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Correlation Error Reduction of Images in Stereo Vision with Fuzzy Method and its Application on Cartesian Robot

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1. Introduction

Stereo vision is one of the most active research topics in machine vision. Finding corresponding points in different images of the same scene could be a tough procedure of depth extraction in this field. Correlation is one of the most common approaches that could be applied in this procedure. There are also methods that have been presented to reduce some existing errors associated with this approach. Here, a fuzzy model is demonstrated. Also the experimental results are presented based on a 3p laboratory robot and improvements are illustrated comparing with a neural network method by simulation outcomes.

Vision method at first was used for estimating robot errors more than one decade ago. So far, different companies and research centers have used for robot positioning, calibration, error estimation and error compensation with genetic algorithm, neural networks and fuzzy control algorithms. In general, recognition of 3D objects requires two or more appropriately defined 2D images. With this approximation many methods have been proposed such as structure from motion, (Seitz et al., 1995) (Taylor & Kriegman, 1995) stereo lenses correspondence and shape (Grosso et al., 1996) (Haralick & Shapiro, 1992). Achour and Benkhelif present a new approach for 3D scene reconstruction based on projective geometry without camera calibration. The contribution is to reduce the number of reference points to four points by exploiting some geometrical shapes contained in the scene (Achour & Benkhelif, 2001). In online applications, these methods have some problems. There is a difficulty in finding the correspondence between one image and the others. The most important step in stereo vision is to find two points of two or more images. A general correlation approach including errors is discussed in (Lopez & Plat, 2000). Also, fuzzy logic has applied in some cases such as process control, decision support systems, optimization and a large class of robotic manipulators and other mechanical systems (Hsu et al., 2001).

Here, a fuzzy approach is applied to reduce existent errors to concern with the aspect of improving correlation based stereo vision by reducing errors on a set of points. The experiments are due to a Cartesian robot. So far a neural network approach has been used to get the optimum point in world coordinate for 3p robot(Korayem et al., 2001). Clearly there is no magic panacea for selecting a neural network for the best generalization and also

Source: Vision Systems: Applications, ISBN 978-3-902613-01-1
Edited by: Goro Obinata and Ashish Dutta, pp. 608, I-Tech, Vienna, Austria, June 2007

because of structure and foundation of neural networks, it has some errors. A fuzzy approach can be used to reduce these.

2. Mapping relations in robots

Stereo vision systems determine depth from two or more images which are taken at the same time from slightly different viewpoints. The most important and time consuming task for a stereo vision system is the registration of both images and the identification of corresponding pixels. Two pixels are corresponding when they represent the same point in the real world. A method based on stereo attempts to determine the correspondence for each pixel, which results in a dense depth map. Correlation is the basic method used to find corresponding pixels. Several real time systems have been developed using correlation based stereo(Konolige ,1997)(Matthies et al., 1995) (Volpe et al., 1996) (Guisse et al., 2000) Images of cameras are in two dimensional spaces and for each point with losing the depth in images can obtain one line in real world. The relations in stereo vision demonstrate that measure of depth's points in each image is obtained as shown in(Gonzalez,1998):

$$Z = \lambda - \frac{\lambda B}{x_2 + x_1} \tag{1}$$

Which x_1, x_2 are x coordinate for one point in real world in each image of two cameras. λ and β is focal distance and distance between two focal, respectively. In 3p robot two cameras are not in the same direction. It means each of x and z axis should be rotated and two rotation matrixes can be concatenated into a single matrix:

$$R = R_\alpha R_\theta \tag{2}$$

According to modified relation of camera, commutative matrix is as follows:

$$R = \begin{bmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta\cos\alpha & \cos\theta\cos\alpha & \sin\alpha & 0 \\ \sin\theta\sin\alpha & -\cos\theta\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

Where θ, α are rotating angles of z and x axis, respectively. Also commutative axis can be obtained with the follow matrix:

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & -z_0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

Where z_0 is coordinating of z in world coordinate. According to Eq. 3 and 4, we have:

$$x_1 = \lambda \frac{X \cos\theta + Y \sin\theta}{-X \sin\theta \sin\alpha + Y \cos\theta \sin\alpha - (Z - Z_0)\cos\alpha + \lambda} \tag{5}$$

And:

$$x_2 = \lambda \frac{-X \sin\theta \cos\alpha + Y \cos\theta \cos\alpha + (Z - Z_0)\sin\alpha}{-X \sin\theta \sin\alpha + Y \cos\theta \sin\alpha - (Z - Z_0)\cos\alpha + \lambda} \tag{6}$$

Where x, y and z are coordinates of the image as a point in the real world. It is noted that these equations reduce to Eq. 1 when $X_0 = Y_0 = Z_0 = 0, r_1 = r_2 = r_3 = 0$ and $\alpha = \theta = 0^0$. Fig. 1 shows the method of stereo vision in 3p robot.

