A Cooperative Object Tracking System with Fuzzy-Based Adaptive Camera Selection

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Abstract- The intelligent environments, built upon many distributed sensors, are promising technology for ubiquitous interaction between robots and human beings. Especially, it is important to track target objects and get the positional information of them in such environments. This paper focuses on adapting camera selection for target tracking in multi-camera system. In this paper, a fuzzy automaton based camera selection method is introduced. In the proposed method, the camera selection decision is driven by fuzzy automaton based on the previously selected camera (previous camera state) and the tracking level of the object in each available camera. Simulations for evaluation of the proposed method and comparison with the previous method are presented. The results show that the proposed method is efficient for adaptive camera selection in multi-camera environment and helps easy construction of multi-camera placement. An actual multi-camera system with the proposed camera selection method was developed for checking tracking performance in the real environment. Experiments in the constructed system show that the proposed method suits well the camera selection task for tracking a moving object in the real intelligent environment.

Index terms: intelligent environment, object tracking, camera selection, fuzzy automaton

I. INTRODUCTION

The research field on intelligent environments has been expanding[1][2]. The intelligent environments include many distributed sensors in the system. Especially, a distributed vision sensor network can also offer a promising infrastructure for robots in order to coexist in a human-robot mixed environment such as houses, factories, hospitals etc.[3][4]. It is beneficial to achieve tracking and localization of target objects in wide-area located, human-sensor contact-free environment.

Many cameras are placed redundantly and randomly in a distributed vision sensor network. In order to solve multi-camera tracking and localization problem, not only the problems of image processing but the difficulties of making a multiple-camera system as sensor system architecture are also appearing. This paper focuses on such multi-camera system architecture for target tracking. There is a camera selection problem for target tracking or localization in multi-camera system. The most suitable camera, according to its tracking capability in a given situation (which expects to have the smallest tracking error) should be selected from many camera candidates. In the past years, several studies on sensor selection have been performed. Chu et al.[5] proposes the Information-Driven Sensor Querying algorithm that selects the sensors with the best measurement. This has to integrate over all measurements. Liu et al.[6] addressed the problem of localization-oriented optimal camera selection based on a tradeoff between accuracy of target localization and the energy consumption. This does not describe how the proposed method is implemented as actual multi-sensor system. Isler et al.[7] considered selecting sensors so as to minimize the error in estimating the position of a target with a generic sensor model with polygonal, convex subsets of the plane. Although camera selection results from 19 cameras are demonstrated, how to configure the multi-camera network is not presented at all. It is not also clear how to deal with the moving target objects in these studies. Yang et al.[8] studied how to task distributed camera sensor nodes to reason about the occupancy of existing objects with visual hulls. Although the experimental results with 16 cameras are presented, information from each camera is transferred to a central computer for calculating the occupancy.

The contents of these studies indicate that actual construction of distributed camera system without any central computers is not easy and problems are still remaining. Camera selection problem emerges more protruding if the vision system is constructed from independent autonomous and decentralized cameras.

This paper aim to develop an object tracking system actually with independent autonomous and decentralized multi-camera, introducing a camera selection method based on fuzzy automaton in handing over protocol[9]. This architecture helps to build a scalable system for expanding the monitoring area because the proposed system does not have a central computer for calculating tracking results in itself.

This paper is organized as follows: In Section II, the camera handing over for object tracking problem will be introduced in more details together with the brief descriptions of the existing solutions. In Section III, a novel camera selection method based on fuzzy automaton is proposed. Section IV shows simulation and comparison with the previous handing over. Section V presents some experimental results of object tracking with an implemented actual multi-camera system. Conclusions and future works are discussed in Section VI.

II. CAMERA HANDING OVER FOR SEAMLESS OBJECT TRACKING

Camera selection method based on handing over protocol has been previously proposed for mobile robot control in Intelligent Space[9]. Distributed cameras were exploited within it for localization and control of mobile robots[10]. If a mobile robot is operating in the monitoring area of a camera, it can monitor and guide the robot on its own without any difficulties. However, to guide robots in a wider area, which cannot be covered by a single camera, more cameras are required. It is defined that the best camera while monitoring a target robot has a control authority of a robot in the system. In case when a robot moves from a monitoring area of a camera with control authority to an another area, the robot's dominant camera has to be automatically changed. This is called "handing over of the control authority".

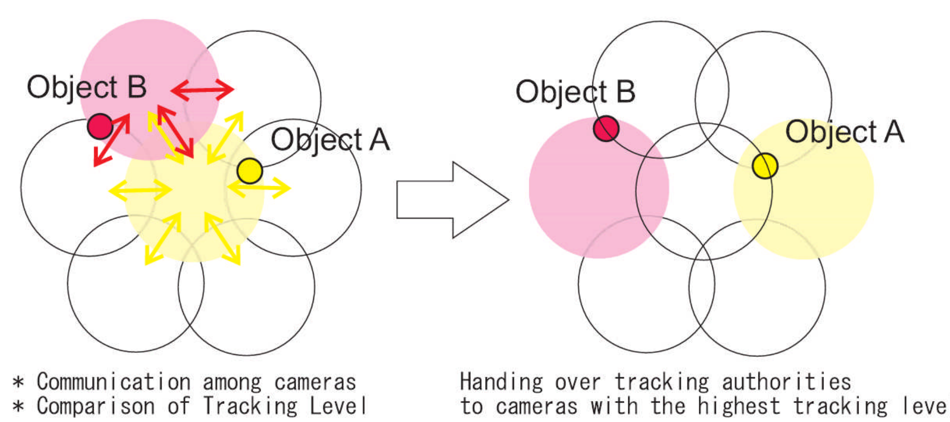


Figure 1. Handing Over

Figure 1 shows a process for handing over of the control authority of a target robot. Circles indicate the monitoring areas of cameras. The monitoring areas of dominant cameras are colored.

In this method, a reliability rank is defined for the monitoring area of each camera. High reliability stands for the meaning that the camera can track and guide a mobile robot robustly and precisely. First, the dominant camera requests information from the other adjacent cameras about the reliability rank of the target robot. The other cameras reply with their reliability ranks concerning the robot and the current dominant camera. Reliability rank is decided from two factors; location of a target robot monitored in a camera image plane and distance from each camera to a target robot. The dominant camera compares reliability ranks with its own rank. If the other camera has a higher rank than its own rank, then the current dominant camera transfers the authority of control to the other camera, which has the higher rank. Then the new dominant camera tracks and controls the target robot. Since in [9] the reliability rank is discretely decided in the monitoring area, overlapping of monitoring areas has to be carefully adjusted for the required comparison of reliability ranks among cameras. That makes the multi-camera setup system more complicated. In this paper, in order to realize handing over in a camera network, a flexible camera selection method, which does not depend on camera placement and overlapping of monitoring areas, based on fuzzy automaton is proposed.

