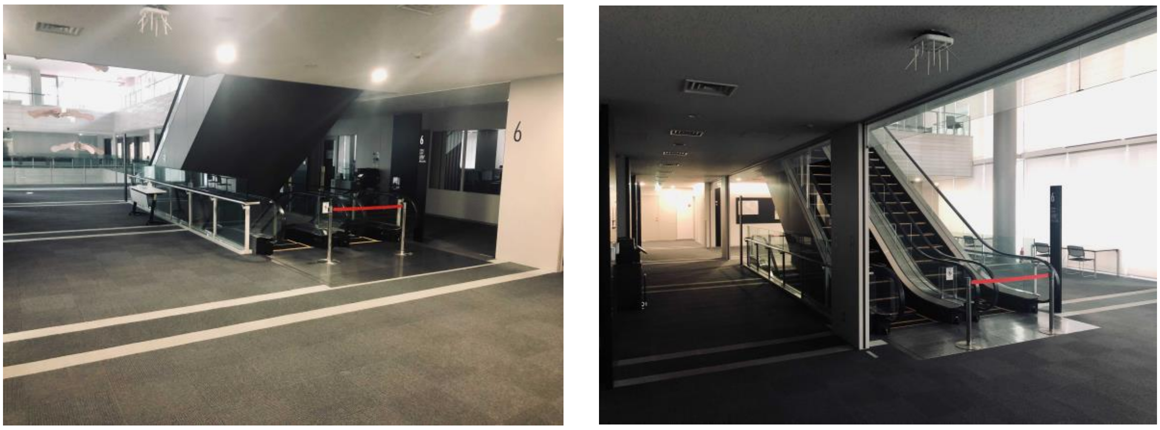

Figure 4. Study area

In this study, we conducted two types of experiments using the RealSense T265. First, we experimented to verify the accuracy of camera position and direction estimation by Visual Odometry. In this experiment, we acquired images with a translation range set within 0.5 [m] for 50 [sec]. We calculated the RMSE using the average of the position estimation results of the three cameras. Next, we conducted an experiment on camera position and direction estimation with movement along a rectangular path to verify the accuracy of Visual Odometry using the IMU stereo camera in a real space.

4. RESULTS

4.1 Accuracy verification results

Figure 5 shows the estimated trajectories of each camera in Visual Odometry. A red line indicates trajectory data of the front camera, a green line indicates trajectory data of the top camera, and a blue line indicates trajectory data of the top camera left camera. We confirmed that camera position and orientation estimation was processed with 200 Hz and all cameras were synchronized with 0.005 [sec] accuracy.

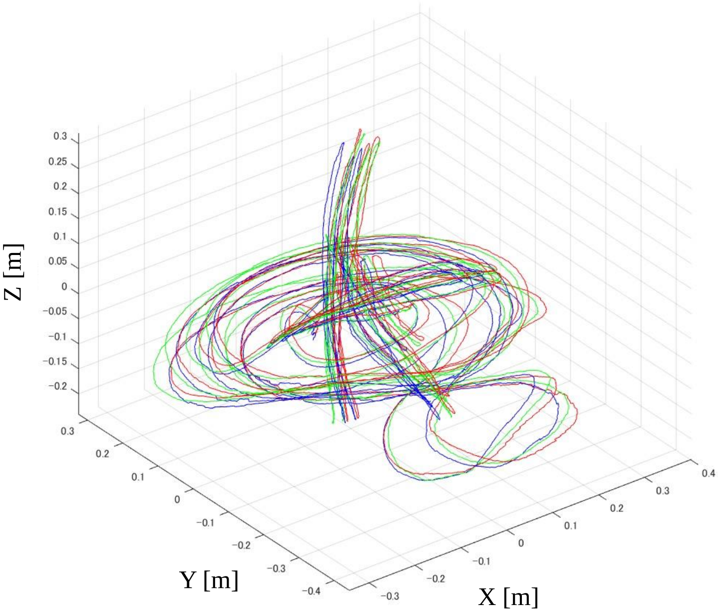

Figure 5. Camera position estimation results (trajectory)

The RMSE calculated for each camera was 0.011 [m] (front camera), 0.008 [m] (top camera), and 0.013 [m] (left camera). Although it depends on the measurement environment, the accuracy was within 0.02 [m]. Camera position estimation results are shown in Figure 6.