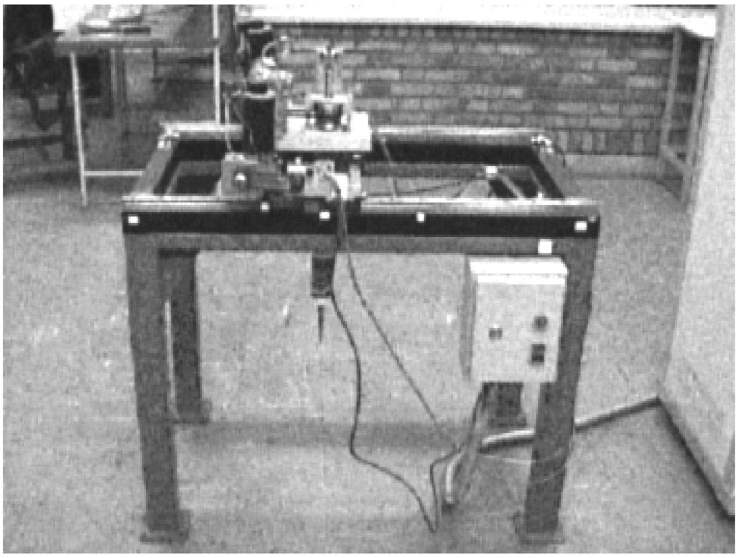

Figure 1. Laboratory Cartesian 3p robot

3. Correlation

Correlation is one of the applied methods in stereo vision and it is discussed in this section.

3.1 Correlation method

Although correlation method can be explained with vector but working with a window's form is commonly used. In its simplest form, the correlation between these two real functions $w(x,y)$, $f(x,y)$ is given by(Paulino et al., 2001):

$$c(s,t) = \sum_x \sum_y f(x,y) w(x-s, y-t) \quad t = 0,1,\ldots,N-1, s = 0,1,\ldots,M-1 \tag{7}$$

Where $f(x,y)$ is a digital image with size $M \times N$ and $w(x,y)$ is a similar region with size $J \times K$ ($J \prec M$ and $K \prec N$). The correlation function given in Eq. 7 has drawback, because it is sensitive to scale changes in the amplitude of $f(x,y)$ and $w(x,y)$. A method that frequently used to overcome this difficulty is to perform matching via the correlation coefficient, defined as:

$$\gamma(s,t) = \frac{\sum_x \sum_y [f(x,y) - \bar{f}(x,y)][w(x-s,y-t) - \overline{w}]}{\{\sum_x \sum_y [f(x,y) - \bar{f}(x,y)]^2 [\sum_x \sum_y [w(x-s,y-t) - \overline{w}]^2\}^{1/2}} \quad (8)$$

$$t = 0,1,\ldots,N-1, s = 0,1,\ldots,M-1$$

Where $\overline{w}$ is the average intensity of the mask (this value is computed only once), $\bar{f}(x,y)$ is the average value of $f(x,y)$ in the region coincident with $w(x,y)$, and the summations are taken over the common coordinate to both f and w. It is not difficult to show that $c(s,t)$ is scaled to the range from -1 to 1, independent of scale changes in the amplitude of $f(x,y)$ and $w(x,y)$. If the functions are in the same size, this approach can be more efficient than a direct implementation of correlation in the spatial domain. It is important to note that the dimension of $w(x,y)$ is usually smaller than $f(x,y)$ in implementing Eq. 7.

