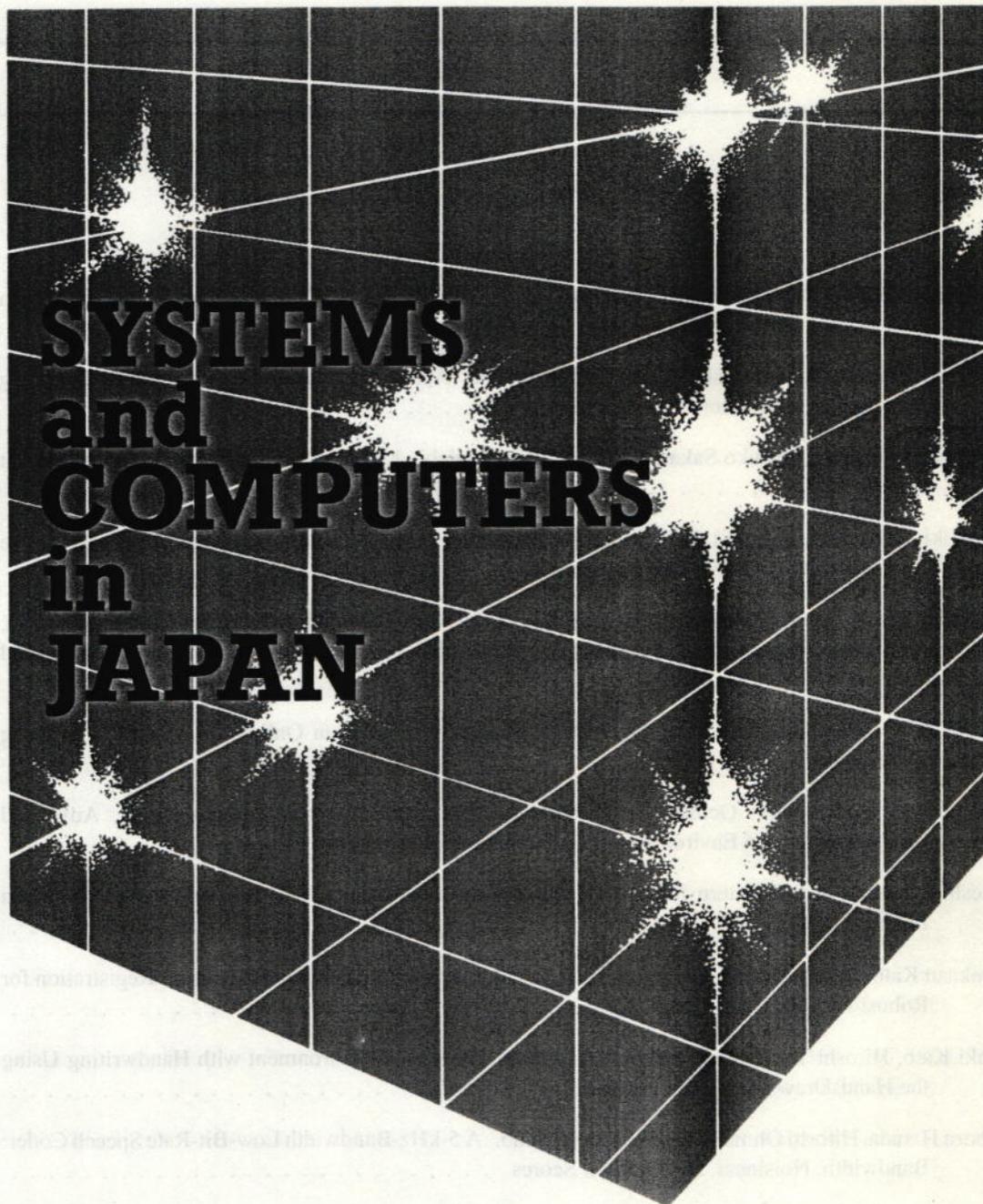


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Cooperative Distributed Registration for Robust Face Recognition

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SUMMARY

This paper describes a cooperative distributed registration system for efficient acquisition of a set of facial images required in realization of robust face recognition. In this system, a lot of agents consisting of a camera and a processor are arranged, and the person detection and tracking as well as registration of facial images are integratively realized. By configuring the cooperative mechanism of this system into a three-layer structure, the required communication capacity is reduced and efficient cooperative operation is realized. In the first layer, each agent independently performs the detection and two-dimensional tracking of the target person. In the second layer, the robust three-dimensional tracking is realized by cooperating agents themselves who are tracking a particular target person within an agency. In the third layer, by the cooperation among agencies, the agency configuration is dynamically changed in accordance with the position and registration conditions of the target person, and the effective registration is realized by changing over the target person of each camera. We will present the experimental results based on a system constructed with eight cameras and confirm the effectiveness of the proposed technique. © 2002 Wiley Periodicals, Inc. *Syst Comp Jpn*, 33(14): 91-100, 2002; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/scj.1179

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Key words: cooperative distributed vision; cooperative distributed registration; person tracking; facial recognition; facial image registration.

