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ADAPTIVE CAMERA SELECTION BASED ON FUZZY AUTOMATON FOR OBJECT TRACKING IN A MULTI-CAMERA SYSTEM

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ABSTRACT:
A research field on intelligent environments for supporting human beings and robots has been expanding. An intelligent environment is composed of many intelligent sensors distributed in the space. In such an environment, it is very important to track human beings and robots seamlessly among multiple sensors. In order to achieve that, multi-camera system is promising as a location system in intelligent environments. Especially, distributed autonomous multi-camera system is desired for scalability of a system.
In this paper, cooperation method of multiple cameras for seamless object tracking is described. An adaptive camera selection method is needed for achievement of tracking task in wide area covered by multiple cameras. This paper proposes fuzzy logic-based handing over of tracking authority for a tracked object. Some simulations are performed and the results show that the proposed method is effective for adaptive camera selection.
KEYWORDS:
Intelligent Environment, Object Tracking, Handing Over, Fuzzy System

1. INTRODUCTION

Recently, a research field on intelligent environments for supporting human beings and robots has been expanding [1], [2]. An intelligent environment is composed of many intelligent devices, such as computers and sensors, distributed in a space. Some intelligent environments utilize a distributed vision sensor network as the sensing basis. A distributed vision sensor network offers promising prospects as an infrastructure for robots in order to coexist with human in the environments such as houses, factories, hospitals and so on [3], [4]. Especially, it is expected to achieve contact-free wide-area location system. It also has a possibility that further information can be obtained depending on image processing.

It is the most important to track moving objects in order to achieve location system by using a distributed vision sensor network. Object tracking in a distributed vision sensor network is regarded as a multi-camera multi-object tracking system. There are two major problems in a multiple-camera multiple-object tracking system. One is a traditional correspondence problem from frame to frame over time in image sequence. The other is an object correspondence problem among different cameras in order to achieve seamless tracking and location estimation.

For solving the first problem, adaptive object models are needed for dealing with the change of the object posture. Colour model based object tracking algorithms, such as MeanShift algorithm [5], are effective with the fast and robust object tracking. On the contrary, there are several approaches to solve the latter problem in the recent literatures. These approaches include feature matching [6], 3D information [7] and etc.

These are mainly problems of image processing. However, in order to solve multi-camera tracking problem, the other problem establishment as sensor system architecture is needed. Many cameras are placed redundantly and randomly in a distributed vision sensor network, and a distributed autonomous system is desired as a multi-camera system for scalability of a system. An appropriate camera for tracking of an object seamlessly should be selected from many candidates according to a tracking capability of each camera. Especially, this problem should be solved in a vision system constructed with independent autonomous-decentralized cameras. Camera selection method based on handing over protocol has been previously proposed for mobile robot control in Intelligent Space [2]. In this method, the reliability rank is defined for the monitoring area of each camera. High reliability stands for that camera, which can track and guide a mobile robot robustly and precisely. Since the reliability rank is discretely decided in the monitoring area, monitoring areas should need proper overlap for comparison of reliability ranks among cameras. That makes a setup of multi-camera system difficult. In this paper, a flexible camera selection method based on fuzzy automaton is proposed.

This paper is organized as follows. In Section 2, a handing over protocol for seamless object tracking is introduced including descriptions of the previous method. In Section 3, a new camera selection method based on fuzzy automaton is proposed. Section 4 shows some simulation results of object tracking in a multi-camera environment. Conclusions and future works are described in Section 5.

