Dynamic camera allocation method based on constraint satisfaction and cooperative search

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Abstract

In this paper, the dynamic allocation of camera resources for moving objects is presented as a model of partial constraint satisfaction problem. The purpose of the camera allocation is described as some simple constraint. The solution is reflexively searched in order to decide the allocation of each camera. The search neighborhood of the solution is limited to the partial solution for each camera. And, the constraint is relaxed for the partial solution of each camera, when the constraint is not satisfied. For a simple allocation problem, simulation was performed. The result of the simulation shows the efficiency of the proposal method.

1. Introduction

Recently, coordination processing systems using the computers which are connected the video camera are proposed [1] [2] [3] [4]. These systems observe persons in the indoor. In these systems [1] [2] [3], the following process are carried out.

- The integration of information observed by multiple cameras.
- Detection, tracking or recognition of observed object.
- The dynamic allocation of the camera resources.

Especially, the dynamic allocation of the camera resources is a general problem concerning the control of the camera. In many observation systems, each camera is controlled according to clarified state transition model and communication protocol. However, the discussion as a camera resources allocation is not sufficient. Modeling as a resources allocation problem is necessary in order to describe complicated purpose. Search method for the solution are also necessary.

In this paper, the camera resource allocation is modeled as a partial constraint satisfaction problem [5]. In the proposed method, the camera allocation is described as constraint satisfaction problem. Then, the allocation of the camera is controlled by the search of the solution. The constraint is separately described for the allocation of each camera. In the allocation of each camera, each partial solution is separately and reflexively searched. And, the constraint is relaxed for the partial solution of each camera, when the constraint is not satisfied. Therefore, the camera resources is dynamically allocated in proportion to the change of the environment.

2. Modeling of observation system

This section presents the definition of the observation system model. In this paper, the system is assumed to observe the position of the multiple persons moving indoor using multiple cameras. In this system, the following is done.

- From the data observed by each camera, the region where the object exists is estimated.
- The allocation of the camera resources is decided in order to observe estimated region.

2.1. Objects and cameras

The configuration of cameras and objects is shown in Fig.1. The environment is modeled as a two-dimensional plane. The objects move in the observation area. The cameras observe objects in the observation area.

It is assumed that objects are persons. The velocity of objects is within v. The direction in which objects move is unpredictable. The coordinate of object j is shown as vector $X_j^{tgt}(t)$. The number of objects is shown as constant N^{tgt}. The value of N^{tgt} is unknown. Radius r of each object is a constant.

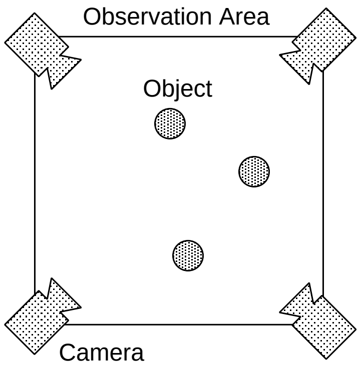


Figure 1. Environment

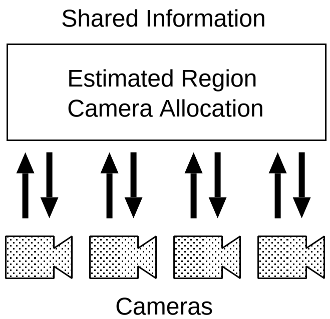


Figure 2. Framework

The viewpoint of each camera is fixed. The visual field of the camera can be controlled. However, the control of visual field is not considered (It is described in sub-section 2.5). It is assumed that there is no restriction of the visual field of the camera in order to simplify the problem. The camera observes whether the objects exist in the each direction. The coordinate of camera i is denoted as vector X_i^{cam}. The number of cameras is denoted as constant N^{cam}.