III. FUZZY AUTOMATON BASED CAMERA SELECTION

In the previous method[9], monitoring areas of cameras are divided and recognition levels are decided by trial and error manner. For stable handing over, some sufficient overlapping of the monitoring areas is also required. It can be a difficult task to find the proper positions for placement of multiple cameras. The existence of a flexible handing over method can simplify the construction of a multi-camera system in a great extent. For the appropriate camera selection method in this paper the adaptation of the fuzzy automaton is suggested. In the proposed concept, the handing over process has the goal of achieving an appropriate dominant camera selection for tracking a target object. Figure 2 shows the structure of the proposed system. In the proposed camera selection method the states of the applied fuzzy automaton are representing the suitability of the corresponding camera for being the dominant camera, which controls the robot. The state-transitions of the fuzzy automaton are driven by fuzzy reasoning (Fuzzy State Transition Rule-base on figure 3.) as a decision based on the previous camera state (S_i) and the tracking level in a field of view (SS_i). S_i represents the suitability of the i-th camera for being a candidate of camera selection for handing over. Each S_i is calculated based on the all cameras' states and tracking levels. Each camera has separate S_i state for every tracked objects respectively. The camera which has the highest camera state for a tracked object among the cameras will be selected for object tracking as the dominant camera. SS_i represents the tracking level in a monitoring area of the i-th camera. Tracking level is defined by estimating the position measurement error in the monitoring area. As it is mentioned in Section II, the distance from the center of monitoring area increases the position measurement error. Hence the tracking level decreases according to the distance from the center of the monitoring area. Based on the tracking level (SS_i) and the previous camera state (S_i), the new camera state (S_i) is calculated by the State-transition Rule-base as shown in figure 3.

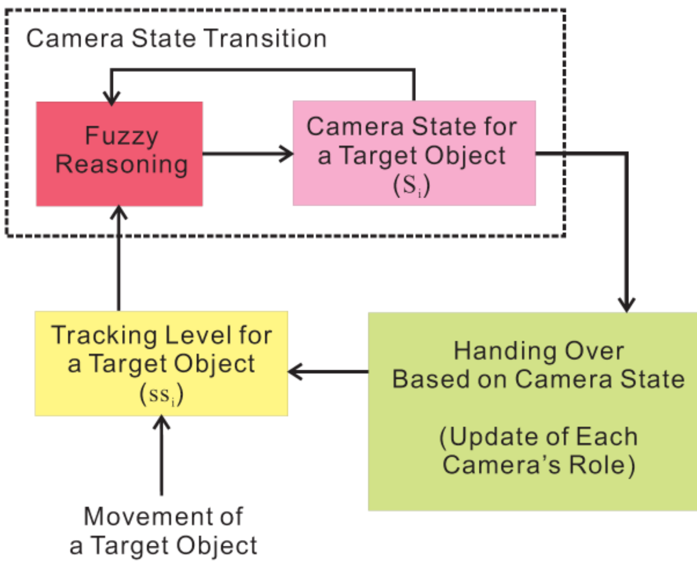
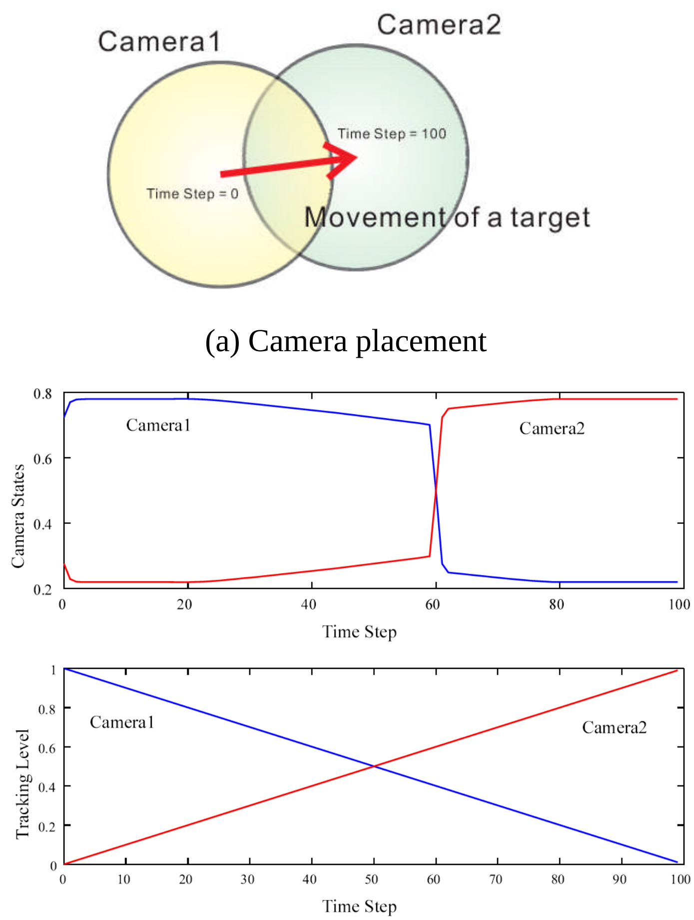


Figure 2. Block Diagram of Camera State Transition

(1) If $S_i = One$	And $SS_i = One$	Then $S_i = One$				
(2) If $S_i = Zero$	And $SS_i = Zero$	Then $S_i = Zero$				
(3) If $S_i = One$	And $SS_i = Zero$	And $SS_k = Zero$	Then $S_i = One$	$\forall k \in [1, N], k \neq i$		
(4) If $S_i = Zero$	And $SS_i = One$	And $S_k = Zero$	And $SS_k = Zero$	Then $S_i = One$	$\forall k \in [1, N], k \neq i$	
(5) If $S_i = Zero$	And $SS_i = One$	And $S_k = One$	And $SS_k = One$	Then $S_i = Zero$	$\exists k \in [1, N], k \neq i$	
(6) If $S_i = One$	And $SS_i = Zero$	And $S_k = Zero$	And $SS_k = One$	Then $S_i = Zero$	$\exists k \in [1, N], k \neq i$	
(7) If $S_i = Zero$	And $SS_i = One$	And $S_k = One$	And $SS_k = Zero$	Then $S_i = One$	$\exists k \in [1, N], k \neq i$	

