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Cooperative Handling Robot with Human Beings

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The focus of this paper is on the analysis of delivery motion of human, development of an image processing method based on the motion analysis and development of the cooperative delivery robot using the image processing method. The proposed image processing method uses two cameras, and it uses a stereo reconstruction technique for measuring position and postures of hands. In addition, this image processing method recognize the number of fingers extending consciously, so the cooperative human beings could choose the kind of tool which he wants by holding out his hand in front of cameras.

1. INTRODUCTION

In every work, the human acts main operation and arrangement operation. And, many tools are used in main operation. An arrangement operation is acted by other human to increase productivity and variety of work. So if this operation can be acted by robot, many work can be acted by one man, and labor cost can be saved[1][2].

In this paper, we develop a robot system to act an arrangement operation, especially, hands over tools which use in the work. This robot can recognize the hand shape to assign the sort of tool, the three dimensional location to supply assigned tools, and supply tools to human's hand under the condition that the direction and angle of tools are determined with consideration of the safety and possibility of direct use.

The proposed image processing method uses two cameras, and it uses a stereo reconstruction technique. We modified the technique in order to compensate the effect of lens aberrations. The cooperative delivery robot system is constructed by using the proposed technique, and the effectiveness of this method is verified.

2. THE COOPERATIVE DELIVERY ROBOT SYSTEM TO DELIVER TOOLS

The cooperative robot system is composed of two elements. (Fig.1) The human receives the tool from the robot. Then, the robot returns tools which have been used by the human. In the tool management system, tools are classified and controlled. Afterwards, tools are supplied in cooperative delivery robot system.

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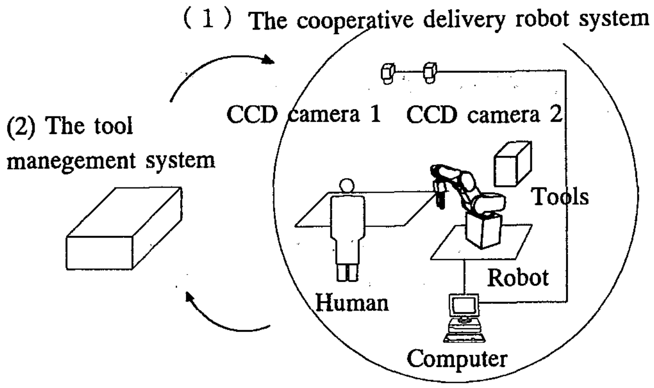


Fig.1 The cooperative robot system.

3. PROPOSED METHOD

3.1 Assumptions

(1) The robot system is constituted by image processor, two fixed cameras and robot with five degrees of freedom.

(2) Two cameras are installed parallel to the downward direction.

(3) The human is standing and the hand is lifted up forward. The height of the human hand from the floor is from 800 mm to 1000 mm. And, length from the shoulder to the tip of fingers is 750 mm, and that from the elbow to the tip of fingers is 450 mm. The viewing area of each camera is 700 mm in length and 900 mm in width.

(4) As the hand extends all fingers, and the palm is made upward. The robot carries the tool and the human receives the tool by the right hand.

3.2 Symbols

Following symbols are used:

(1) i $(0 \leqq i \leqq 649)$: The lateral pixel of the input image.

(2) j $(0 \leqq j \leqq 479)$: The vertical pixel of the input image.

(3) V(i,j) $(0 \leqq V \leqq 255)$: The luminance value at the pixel (i,j) of the image processing board

(4) C_l : The pixel of the contour line of subject. (l=1 ~ N)

(5) L : The image of the left camera. R : The image of the right camera.

(6) (X_R, Y_R, Z_R) : The coordinate system of the robot

(7) W1 : A point of wrist of the little finger side. W2 : A point of wrist of the thumb side.

(8) tip of fingers : F1 : the little finger. F2 : the third finger. F3 : the middle finger. F4 : the forefinger. F5 : the thumb.

