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Intelligent Monitoring System Using Multiviewpoints for Teleoperation

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In this paper, we propose the method to determine the position of the 2 cameras for the multiviewpoints as the robot is installed in the work place. The optical axis's direction of the 1st camera is determined in the base of work contents in teleoperation. The multiviewpoints system uses the 2 camera units that aren't installed side by side, so that the direction of the 2nd camera is decided in the base of the angle between the optical axes' direction of 2 cameras. Next, the distance from the camera to the work place is determined according to the distance resolution of image on the monitor, and the camera type of which the point-blank range is not this distance is selected. And the efficacy of this system is examined with an experiment.

1. INTRODUCTION

The telerobotic system is of practical use for the space development project. Recently these system is used Sojourner that is unmanned survey instruments of Mars and supporting the extra vehicular activities (EVA). In the medical field, the teleoperation system is developing for a operation by the doctor[1]. The telerobotic system for the industrial filed is acquiring under the condition of the position of camera in work area is different from each field, and is not only good quality for the product but also low cost of the system.

The control of telerobot[2], time delay[3] and limited communication capacity[4] are researched actively in the field of telerobotic system. The monitoring system is one element of the telerobotic system and is very important for the operator to watch the work area.

In this paper, we propose the method to determine the position of the 2 cameras for the multiviewpoints as the robot is installed in the work place. The optical axis's direction of the 1st camera is determined in the base of work contents in teleoperation. The multiviewpoints system uses the 2 camera units that aren't installed side by side, so that the direction of the 2nd camera is decided in the base of the angle between the optical axes' direction of 2 cameras. Next, the distance from the camera to the work place is determined according to the distance resolution of image on the monitor, and the camera type of which the point-blank range is not this distance is selected. And the efficacy of this system is examined with an experiment.

2. PROPOSED METHOD

As the positions of cameras are limited in the work area for the space and the human body, the stereoscopic display system is used usually 2 camera units installed side by side that viewpoint of this system is the same as human eyes. Therefore we propose the multiviewpoints system as a part of the intelligent monitoring system under the condition that the cameras are able to arrangement comparatively freely. This system composes with 2 or more monocular vision system, so that we propose the method to determine the position of these camera.

2.1 Definition of Symbols

Following symbols are used in this paper.

Σw : The world coordinate system.

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O_w : The origin of the world coordinate system(Σw).

x_w, y_w, z_w : The rectangular coordinate axis of the world coordinate system(Σw).

$\boldsymbol{x}_w, \boldsymbol{y}_w, \boldsymbol{z}_w$: The unit vector of each axis on the world coordinate system(Σw).The direction of $\boldsymbol{z}_w$ is one of the opposite to gravity.

Σb : The robot base coordinate system.

O_b : The origin of the robot base coordinate system(Σb).

$\boldsymbol{P}_b$: The position vector of the position coordinate O_b on the world coordinate system. $\boldsymbol{P}_b = x_{p_b}\boldsymbol{x}_w + y_{p_b}\boldsymbol{y}_w + z_{p_b}\boldsymbol{z}_w$. So $(x_{p_b}, y_{p_b}, z_{p_b})$ represents the position coordinate O_b.

x_b, y_b, z_b : The rectangular coordinate axis of the robot base coordinate system(Σb).

$\boldsymbol{x}_b, \boldsymbol{y}_b, \boldsymbol{z}_b$: The unit vector of each axis on the robot base coordinate system(Σb). In this paper, The directions of unit vectors on the robot base coordinate system are same as the world coordinate system.

Σt : The tool coordinate system. This coordinate system also consists of O_t, P_t and so on like the robot base coordinate system. $\boldsymbol{z}_t$ is the direction of fingers with robot hand.

Σo : The object coordinate system. This coordinate system also consists of O_o, P_o and so on like the robot base coordinate system. In this paper, The directions of unit vectors on the object coordinate system are same as the world coordinate system.

Σc : The camera coordinate system. This coordinate system also consists of O_c, P_c and so on like the robot base coordinate system. $\boldsymbol{z}_c$ is the direction of optical axis and $\boldsymbol{x}_c$ is the upper side of camera.

m : The magnification of the camera. $1 \leq m \leq M$.

α : The visual angle of $\boldsymbol{x}_c$ axis in the camera. $\alpha_{\max}$ is the visual angle of the camera adjusted to 1 magnification.