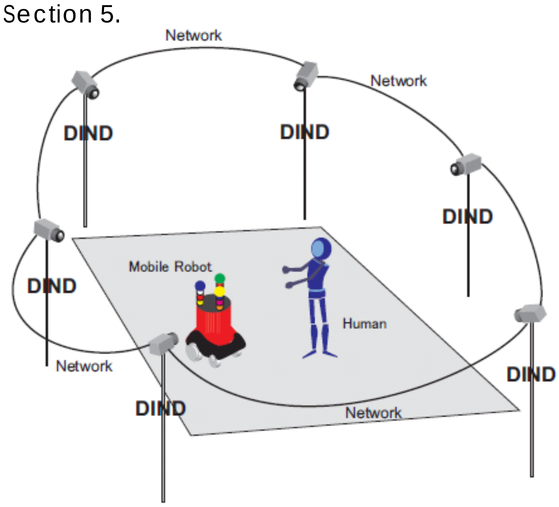


FIGURE 1. INTELLIGENT SPACE

2. HANDING OVER FOR TRACKING OF OBJECTS SEAMLESSLY

Camera selection method based on handing over protocol has been previously proposed for mobile robot control in Intelligent Space [8]. "Intelligent Space (iSpace)" [2] is a platform of human-centred services for accelerating the physical and psychological interaction between human beings and robots. Intelligent Space is achieved by distributing autonomous intelligent devices which do not affect the present living environment greatly. We call these intelligent devices "DINDs (Distributed Intelligent Network Devices)". A DIND includes a colour CCD camera as sensor part and a computer as processing and networking part. Intelligent Space is constructed as shown in Fig.1.

A DIND is an independent device, and its functions, that include tracking of moving objects [9], localization and control of mobile robots [10], are performed completely within it. Thus, if a mobile robot is moving in an area that a single DIND is monitoring, the robot is guided without any difficulty. However, to guide robots in a wider area, which a single DIND cannot cover, we define the DIND that has the control authority of a robot as the dominant DIND for the robot. When a robot moves from an area to a different area, the robot's dominant DIND should be automatically changed. This is called ``handing over of control authority". A dominant DIND has the control authority of the robots and at one time only a single dominant DIND exists for each robot. Therefore, the control authority has to be smoothly handed over to the next DIND at the proper time and location. To solve this problem, a reliability rank is devised. High reliability stands for the DINDs, which can guide a robot robustly and precisely. Generally, the area near a DIND and the centre area of an image captured by a DIND, have the highest reliability rank; while the boundary of the image and the area far from the DIND have the lowest reliability since a camera is adopted as a sensor for a DIND. Fig.2 shows an example of a monitored area divided into several areas with reliability ranks.

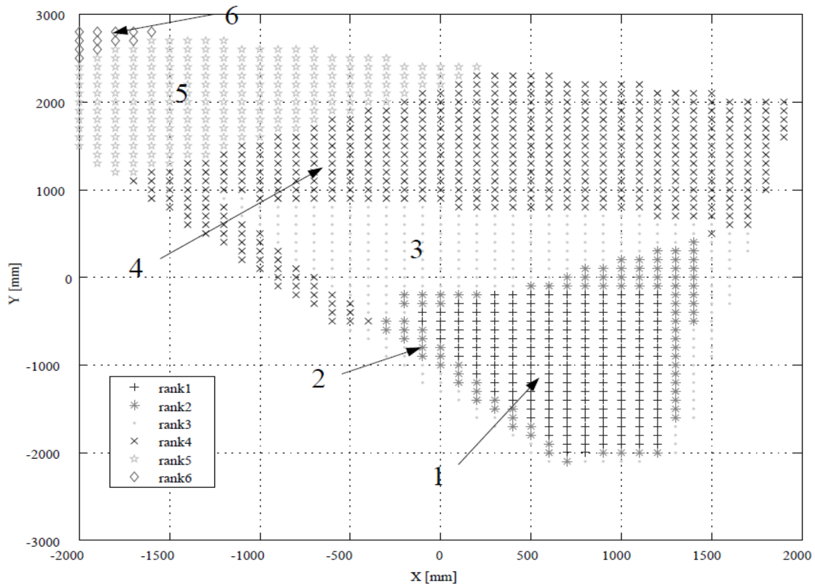


FIGURE 2. RELIABILITY RANK

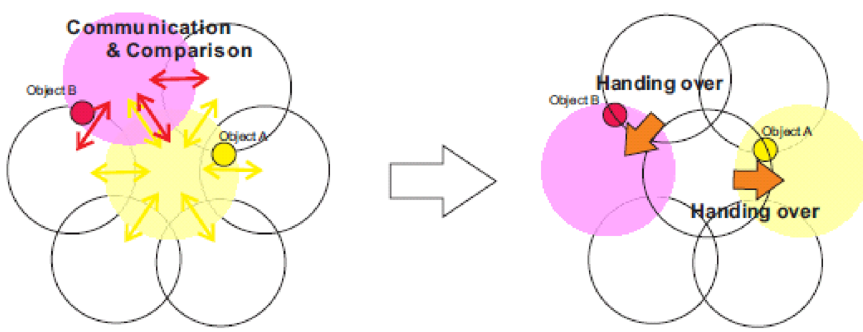


FIGURE 3. HANDING OVER

Fig.3 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 DINDs are coloured. First, the dominant DIND requests reliability ranks of a target robot from the other DINDs. The other DINDs reply with their reliability rank concerning the robot to the current dominant DIND. The dominant DIND compares these values with its own rank. If the other DIND has a higher rank than its own rank, then the current dominant DIND transfers the authority of control to the other DIND, which has the higher rank. Then the new dominant DIND tracks and controls the robot.