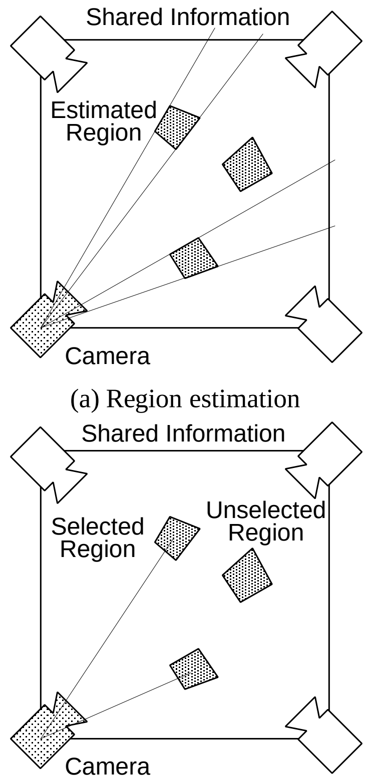
2.2. Observed data

When camera i observes object j at time t, the observed data $f_{t,i,j}(\theta)$ is given by the following equation :

$$\begin{aligned} f_{t,i,j}(\theta) &= \begin{cases} 1 & if \ \ |\theta - \alpha_{t,i,j}| \leq \beta_{t,i,j} \\ 0 & otherwise \end{cases} \\ \alpha_{t,i,j} &= \arg(X_j^{tgt}(t) - X_i^{cam}) \\ \beta_{t,i,j} &= \sin^{-1} \frac{r}{|X_j^{tgt}(t) - X_i^{cam}|} \end{aligned} \quad (1)$$

Observed information $\hat{f}_{t,i}(\theta)$ is shown by the following equation, when camera i observes all objects at time t.

$$\hat{f}_{t,i}(\theta) = \max_{j=1,\cdots,N^{tgt}} f_{t,i,j}(\theta) \quad (2)$$



(a) Region estimation

(b) Camera allocation

Figure 4. Processing for each camera

An example of the data observed by camera i in each time step is shown in Fig.3. The camera can not observe the distance of the object. The object also can not be distinguished by the camera. Therefore, the observation system must integrate observed data from multiple cameras in order to estimate the region where the object exists.

2.3. Framework of the processing

The observation system estimates the region where the object exists, and it decides the allocation of the camera resources for estimated region (Fig.4). Information of estimated region and camera resource allocation is shared by all cameras(Fig.2).

The estimated region is shown as function $\hat{G}_t(X)$. X is a coordinate in the environment. $\hat{G}_t(X)$ is 1, if objects exist. $\hat{G}_t(X)$ is 0, if it is not exist. Region $\hat{G}_t(X) = 1$ is labeled as some part regions $G_{t,k}$ in order to distinguish individual object.

The allocation of camera i for each part region $G_{t,k}$ is shown as variable $a_{t,k,i}(k = 0, \cdots, N_t^{Rgn}, i = 0, \cdots, N^{Cam})$. N_t^{Rgn} is the number of part regions. $a_{t,k,i}$ is 1, if the part region is selected. $a_{t,k,i}$ is 0, if it is not

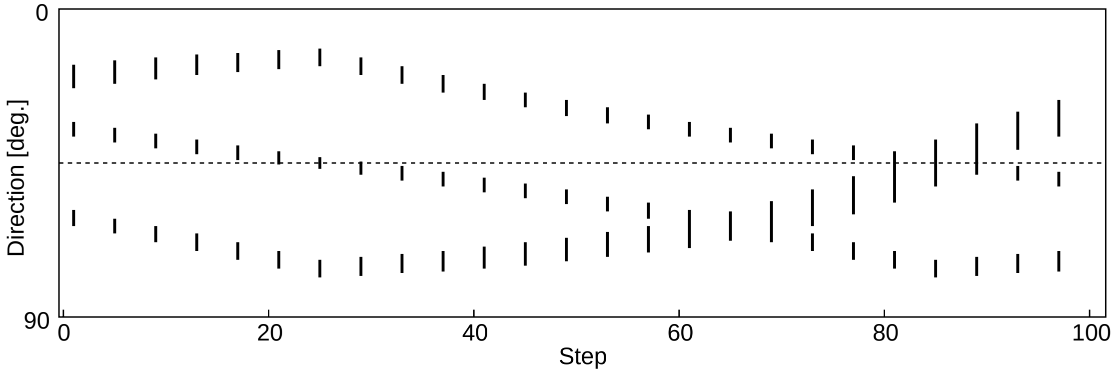


Figure 3. An example of observed data

selected.