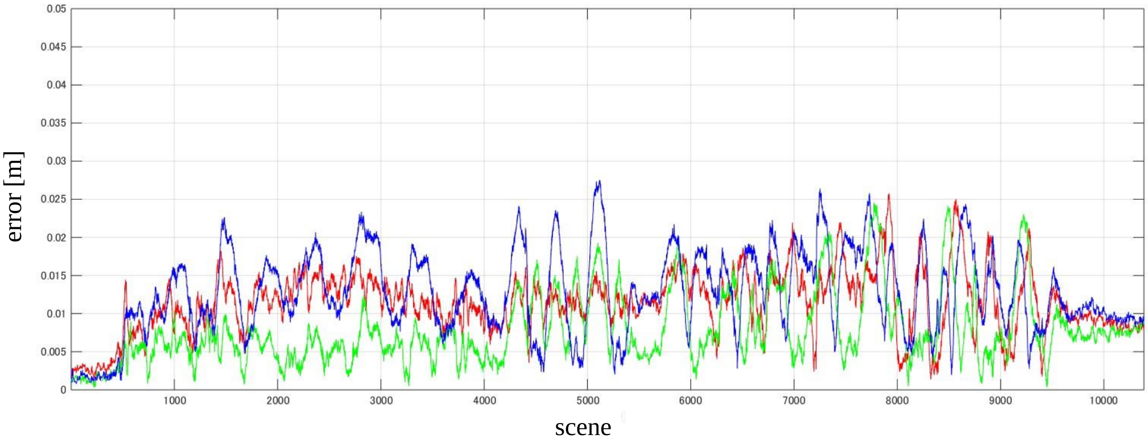

Figure 6. Camera position estimation results (accuracy)

4.2 Adjustment control results of accumulation error

The trajectory and correction data estimated from the front camera were compared as shown in Figure 7. The red line indicates the actual path and the black dots indicate the estimated position data. The points in the green circle are skipped trajectory data due to the rapid position correction. In the lower part of the two figures, differences exist between the actual and the estimated route because the processing error occurred by fewer feature points extracted from images.

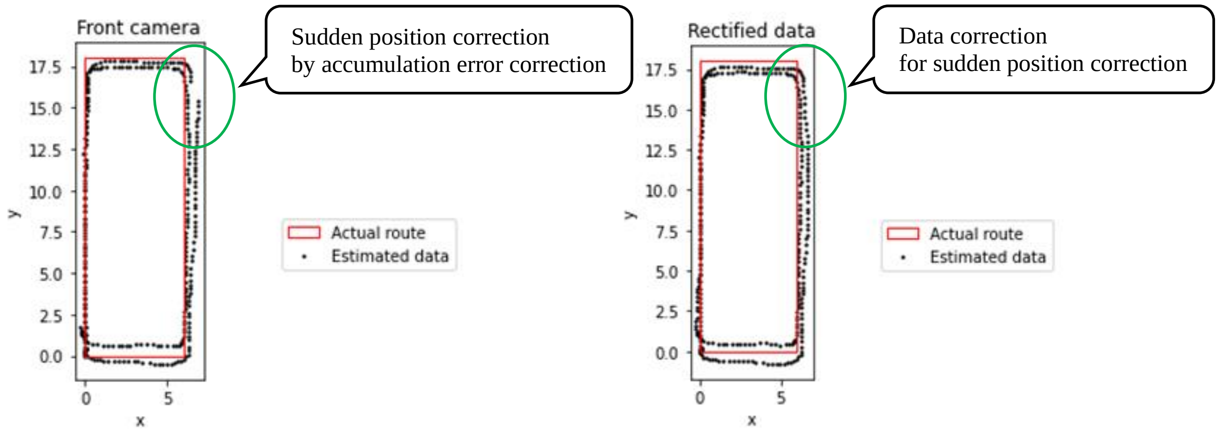

Figure 7. Comparison of trajectory data (rectangular path)

Next, we compared the temporal changes at each frame in the camera position estimation of the acquired and the corrected data. From the results of the front camera, sharp position changes due to loop closure were observed at 38 and 55 [sec] assumed as loop closing points (Figure 8). Thus, we readjusted the accumulated error values at these points (Figure 9).

