Strategic Layout of Multi-cameras Based on a Minimum Risk Criterion

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Abstract. This paper proposes a method to allocate multiple cameras to a better or the best positions. In RoboCup Small Size League(SSL), two or more cameras are used, and we have to decide the layout of them at the venue. This paper gives a criterion which minimizes the risk, for example, the occlusion of a ball by robots, and solves it by using Fletcher-Reeves conjugate gradient algorithm. Experimental result shows the effectiveness of the proposed method.

1 Introduction

Figure 1 shows an example of multi-camera's layout in RoboCup SSL, and in this case, the cameras are placed to cover whole of the game field. These kinds of cameras are set at the suitable places based on the human experiences where the cameras could catch an object around the center of the image.

Kono et al. have reported an assist system which utilizes several cameras attached on the human's body[1]. Although they allocate multiple cameras based on a subjective criterion, there is no objective criterion. When we use multi-camera system, we are requested to decide the number and the places of the cameras. It is necessary to solve the most suitable number of cameras. How to solve the minimum number of security cameras is expressed in Art Gallery Problem[2]. This research provides only the cost minimum criterion. On the other hand, Kato et al. have treated the data traffic in the network and showed how to solve the maximum number of cameras[3].

As shown in Fig. 2, according to the number of the cameras increases, the computing cost or the traffic on the network increases, on the other hand, the

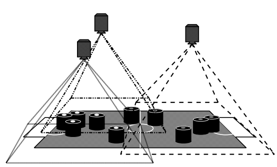

Fig. 1. An example of multi-camera's layout

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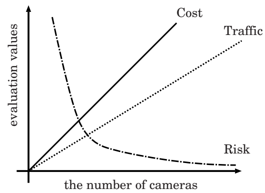


Fig. 2. The relation between the number of cameras and some evaluation values

Fig. 3. Cameras attached on the truss(interruption to other team's view is not allowed)

risk such as missing a ball decreases. An answer for the former is obtained by solving the trade-off problem between the computing cost and the risk, for example. This answer gives us one of the most suitable number of cameras. For the latter problem, a kind of criterion such as minimum cost, minimum data transfer traffic in the network, minimum risk, and so on, is required to decide a better or the best positions of them.

As for the places of multi-cameras, some criterion have been provided. There is a system which measures the shape of insects for the electronic museum. The paper resulted that it is better to place many cameras near the thready places than to place them at regular intervals around the measured insects[4].

Furthermore, there sometimes exists spatial restriction as shown in Fig. 3. It is not allowed to interrupt other camera's view. We have to decide a better or the best positions of cameras under these conditions or the restrictions at the venue.

This paper proposes a method to decide a better layout of multiple cameras under the condition that the risk is minimum. In the following, sections 2. and 3. describe how to model and calculate the risk and how to decide the best positions of cameras, respectively. Section 4. shows the effectiveness of the proposed method based on the experimental simulation results.

2 Risk Model in RoboCup Competition

Figure 4 shows a robot in RoboCup SSL. It is limited less than $18cm$ diameter and less than $15cm$ height. In RoboCup SSL, the robots game on a field of size $5.5m \times 4.0m$ including $0.3m$ width technical area. In the competition, each team uses 5 robots and an orange color golf ball on the field.

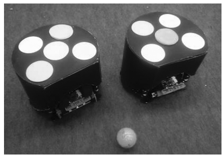


Fig. 4. Robot's overview

(a) A robot is close to the ball. (b) In the image through a camera, the ball can't be observed.

Fig. 5. Occlusion by a robot

There are two methods to take the coordinates of robots and a ball. Global vision overlooks robots and ball from the ceiling and local vision detects circumjacent robots and ball from a robot. Multiple cameras in the global vision system are placed on the truss built on $4m$ high. Many teams use multi-camera global vision system in RoboCup SSL because it is difficult to overwatch the whole field with one camera.

One of the risk in RoboCup SSL is the occlusion by the robots. The global vision loses a ball if the robot moves closer to or many robots close up the ball. Figure 5 is a typical case of the occlusion in RoboCup SSL. Figure 5 (a) shows that a robot is near the ball. Figure 5 (b) is an occluded image through a camera. There appears only robots in the image and the ball is not observed in it. If the occlusion occurs like this, it affects on the strategic planning of robots.

The area S of occlusion caused by a robot is defined as a function of the coordinates of camera $C(x, y, z)$, robot $R(x, y, z)$ and ball $B(x, y, z)$. Let the probability distribution of a robot be $P_{(R)}(x,\ y)$ in the field F. Then, $P_{(R)}(x,\ y)$ satisfies

$$\iint_F P_{(R)}(x,\ y)dxdy = 1. \tag{1}$$

So, the evaluation value E of occlusion is defined and expressed as

$$E = \iint_F S\ P_{(R)}(x,\ y)\ dxdy. \tag{2}$$

3 How to Decide Multi-cameras Layout

This paper calculates camera's coordinates $C_{(i)}(x,\ y,\ z)$ $(1 \leq i \leq N)$ that minimize E. E is minimum means that the risk is minimum, so, this solution is one of the optimal positions of cameras.