Flow of the processing in the observation system is stated as follows.

1. In the initial state, it is assumed that objects exist in the whole observation area.
2. In the every unit time step, estimated region is grown (It is described in sub-section 2.4).
3. The following is done, when the data observed by camera i was obtained.
   (a) According to observed data, estimated region is reduced (It is described in sub-section 2.5).
   (b) The allocation of camera i for estimated region is decided.
4. The process is repeated from 2.

2.4. Estimation of the region in every step of time.

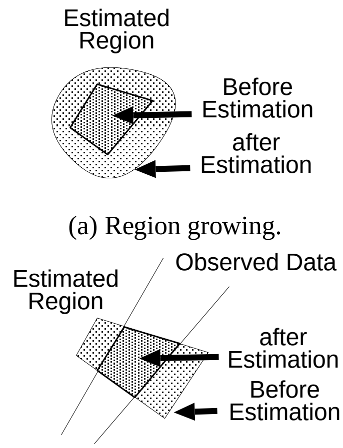
The velocity of the object is within v. Therefore, the region is grown in the every unit time step in order to estimate the movement of the object (Fig.5(a)). When the time passed Δt from t, the estimated region is shown by the following equation.

$$G_{t+\Delta t,k}(X) \leftarrow \max_Z (G_{t,k}(Z) \cdot S(X-Z, \Delta t)) \quad (3)$$

$$S(X, \Delta t) = \begin{cases} 1 & if \ \ |X| \leq v \cdot \Delta t \\ 0 & otherwise \end{cases}$$

2.5. Estimation of the region according to observed information.

Estimated region is reduced, when the data observed by camera i was obtained (Fig.5(b)). Observed data is information of the direction in which the object exists. Therefore, observed data is projected on the two-dimensional plane, and the intersection with estimated region is obtained. The operation between estimated region and observed data is shown by the following equation.



(a) Region growing.

(b) Region reduction.

Figure 5. Region operation

$$G_{t,k}(X) \leftarrow \begin{cases} min(\hat{F}_{t,i}(X), G_{t,k}(X)) & if \ \ a_{t,k,i} = 1 \\ G_{t,k}(X) & otherwise \end{cases} \quad (4)$$

$$\hat{F}_{t,i}(X) = \hat{f}_{t,i}(\arg X)$$

The region which is not selected by camera i is not changed. Therefore, the direction of unselected region may not be observed. By this fact, it is possible to limit the visual field of the camera. However, the control of visual field is not considered in this paper.

3. Camera resource allocation problem.

The camera of the observation system is used for not only observation for all objects but also observation for the special object. The trade-off between global observation and partial observation is important in the allocation of the camera resources. In this paper, to simplify the problem only the following purposes are considered :

1. The region where the object exists is estimated at the sufficient accuracy
2. The observation system uses less cameras. (i.e. Unused cameras which can be used for the partial observation are prepared).

3.1. Modeling as constraint satisfaction problem.

The following must be considered for the above problem.

- The accuracy of estimated region.
- The prediction of observation result and estimated result for the camera resource allocation.
- The trade-off between accuracy of the region and number of unused cameras in proportion to the situation.
- Local optimal solution in the resource allocation.
- etc.

It is not easy to formulate the problem accurately. Then, the problem is modeled as constraint satisfaction problem. The purpose of the resource allocation is described as a constraint. By the search of the solution which satisfies described constraint, the allocation of the camera resources is decided.

However, the condition to be considered in the resource allocation is complicated. In addition, the environment dynamically changes by the movement of the object. Therefore, the description of the constraint to be always satisfied is difficult. Therefore, we consider the problem as a partial constraint satisfaction problem. The purpose is described as multiple constraint. The constraints are relaxed when they are not satisfied.