Figure 3. Fuzzy rule for handing over

The suggested heuristic for the state-transition rule base is very simple. If a suitable camera (S_i) is already selected, and enough tracking level (SS_i) is still observed, its selection needs to be kept, even if the tracking level of the other camera began to support some other selections too. If there were no suitable cameras for handing over, but the tracking level observation began to support one, it has to be ``picked up" at once, to support the quick convergence. Figure 4 shows an example of the camera state transition between two cameras. Two cameras are placed as shown in figure 4(a), so that the monitoring areas are overlapped each other. A target object moves from the center of monitoring area of camera 1 at time step = 0 toward the center of the monitoring area of camera 2 at time step = 100. Tracking level for camera 1 gradually decreases, and tracking level for camera 2 increases. Even if tracking level for camera 2 becomes higher than camera 1, handing over is not needed as long as enough tracking level is observed in camera 1. On the other hand, an appropriate camera should be quickly selected in the case of handing over.



(a) Camera placement

(b) State transition

Figure 4. Exapmle of state transition between 2 cameras

In case of fuzzy rule interpolation[12][13], the above heuristic can be simply implemented by the state-transition fuzzy rule base[14][15] as shown in figure 3. For the i-th state variable S_i, $\exists k \in [1,N]$ of the state vector S. N is the number of the candidate cameras for handing over. That generally includes the center camera and surrounding cameras. The structure of the state-transition rules is similar for all the state variables. Zero and One are linguistic labels of fuzzy sets (linguistic terms) representing high and low similarity. The interpretations of the "*Zero*" and "*One*" fuzzy sets can be different in each S_i, SS_i universes. In this paper, membership functions for S_i and SS_i are decided as shown in figure 5 and figure 6.

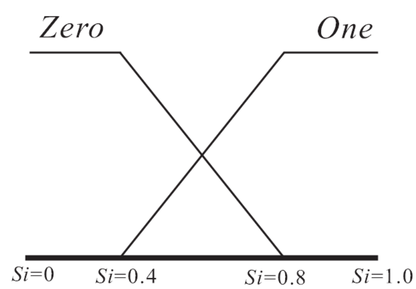


Figure 5. Membership function of camera state

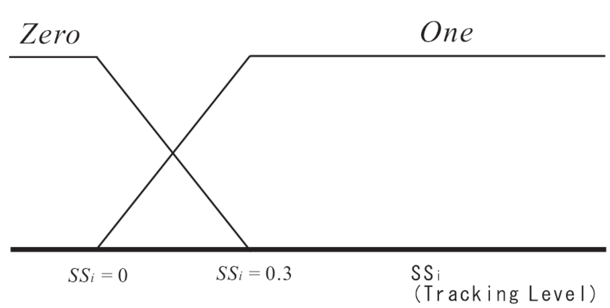


Figure 6. Membership function of tracking level

Please note that rule base of figure 3 is sparse. It contains the main rules for the following straightforward goals only: Rule (1) simply keeps the previously chosen state values in the case if the corresponding tracking level also supports it. The rule (2) has the opposite meaning, if the state values were not chosen, and moreover the corresponding tracking level is also inappropriate the state value should be suppressed. The rule (3) keeps the already selected state values (previous selection), even if the corresponding tracking level is insufficient, if it has no better "idea". Rules (4) and (5) have the task of ensuring the relatively quick convergence of the system to the sometimes unstable (changeable) situations, as new state variables which seem to be fit, can be chosen in one step, if there is no previously chosen state with appropriate tracking level. (Rule (5) has the task to suppress this selection in the case if exists a still acceptable state which has already chosen.) Rules (6) and (7) have the task of ensuring the quick selection in case that the camera state is different from the tracking level observation. The goal of this heuristic is to gain a relatively quick convergence for the system to fit the demands of selecting the appropriate camera, if there is no state value high enough to be previously accepted. This quick convergence could be very important for stable tracking among multi cameras where the unnecessary camera handing over should be suppressed. The application of fuzzy rule interpolation (FRI) also has some benefits in the complexity reduction of the fuzzy rule base as it is discussed more detailed in [16] and [17] (i.e. the fuzzy rule base of FRI do not have to be exponential sized with the number of the input dimensions, which is a common problem with classical fuzzy rule based systems).

IV. SIMULATION

In order to clear the performance of the proposed method, several simulations have been performed. Figure 7 shows a part of camera placement used in the simulations. Cameras are placed in the honeycomb structure with overlapping each other. Six cameras are placed around one camera, and these structures are set out in order to cover wider area. In this simulation, a monitoring area is a circle with radius 5000 [mm]. Target objects are able to be measured and tracked in the circle. In figure 7, d [mm] means a distance between centers of circles. Since it is not easy to place all cameras precisely, errors with up to 1000 [mm] are randomly added to d. Center camera and surrounding 6 cameras are candidates of camera selection in this placement. Figure 8 shows an example of simulation environment. 100 cameras composed of 10 cameras in vertical row and 10 cameras in horizontal row are placed in this simulation. This example shows a case of d =8000. A camera at bottom-left is labeled as camera<0,0>. A camera at m-th in vertical row and n-th in horizontal row is labeled as camera<m,n>. This simulation assumes that each camera can estimate two-dimensional position of a target object. Estimated position of a target object also includes measurement errors with up to 500 [mm] in this simulation.