1. Introduction

The surveillance of persons using cameras is important for realizing not only a security system but also a natural interface between humans and the environment. In the case of performing surveillance of persons in a wide space such as an entire building as the observation range, since it is difficult to observe the entirety using only one camera, it is necessary that the observation be performed using multiple cameras and to identify the person observed by each camera. In a real environment, use of the person's inherent information such as fingerprints is difficult in the case of identifying a freely moving person. Accordingly, in this research, we perform person identification by means of the face which can be photographed without the awareness of the target person.

Various face recognition techniques have been proposed to date [2, 4, 7]. With these techniques, a certain degree of recognition can be performed if the facial images of all views for the target person to be recognized are registered in a dictionary. However, when the target person to be recognized cannot be specified beforehand, since the facial image cannot be registered in advance, a method of registration becomes important. Namely, when an unregistered person is observed, a system becomes necessary for performing the detection and tracking as well as the registration newly. In the conventional research on face recogni-

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tion, it is assumed that the facial images have been registered sufficiently beforehand under a limited environment, and the registration under a real environment has not been studied sufficiently. Accordingly, in this paper, we will propose a cooperative distributed registration which deals integratively with the detection and tracking as well as registration of persons under the framework of cooperative distributed vision [3].

In the cooperative distributed registration, because the multiple cameras (agents) arranged distributively perform the cooperative operation mutually, effective registration is realized while tracking multiple persons. In this case, since the purpose is in the effective registration, it becomes important to acquire a set of registration images for the realization of robust face recognition by appropriately changing over the target person registered by each camera in accordance with the position, posture, and registration conditions of the target person. In order to appropriately select the target person of each camera, the cooperative operation of all cameras is necessary; however, when the system scale becomes larger, the amount of communication required in cooperation becomes huge and there is a danger that the system may fail. Accordingly, the amount of communication can be reduced by appropriately limiting the range of cooperative operation using a cooperative distributed registration system with a three-layer structure.

2. Cooperative Distributed Registration System with Three-Layer Structure

2.1. Agent and agency

The cooperative distributed registration system is composed of an active camera which can control pan, tilt, and zoom; a processor with image processing function and communication function; and a network. As shown in Fig. 1, the set of active camera and processor is treated as a constituting unit and called an agent. Each agent can operate autonomously and the cooperative operation can be realized by communication.

The set of agents with the same purpose will be called an agency. On the other hand, the agent making up the agency will be called the member agent. As shown in Fig. 2, there are two kinds of agencies in the cooperative distributed registration system. The agency with a fixed observation range for detecting a person newly appearing is called the detection agency and its member agent is called the detection agent. On the other hand, the agency tracking a certain specified person and registering the facial image is called the tracking agency, and its member agent is called the tracking agent.

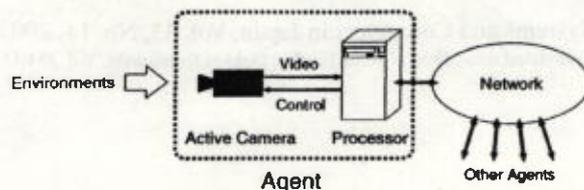


Fig. 1. Configuration of agent.

There exists a special agent called the agency master in each agency. The agency master works as a representative of the agency and is responsible for the management of member agents and the communication with other agencies.

In the initial state, only the detection agency exists and all agents belong to the detection agency. When a detection agent detects a new person, a tracking agency with that agent as an agency master is newly generated and begins tracking of the person. Moreover, when all member agents can no longer track the target person, that tracking agency ceases to exist.

2.2. Three-layer structure

In the cooperative distributed registration system, each agent observes only a limited range and the observation of the entire scene is realized by cooperative operation among agents. Here, for robust person tracking, a real-time processing is required and effective cooperation among agents becomes necessary. On the other hand, for effective registration, it is necessary to consider the registration state, position, and posture of all target persons, and the cooperation in the entire system becomes important. However, when the entire system is closely coupled, the communication required becomes huge and there is a danger that effective cooperation cannot be realized. Accordingly, as

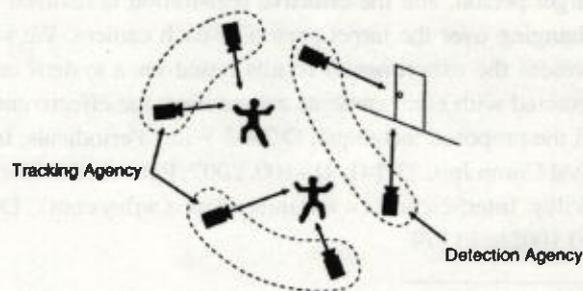


Fig. 2. Detection agency and tracking agency.