3. FUZZY LOGIC-BASED CAMERA SELECTION

In the previous method, monitoring areas of cameras are divided and labeled by trial and error. Enough overlapping among monitoring areas is also needed for stable handing over based on reliability rank. It is not easy to place many cameras so that stable handing over can be achieved in all overlapping areas. A flexible handing over method is needed for easy construction of a multi-camera system. For the appropriate camera selection in this paper the adaptation of the fuzzy automaton is suggested. In this concept, the handing over process has the goal of appropriate dominant camera selection for tracking a target object. Fig.4 shows a structure of the proposed system. The state-transitions of the fuzzy automaton are driven by fuzzy reasoning (see Fuzzy state transition rulebase on Table.1.) as a decision based on the previous camera state (S_i) and the tracking level in a monitoring area (SS_i). Camera state S_i represents the suitability of the i-th camera as a candidate of camera selection for handing over. Each S_i is decided from the other cameras' states and tracking levels in addition of own state and tracking level. Each camera has separate S_i state for every tracked object respectively. The camera which has the highest state value among adjacent 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. In general, a distance from the center of monitoring area makes position measurement error increases. It means that the tracking level decreases according to the distance from the center of 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 rulebase as shown in Table.1.

The suggested heuristic for the state-transition rule base is very simple. If a suitable camera (S_i) 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 as well. 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. Fig.5 shows an example of the camera state transition between two cameras. Two cameras are placed as shown in Fig.5(a), so that the monitoring areas are overlapped. At first, a target object is in the center of monitoring area of camera 1. A target object moves toward the monitoring area of camera 2. Tracking level for camera 1 gradually decreases, and tracking level for camera 2 increases. Even if tracking level for camera 2 becomes higher than tracking level for camera 1, handing over is not needed as long as tracking level is enough for camera 1. On the other hand, an appropriate camera should be quickly selected in the case of handing over. In case of fuzzy rule interpolation [11], [12], [17], the above heuristic can be simply implemented by the state-transition fuzzy rule base [13], [14] as shown in Table.1. In this implementation, the i-th state variable S_i is calculated from former state S_i, S_k, tracking level SS_i and SS_k, $\exists k \in [1, N]$. N is the number of the candidate cameras for camera selection in 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 Fig.6 and Fig.7.

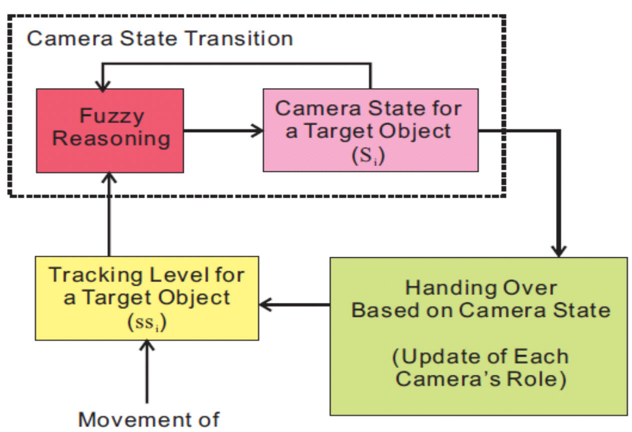
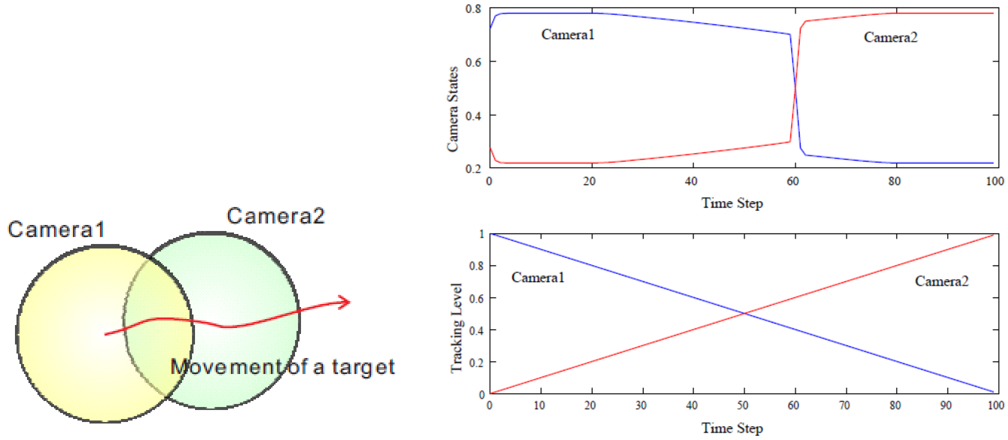