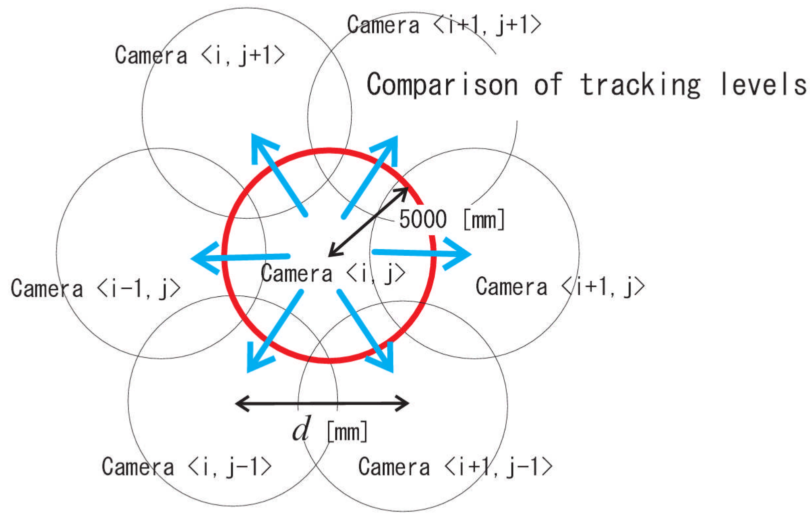


Figure 7. Camera Placement in Simulation

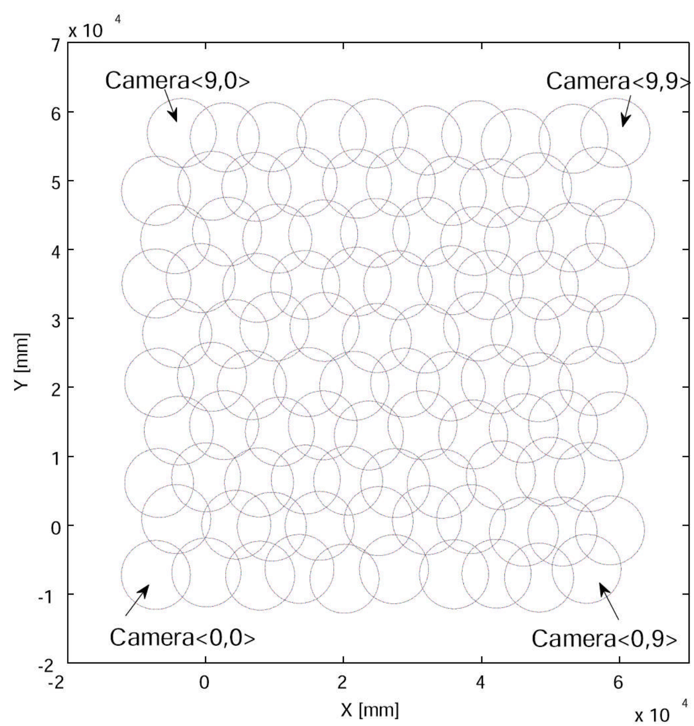


Figure 8. An Example of Whole Camera Placement in Simulation

a. Tracking simulation in wide area

The most important task of multi-camera system is object tracking in wide area. Figure 9(a) shows the examples of simulation results and Figure 9(b) shows the enlarged view of figure 9(a). In this simulation, a target object moves from (0,0) to (40000, 40000) with 45 degree heading.

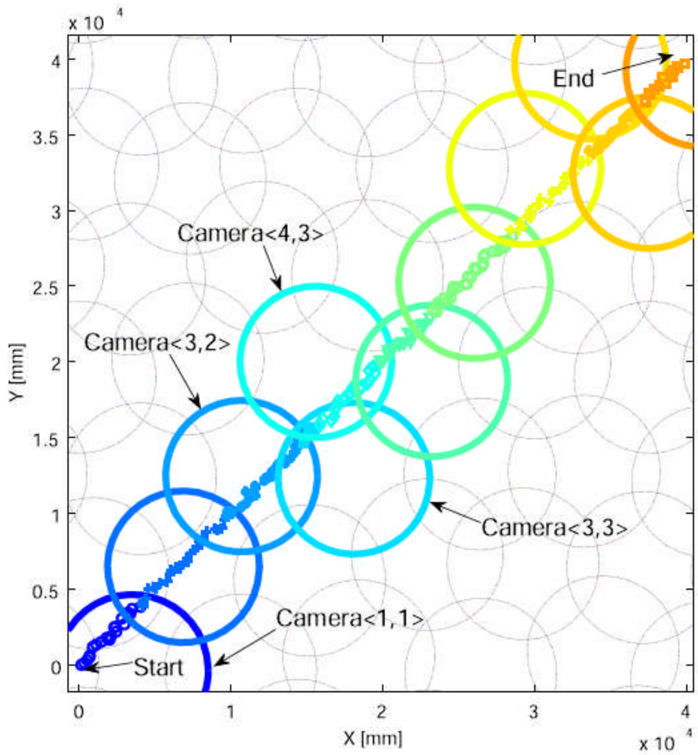
Camera distance *d* is 7500. Colored circles show cameras selected for tracking of a target. Plots show measurement positions of a target object. Each plot color means that a target object is tracked by the camera with the corresponding color.

At first, a target object is located in the monitoring area of camera<1,1>. After that, appropriate cameras are selected in the order of <2,2>, <3,2>, <3,3>, <4,3>, <4,4>, <5,4>, <6,5>, <6,6>, <7,5> and <7,6> according to movement of a target object. This result shows handing over is performed in the overlapping areas among cameras. The monitoring areas among cameras are randomly overlapped in this simulation. However, handing over is performed correctly as shown from (1) and (2) of the enlarged view figure 9(b). This indicates that a flexible camera placement is acceptable for developing a multi-camera system. Figure 10 shows the camera state transition while tracking a target object. Red line means the states of cameras selected by the proposed fuzzy transition rule. Tracking levels of (1) and (2) in bottom figure correspond to values at positions of (1) and (2) in Figure 9(b) respectively. This shows that a camera with the highest state value is selected for tracking. On the other hand, a camera with the highest tracking level is not necessarily selected as shown in around (1) of figure 10, because its selection needs to be kept in the situation that enough tracking level is still measured in the monitoring area of a selected camera.