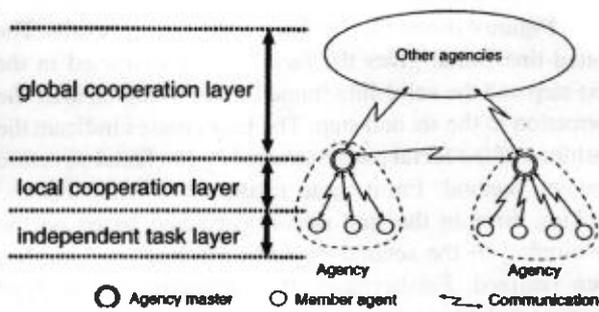


Fig. 3. Three-layer framework.

shown in Fig. 3, a three-layer structure is introduced and the other party each agent is cooperating with is limited to an appropriate range according to its purpose.

Independent task layer

Each agent operates autonomously, and the detection and tracking of the person's face are performed without information sharing and synchronization among agents. The details of agent operation in the independent task layer is described in Section 3.

Local cooperation layer

The member agents themselves within an agency cooperate locally to realize the agency's purpose. In the tracking agency, robust tracking is realized by sharing the position information of the target person within the agency. In the detection agency, the observation range of the agency is divided and assigned to the member agents. The details of the cooperative operation is described in Section 4.

Global cooperation layer

Effective registration is realized by global cooperation among agencies and control of the operation of the entire system. The required communication in the entire system is reduced by performing the communication among agencies with the agency masters as representatives. The details of the cooperative operation in the global cooperation layer is described in Section 5.

3. Person Detection and Tracking in Independent Task Layer

Below we describe the autonomous process of each agent in the independent task layer.

3.1. Detection of person's face by detection agent

The detection agent detects the facial region of the person newly appearing. In the facial region detection, both the subspace method [6] and the facial structure analysis [5] are used. The facial structure analysis is a technique for detecting the facial region by extracting the facial parts (eyes, nose, and mouth) and verifying their positional relations; it can achieve high-accuracy detection but is weak regarding background variations, and the time taken in processing when the search range is wide becomes a problem. Accordingly, several facial region candidates are detected by the subspace method and then the facial structure analysis method is applied for each candidate region.

3.2. Tracking of person's face by tracking agent

In order to perform the stable person tracking by controlling the pan and tilt of the camera, processing at the frame rate is required. On the other hand, since the facial images are used in registration and recognition, high-accuracy positioning of the facial region is required. Accordingly, high-speed and high-accuracy tracking of a person's face is realized by the following two-step processes.

(1) Using the facial region obtained in the preceding frame as a template, the rough positioning of the facial region is performed by template matching. Employing this result, tracking is realized by controlling the pan and tilt of the camera such that the facial region keeps in the center of the image.

This method is capable of high-speed processing; however, it is difficult to determine a high-accuracy position and there is a problem that the position slips accumulate due to the successive updates of templates. These errors and position slips are corrected by step (2).

(2) For the facial region obtained in the preceding step, high-accuracy positioning is performed by applying the facial structure analysis method. The positions of the respective facial parts are determined by the facial structure analysis method; based on the position information of the obtained facial parts, the position, direction, and scale of the facial region are corrected. The facial images are extracted based on this result and used in registration and recognition. In addition, the template of step (1) is corrected. Moreover, the detection of the facial region is performed similar to Section 3.1 at the start of tracking and the failure of tracking.

The tracking agent classifies the facial image being tracked according to the direction of the face; after performing the normalization by affine transformation, the facial image is cut out and registered along with the information

on facial direction. In the discrimination of the facial direction, the results of the facial structure analysis method [5] are used. Among the data on the three-dimensional direction of the face obtained by the facial structure analysis method, based on the angle around the vertical axis, they are classified into three kinds: the front (-20° to 20°), the right (20° to 50°), and the left (-20° to -50°). The facial images in directions other than those three are not registered. The normalization and cutting out of the facial images are performed as follows. From the positions of the facial parts obtained from the facial structure analysis method and the positions of the facial parts of the standard facial model for every facial direction, the affine transformation matrix is determined; the normalization of the position is performed for the input image and then it is cut out in a fixed range.

3.3. Detection and tracking results by a single agent

Here we present the results of performing detection and tracking of the facial images by one agent. In the experiments, the agent is configured by one unit of pan/tilt/zoom camera (SONY EVI-G20) and one unit of PC (PentiumIII-600 MHz). The image photographed by the camera is input into the PC as a color image of 320×240 pixels and 24 bits. The camera is connected to the PC via RS-232C and the control of pan/tilt/zoom is performed. The photographing environment uses fluorescent-light illumination inside a room about 6 m in length and breadth. A camera is installed at one side of the wall in the room and the person appearing is detected and tracked from the edge of the opposite side of the wall. The facial directions of the subspace used in the detection in the initial state are 0° , 40° , and -40° . The scale of the facial image is set in five steps from 64×64 pixels to 38×38 pixels.