β : The visual angle of $\boldsymbol{y}_c$ axis in the camera adjusted to 1 magnification.

MI : The number of picture elements in a row on the monitor.

MJ : The number of picture elements in a column on the monitor.

2.2 Determination of the camera position

2.2.1 Visual angle of a camera

An visual angle of a camera is very important factor to watch the work area. The visual range of $\boldsymbol{x}_c$ axis direction at distance l from the origin of the camera coordinate system is shown as $fx(l)$. It is given by the eq.(1).

$$f_x(l) = 2l\tan\left(\frac{\alpha}{2}\right) \tag{1}$$

Similarly the visual range of $\boldsymbol{y}_c$ axis is shown as $f_y(l)$ and it given by the eq.(2).

$$f_y(l) = 2l\tan\left(\frac{\beta}{2}\right) \tag{2}$$

(1) Zoom function

There is a zoom function by the zoom lens and by digital processing. A picture element on charge coupled device (CCD) shows with a plural picture element of a rectangle on the monitor, so that an information volume is not changing. Therefore, a zoom action by the zoom lens is only considered in this paper. When the zoom lens is adjusted to 1 magnification, the visual angle of camera is the biggest angle and even a visual range becomes the biggest. A visual range in the point at distance l from a camera is shown with eq.(3), (4) as $f_x(l)_{\max}$ and $f_y(l)_{\max}$.

$$f_x(l)_{\max} = 2l\tan\left(\frac{\alpha_{\max}}{2}\right) \tag{3}$$

$$f_y(l)_{\max} = 2l\tan\left(\frac{\beta_{\max}}{2}\right) \tag{4}$$

$\alpha_{\max}$, $\beta_{\max}$ are the visual angle with 1 magnification. As a zoom lens is adjusted to m times magnification, a visual range becomes the length of $1/m$ times. So a visual range with m magnification is shown with eq.(5), (6) as $f_x(l)_m$ and $f_y(l)_m$.

$$f_x(l)_m = \frac{f_x(l)_{\max}}{m} \tag{5}$$

$$f_y(l)_m = \frac{f_y(l)_{\max}}{m} \tag{6}$$

(2) Pan/tilt action

Some cameras have a pan/tilt action that moves the optical axis to see widely. The each moving range around $\boldsymbol{y}_c$ axis and $\boldsymbol{x}_c$ axis is shown as ϕ and ψ. The visual ranges of $\boldsymbol{x}_c$ and $\boldsymbol{y}_c$ axis at distance l from the origin of the camera coordinate system are given by the eq.(7) and (8) as $\mathit{ff}_x(l)$ and $\mathit{ff}_y(l)$. But the visual ranges on the monitor for worker are $f_x(l)$ and $f_y(l)$.

$$\mathit{ff}_x(l) = 2l \tan\left(\frac{\alpha + \phi}{2}\right) \tag{7}$$

$$\mathit{ff}_y(l) = 2l \tan\left(\frac{\beta + \psi}{2}\right) \tag{8}$$

2.2.2 Determination of the direction of the optical axis

If a optical axis faces towards the work area, a worker is possible to operate a robot as easy task. But it is difficult to operate a robot as the exact task without necessary information for recognizing a position of objects in the work area. We propose the method to install cameras for the known contents of a work and an unknown one in the work area.

(1) Case of known work

The most operation for telerobotic system is composed of 2 kinds of movement that are a parallel displacement and a vertical migration in the work plane. The operator sets a object in the prescribed position in the work to screw and to insert a object to the work place, and after that a object is approached to the perpendicular direction to the work place. While a object is approached to the work place in the work to paint, and moves on the work place. But these works are classified into a parallel displacement and a vertical migration in the work place. The work place coordinate system is shown as Σp that has the center of the work place as the origin of this coordinate system(O_p) and the normal vector of the work place as $\boldsymbol{z}_p$ and the vector directed from the work place to the origin of robot coordinate system as $\boldsymbol{x}_p$. In this paper, the origin of the work place coordinate is equal to one of the object coordinate system when the object reaches the goal. The direction of the optical axis is determined with the eq.(9) and (10).