3.3 Posture of hands

The kind of tool is ordered by the posture of hand shape. The image processing method recognize the number of fingers extending consciously, so that the subject could choose the kind of tool which he wants by holding out his hand in front of cameras. When the subject extends only the forefinger, it corresponds to "one". When forefinger and middle finger are extended, it means "two". The case in which the thumb and little finger are bended corresponds to "three". The case in which the only the thumb is bended, it means to be four. The case in which all of fingers are extended, it corresponds to "five". The case in which the human extends thumb and forefinger shows to "six". The case in which the human is bending little finger and third finger shows "seven". The case in which the human is bending the little finger shows "eight". Following above mentioned classification, a subject could use eight kinds of indications.

3.4 The method for recognition of the position of the right hand

The shape of the hand is recognized so that subjects could indicate the kind of tools. Moreover the position of the right hand is recognized in order to supply the tool accurately.

3.4.1 Procedure of the image processing

(1) Contour tracing method [3]

We require start point (i_1,j_1) and end point (i_N,j_N) at the pixel of the image processing board.

(2) The position of the fingertip.

We obtain the distance from the middle point of start point and end point to the each contour point. We can obtain the coordinate of the position of each fingertip.

(3) The position of the robot

Symbol (i_L,j_L) is a coordinate of the image from the left camera. Symbol (i_R,j_R) is a coordinate of the image from the right camera. The symbol (a,b) is a difference in origin coordinate between the coordinate system of the robot and coordinate system of the image processing board. The symbol ϕ is a difference in the angle between the coordinate system of the robot and coordinate system of the image processing board. Symbol (ic,jc) is a coordinate of the image after the transformation of coordinate system, and it is shown by equation (1).

$$\begin{aligned} ic &= (i-a)\times\cos\phi-(j-b)\times\sin\phi \\ jc &= (i-a)\times\sin\phi-(j-b)\times\cos\phi \end{aligned} \quad (1)$$

Position (X_R,Y_R,Z_R) of the robot is shown by equation (2). Symbol H is a height of the camera lens in robot coordinate. Symbol D is a distance between right camera and left camera. Symbol d is a distance from the camera lens to the CCD element.

$$\begin{aligned} D/(H-Z_R) &= (ic_L+ic_R)/d \\ X_R/(H-Z_R) &= (ic_L-ic_R)/d \\ Y_R/(H-Z_R) &= (jc_L-jc_R)/d \end{aligned} \quad (2)$$

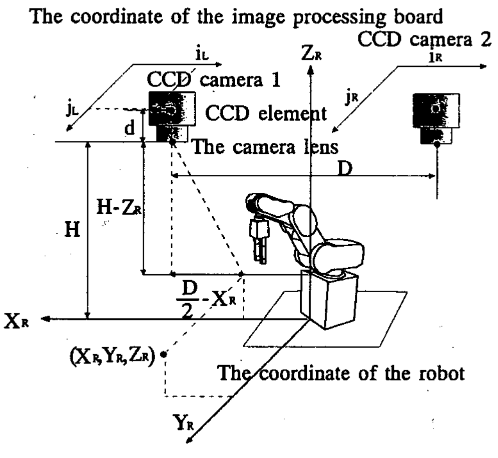


Fig.2 The coordinate of the position of the robot.

The effect of lens aberrations increases, as it is away from the center. Position (X_R,Y_R,Z_R) of the robot is shown by equation (3). Symbol R is a distance between each points from the central position (320,240) of the image processing board. Coefficient l ~ t are obtained by the multiple regression analysis.

$$\frac{1}{H-Z_R} = l_Z \times i_L + m_Z \times i_R + n_Z \times j_L + o_Z \times j_R$$
$$+ p_Z \times R \times i_L + q_Z \times R \times i_R + r_Z \times R \times j_L + s_Z \times R \times j_R + t_Z$$
$$\frac{X_R}{H-Z_R} = l_X \times i_L + m_X \times i_R + n_X \times j_L + o_X \times j_R$$
$$+ p_X \times R \times i_L + q_X \times R \times i_R + r_X \times R \times j_L + s_X \times R \times j_R + t_X$$
$$\frac{Y_R}{H-Z_R} = l_Y \times i_L + m_Y \times i_R + n_Y \times j_L + o_Y \times j_R$$
$$+ p_Y \times R \times i_L + q_Y \times R \times i_R + r_Y \times R \times j_L + s_Y \times R \times j_R + t_Y \qquad (3)$$