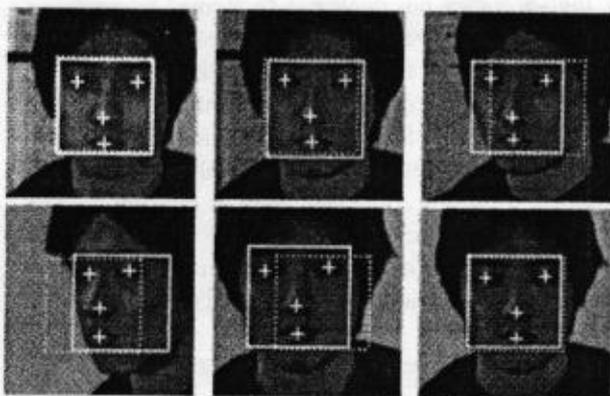


Fig. 4. Experimental results in independent task layer.

Figure 4 shows the detection and tracking results. The dotted-line frame gives the facial region extracted in the first step and the solid-line frame the facial region after the correction in the second step. The four crosses indicate the positions of the facial parts extracted by the facial structure analysis method. From these results, it is seen that the tracking error in the first step is corrected based on the positioning of the second step and a robust tracking has been realized. Furthermore, the successive update-type template matching process can be performed within a video rate (33 ms/frame) and the tracking in real time has been realized.

4. Cooperation within Agency in Local Cooperation Layer

Here we describe the cooperative operation within the agency for the respective detection agency and tracking agency.

4.1. Assignment of observation range by detection agency

The detection agency has the location where the person appears newly as the observation range. The agency master divides the observation area and assigns to the respective member agents, and the member agent detects the person inside the assigned observation range. The observation range depends on the range which is required to observe the target person in the scene as well as the number of member agents and their positions. In this research, for simplicity, the location where the person appears newly is limited to one place and he is detected by one member agent.

4.2. Cooperative tracking by tracking agency

In the tracking for each agent, the tracking will become unstable when the target person is occluded by an obstacle or other person or when the distance from the camera is large. Accordingly, robust tracking is realized by taking the matchableness of the position of the target person among the member agents within the same agency.

(a) When only one member agent has succeeded in tracking, since it is seen in the other member agents that the target person exists on the corresponding epipolar line, the facial region can be detected in the surrounding region of this epipolar line [Fig. 5(a)]. The member agent that finds the facial region starts the tracking.

(b) When two or more member agents have succeeded in tracking the target person, the three-dimensional

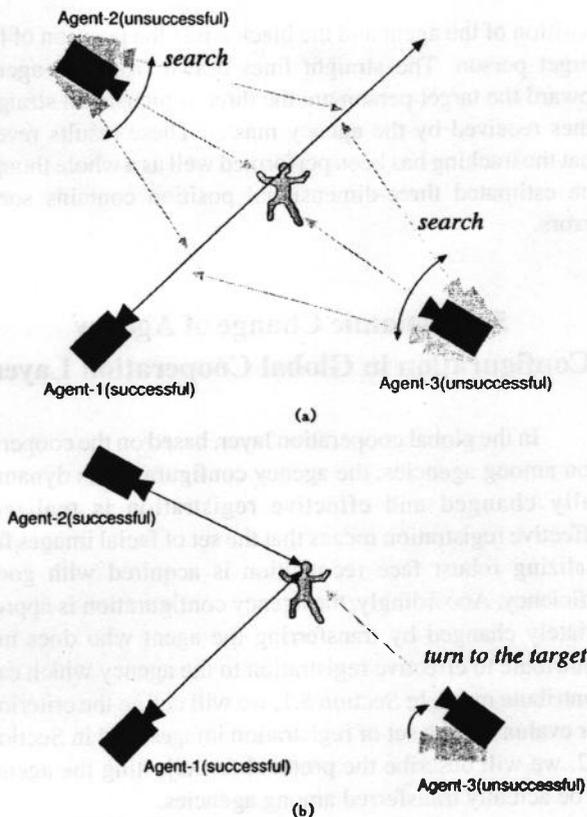


Fig. 5. Verification and correction using 3D position of target person: (a) one agent is successfully tracking; (b) two or more agents are successfully tracking.

position of the target can be estimated by the principle of triangulation. As shown in Fig. 5(b), the target person exists at the intersection of the straight lines corresponding to the tracking results of the respective agents. However, errors are contained in the tracking results of the respective member agents. Moreover, since each member agent is independently tracking, slips will occur in the times of acquiring the positions of the target person. For that reason, there is no guarantee that the respective straight lines will exactly intersect at one point. Accordingly, the point at which the square sum of the distances from the respective straight lines becomes a minimum is regarded as the three-dimensional position of the target person.