3.2. Reactive search for the allocation of each camera.

The size of search space of camera resources allocation $(..., a_{t,k,i}, ...)$ is $(N_t^{Rgn} \times N^{Cam})^2$. Especially, the cost of this search becomes a problem in initial step of the system, since the fragment of many estimated regions exists. Therefore, it is necessary to reduce the neighborhood in the search.

Each camera separately observes the object. So, it is appropriate to divide the decision of the allocation for each camera. In addition, the allocation must be immediately decided, because the environment dynamically changes.

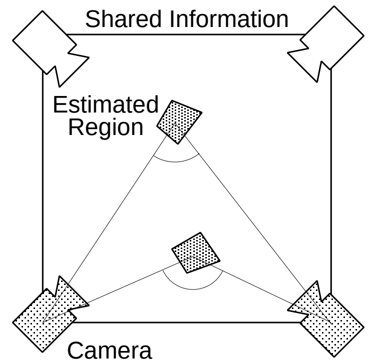


Figure 6. An example of best allocation

Then, the neighborhood in the search is limited to the variable for camera i which should decide the allocation at present. In the viewpoint of the whole system, the partial solution for one camera is searched at one time. By the repetition of such reactive search, the system follows the dynamic environment. This operation is a kind of hill-climbing method.

3.3. Relaxation of the constraint for each camera.

The neighborhood in the search is limited for each camera, and the hill-climbing method is reaction-ally executed. Therefore, following approaches are used for the description and satisfaction of the constraint.

1. Constraint is separately described for each camera.
2. Constraint is separately relaxed for each camera.

Let denote the constraint for each camera as $C_{i,l}(..., a_{t,k,i}, ...)$. Suffix $l = 0, 1, 2, ...$ is the priority of the constraint. The priority of $C_{i,0}$ is the highest. The threshold of the constraint relaxation is given by L_i. $C_{i,l}$ is satisfied for all $l \leq L_i$. And, $C_{i,l}$ is not satisfied for all $l > L_i$. $C_{i,0}$ is always satisfied.

3.4. The design of the constraint.

We designed the following constraint.

[Reduction of estimated region]

Two cameras observe estimated region in order to reduce the region. And, it is necessary that line of sight of cameras has sufficient crossed axes angle(Fig.6). The line of sight is defined as a vector from coordinate of the camera to barycentric coordinate of the region. It may not be able to achieve this goal at one step (The goal can not be achieved by the change of the allocation of the one camera, if no

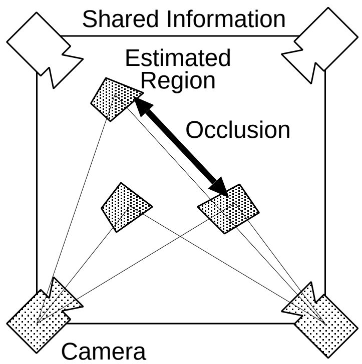


Figure 7. An example of occlusion

camera has been allocated). Then, it is described as two constraint.

$C_{i,0}$: For all estimated regions, the region must be selected, if the number of cameras which have selected the region is less than 2.
$C_{i,1}$: For all estimated regions, the region must be chosen, if the crossed axes angle of line of sight of some 2 cameras is less than the threshold.

[Reduction of the occlusion]

The occlusion causes the error in the estimation of the region(figure 7). Therefore, it is necessary to reduce the occlusion by other cameras.

$C_{i,2}$: For all observed regions, the region must be selected, if the number of the cameras which has selected the region with no occlusion is less than 2.

[Reduction of observing camera]

The camera may not select the unnecessary region in order to reduce the number of observing camera. However, it is necessary to pass the region between cameras to avoid the deadlock(figure 8). Then, following constraint is used.

$C_{i,3}$: The number of the region observed from camera i without the occlusion is given by N_i. The number of the region observed from other camera o with the occlusion is given by N_o. If $N_i > N_o$, the region which satisfies next condition must be selected.

- The region has been selected by camera o.
- The region can be selected by camera i without the occlusion.