FIGURE 4. BLOCK DIAGRAM OF CAMERA STATE TRANSITION

TABLE 1. FUZZY RULRBASE FOR HANDING OVER

(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 $S_i = One$	$\exists k \in [1, N], k \neq i$



(a) Camera Placement (b) State Transition

FIGURE 5. EXAMPLES OF STATE TRANSITION BETWEEN 2 CAMERAS

Please note that rule base of Table.1 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 there is 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 handling over should be suppressed. For the complexity reduction, benefits of the fuzzy rule interpolation (FRI) in case of the proposed rule base, as an example, see more detailed in [15] and [16].

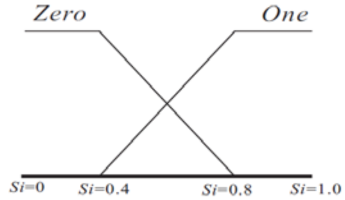


FIGURE 6. MEMBERSHIP FUNCTIONS ABOUT CAMERA STATE

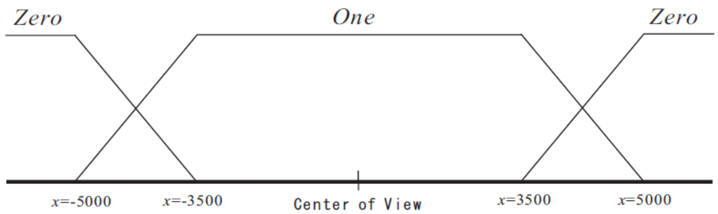


FIGURE 7. MEMBERSHIP FUNCTIONS ABOUT TRACKING LEVEL

4. SIMULATION

In order to clear the performance of the proposed method, several simulations have been performed. Fig. 8 shows a part of camera placement used in the simulations. Cameras are placed in the honeycomb structure with overlapping each other. 6 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]. A distance between centres of monitoring areas is 4000 [mm]. Since it is not easy to place all cameras precisely, errors with up to 1000 [mm] are randomly added in a distance between cameras. Centre camera and surrounding 6 cameras are candidates of camera selection for tracking in this placement. Position of target objects are also calculated with including measurement errors like actual image processing in DINDs. Estimated position of a target object includes measurement errors with up to 500 [mm] in this simulation.