(4) The position of the wrist

Position (i_{w1}, j_{w1}) of the wrist in the little finger side is shown by equation (4). Symbol AM is average angle of the arm's contour line, and it is shown by equation (5). Symbol s is a pixel of arm's contour line. Symbol ka is an interval on the contour line. Symbol NG is total numbers of the angles of arm's contour line for obtaining the average angle. In the wrist of contour line, the difference of angle increases from ATM.

$$\left| \arctan\left(\frac{j_{N+ka} - j_N}{i_{N+ka} - i_N}\right) - AM \right| > ATM \qquad (N=s, \cdot\cdot\cdot ,N\text{-}ka) \qquad (4)$$

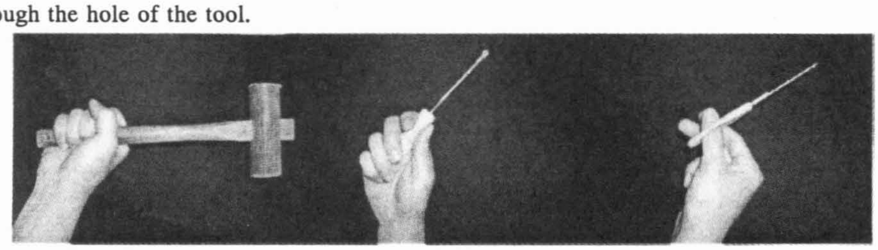
$$AM = \frac{1}{NG}\sum \arctan\left(\frac{j_{N+ka} - j_N}{i_{N+ka} - i_N}\right) \qquad (N=s, \cdot\cdot\cdot\ s+NG) \qquad (5)$$

3.4.2 Recognition of finger's posture

The posture of fingers are recognized by a method that has been developed by us for recognizing the Japanese sign language [4]. The summary is shown in the following. The length of the straight line which connects the wrist with each fingertip is obtained. It is judged that the finger is extended when the length of the straight line is longer than the standard value. It is judged that the finger is bent when the length of the straight line is shorter than the standard value.

3.5 Tool supplying system

The tools are supplied with appropriate posture so that the subjects could use them efficiently. Three following methods are classified. Fig.3 (1) shows a case that the tool is used by holding four fingers except the thumb. Fig.3 (2) shows the case that the tool is used by holding with forefinger and thumb. Fig.3 (3) shows the case that the tool is used through the hole of the tool.



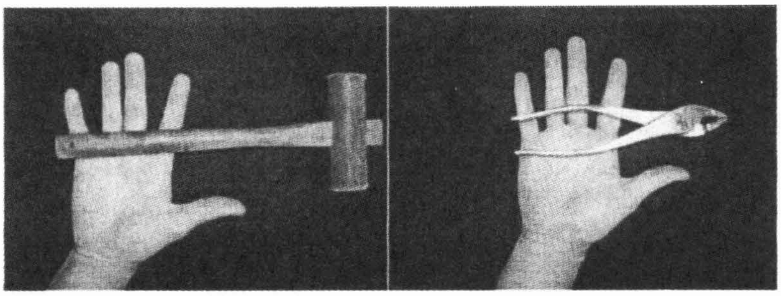
(1) The hammer (2) The driver (3) The pair of scissors

Fig.3 Posture of the right hand for grasping objects.

3.5.1 The supply of the tool which would be hold with four fingers

The tool is used by holding its grip. Therefor, hand tools are supplied so that the holding part of the tool are put on between second and third joint of the forefinger, and between second and third joint of the little finger. The supply angle of the tool is decided so that the extended shaft of the tool and center line of middle finger become

perpendicular. When the tool is used actually, and the tool is classified into following two kinds.
(1) When the tool is used, the tool was held always. For example, it is a hammer.
(2) When the tool is used, the hand is opened and shut. For example, it is a nipper.