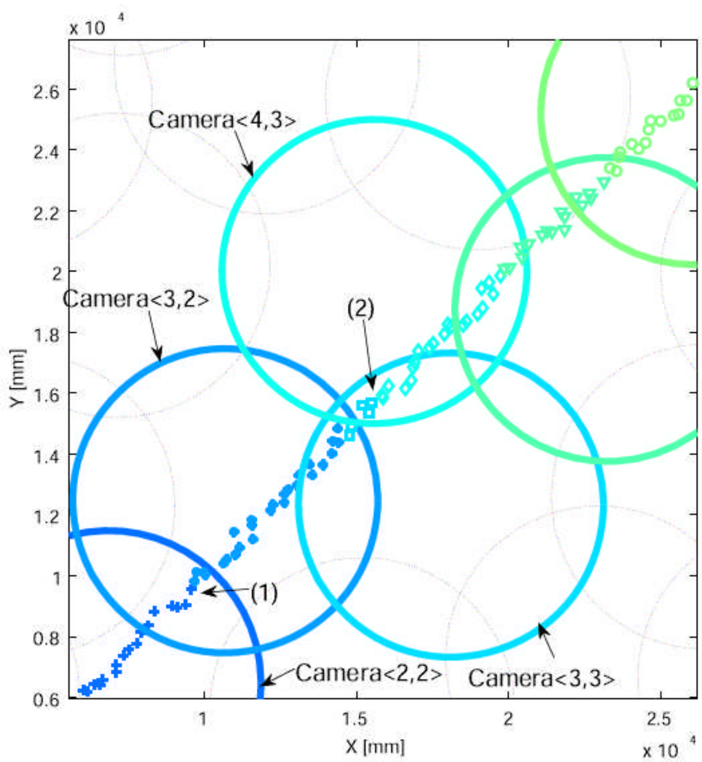
b. Comparison with the previous method

In order to present effectiveness of the proposed method, a simulation for comparison with the previous method was performed. The monitoring area of each camera is divided and labeled from 1 to 5 according to tracking reliability as shown in figure 11. Distributed cameras communicate reliability ranks of a target object to the adjacent cameras, reliability ranks are compared. If R_{other} is higher than $R_{dom}+1$, where R_{dom} and R_{other} are reliability ranks of the dominant camera and the other camera respectively, the other camera becomes a new dominant camera. This condition is used to avoid chattering of handing over[9].

Figure 12(a) shows the simulation results and figure 12(b) shows the enlarged view of figure 12(a). Simulation conditions except the method of handing over and figure legends are same with the above simulation. Here, Camera<2,2>, Camera<3,2> and Camera<4,3> are focusd for explanation of handing over. In figure 12(b), plots "×" of same color with Camera<2,2> means that a target was tracked by Camera<2,2>.



(a) Camera Selection



(a) Extended View

Figure 9. Fuzzy-Based Camera Selection Result

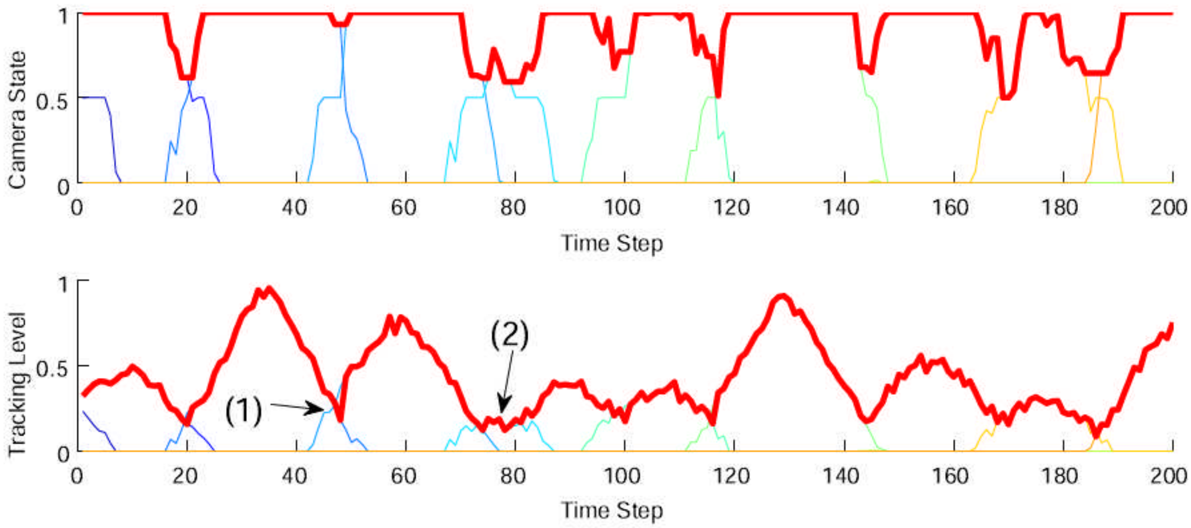


Figure 10. Camera State Transition in Fuzzy-Based Method

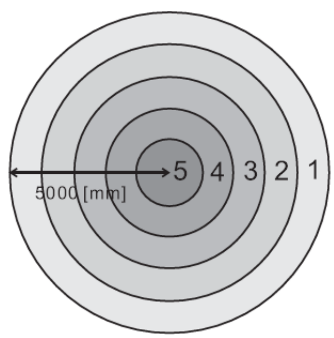
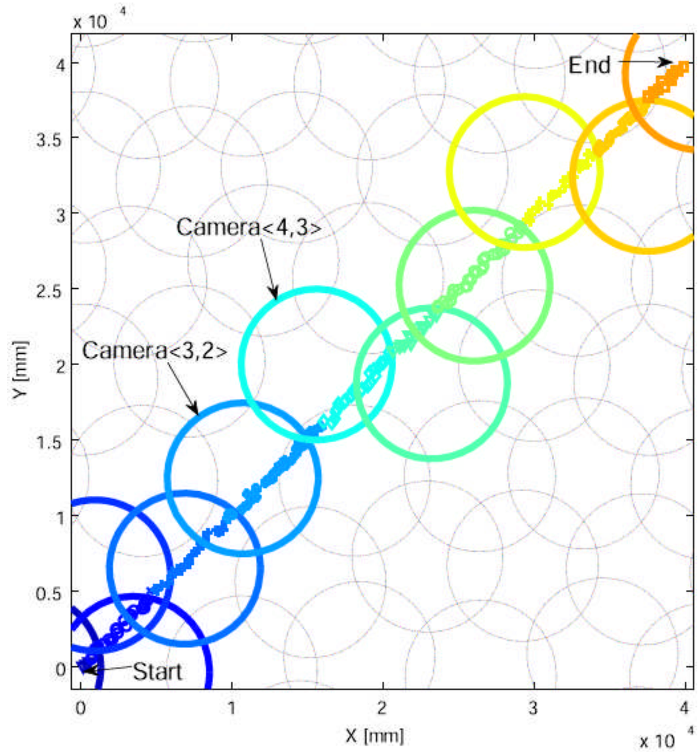
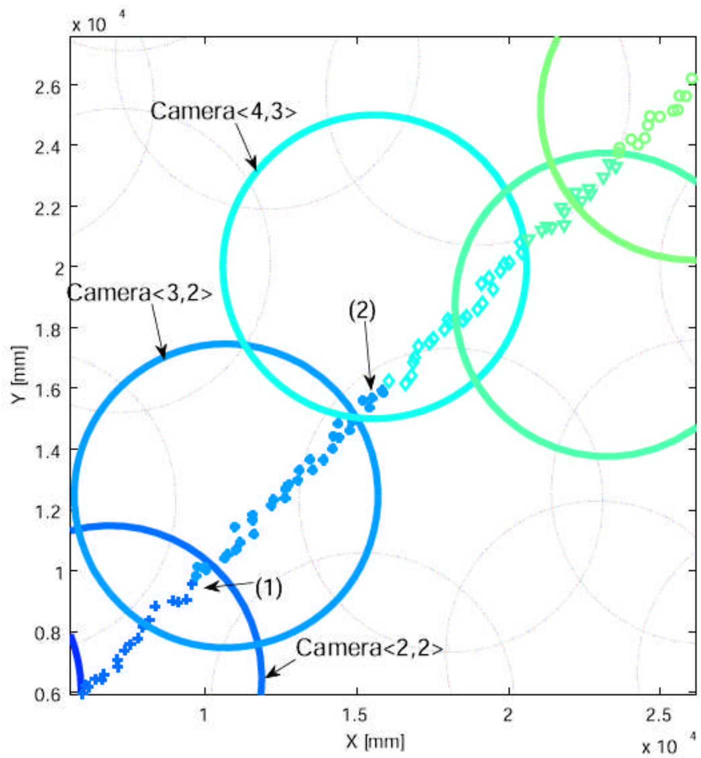