$C_{i,4}$: No estimated region must be selected.

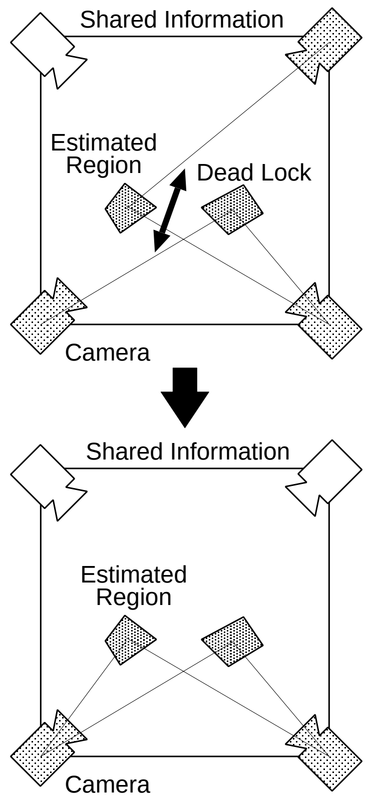


Figure 8. Avoid dead lock

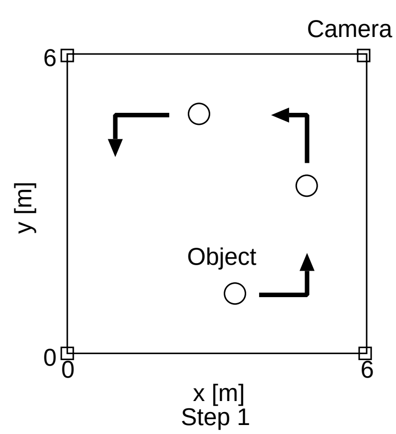


Figure 9. Initial state of experiment

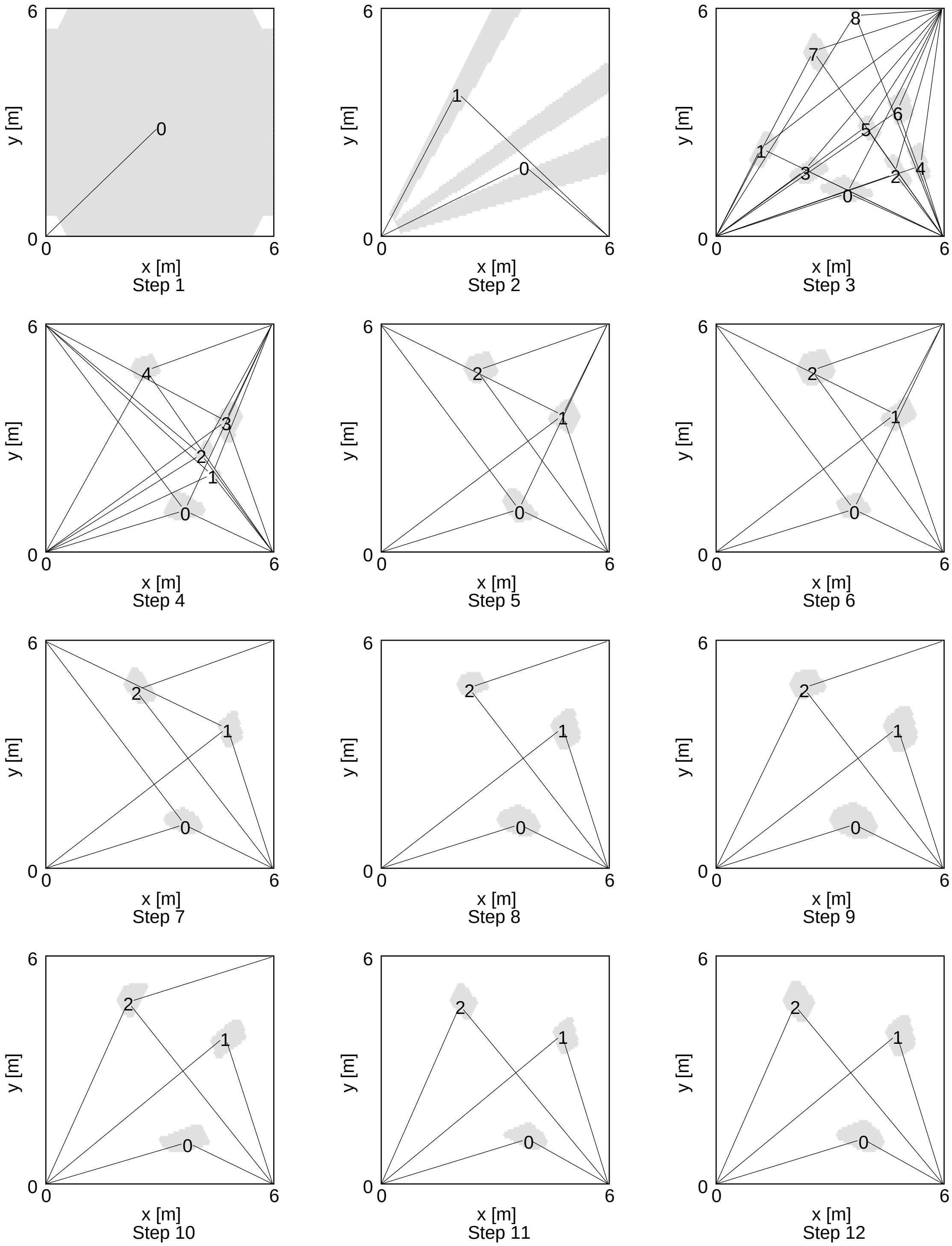


Figure 10. Estimated region and camera allocation

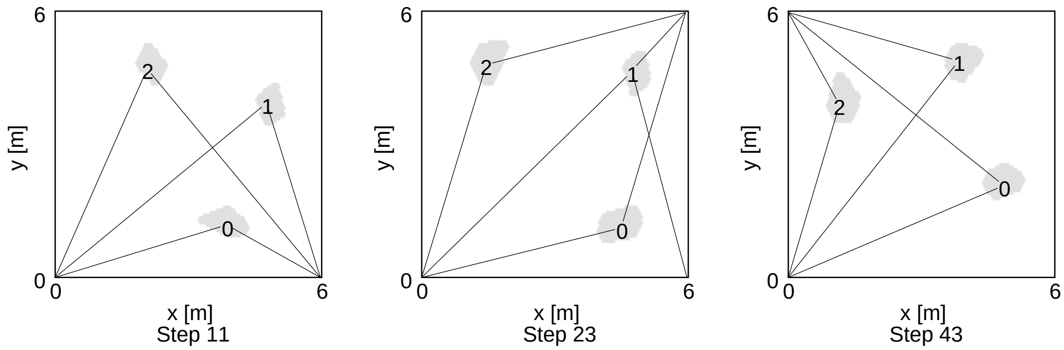


Figure 11. Estimated region and camera allocation

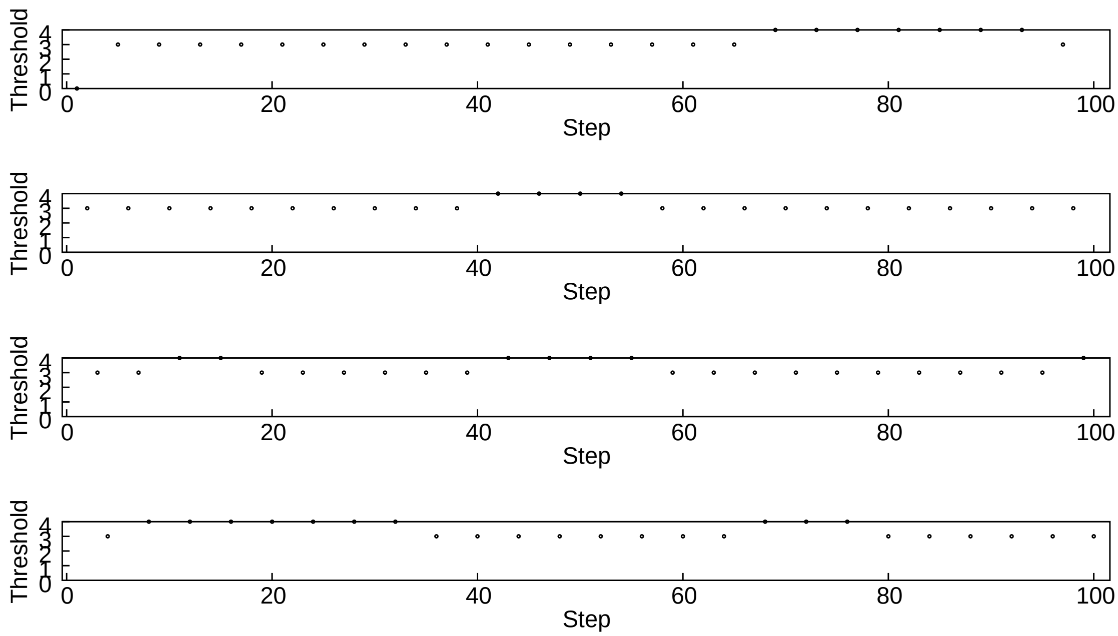


Figure 12. Threshold for constraint relaxation

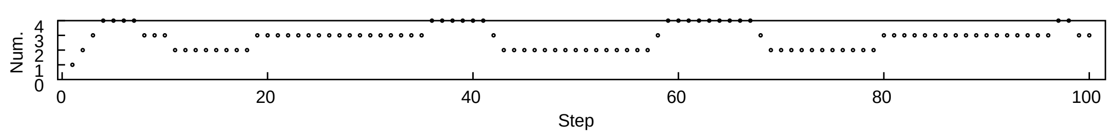


Figure 13. Number of used camera

4. Experiment

For the above, simulation was performed. This section presents the computer simulations to evaluate the performance of the proposed algorithm. The configuration of object and camera is shown in Fig.9. The size of the observation area is $6m \times 6m$. Cameras are placed in 4 corners in the observation area. Objects orbit in the observation area. The velocity of the objects is $1.2m/s$. The inner product of the threshold of constraint $C_{i,2}$ is $\cos(\pi/12)$. The operation of the region was approximated using the bitmap. The