(1) The hammer (2) The nipper

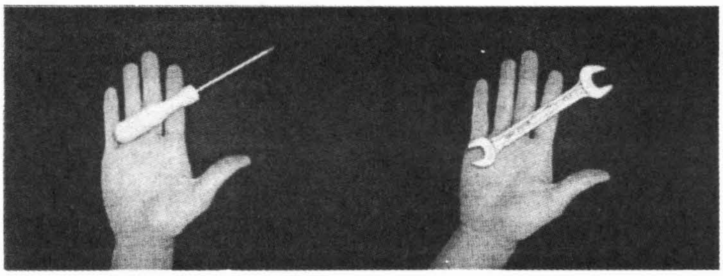
Fig.4 The supplying pattern of the tools which are hold with four fingers.

3.5.2 The supply of the tools which would be pinched by forefinger and thumb

It is the case in which tool is used by pinch in thumb and forefinger. It is supplied so that the holding part of the tool may consist between the first and second joint of the forefinger. The supply angle would overlap with the straight line where extended shaft of the tool connects the point of the base of first joint of the forefinger and middle point of the second joint and little finger and third finger. When the tool is used actually, the usage of the tool is different, and the tool is classified into following two kinds.
(1) The tool is used by intensifying forefinger and thumb.

The tool is supplied so that the tip in the hold position of the tool may come to the position of the forefinger. For example, it is a driver.
(2) The tool is used by intensifying the little finger.

The tool is supplied so that the end in the hold position of the tool may come to the position of third joint of the little finger. For example, it is a spanner.



(1) The driver (2) The spanner

Fig.5 The supplying pattern of the tools which are pinched by forefinger and thumb.

3.5.3 The supply of the tool which will be used by getting fingers through

After the tool is received, it is difficult to pass the finger through hole of tool one-handed. The tool is perpendicularly supplied for the surface of the hand. It makes the angle in supplying the tool the obliqueness. After the tool touches hand, the human pass his finger through hole of the too, and he receives the tool. For example, it is the pair of scissors.

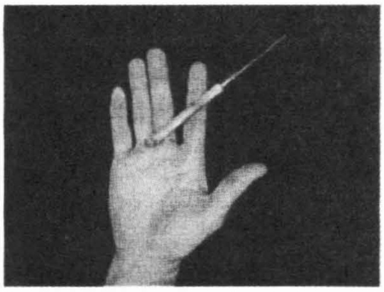


Fig.6 The supplying pattern of the scissors.

4. THE APPLICATION EXAMPLE

Fig.7 shows the actual cooperative handling robot system. This system is composed one industrial robot with 5.D.O.F.[5] This robot system could deliver all five kinds of tools successfully. The positioning errors of the robot system were 10 mm in X-axis, 10 mm in Y-axis, 20 mm in Z-axis.

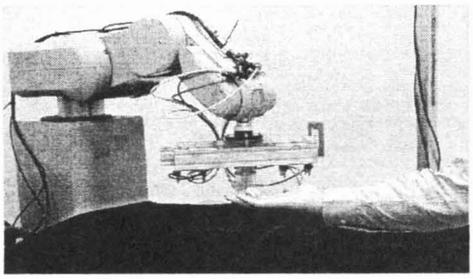


Fig.7 The cooperative handling robot system.

5. CONCLUSION

This research developed a robot system which could supply tools to human's hand.
The image processing method was proposed to recognize the number of fingers extending consciously, so that the subject could choose the kind of tool which he wants by holding out his hand in front of cameras. Posture of hand and kinds of tools are considered, and tools are supplied with appropriate posture so that the subjects could use them efficiently.
Finally, the cooperative delivery robot system is constructed by using the proposed method, and the effectiveness of this method was verified.

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