Figure 11. Reliability map monitoring area of camera in the simulation

In the same manner, " ∗ " and " ◊ " are plots tracked by Camera<3,2> and Camera<4,3> respectively. If enough overlapping appears among cameras shown in (1) of figure 12(b), dominant cameras are changed in the overlapping areas. In this case, handing over is achieved. However, (2) of figure 12(b) shows that handing over is not achieved in the overlapping areas among cameras correctly. Several plots of Camera<3,2> are placed outside from a circle of Camera<3,2>. This shows that a target is measured at outside of selected camera without correct handing over. This means that correct handing over between Camera<3,2> and Camera<4,3> is not achieved and seamless tracking fails. On the other hand, handing over is achieved in (2) of figure 12(b) simulated by the proposed method becacuse Camera<3,3> is selected before Camera<4,3>, where " □ " represents tracked by Camera<3,3>.



(a) Camera Selection



(a) Extended View

Figure 12. Camera selection result with the previous method

Figure 13 shows the camera state transition while tracking a target object in the previous method. Especially, reliability rank becomes "0" in (2) because of small overlapping among monitoring areas of cameras. At this point, a target object moved from the monitoring area of the dominant camera in spite that handing over to the other camera had not been completed. This also shows that seamless tracking among cameras failed.

Table 1 shows the other comparison between previous and proposed methods. In this simulation, target tracking for camera placements of 100 patterns in each *d* and each method are performed respectively. Positional errors are added in camera placements and object movements as described above. *d* is changed from 6500 to 8000. Values of this table mean the success rate of tracking in each *d* and each method. This simulation deals cases as shown in (2) of figure 12(b) with tracking failure. When tracking is completed without any failure, the tracking is regarded as success. As shown in Table 1, the proposed method has higher success rate than the previous method.

These results indicate that multi-camera placement has a constraint in order to acquire enough overlapping in the previous method. On the other hand, the proposed method does not have such a constraint for camera placement. That is why the proposed method is efficient for adaptive camera selection in a multi-camera environment.

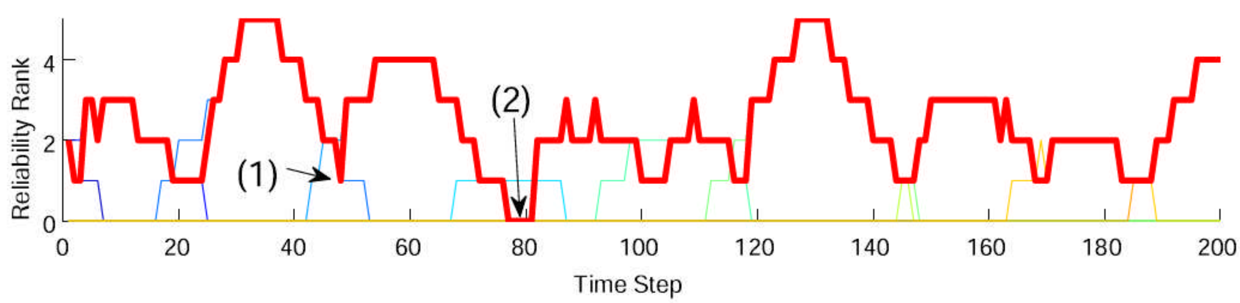


Figure 13. Camera state transition in previous method

Table 1: Success Rate

b [mm]	6500	7000	7500	8000
Previous (%)	97	80	32	3
Proposed (%)	100	95	72	24

V. EXPERIMENTS

Simulations showed that target tracking with the proposed method works in various patterns of multi-camera placement. When multi camera system is implemented with previous method, camera placement and separation of monitoring area must be decided through trial and error for seamless tracking, even if monitoring areas of cameras are overlapped enough. That is time-consuming procedure. On the other hand, the proposed method does not need such advance preparations in the case of enough overlapping of monitoring areas.

This section aims to show that the proposed method can also work well in a real (not simulated) environment without any advance preparations. The experiments performed with the test environment and their results are discussed in the followings.

a. Experimental Setup

Figure 14 shows the camera placements and fields of views in the studied test system. Four cameras are placed in the four corners of our experimental room with overlapping fields of views to each other. A captured image size from each camera is 640×480. Each camera is calibrated with Zhang's method[19]. Because it is assumed that the height of a tracked target is known in this experiment, the estimated 3D position of a target object can be calculated in each camera. Figure 15 shows tracking level of Camera No2. In this figure, higher tracking level is set to the area spatially close to the position of Camera No2, because a target object is generally tracked better in an area which is spatially close to the camera and in the center area of captured image. Tracking levels of the other cameras are also calculated in a similar way. The field of view related to each camera in Fig.14 indicates the area where the tracking level is higher than zero.

