Projective indices for AR/MR benchmarking in TrakMark

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***Abstract*—We propose to exploit "projective indices" to compare camera tracking methods for augmented reality (AR) and mixed reality (MR). Projective indices are calculated by projection error of virtual points that are placed in the scene. The number of virtual points, their positions, and how to calculate the indices are important to compare different camera tracking methods as these parameters largely affect on the projective indices. We show evaluation results of two kinds of projective indices on TrakMark dataset.**

Keywords*—*camera tracking; augmented reality; mixed reality; benchmarking; TrakMark

I. Introduction

Many vision-based camera tracking methods have been proposed for a wide variety of applications such as navigation, reconstruction, augmented reality (AR) and mixed reality (MR). The tracking accuracy of these methods on a same sequence can be compared by 3D geometric indices such as positional and rotational error between an estimated camera pose and the ground truth. In some applications such as AR/MR, however, it is important whether virtual objects are displayed at correct positions on the camera image or not. Therefore, projection errors of virtual objects rather than positional and rotational errors of the camera are important.

The working group "TrakMark" [1] are working for establishing an automated benchmarking of camera tracking methods for AR/MR. Makita et al. [2] introduced 2D projection error of virtual 3D points that are placed in front of the camera as a benchmark index. The number of virtual points, their positions, and how to calculate the indices are important to compare different camera tracking methods as these parameters largely affect on the projective indices.

In this paper, we discuss appropriate parameters of "projective indices" which are calculated by projection error of virtual points to give fair and easy comparison of camera tracking methods for AR/MR. Because the virtual points can be placed arbitrarily, projective indices are suitable than re-projection error which only evaluates the re-projection error of feature points. We show evaluation results of two kinds of projective indices on TrakMark dataset. One is focused on the individual projection error of nine virtual points. The other is focused on mean projection errors of 289 virtual points. The virtual points are placed at relative position from the camera of the ground truth.

II. Projective Indices

Many of camera tracking methods minimize re-projection error of feature points. The re-projection error can be an index to evaluate tracking accuracy. However, on AR/MR literature, it is important to estimate the projection error of a virtual object that may not be close to the feature points. Therefore, projection error of virtual points has been introduced as benchmark index [2].

A. Number of virtual points and their positions

Positions of virtual points in 3D space are crucial on evaluating camera tracking methods in AR/MR. They should be placed within the field of view of the camera. There are two positioning strategies. First is relative placement: to place it at a relative position from the camera of the ground truth. Second is absolute placement: to place it at a fixed point in the world coordinate. In relative placement strategy, we place the virtual points on a virtual plane that is parallel to the image plane of the ground truth camera at a certain distance.

We first examine the 2D projection errors of nine virtual 3D points placed by relative strategy. As transitions of the errors are similar among the nine points, we placed more virtual points within the field of view of ground truth camera and examine the mean projection error.

B. Two stage projective indices

In evaluating a camera tracking method for AR/MR, we concern about the visibility of a virtual point at a certain distance from the camera. If it is visible, the amount of 2D projection error is also important. Therefore, projective indices should be defined on two stages below.

(1) Is a virtual point visible and within the frame of the estimated camera?

(2) If yes on (1), 2D Euclidean distance between the projection of virtual point that is placed in front of the ground truth camera and the corresponding projection of virtual point in front of the estimated camera.

III. BENCHMARKING BY TWO STAGE PROJECTION INDICES OF NINE POINTS

As benchmark supporting tool, we made a program in R language. To run the program, a user needs to prepare estimated extrinsic camera parameters, ground truth of extrinsic camera parameters, position data of virtual points, intrinsic camera parameters, resolution of camera images, and parameters for creating graphs.

In current implementation, we use index number *Id* from zero to four to indicate the projective index of the first stage. A virtual point P is judged as “IN” if projected position:(u,v) is in the camera image and P is in front of the camera, otherwise P is judged as “OUT”. P’ is also judged with following the same process. Then, in case (P, P’) = (IN, IN), *Id* = 0. Also *Id* = 1 for (P, P’) = (IN, OUT), *Id* = 2 for (P, P’) = (OUT, IN), and *Id* = 3 for (P, P’) = (OUT, OUT). Finally, *Id* = 4 in case there is not an estimated camera parameter for the frame.

We created benchmarking results with the R program using “NAIST Campus Package 01” dataset [3] shared in TrakMark web site. The dataset includes both monocular camera sequence and omnidirectional camera sequence. We applied monocular camera sequence that includes intrinsic camera parameters computed by Tsai's method [4], and two types of extrinsic camera parameters as reference data. One is a camera path estimated from known points made by hand work (this one can be treated as ground truth). The other is a camera path estimated by a landmark-based tracking method [5]. Fig.1 shows positions of virtual points on a virtual plane. In current implementation, we set nine virtual points from A to I with Tsai's intrinsic parameters: (*f, sx, dx, dy*), the resolution of the camera image: (*h*, *w*) = (480, 720), and a distance between the camera position of ground truth and the virtual plane: *a*.