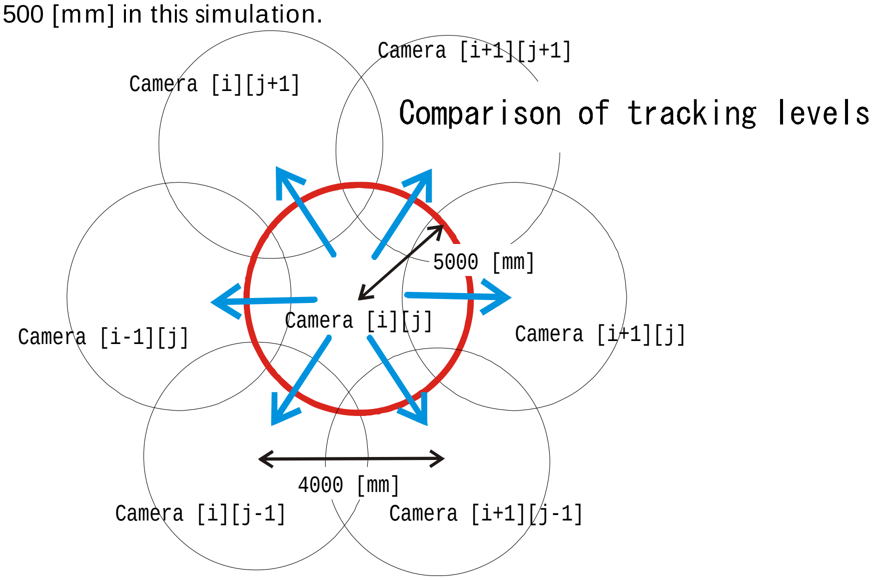


FIGURE 8. CAMERA PLACEMENT FOR SIMULATION

A. Simulation 1: Tracking in Wide Area

The most important task of multi-camera system is object tracking in wide area. Fig.9 shows the simulation environment and tracking results. 100 cameras composed of 10 cameras in vertical row and 10 cameras in horizontal row are placed in this simulation. A camera at bottom-left is labelled as camera [0][0]. A camera at *m*-th in vertical row and *n*-th in horizontal row is labelled as camera [m][n]. A target object moves from (0,0) to (40000, 40000) with 45 degree heading. Coloured circles show cameras selected for tracking of a target. Plots show measurement positions of a target object. Each plot colour means that a target object is tracked by the camera with the corresponding colour. At first, a target object is located in the monitoring area of camera [1][0]. After that, appropriate cameras are selected in the order of [1][0], [1][1], [2][2], [3][2], [3][3], [4][4], [5][4], [5][5], [6][6] 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 accurately. This indicates that a flexible camera placement is possible for developing a multi-camera system. Fig.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. Fig.11 shows the extended view between time step 250 and 300 in Fig.10. Fig.10 shows that a camera with the highest state value is selected for tracking. However, a camera with the highest tracking level is not necessarily selected because its selection needs to be suppressed in the situation that enough tracking level is still available in the monitoring area of a previously selected camera.

