Prioritization and Static Error Compensation for Multi-camera Collaborative Tracking in Augmented Reality

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ABSTRACT

An effective and simple method is proposed for multi-camera collaborative tracking, based on the prioritization of all tracking units, and then modeling the discrepancy between different tracking units as a locally static transformation error. Static error compensation is applied to the lower-priority tracking systems when high-priority trackers are not available. The method does not require high-end or carefully calibrated tracking units, and is able to effectively provide a comfortable augmented reality experience for users. A pilot study demonstrates the validity of the proposed method.

Keywords: Augmented reality, multi-camera tracking.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities I.4.8 [Image Processing and Computer Vision]: Scene Analysis—Tracking

1 INTRODUCTION AND BACKGROUND

Augmented reality (AR) provides the user with the perception of a virtual environment in addition to the real world, which enhances the understanding of the current situation. Tracking is a required component in many AR applications in order to correctly relate the coordinate systems of the user's view to the world. A tracking system can be characterized into: *world-anchored* and *user-anchored tracking system* based on its spatial relationship to the system.

In a *world-anchored tracking system*, the pose of the tracker coordinate system remains unchanged with respect to the world coordinate system. A world-anchored tracking system can potentially be accurate, since it is not constrained by power, computation resources, size and the type of technology used. Examples include reflective markers, electromagnetic sensing and etc. With the advent of many head-mounted displays in the consumer market, cameras are widely used for tracking, acting as *user-anchored tracking systems*. This type of tracking system is attached to the user, and provides a perspective that is closer to that of the user [1]. AR applications which incorporate multiple tracking units can mitigate occlusion problem, and the fusion of tracking data from multiple sources can improve the tracking accuracy. However, a collaborative tracking system is usually hard to set up [4], and requires costly systems or sophisticated calibration platforms that are not typically accessible to general users.

In this study, a simple yet effective method is proposed to fuse tracking information generated by a multi-camera tracking system for AR applications, desired for a wider range of users. The method is composed of two phases, the prioritization of individual tracking units and the compensation for the discrepancy between different tracking units as locally static error.

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Data: Priority value P_i of all tracking units U_i
Result: Pose T of the target object
begin
  Initialize tracking result for all tracking units T_i;
  Find the tracking unit with highest priority U_{max};
  Initialize static transformation error D_i between U_{max} and all other tracking units $U_i, U_i \in \{U\} \backslash U_{max}$;
  while *running* **do**
    if $T_{max} \neq \emptyset$ **then**
      $T = T_{max}$;
      Update static transformation error D_i, s.t. $T_{max} = D_i \cdot T_i$;
    else
      Find the available tracking unit with highest priority U_k, where $P_k = max\{P_i \mid T_i \neq \emptyset\}$;
      $T = D_k \cdot T_k$;
    end
  end
end

Algorithm 1: Prioritization and static error compensation for multi-camera collaborative tracking

2 METHOD

2.1 Prioritization

Prioritization is the first phase of the proposed method. All the tracking units $U_i, i = 1, ...n$ are labeled with a priority value P_i based on their tracking performance. In a multi-camera tracking system, the tracking quality of each tracking unit varies depending both on the hardware quality of the camera, and type of anchoring (world-anchored or user-anchored). Error analysis of fiducial marker tracking reveals that planar location of the marker is more reliable than its depth information [2]. Therefore, a user-anchored tracking system is usually preferred, and is labeled a higher priority in our proposed method.

2.2 Assumption

Consider two tracking units U_i and U_j, measuring an object with pose T (ground truth) in the scene twice within a small time period, with measurement error. The measurements are:

$$T_i(t) = \Delta T_i(t) \cdot T, \quad T_i(t+\Delta t) = \Delta T_i(t+\Delta t) \cdot T$$
$$T_j(t) = \Delta T_j(t) \cdot T, \quad T_j(t+\Delta t) = \Delta T_j(t+\Delta t) \cdot T$$

Therefore, the discrepancies of the two tracking units at time t and $t+\Delta t$ are:

$$D_{ij}(t) = T_j(t)^{-1} \cdot T_i(t) = \Delta T_j(t)^{-1} \cdot \Delta T_i(t)$$
$$D_{ij}(t+\Delta t) = T_j(t+\Delta t)^{-1} \cdot T_i(t+\Delta t) = \Delta T_j(t+\Delta t)^{-1} \cdot \Delta T_i(t+\Delta t)$$

Given the fact that the tracking system is neither perfectly calibrated, nor advanced in terms of accuracy, system error contributes more to the measurement error when compared to a random noise, and the system error is correlated with the pose of the target. The

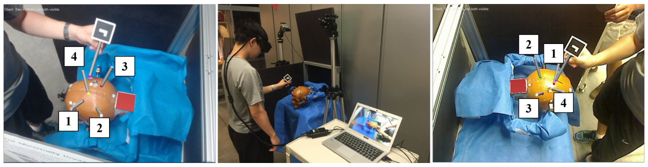
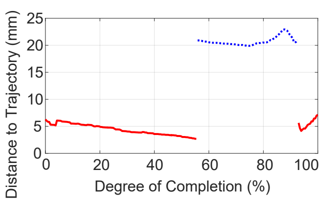
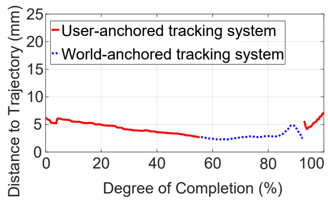


Figure 1: System setup and views from world-anchored cameras



(a) Sample trial of user's motion



(b) The same trial with proposed method

Figure 2: Experimental result of a sample trial, with and without the proposed method: prioritization and static error compensation

assumption is that within a small time period, the motion of the object is relatively small; therefore the tracking error of each tracking unit is relatively stable: $\Delta T_i(t) \doteq \Delta T_i(t+\Delta t), \Delta T_j(t) \doteq \Delta T_j(t+\Delta t)$. As a result, the discrepancy between the tracking results of two tracking systems is approximately static: $D_{ij}(t) \doteq D_{ij}(t+\Delta t)$.