$$\boldsymbol{z}_c \cdot \boldsymbol{z}_p = 0 \tag{9}$$

$$t\boldsymbol{z}_c + \overrightarrow{O_w O_c} = \overrightarrow{O_w O_p} \tag{10}$$

Image from the camera satisfied with eq.(9) shows a distance of approach, as a manipulator approaches to a work place. But there are an infinite number of the optimal axes that is satisfied with eq.(9) and (10) in the work area. Therefore it is added to criteria for determining the camera position that the optical axis is nearer the opposite direction from the origin of the work place coordinate system to one of the robot base coordinate system. So the optical axis is satisfied with eq.(11).

$$\left\{ \boldsymbol{z}_c \middle| \min_{1 \le i \le I} \left(\boldsymbol{z}_{ci} \cdot \overrightarrow{O_b O_p} \right) \right\} \tag{11}$$

where $\boldsymbol{z}_{ci}$ $(1 \le i \le I)$ is satisfied eqs.(9) and (10).

The manipulator links with the origin of the robot base coordinate by the robot arms. If the position of the camera is satisfied with eq.(11), the robot arms hardly comes between the camera and a work area on the optical axis.

The upper side of the camera is decided as the direction of the normal doesn't shows at a slant on the monitor, so that the upper side is decides on the basis of $\boldsymbol{z}_p$ axis and is satisfied with eq.(12).

$$\boldsymbol{z}_c = \begin{cases} \boldsymbol{x}_c & \left(\frac{\boldsymbol{z}_w \cdot \boldsymbol{z}_c}{|\boldsymbol{z}_w||\boldsymbol{z}_c|} > \frac{1}{\sqrt{2}} \right) \\ \boldsymbol{y}_c & \left(\frac{\boldsymbol{z}_w \cdot \boldsymbol{z}_c}{|\boldsymbol{z}_w||\boldsymbol{z}_c|} < \frac{1}{\sqrt{2}} \right) \\ -\boldsymbol{x}_c & \left(\frac{\boldsymbol{z}_w \cdot \boldsymbol{z}_c}{|\boldsymbol{z}_w||\boldsymbol{z}_c|} < -\frac{1}{\sqrt{2}} \right) \end{cases} \tag{12}$$

(2) Case of unknown work

A human thinks empirically that images on the bottom side of the monitor is the direction of gravity. Therefore, in the case of unknown work, the upper side of camera is decided as the direction of $\boldsymbol{z}_w$ and is given by eq.(13).

$$\boldsymbol{x}_c = \boldsymbol{z}_w \tag{13}$$

And the optical axis of the camera is facing in the origin of the robot base coordinate system through the work area.

(3) Position of the two cameras

Two cameras are installed side by side in the stereoscopic vision system. In the multiviewpoints vision system, two cameras are installed to shoot the work area from the different direction. The position of one camera (1st camera) is decided by last section and the other camera (2nd camera) is decided on the basis of a position of 1st camera. Therefore the direction of the optical axis ($\boldsymbol{z}_{c2}$) of the 2nd camera unit is satisfied with eq.(14).

$$\boldsymbol{z}_{c2} \cdot \boldsymbol{z}_{c1} = 0, \boldsymbol{z}_{c2} \cdot \boldsymbol{x}_{c1} = 0 \tag{14}$$

where $\boldsymbol{z}_{c1}$ is the optical axis of the 1st camera and $\boldsymbol{x}_{c1}$ is the upper side of one. And $\boldsymbol{z}_{c2}$ faces toward the center of the work place.

2.2.3 The distance from the camera to the work area

As the operator watches the telerobot and the work area on the monitor, the operator operates the telerobotic system. So the distance resolution of images on the monitor is higher than a dimensional deviation of the objects. Image is composed of $MI \times MJ$ picture elements. The dimensional deviation is shown as *varepsilon*, and eq.(15) is given as the relation among the dimensional deviation, the picture elements and the range of camera.

$$\varepsilon \geq \frac{f_x(l)}{MI}, \varepsilon \geq \frac{f_y(l)}{MJ} \tag{15}$$

Eq.(15) rewrites as eq.(eq:epsilon) by using an arbitrary constant k that is magnifying power.

$$\varepsilon = k\frac{f_x(l)}{MI}, \varepsilon = k\frac{f_y(l)}{MJ} \tag{16}$$

As k is equal to 1, a picture element shows the length of a limit of dimensional deviation at distance l form the camera. Therefore the distance from the camera to the center of the work area is decided by eq.(17).

$$l = \min\left\{\varepsilon\frac{MI}{k\tan\frac{\alpha}{2}}, \varepsilon\frac{MJ}{k\tan\frac{\beta}{2}}\right\} \tag{17}$$

3. EXPERIMENT

The experimental work is positioning the object on the another object using telerobotic system. The 1st experiment changes the distance resolution on the monitor, so that the distance from the camera to the work area is changed. The 2nd experiment changes the optical axis' direction of the 2nd camera unit.