neighborhood of the bitmap is 6. The number of cells is 100×100 for the whole observation area. 1 time step is $50ms$. The object moved in every step. By the round robin system, one camera observes objects in every step. In every step, the estimated region grows.

Figure 10 shows the estimated region and camera allocation from step 1 to 12. In step 1, the region is selected by constraint $C_{i,0}$. In the beginning, the occlusion occurred because of the fragment of many regions. However, the allocation of the camera is reduced, when the region is sufficiently reduced.

Figure 11 shows the camera allocation at 11,23 and 49 steps. The camera allocation is changed in order to avoid the occlusion which is occurred because of the movement of objects. In 23 steps, 3 cameras are allocated for region 1. It is the effect of the constraint $C_{i,2}$.

Figure 12 shows the threshold of the relaxation of the constraint for each camera. The camera is not used, when the threshold is 4. The role of the camera (i.e. unused camera) changes in proportion to the situation.

The figure 13 shows the number of allocated camera. The number of allocated camera follows the occlusion.

5. Summary

In this paper, the dynamic allocation of the camera resources was presented as a model of partial constraint satisfaction problem. Then, the framework to solve the problem was proposed. The constraint is described for the partial solution for each camera. The partial solution is reflexively searched for each camera allocation. And, the constraint is relaxed for each camera.

The result of the simulation shows the efficiency of the proposal method. The allocation of the camera resources was dynamically changed in proportion to the change of the environment.

The following points are the future work of this study. In this paper, the heuristic constraint was used. Theoretical analysis for this constraint are necessary. The algorithm of coordination search [6] and reflexive planning should be introduced in order to handle more difficult problem. Control of the visual field of the camera and more practical estimation model are also future goals.

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