Based on the tracking results of the member agents who have succeeded in tracking, the agency master determines the three-dimensional position of the target person and informs the respective member agents. The member agents who have succeeded in tracking compare, on the image plane, the point which is obtained by projecting the three-dimensional position received from the agency master and the two-dimensional position which is the tracking

result of the agent. When the distance is smaller than the threshold value \mathcal{T} , it is judged that the tracking result is correct and the tracking is continued. On the other hand, when the distance exceeds \mathcal{T} , it is judged that the tracking has failed. The member agent who has failed in tracking performs the detection of the facial region in the surrounding of the three-dimensional position received and the tracking is started if the facial region is found.

When the time slip between respective agents is small, the consistency of estimated position between agents can be maintained in high accuracy by making the threshold value \mathcal{T} smaller. On the other hand, when the time slip is large, it is necessary to make \mathcal{T} larger in order to realize the robust cooperative operation in accordance with the time slip. Thus, giving priority to the tracking results of the respective agents, only when the tracking fails or when the consistency of the tracking results cannot be taken, robust tracking can be realized in the tracking errors of the respective agents and the time slips by correcting the tracking using the three-dimensional position.

4.3. Cooperative tracking experiments

To confirm the stability of person tracking in the local cooperation layer, we have performed experiments tracking a single person. The experimental system is constructed using four agents. The configuration of the respective agents and the input image size are the same as in Section 3.3, and the cameras are installed, respectively, at the edges of the wall of all sides of a room about 6 m in length and breadth. The respective agents are connected by a 100 Base-TX network. The threshold value \mathcal{T} is set at 320 pixels.

Figure 6 shows an example of the input image sequence of the respective agents. The frame gives the facial region each agent is tracking. At time t_1 , Agent 1 has detected the new person and started tracking. At this time, Agents 3 and 4 have already started the search on the epipolar line shown by the dashed line in Fig. 6. Next, at time t_2 , Agent 4 has detected the facial region and started tracking. Agent 3 has failed in tracking at t_3 but corrected at time t_7 . This is because the failure is detected based on the three-dimensional position determined from the tracking results of Agents 1 and 4, and the search is performed again. Thus, it is seen that the mistake of tracking of each agent is corrected by using the results of other agents and robust tracking has been realized as a whole. Moreover, at time t_{11} , since the target person has gone out of the observation ranges of Agents 1 and 4, these agents have failed in tracking; however, the tracking has been continued by Agents 2 and 3 since then.

Figure 7 shows the relationship between agents and target person from time t_0 to t_{11} . The white circle gives the



Fig. 6. Experimental results in local cooperation layer.

position of the agent and the black circle the position of the target person. The straight lines drawn from the agents toward the target person are the three-dimensional straight lines received by the agency master. These results reveal that the tracking has been performed well as a whole though the estimated three-dimensional position contains some errors.

5. Dynamic Change of Agency Configuration in Global Cooperation Layer

In the global cooperation layer, based on the cooperation among agencies, the agency configuration is dynamically changed and effective registration is realized. Effective registration means that the set of facial images for realizing robust face recognition is acquired with good efficiency. Accordingly, the agency configuration is appropriately changed by transferring the agent who does not contribute to effective registration to the agency which can contribute more. In Section 5.1, we will define the criterion for evaluating the set of registration images, and in Section 5.2, we will describe the protocol for adjusting the agents to be actually transferred among agencies.