3.1 Distance from camera to work area

This experiment compares the accuracy of positioning under distance conditions that are determined using magnifying power function (MPF) k.

3.1.1 Experimental condition

The direction of the optical axis is determined by the proposed method. The optical axis of 1st camera unit shoots toward the origin of the robot base coordinate system through the work place, and this direction is determined the negative direction of the unit vector of x axis on robot coordinate system ($\boldsymbol{x}_b$ axis). Therefore the direction of the optical axis of 2nd camera unit is determined the negative direction of the $\boldsymbol{y}_b$ axis. This experiment is performed under these directions and changing the distance from the camera unit to the center of the work place. The distance is determined under changing MPF with 0.5, 1, 2. The picture element on the monitor theoretically displays 0.5mm in the work area when MFP is equal to 1. The operator operates the robot system using the multiviewpoints monitoring system. The task is that the robot puts the cylinder on the same diameter cylinder in the work place. The operator carries out the task in 20 times, and each positioning point and the goal position that is the center of cylinder in the work place are compared.

3.1.2 Results and discussion

The experimental results is shown as Table 1. This table shows the mean deviation and the standard deviation of the positioning points using the multiviewpoints system. The standard deviation to $\boldsymbol{x}_b$ is 0.14mm and one of $\boldsymbol{y}_b$ is 0.17mm under MFP is equal to 1, so that the almost positioning tasks are carried out into the area that size is 0.56mm times 0.68mm as length as the distance resolution theoretically. As MFP is equal to 0.5 (1mm per picture element), the distribution area of positioning is 1.04mm times 1.20mm. So we verify the distance resolution exerts an influence the accuracy of positioning experimentally. But the distribution area size (0.36 x 0.40mm) under MFP with 2 is larger than the distance resolution on the monitor. We consider that the operator could not operate small amount of movement in the telerobotic system in this experiment, so that the positioning points are distributed against the

Table 1 Deviation from the positioning point

Magnifying power factor (k)	Mean deviation to x_p	Mean deviation to y_p	Standard deviation to x_b	Standard deviation to y_b
0.5	0.23	−0.10	0.26	0.30
1.0	−0.09	−0.04	0.14	0.17
2.0	−0.08	0.01	0.09	0.10

(mm)

Table 2 Deviation from the positioning point

Intersection angle of optical axis (deg.)	Mean deviation to x_p	Mean deviation to y_p	Standard deviation to x_b	Standard deviation to y_b
90	−0.09	−0.04	0.14	0.17
60	−0.14	−0.08	0.24	0.13
30	−0.15	−0.07	0.52	0.15
stereoscopy	−0.18	0.00	1.12	0.22

(mm)

distance resolution. So the monitoring system for a precise task needs to change the minimum operating movement of telerobotic system according to the value of MFP.

3.2 Angle between optical axes' direction of 2 camera units

This experiment compares the accuracy of positioning under changing angle between optical axes' direction of 2 camera units.

3.2.1 Experimental condition

It is determined under MFP with 1 to the distance from each camera unit to the center of the work place. The direction of the 1st camera's optical axis is determined the same as section 3.1. The direction of the 2nd camera's one is determined to intersect the one of the 1st camera at an angle of 90, 60, 30deg. on the $x_b - y_b$ plane. The task is a same one as section 3.1 and is carried out in 20 times. And the experiment using the stereoscopic vision system is carried out to compare with the multiviewpoints system, provided that the cameras for the stereoscopic vision system are installed under the same distance resolution as the multiviewpoints system.