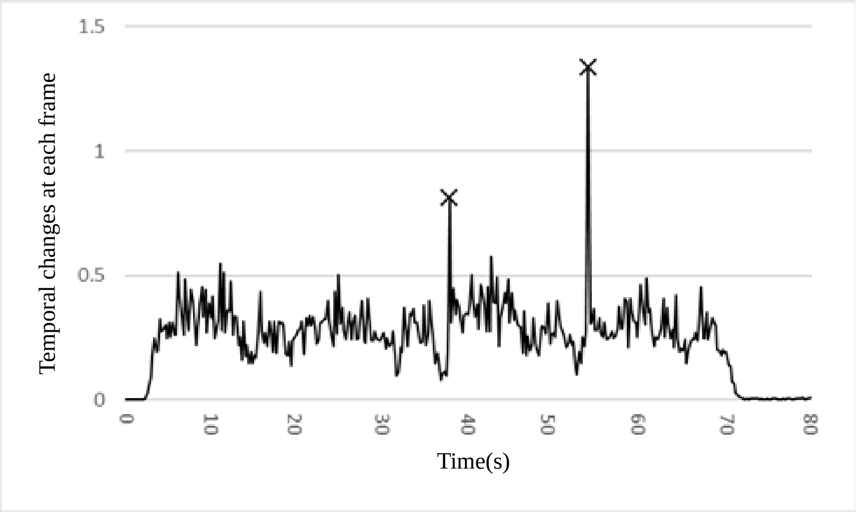

Figure 8. Temporal changes at each frame in camera position estimation

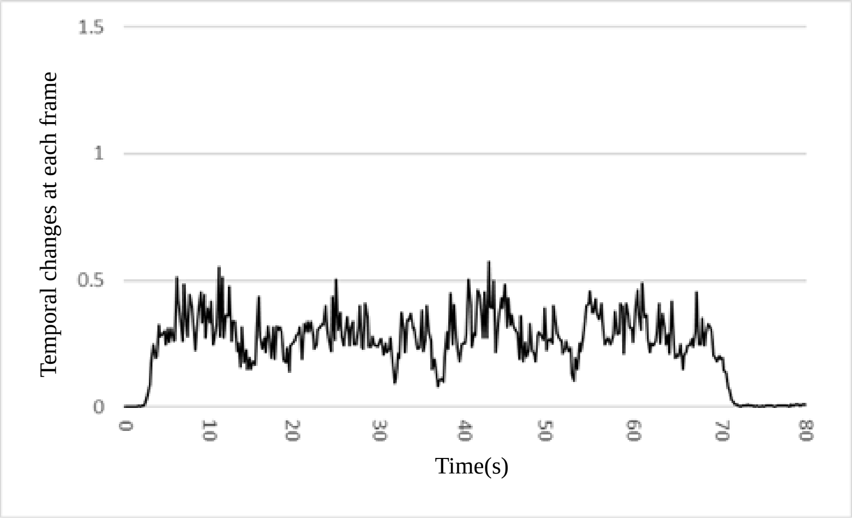

Figure 9. Temporal changes at each frame in camera position estimation of correction readjusted

5. DISCUSSION

In conventional SLAM processing (Kneip et al., 2011), Visual Odometry performance is improved by combining IMUs with stereo or single cameras that have the advantage of being inexpensive and light. However, due to sudden position changes caused by landmark updates, the continuity of location information was lost. Alternatively, in our proposed methodology, we readjusted the correction values to avoid the sudden position changes step by step to achieve a stable position estimation for UAVs. Next, Figure 10 shows where the landmark updates occurred. After repeating the experiment multiple times, we confirmed that the landmark updates occurred at the start point and recaptured points. In both cases, they occurred at positions we slowed down in walking.