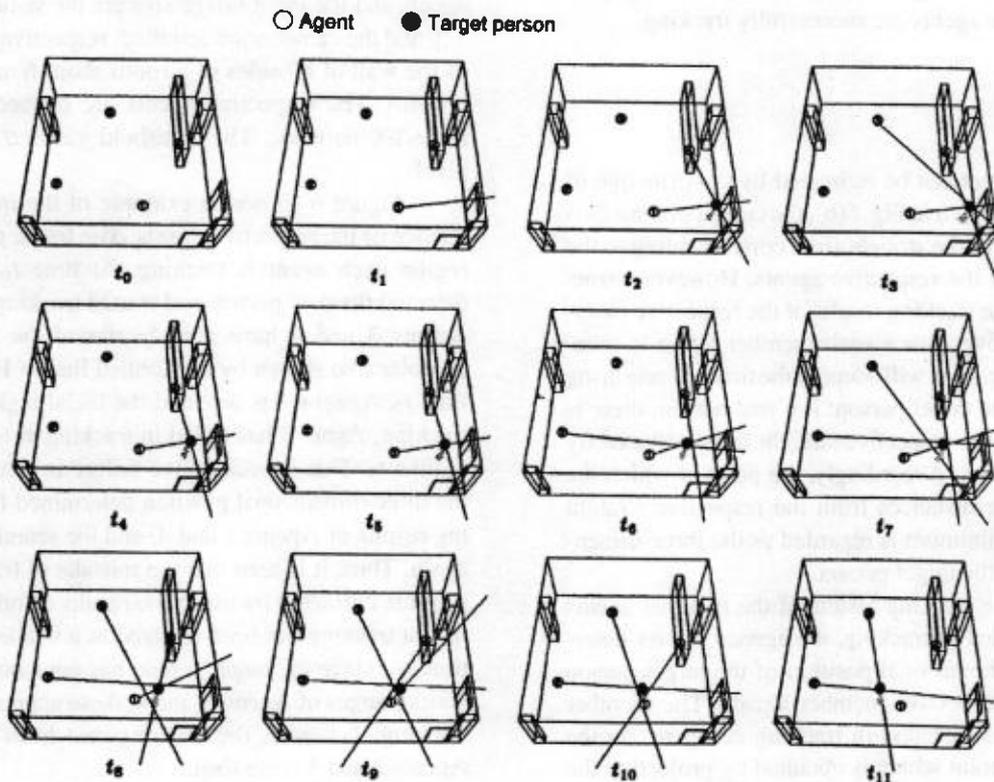


Fig. 7. Experimental results in local cooperation layer (3D position).

5.1. Evaluation of the set of registration images

The registration images obtained by the respective agents along with the information on the facial directions are collected by the agency master. The agency master classifies the collected set of registration images in facial directions (front, right, and left) and perform the evaluation.

The evaluation method for the set of registration images is determined depending on the recognition method. Face recognition by the subspace method [6] is performed in the proposed system. For the respective sets of registration images, the main component analysis is performed and the subspaces are generated. During recognition, the distance with the subspace (DFFS) [4] corresponding to the facial direction of the input image is determined for every person and the person whose DFFS becomes the smallest is regarded as the recognition result.

In order to realize robust face recognition by the subspace method, facial images photographed under various conditions such as facial directions and lighting conditions are required. Accordingly, we should know how many sufficient changes of the lighting conditions are contained in the set of registration images for every facial direction, and regard that as the estimation value of the set of registration images. In particular, the facial images under various lighting conditions are prepared beforehand; then, the DFFS of these facial images with the subspace generated from the set of registration images are determined, and its maximum value is regarded as the estimation value of the set of registration images. If the set of registration images is not sufficient, the estimation value also becomes large because the DFFS with the facial images under deficient lighting condition becomes large. Namely, it can be judged that the smaller this estimation value is, the more ideal is the set of registration images. Moreover, when not one registration image has been obtained, let the estimation value be infinite because the recognition cannot be made.

In reality, since the target person is not specified, the facial images under all lighting conditions for the respective persons cannot be prepared beforehand. Accordingly, the standard lighting patterns using average images are used as the substitute. The facial images of many persons are photographed under several typical lighting conditions and the average image is determined for every lighting condition. The set of average images is called the set of standard lighting patterns and used in the evaluation of the set of registration images.

Figure 8 shows the set of standard lighting patterns actually used in the evaluation. In this example, for 50 persons (45 males and 5 females, 9 of whom wear eye glasses), the photographing is performed under 24 lighting conditions excluding the lighting position of becoming the shadow of the camera itself, by changing the halogen lamp

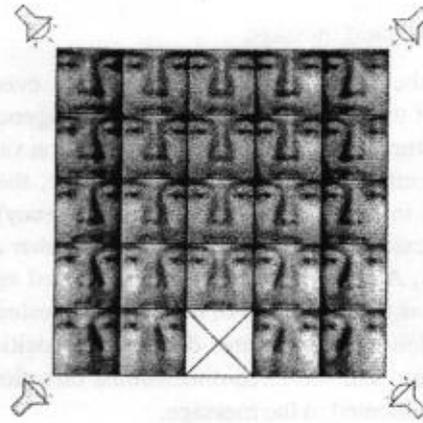


Fig. 8. Frontal average images in all lighting conditions.

5 steps on the right and left and 5 steps in height. Moreover, for the respective facial images, the positions of both eyes, nose, and mouth are determined semiautomatically (after the rough positions are given by hand, the detailed positioning is performed by template matching); and after performing the normalization by affine transformation, the average image is generated.

5.2. Agent transfer protocol

The agent who will be actually transferred between agencies is decided by the message exchange between agency masters. The procedures for this purpose will be called the agent transfer protocol. Using this protocol, by transferring the member agent who has not contributed to the effective registration to the agency which can contribute more, the agency configuration is appropriately changed for each agency. The agent transfer protocol (Fig. 9) consists of the following four kinds of messages.