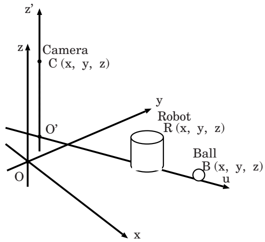


Fig. 6. Definition of u-z' plane

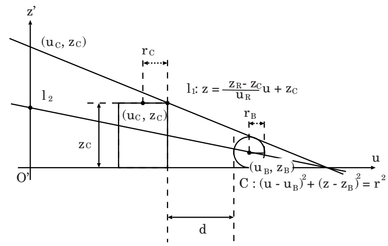


Fig. 7. Modeling to calculate the distance between a robot and a ball

3.1 Simulation of Occlusion with a Cameras

When camera, robot, ball are in the same plane, a ball is frequently occluded by a robot. In order to discuss simply, let a line connected with the centers of them on the x-y plane be u-axis, and its vertical line which passes C be z'-axis, respectively as shown in Fig. 6, then the following equations are devised.

$$u = \sqrt{(x - x_C)^2 + (y - y_C)^2} \tag{3}$$

$$x = u \times cos\left\{tan^{-1}\left(\frac{y_B - y_C}{x_B - x_C}\right)\right\} + x_C \tag{4}$$

$$y = u \times sin\left\{tan^{-1}\left(\frac{y_B - y_C}{x_B - x_C}\right)\right\} + y_C \tag{5}$$

Figure 7 demonstrates how to calculate the distance d between the robot and the ball. d is calculated on u-z' plane using the relation between the circle and the tangential line in Fig. 7.

A tangent line is drawn from the camera to the robot (displayed as a rectangle in Fig. 7). The equation of this line(L_1) is obtained as:

$$z = \frac{z_R - z_C}{u_R + r_R} u + z_C. \tag{6}$$

The coordinates $U(u_0,\ 0)$ is obtained as the point at the intersection of this line and u-axis. L_2 is a line passing through $(u_B,\ z_B)$ and $(u_0, 0)$. The following equation

$$\frac{z_B}{u_0 - u_B} \simeq \frac{1}{2}\frac{z_C}{u_0} \tag{7}$$

satisfies the gradient of L_1 and that of L_2. In consideration of robot and ball radius, d is calculated as

$$d = |u_B - u_R| - r_R - r_B. \tag{8}$$

If d is less than 0, it means that a ball is not occluded by a robot. So, in this case, let it be $d = 0$. By using this value d instead of S, a new evaluation value E', replacing to Eq.(2), is obtained as:

$$E' = \iint_F d \times P_{(R)}(x,\ y)\ dxdy. \tag{9}$$

3.2 Simulation of Occlusion with Multiple Cameras

When multiple cameras are used, it is necessary to consider the overlapped area. $d_{(i)}$ denotes d of the i-th cameras($1 \leq i \leq N$). Considering that at least one camera could catch the ball, Eq. (9) is rewritten as:

$$E'' = \iint_F \min_i\{d_{(i)}\} P_{(R)}(x,\ y)\ dxdy \tag{10}$$

due to evaluate multiple cameras. This paper solves all the positions $C_{(i)}(x,\ y,\ z)$ $(1 \leq i \leq N)$ of all cameras which minimize E''.

4 Experiment

4.1 Simulation Environment

Simulation experiment was done with parameters using RoboCup SSL. Based on the official regulation, Laws of the F180 League 2006, the field size is 5500mm $\times$ 4000mm including 4900mm $\times$ 3400mm court and 300mm width technical area, the maximum size of the robot height is 150mm and the radius is 90mm, respectively. The radius of a ball is 21.5mm, the heights of the cameras is 4000mm because the height of truss shown in Fig. 3 is $4000mm$. So the coordinates of the cameras are $C_{(i)}(x,\ y,\ 4000)$ $(1 \leq i \leq N)$. Based on Eq.'s (3), (8) and (10), the occlusion probability is obtained.

We have reported the result of multi-camera's layout which minimizes the occlusion for SSL. This was calculated under the condition that the robots existed equally in the field[5]. Figure 8 shows the probability distribution of our robots. It was given by analyzing the five logs of the past RoboCup SSL competitions. The logs recorded the coordinates and the velocity information of robots and ball, referee signal, time and so on. The coordinates information of our team's robots is used to make this distribution. According to the Laws of the F180 League 2006, the teams change their attack side in each half. And E'' is regarded as an approximate solution as

$$E''' = \sum_F \min_i\{d_{(i)}\} P_{(R)}(x,\ y). \tag{11}$$

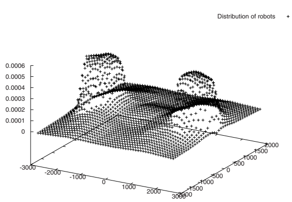


Fig. 8. Probability distribution of our robot

Table 1. Strategic camera coordinates (N = 9)