Each camera is implemented as a camera component of OpenRTM-aist[20] developed by the National Institute of Advanced Industrial Science and Technology in Japan. Each camera component is built upon an IEEE1394 camera and a normal computer. These devices include software components for image processing of target tracking, resources for fuzzy reasoning and network communication. Center camera and the surrounding six cameras are connected via network as the candidates of camera selection in the above simulation. In this real experimental setup introduced four neighboring cameras are placed in the room and all camera components are connected via network as the candidates of camera selection. Each camera component communicates its camera state (S_i) and tracking level (SS_i) related to a tracked object with the other camera components. The system does not have any central component for collecting information from all the camera components. Each camera component makes the camera selection decision on its own based on the information received from the other cameras.

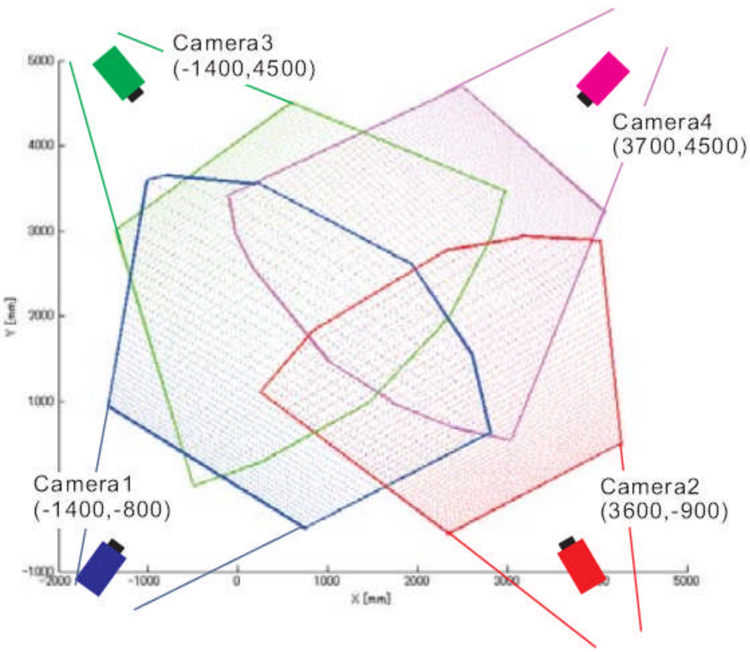


Figure 14. Camera placement and field of view

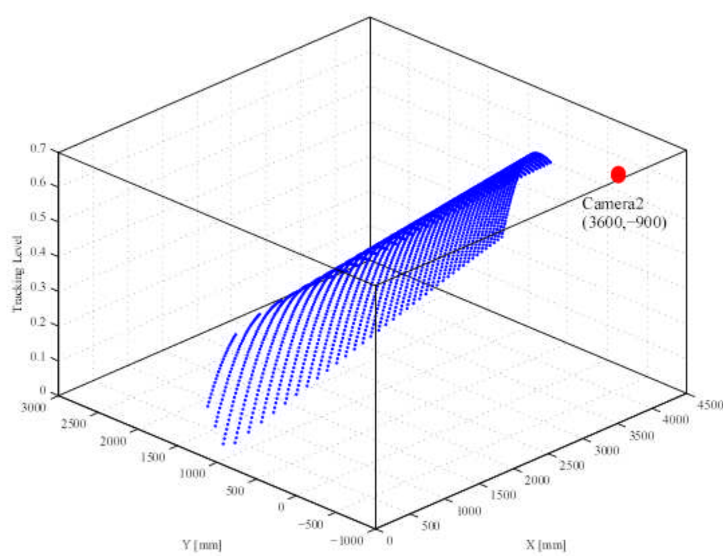


Figure 15. Tracking level in field of view (Camera2)

b. Experiment 1: Tracking in Wide Area

The most important task of multi-camera system is object tracking in wide area. In this subsection, as the first experiment, target tracking in wide area is studied more in details.

In this experiment a wheeled mobile robot acts the target object.

For the proper evaluation of the proposed camera selection method, the object tracking in each camera component should be stable. To simplify the object tracking task, a color marker is installed on the top of the mobile robot. A color marker is set to the height of 650mm. Particle filter based color tracking algorithm is implemented in each camera component, when the tracked color marker positions are regarded as the positions of the target object. The tracking levels in each camera component are calculated from the target positions as shown in figure 15.

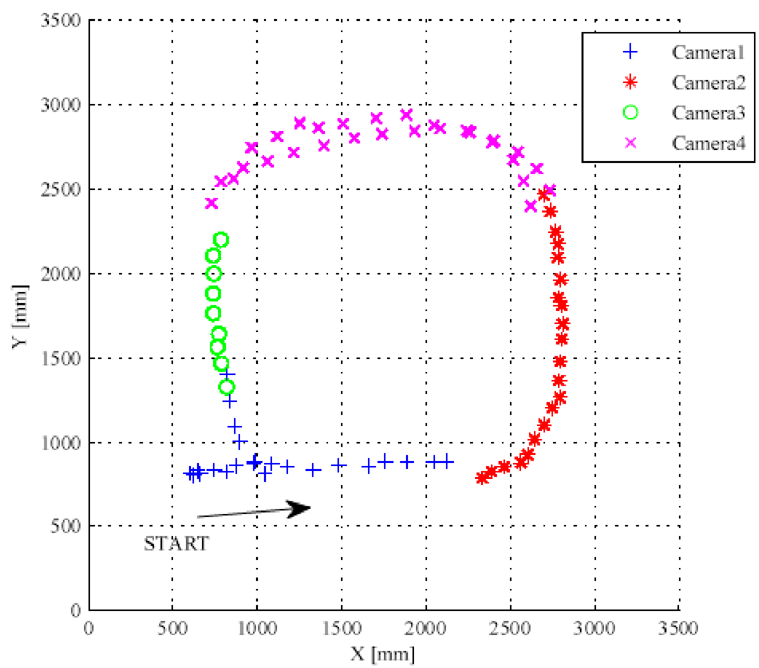


Figure 16. XY plots of target object and camera selection result

Figure 16 shows the XY position plots of the target object. The target object moves in a circular motion from the "Start" point. Colored markers shows the plots measured in the dominant camera selected for target object tracking. This figure shows that at first Camera No1 is selected, and then the dominant cameras are switched in the order of Camera No2, Camera No4, Camera No3 and Camera No1 again during the way of the circular motion. This result shows that the proposed method performed quite efficiently for camera selection even while tracking in a wide area. Top of figure 17 shows the camera state transition while tracking the target object. Thick lines notes the states of cameras selected as the dominant cameras by the proposed fuzzy state-transition rule base. Bottom of figure 17 shows the tracking level calculated in the four cameras. Thick lines in this figure notes the tracking level when they are selected as the dominant cameras. Although a camera with the highest state value is selected for tracking as a dominant camera, a camera which has the highest tracking level is not necessarily selected. This example shows that its selection needs to be suppressed in the situations, where enough tracking level is still available in the field of view of a previously selected camera.