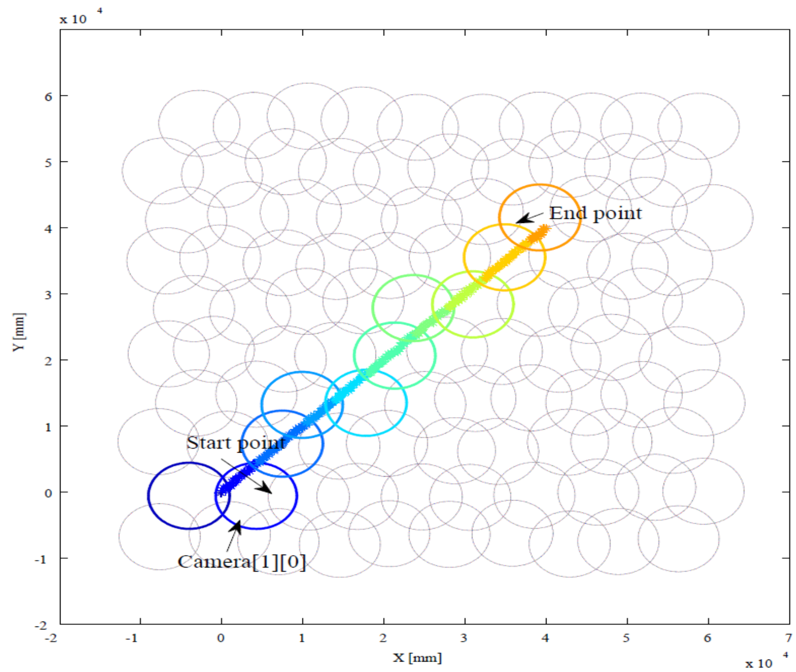


FIGURE 9. CAMERA SELECTION RESULT 1

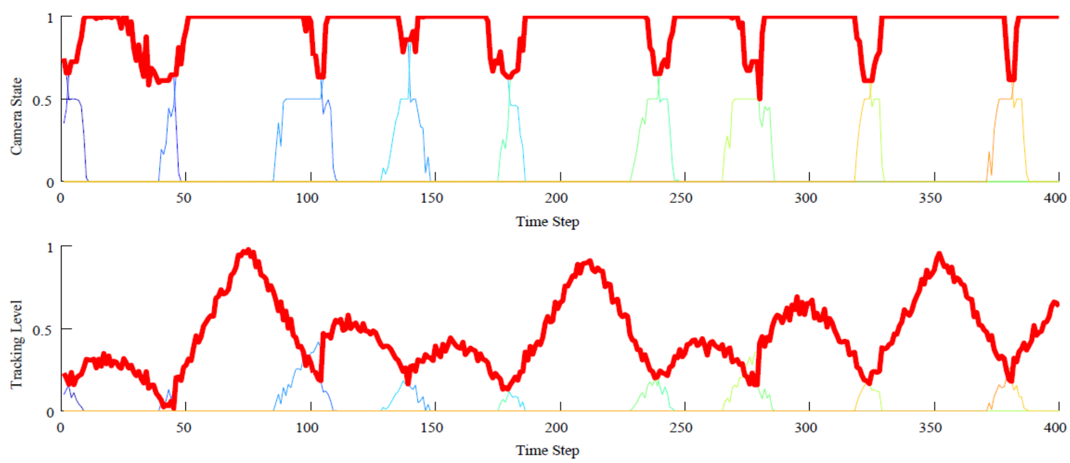


FIGURE 10. CAMERA STATE TRANSITION 1

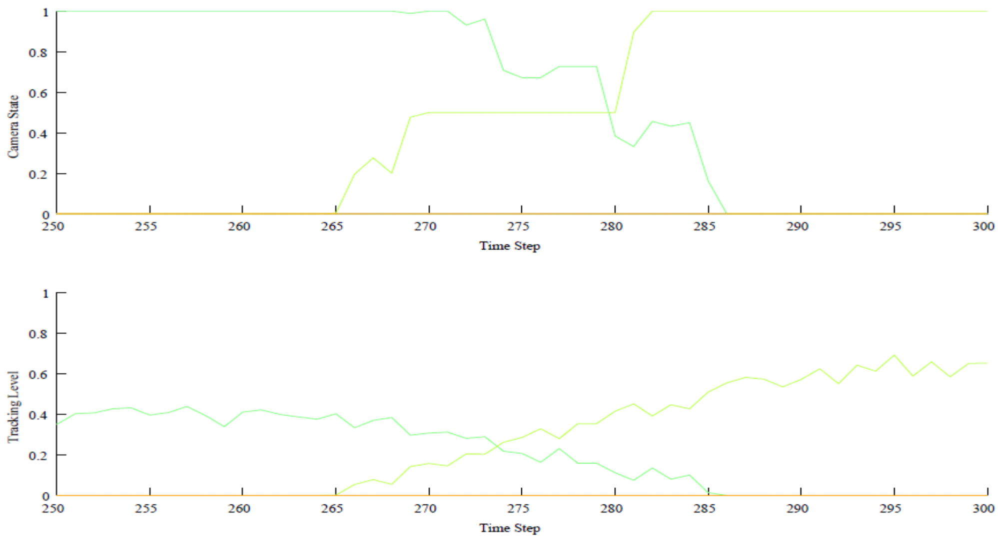


FIGURE 11. CAMERA STATE TRANSITION 1 (EXPANDED VIEW)

B. Simulation 2: Keeping of Selection

This simulation shows keeping of camera selection while stable tracking in one camera. Fig.12 shows the results of this simulation. The meanings of circles and plots are same with Simulation 1 in Fig.12.