Camera Number	$C^*_{(i)}(x, y)$	$C_{(i)}(x, y)$	Camera Number	$C^*_{(i)}(x, y)$	$C_{(i)}(x, y)$
1	(-1955, -948)	(-1877, 27)	6	(1851, 1969)	(1393, 1215)
2	(310, 700)	(2044, 15)	7	(-411, -1058)	(-421, -833)
3	(-2148, 693)	(-1784, 1258)	8	(-1679, -1634)	(-1734, -1196)
4	(679, -1879)	(1496, -1216)	9	(-1618, 521)	(-471, 782)
5	(-243, -862)	(707, -32)			

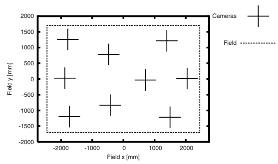


Fig. 9. Strategic multi-cameras layout ($N = 9$)

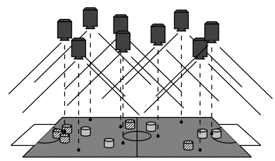


Fig. 10. Layout example ($N = 9$)

It takes about a day to calculate the minimal solution with full search in the range of $-2750 \leq x \leq 2750$, $-2000 \leq y \leq 2000$. So, we utilized Fletcher-Reeves conjugate gradient algorithm to obtain an optimized solution.

4.2 Algorithm

The algorithm used in this experiment is shown below.

Step 1. Set the initial position for $(x,\ y)$ with pseudo random number in the range $-2750 \leq x \leq 2750$ and $-2000 \leq y \leq 2000$.

Step 2. Move a robot in the raster scan procedure on the field F. $\Delta x = \Delta y =$ 50mm for the reduction of computing time.

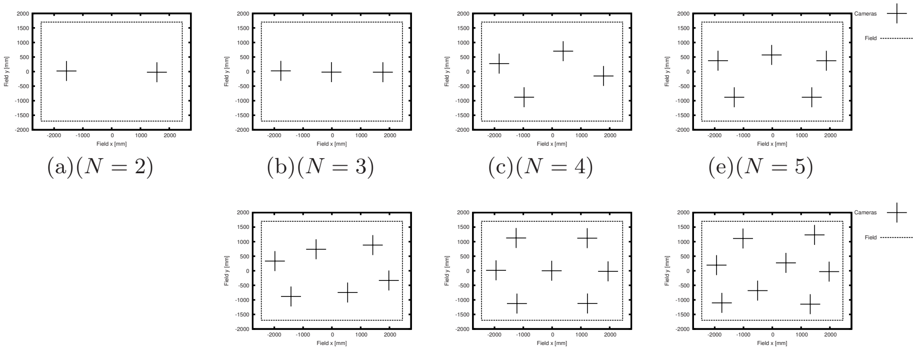
Step 3. Calculate the distance $d_{(i)}(1 \leq i \leq N)$ for all i. Search $\min_i\{d_{(i)}\}$ and calculate E''' by Eq.(11).

Step 4. By using Fletcher-Reeves conjugate gradient algorithm, update camera coordinates $C_{(i)}(x,\ y)$ for all i to the direction that E''' decreases.

Step 5. Repeat from Step 2 to Step 4 while E''' decreases. If this is not satisfied, terminate this algorithm.

4.3 Experimental Result

Table 1 shows the result of strategic multi-cameras layout that nine cameras ($N = 9$) are used. Figure 9 demonstrates the result $C_{(i)}(x,\ y)$ plotted on the 2-dimensional field of 4900mm × 3400mm. Figure 10 is an example of multi-cameras layout on the 3-dimensional space. Figure 11 shows the simulation results for other numbers.



(a)($N = 2$) (b)($N = 3$) (c)($N = 4$) (e)($N = 5$)

(e)($N = 6$) (f)($N = 7$) (g)($N = 8$)

Fig. 11. Strategic multi-cameras layout ($N = 2, 3, \cdots 8$)

Table 2. Results of E''' ($N = 2, 3, \cdots 9$)

N	E''' [mm]	N	E'''
2	7.809	6	1.813
3	5.558	7	1.263
4	4.026	8	0.951
5	2.668	9	0.636

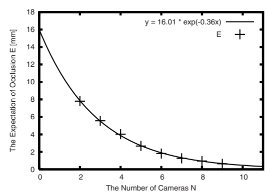


Fig. 12. Relation between N and E'''

5 Discussion

In order to obtain the best number of cameras, we experimented by changing the number of cameras N from 2 to 9 and calculated each E'''. Table 2 and Fig. 12 show the relation between N and E'''. Here, the values(N, E''') in Table 2 are plotted in it, and the curves are solved approximately as $y = a * exp(-bx)$ with least square method. In this experiment, the data are fitted as $y = 16.01 * exp(-0.38x)$. From this result, it is considered that the risk (occlusion) obeys exponentially.

6 Conclusion

This paper proposed optimal cameras' layout for global vision in RoboCup SSL. By giving a criterion that minimizes the risk of occlusion by the robots, a method to decide the camera's coordinates is realized. The occlusion was modeled from the positional relations of cameras, robots, a ball and probability distribution of the robots. This method was applied to the concrete parameters used in RoboCup SSL and solved the optimal camera's positions.

Though the simulation was done on the condition that cameras looked down directly below, it is concretely difficult to satisfy this condition. To improve simulation parameters like direction and angle of view, and to realize high speed simulation are coming subjects.

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