3.2.2 Results and discussion

The experimental results is shown as Table 2 and Fig. 1 to Fig. 4. The contents of table are the same as Table 1. And these figure shows the distribution of the positioning points at each conditions. As it becomes small to the angle of the optical axis between camera units, the dispersion in positioning points varies widely along x_b axis using the multiviewpoints system (0.14mm(90deg.), 0.24mm(60deg.), 0.52mm(30deg.)). But the dispersion perpendicular to the optical axis at each camera unit doesn't vary widely (see Fig. 1 to Fig. 3). The multiviewpoints system gets information from each monitor as a plan, so that it doesn't get to information about depth and distance in the work place. Therefore the vertical position of 2 camera is the best arrangement. The recognizing depth and distance is difficult using the stereoscopic vision system as the same distance resolution as the multiviewpoints system (see Table 2).

4. CONCLUSION

We proposed the multiviewpoints system as a part of the intelligent monitoring system. This system composes with 2 or more monocular vision system. And we proposed the method determining the optical axis and the distance from camera to the work area in the base of the distance resolution on the monitor. The proposed system are verified experimentally.

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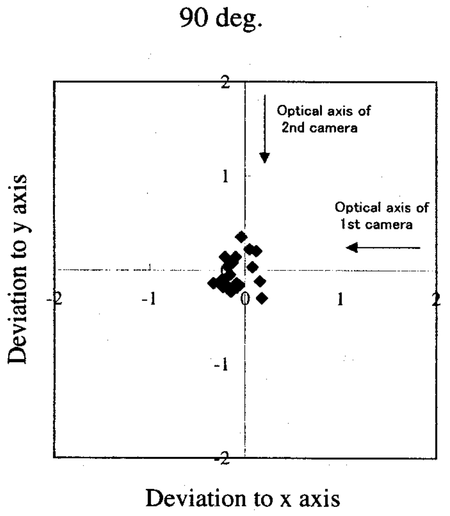

Fig. 1 Positioning distribution (90 deg.)

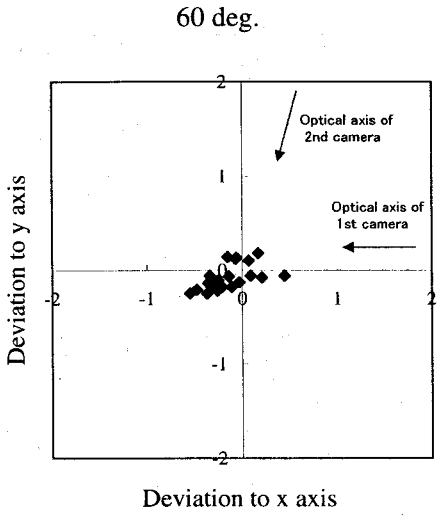

Fig. 2 Positioning distribution (60 deg.)

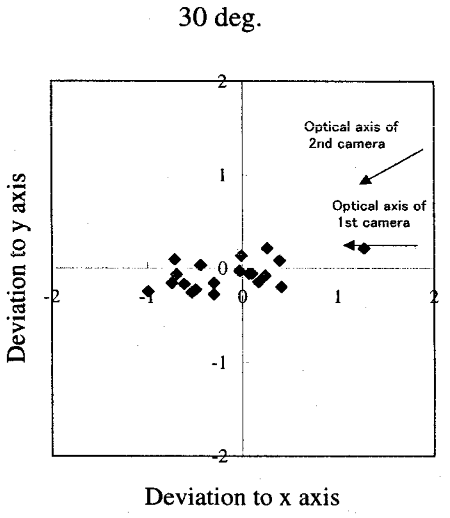

Fig. 3 Positioning distribution (30 deg.)

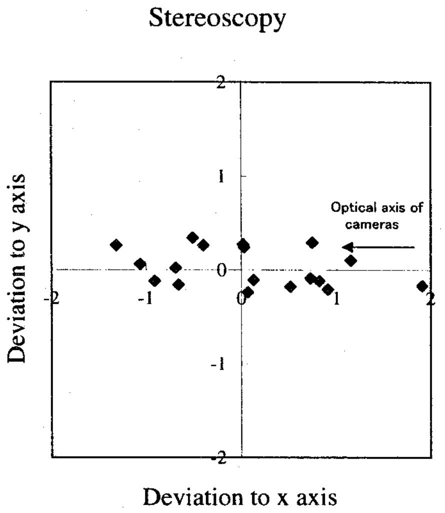

Fig. 4 Positioning distribution (Stereoscopy)

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