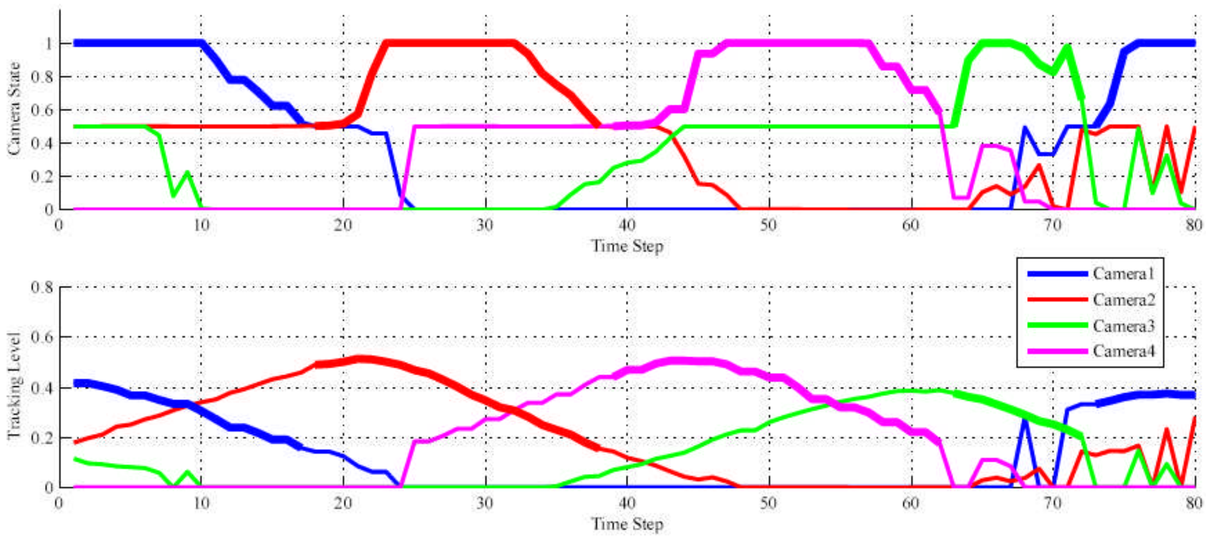


Figure 17. Camera state transition 1

c. Experiment 2: Occlusion of the Target Object

This experiment studies the suggested camera selection method in the common situation when the target object is suddenly occluded in one camera image during the tracking. The target object and the image processing method are same as it was introduced in the previous experiment. Figure 18 shows the transitions of camera states and the tracking levels during the experiment. Similarly to the charts of the previous experiment, thick lines mean the camera states and tracking level when they are selected as the dominant cameras. The target object is located in almost the middle position of the overlapped region between Camera No1 and Camera No2. At first, Camera No1 is selected as a dominant camera. In the 60th time step of figure 18, the target object is fully occluded by another object, which event leads to the tracking level in Camera No1 dropping down to zero. However, because Camera No2 has still enough tracking level to handle the situation, Camera No2 is immediately selected as a new dominant camera by the proposed method after the occlusion. This result shows that a suitable camera can be effectively selected in spite that the tracking level drops down by sudden occlusion.

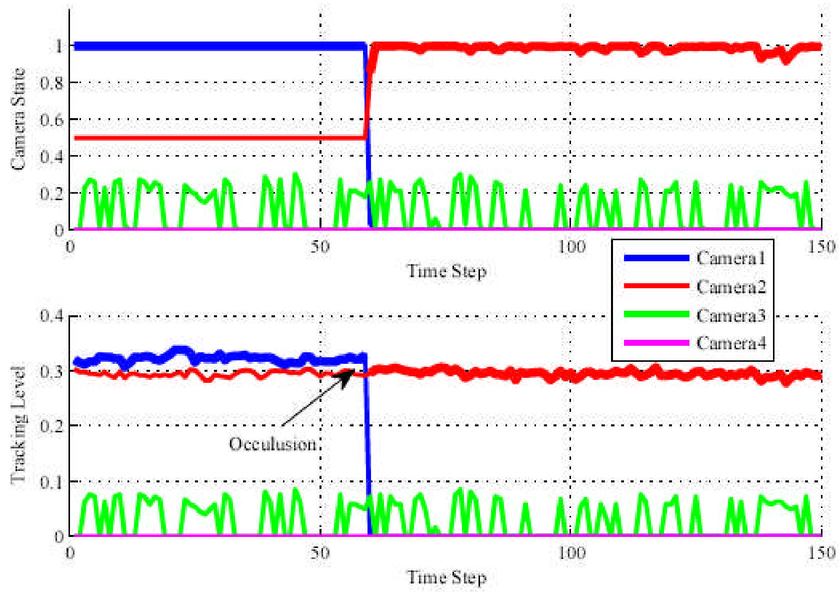


Figure 18. Camera state transition 1

VI. CONCLUSIONS

This paper presented fuzzy-based adaptive camera selection for object tracking in a distributed vision system. Simulation results show that the proposed method is more efficient than the previous method. An actual multi-camera system with the proposed method was developed, and the object tracking in a real environment was achieved. Experimental results shows that the proposed method also works well in the real environment.

Several directions of the future works are planned. For calculating the tracking level in this paper, 2D field of views and fixed target object height were applied. Moreover the target object was represented by a point of color marker for the image processing in order to simply the experimental setup. Simulation and experiments related to simultaneous multiple objects tracking should be also performed.

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