2.3 Static Error Compensation

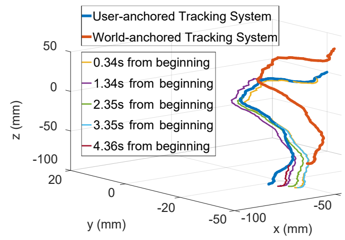
With the above assumption, the discrepancy between the different tracking units can be modeled as a static error term within a short time period. When the higher-priority tracking unit is not available, the error term can be applied to the lower-priority tracking unit to obtain a better tracking result. The static error term is updated whenever both high-priority and low-priority measurements are available. The detailed algorithmic workflow is listed in Tab. 1.

3 Experiment

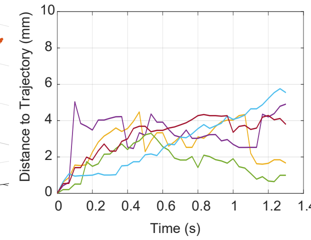
The collaborative tracking system setup (Fig. 1) involves three tracking units, two *world-anchored cameras* (Logitech Pro c920 and c9000) on tripods, and a *user-anchored camera* embedded on Meta One (MetaVision, CA). The software is implemented using Unity3D and ARToolKit [3]. The user-anchored camera is labeled with the highest priority, and the priority of side cameras is determined according to their distance to the scene. A fiducial marker is placed in the scene as a common base coordinate system, while the other is attached to the tool held by the user. Four cylinder trajectories are displayed on Meta One in optical see-through mode. The user is asked to hold the tool and follow the trajectory. A pilot user study was conducted, and 32 trajectories (16 with and 16 without our algorithm) were recorded.

4 Results and Discussion

Fig. 2a demonstrates the discrepancy between the tracking results of user-anchored and world-anchored cameras. The moment in which the user-anchored camera becomes unavailable, there is a significant gap between the tracking results of the two cameras, and instant switch of the tracking unit causes visual discomfort for the user. With our method, the user-anchored camera is granted higher priority, and the static transformation error is calculated between the user-anchored and the world-anchored camera. Fig. 2b demonstrates the tracking result with the static error compensation. This way, switching from the user-anchored camera to the world-anchored camera becomes smoother, and the augmented reality experience for the user is thus improved. However, with extended



(a) Trajectories of applying static error compensation to the world-anchored camera



(b) Distance to the desired trajectory within 1.2 seconds

Figure 3: Comparison between the tracking result of the user-anchored camera and the world-anchored camera with the proposed method applied at different time periods

unavailability of the user-anchored camera, the transformation error is driven further from the static approximation, consequently switching back to the higher-priority tracking unit is not desirable.

Fig. 3a visualizes the effect of the proposed method applied at different time periods for one sample trial. The unavailability of the user-anchored camera is simulated at different times. Fig. 3b shows the remaining error after applying the proposed method within 1.2s, compared to the tracking result from the user-anchored camera. The error is significantly reduced when compared to the direct application of the tracking result from the low-priority camera.

5 Conclusion

An effective and simple multi-camera collaborative tracking approach is proposed that can overcome occlusion problem in augmented reality applications and reduce uncomfortable experience for the user caused by the temporary unavailability of tracking units. The method neither requires advanced tracking devices, nor careful calibration of the cameras and application environment, which is desirable for ordinary users. The first phase of the proposed method, *prioritization*, labels each tracking unit by its suitability for the application, depending on the viewpoint and its quality. In the second phase, the discrepancy between a certain tracking system and the best tracking system is modeled as a *static transformation error*, and the error is compensated when the specific tracking system is in use, based on the assumption that the motion of the object is relatively small within a small time period. The pilot study validates the efficacy of the proposed method.

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References

[1] E. Azimi, J. Doswell, and P. Kazanzides. Augmented reality goggles with an integrated tracking system for navigation in neurosurgery. In *2012 IEEE Virtual Reality Workshops (VRW)*, pages 123–124. IEEE, 2012.

[2] M. Bauer, M. Schlegel, D. Pustka, N. Navab, and G. Klinker. Predicting and estimating the accuracy of n-occular optical tracking systems. In *2006 IEEE/ACM International Symposium on Mixed and Augmented Reality*, pages 43–51. IEEE, 2006.

[3] H. Kato and M. Billinghurst. Marker tracking and hmd calibration for a video-based augmented reality conferencing system. In *Augmented Reality, 1999.(IWAR'99) Proceedings. 2nd IEEE and ACM International Workshop on*, pages 85–94. IEEE, 1999.

[4] B. Li, L. Heng, K. Koser, and M. Pollefeys. A multiple-camera system calibration toolbox using a feature descriptor-based calibration pattern. In *2013 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pages 1301–1307. IEEE, 2013.