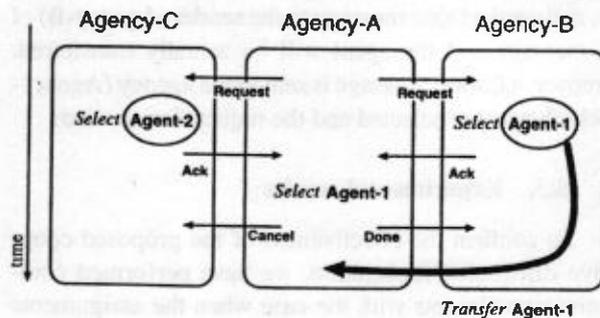


Fig. 9. Agent transfer protocol.

(a) Request message

For the set of registration images for every facial direction of the target person, each tracking agency calculates the estimation value. When the estimation value for a certain direction exceeds the threshold value, the agency (Agency-A in Fig. 9; to be called Request agency) sends a Request message asking for an agent to the other agencies (Agency-A, Agency-B; to be called Requested agencies). Moreover, as the conditions of the agent requested, the set of registration images, the three-dimensional position of the target person, and the three-dimensional direction of the face are augmented to the message.

(b) Ack message

The Requested agency which received the Request message selects an agent, from among the member agents, who matches the conditions augmented to the message as a candidate agent. Here, when there are multiple candidates, the degree of contribution within the agency is compared and the agent whose degree of contribution is the smallest is selected. In addition, the degree of contribution will be regarded as the estimation value of the facial direction of the target person whom that agent is currently observing. Namely, since the direction at which sufficient facial images have already been obtained is being observed, the smaller the estimation value is, it is judged that he has not made a contribution to the agency. However, when the agent has failed in tracking of the target person, the degree of contribution is regarded as 0, and he will be selected.

When the degree of contribution of the candidate agent is smaller than the estimation value added to the Request message, the respective Requested agencies return the Ack message to the Request agency. At this time, the degree of contribution of the candidate agent is augmented to the message.

(c) Done and Cancel messages

When the Request agency (Agency-A) receives the Ack message, it selects from among the candidate agents, the one (Agent-1) who has the smallest degree of contribution, and send a Done message to the sender (Agency-B) of that message and the agent will be actually transferred. Moreover, a Cancel message is sent to the agency (Agency-C) which was not selected and the request is canceled.

5.3. Experimental results

To confirm the effectiveness of the proposed cooperative distributed registration, we have performed comparative experiments with the case when the assignments of the member agents are random at the respective agencies (random registration). The configuration of each agent, the

connection between agents, and the size of input image are the same as in Sections 3 and 4.

So as to maintain the fairness of the comparison, the experiments are simulation experiments using the facial image sequences photographed beforehand. For this reason, first, the aspect that one person of the two target persons moves one at a time inside the room is tracked by using eight agents, and the facial image sequences of the respective target persons are prepared for every agent. By using these facial image sequences, according to the assignment of the agency at each time, each agent selects one of the target persons and registers the facial images; by doing so, the tracking and registration of the case when two target persons move inside the room simultaneously are simulated.

Figure 10 shows the changes of the estimation values of the cooperative distributed registration and random registration. The horizontal axis is the time, and the vertical axis is the average of the estimation values of two persons and three directions. The solid line is the result of the cooperative distributed registration, and the dashed line is the average value of the case when 100 trials are repeated by random registration; the vertical bar expresses the standard deviation. Since the estimation value of the cooperative distributed registration case is much lower than the random registration case, it is seen that effective registration can be realized by the cooperative distributed registration.

Next, the tracking and registration experiments are performed for the case when the two target persons are actually moving inside the room simultaneously. Figure 11 shows the experimental environment. The portion shown by the white circle is one of the cameras used in this experiment. The portion shown by the white rectangle is the entrance used by the two target persons to enter the room,

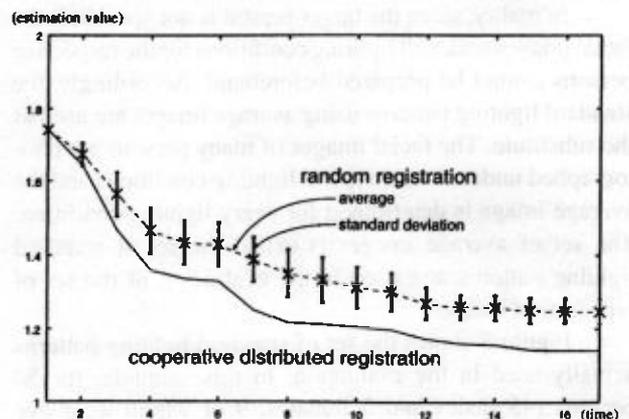


Fig. 10. Comparison between cooperative distributed registration and random registration.

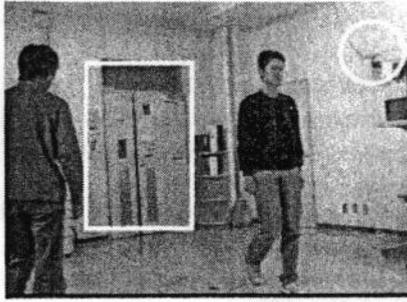


Fig. 11. Experimental environment.

and tracking and registration of these persons are performed.