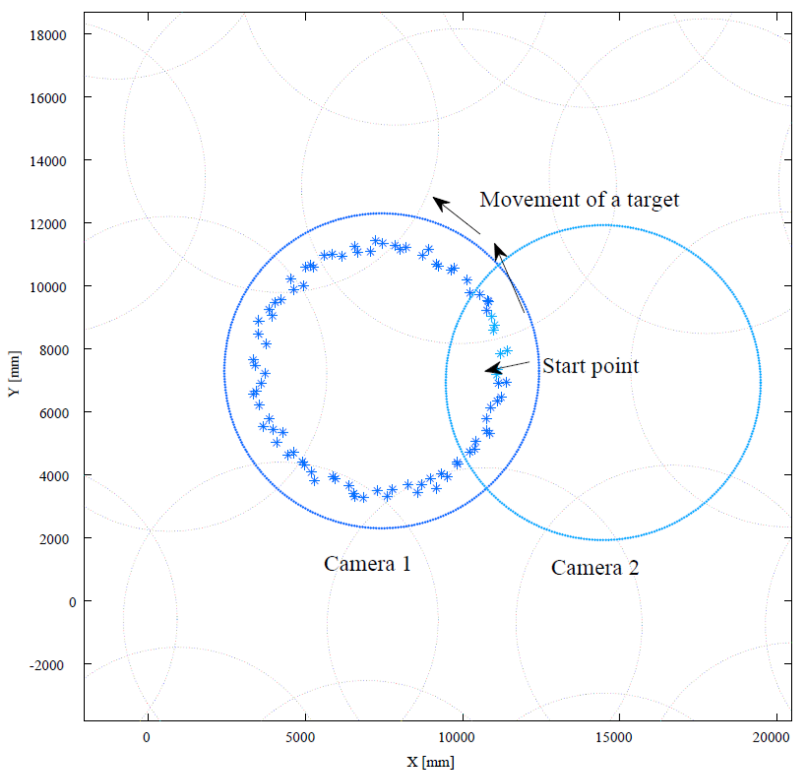


FIGURE 12. CAMERA SELECTION RESULT 2

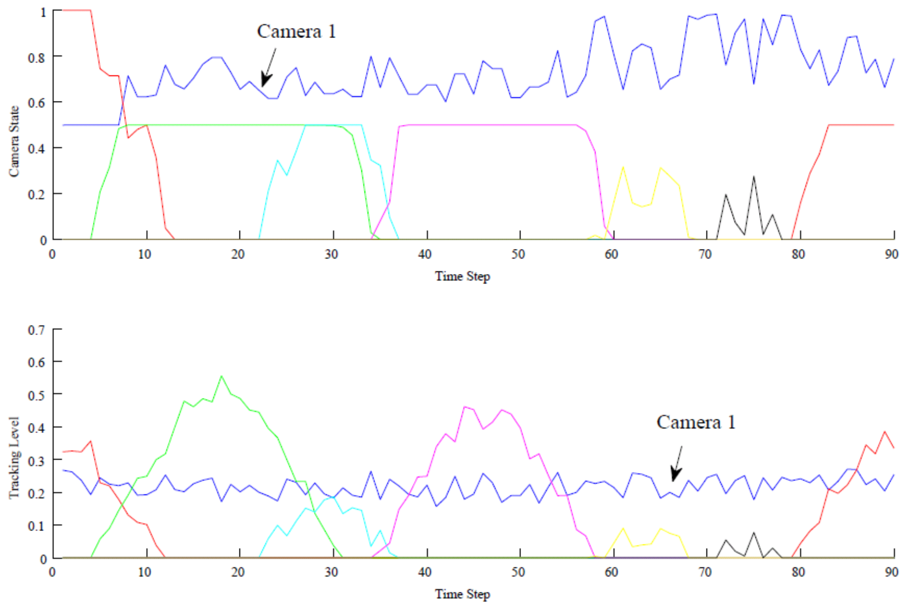


FIGURE 13. CAMERA STATE TRANSITION 2

Fig.13 shows the camera state transition while tracking a target object. Blue line shows the state and the tracking level of camera 1. The other colours show the surrounding cameras including camera 2. At first, a target object located in the start point indicated in Fig.12. Camera 2 is selected for first tracking. A target object moves in a circular motion from start point. Camera 1 is selected for tracking on the way of a circular motion. After that, camera 1 continues tracking although the higher tracking levels are observed for relatively long time steps by the other cameras. This result indicates that the proposed method is effective for keeping a selection while enough tracking level is available in spite of the higher tracking levels of the other cameras.

5. CONCLUSION

This paper described the cooperation method of cameras for object tracking in wide area covered by multiple cameras. Fuzzy automaton-based camera selection for a tracked object was proposed. Some simulations were performed and the results show the proposed method is suitable for camera selection in multi-camera system. Especially, the previous method needed enough overlapping of monitoring areas among cameras is for stable camera selection. That made the placement of multiple cameras difficult. The proposed method achieves the flexible placement of cameras. There are several future works as described in followings. In this paper, 2D monitoring areas are used for simulation. A target object is represented as just a point in the simulation environment. However, actual 3D monitoring areas and a size of a target object should be considered. Simulation of multiple objects tracking should be also needed. That includes the problems about occlusions that make drastic reduction of tracking level. Actual multi-camera system will be developed for checking the performance of the proposed method. Positional relationships among cameras should be obtained automatically for easy construction of the multi-camera system.

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