Fig.2-5 shows benchmarking results automatically created by the program. In this test, we applied relative positions of virtual points, and set the distance *a* = 1000 and 5000[mm]. When the distance is short, position error is dominant for projection error. In the results as shown in Fig.3, *Id* = 1 were observed at several frames when *a* = 1000, but were not observed when *a* = 5000. Fig.4 and Fig.5 show projection errors of nine points. Both when *a* = 1000 and 5000, transitions of the errors are similar among the nine points. Therefore, the tracking method [5] is supposed to be balanced to overlay virtual objects for this scene.

As future works of the program, we plan to introduce a function to input and compare multiple tracking results with ground truth data. Moreover, another type of projection error that independent of intrinsic camera parameters will be added.

IV. BENCHMARKING BY MEAN PROJECTIVE ERROR

We evaluated parallel tracking and mapping (PTAM) [6] by mean projective error using the evaluation procedure proposed by [7]. In this example, virtual points are placed on 17x17 grid points on a virtual plane by relative placement strategy. The distance *a* = 1000, 2000, 5000, 10000, and 50000[mm]. We calculate the mean projection error from all virtual points, including the virtual points judged as “OUT” as projective index of the first stage.

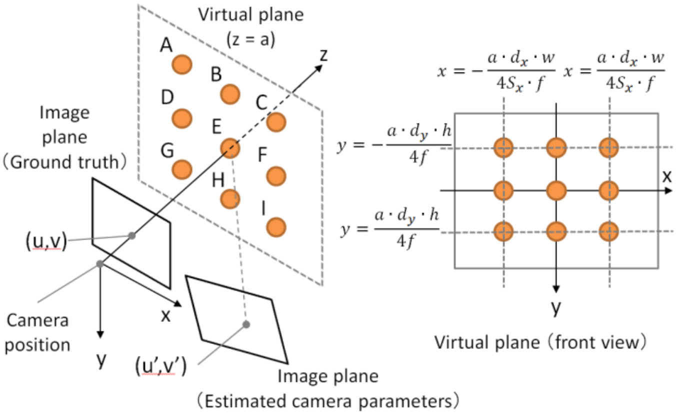


Fig.1 : Positions of virtual points

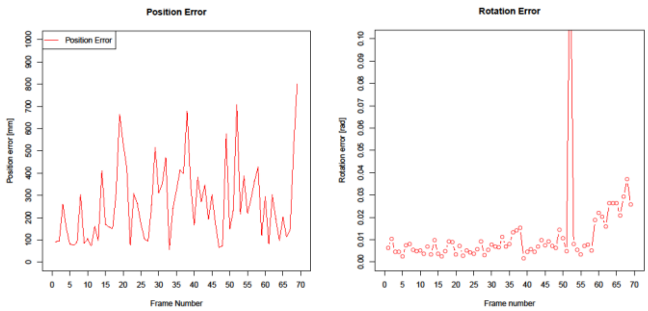
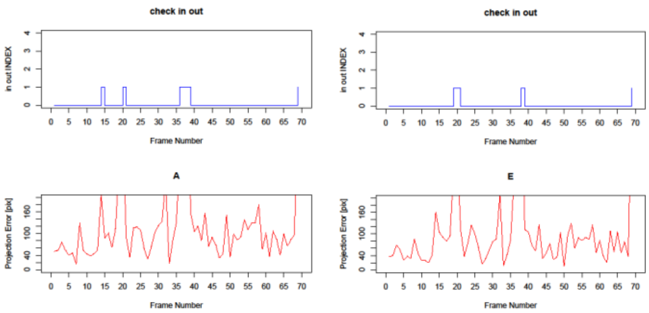
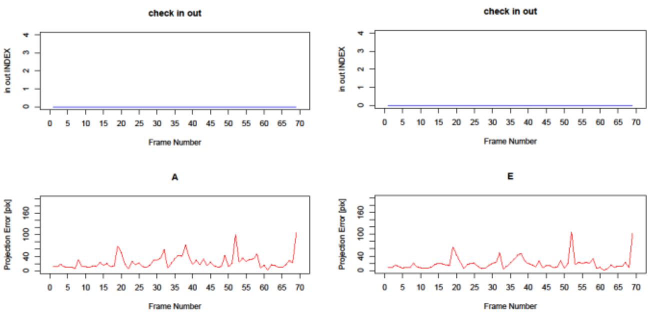


Fig.2 : Position and rotation error



Distance : 1000[mm]



Distance : 5000[mm]