Figure 12 shows the relationships between the camera and the target persons. ● denotes the target persons (Target-A, B), ○ the detection agents, and △ and □ the tracking agents for Target-A and B, respectively. The straight lines drawn from the tracking agents toward the target persons express the tracking results of the respective agents. The first target person (Target-A) is detected at time t_1 , and the second target person (Target-B) is detected at

time t_4 . After that, from time t_6 to t_{11} , the respective agents continue to track while changing over the target persons (Target-A, B). These results reveal that when there exist multiple target persons, the tracking has been made while the respective cameras switch over the target persons in accordance with the registration conditions of the facial images.

6. Conclusions

In this paper, we have proposed a cooperative distributed registration system with a three-layer structure and confirmed by experiments that effective registration can be realized by dynamically changing the agency configuration in accordance with the registration conditions of the facial images. Moreover, it was confirmed in an experimental system using eight cameras that two persons can be tracked and registered simultaneously.

In the proposed system, since the three-dimensional position of the target persons is required, at least two cameras per person are necessary; moreover, for realizing robust tracking and registration while performing the changeover of the cameras for effective registration, three

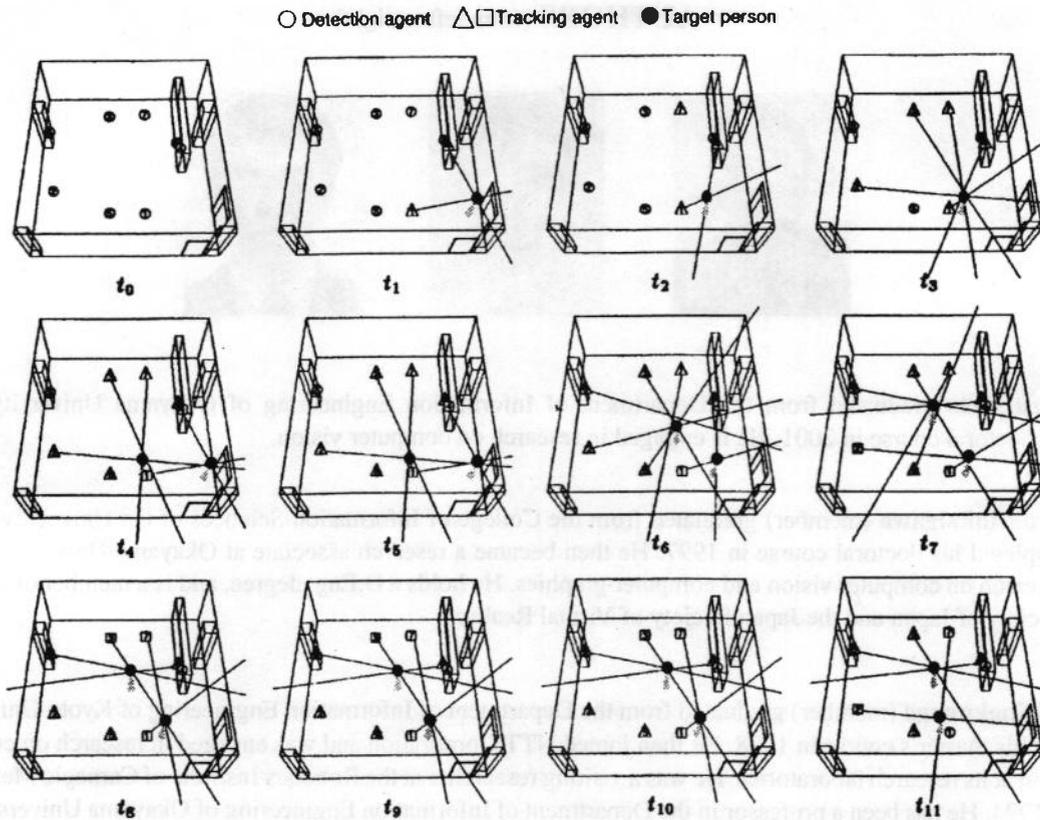


Fig. 12. Dynamic agency configuration in global cooperation layer.

or more cameras become necessary. For that reason, it has been difficult to track and register three or more persons simultaneously in an experimental system using eight cameras. Thus, when multiple persons are to be tracked and registered simultaneously or when the observation range is wide, it is necessary to perform the tracking and registration by using more cameras. In the system proposed in this paper, by performing the cooperative operation using a three-layer structure while reducing the required communication, it may be possible even to cope with the increase of a certain extent of scale. As a future subject, to what extent of scale the extension is actually possible should be evaluated quantitatively.

Moreover, the ultimate purpose of this research is a person surveillance system dealing with a wide region; for that reason, the construction of a system integrating person registration and recognition as well as the establishment of its evaluation method may be cited as future subjects.

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