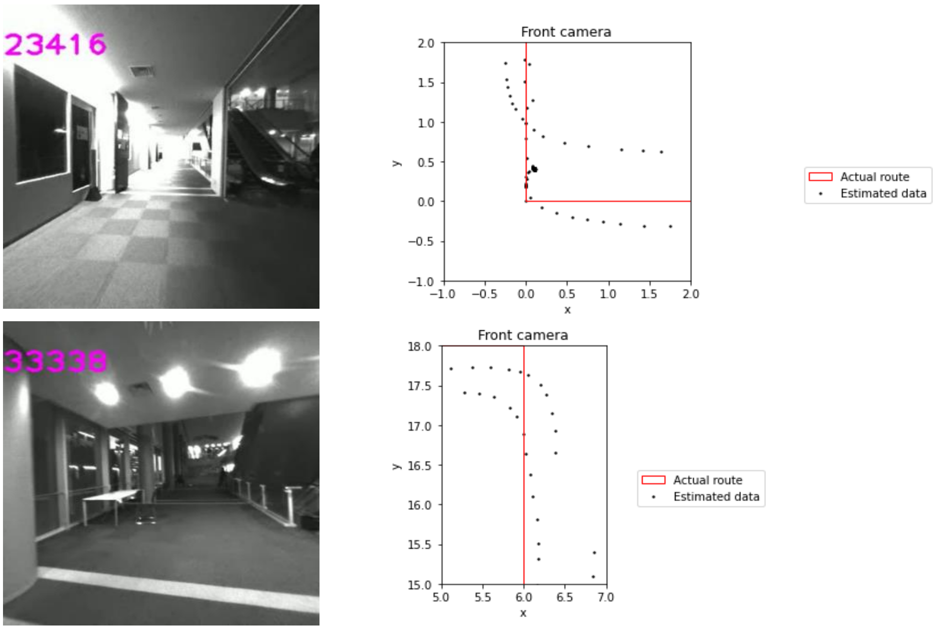

Figure 10. Landmark update on the front camera (left images: captured images, right figures: trajectory data)

We confirmed that the accuracy of position estimation on the camera direction. Figure 11 shows two types of results of Visual Odometry obtained along a straight path (5 [m]). First, we acquired images with the same direction in movement and camera in a round trip (front camera 1). In this case, the camera direction was changed at the endpoint. Second, we acquired images with the same camera direction in a round trip (front camera 2). In this case, the camera direction was not changed. The relocalization error value of front camera 1 was 0.027 [m], and that of front camera 2 was 0.009 [m]. Thus, we indicate that the camera direction is one of the factors on measurement accuracy improvement in the position estimation.

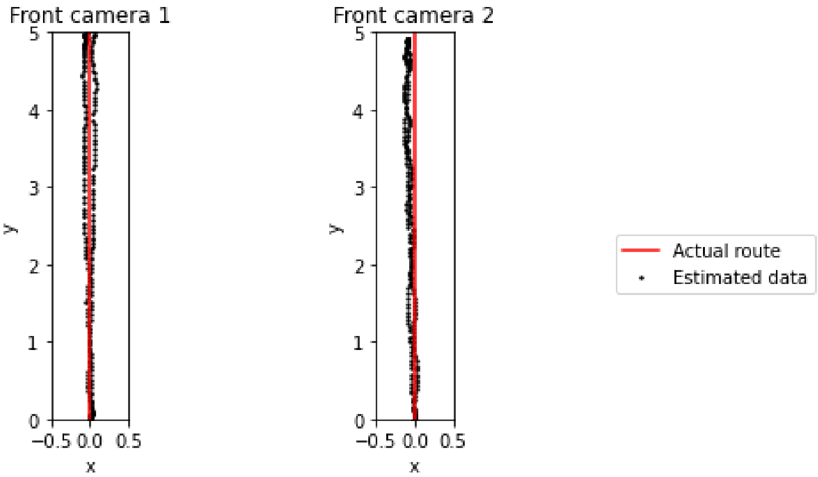

Figure 11. Trajectory data for different camera directions (straight lines)

6. CONCLUSION

We proposed a methodology to improve the performance of Visual Odometry using an IMU stereo camera with adjustment control of accumulation error in SLAM for more stable positioning. We confirmed that our methodology achieved approximately 0.02 [m] positioning accuracy. We also confirmed that our methodology modified sudden error adjustment in the relocalization process of Visual Odometry. Through our experiments, we verified that our methodology can be used for the stable control of indoor UAVs. Our future works are more accurate methodology, more stable methodology, and practical experiments using UAVs

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