Fig.3 : Projection errors of A and E with In/Out indexes

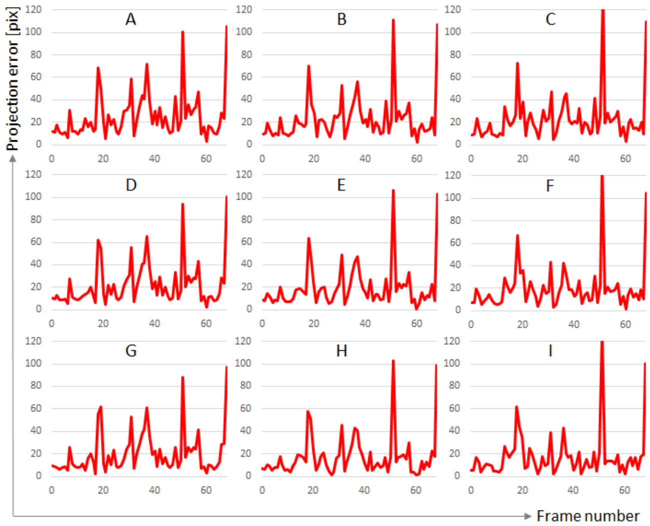


Fig.4 : Projection errors of nine points (distance : 1000[mm])

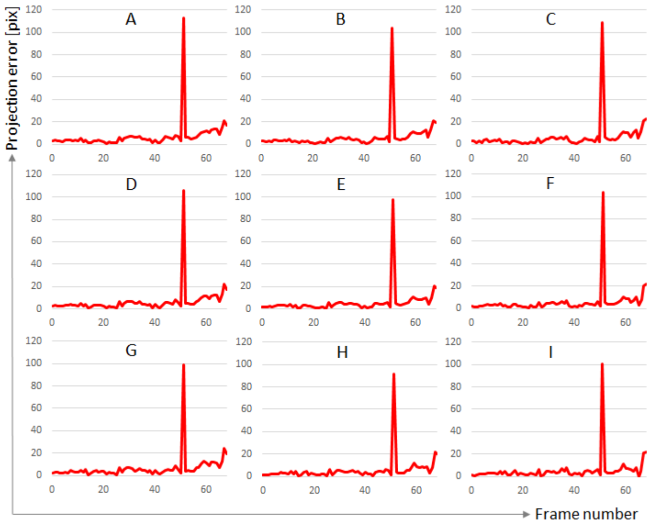


Fig.5 : Projection errors of nine points (distance : 5000[mm])

Fig.6-7 shows the result of "NAIST Campus Package 01" dataset [3] after stereo initialization of PTAM (we use initial 30 frames for the initialization). As the camera start moving, position error of the estimation increases gradually. The rotation error becomes large when the camera rotates rapidly. The mean projection error is 100 to 300 pixels approximately at least, in most of the frames. Projection error of far points is smaller than projection error of near points, because the positional error is large.

V. Conclusion

We discussed appropriate parameters of projective indices to compare camera tracking methods for AR/MR, and showed two evaluation results on TrakMark dataset. We proposed to exploit two stage projective indices. Projective index of the first stage is useful to know that a virtual object at a certain

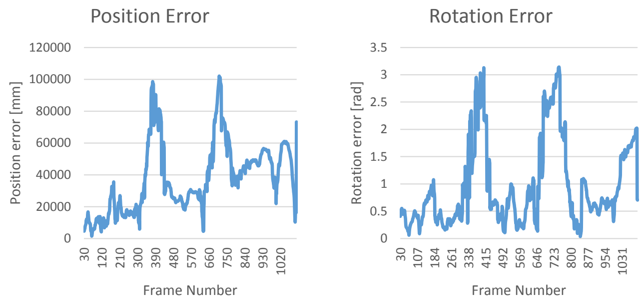


Fig.6 : Position and rotation error

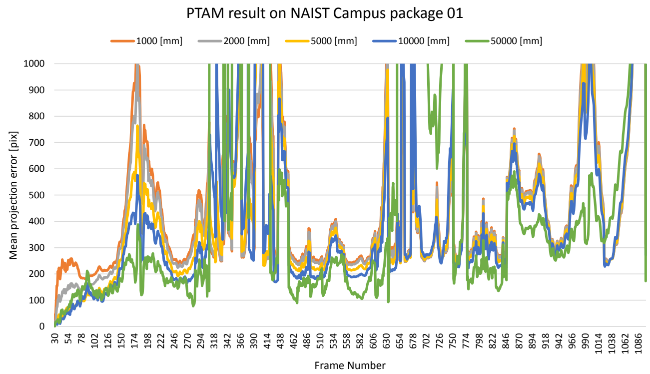


Fig.7 : Mean projection error of 17x17 points

position is visible or not. Projective index of the second stage is useful to know the amount of the projection error. Two stage projective indices are essential to establish a benchmark test of camera tracking methods for AR/MR.

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