3.2 Problems of using correlation based stereo vision

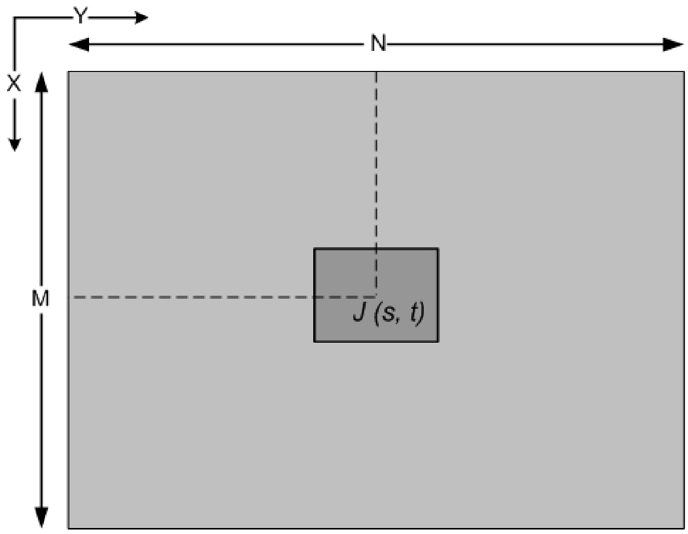

Figure 2. The correlation method

Correlation is used with a fixed rectangular window containing image as shown in Fig.2. The image will be correlated with a second window swiping the area of image. The possible trajectories are defined by the minimal possible existing distance between the camera and object, which suggests the maximum disparity. The position with the highest correlation value determines the pixel that corresponds to the pixel of interest. Larger correlation windows increase the reliability by averaging over a larger area, besides reducing the effects of noise. Generally, the choice of the correlation window size is a trade off between increasing reliability in areas with constant depth and decreasing errors where depth changes. The use of a smaller correlation window reduces the problem, because smaller window does not overlap the depth discontinuity to the same extent(Paulino et al., 2001).

4. Fuzzy System

Fuzzy logic controller utilizes fuzzy to convert the linguistic control strategy based on expert knowledge into an automatic control strategy. This section describes the design of fuzzy system for vision of 3p robot. It also discusses the heuristic approach that has been applied to determine the number of necessary fuzzy input and output set. In the first step, the border points are obtained by exploiting some geometrical relations. Then the fuzzy system is applied to points of correlation area. The best point that is achieved with heuristic method is shown in Fig.3.

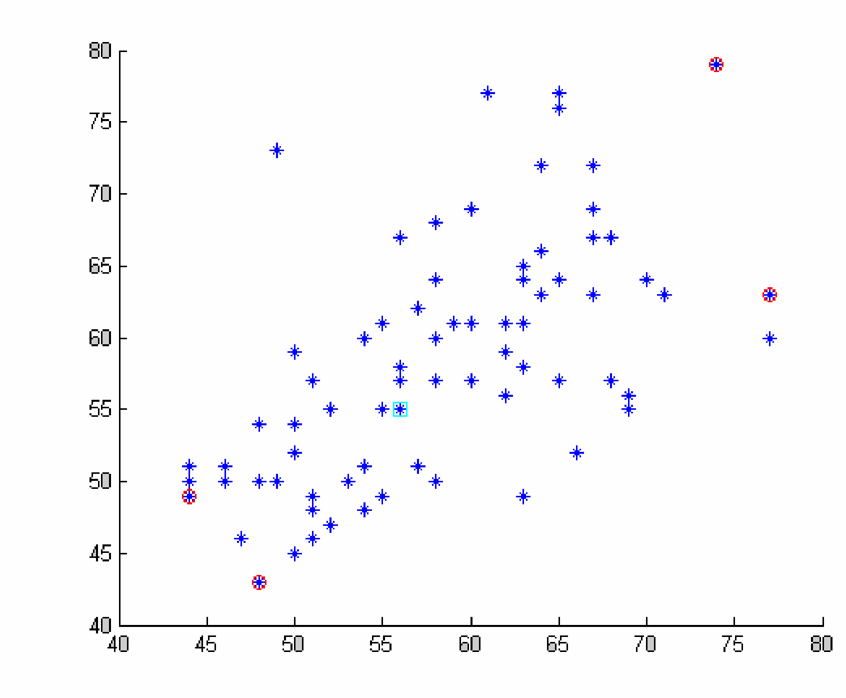

Figure 3. Getting the best point of correlation area

4.1 Getting the border points

The goal is to find the best point of correlation area. In this case, a heuristic method is used to find four points. These points are maximum and minimum coordinates of each axis' correlation area. Then, Eq.9 gives the distance of correlation from these four points as follows:

$$\|\mathbf{X}_1 - \mathbf{X}_2\| = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \quad (9)$$

Where $\mathbf{X}_1, \mathbf{X}_2$ are the coordinate of two points(Hirschuller et al., 2001).

4.2 Fuzzy Method

Recently fuzzy system approaches have achieved superior performance. The identification of fuzzy models from input-output data of the process normally lead to representations which are difficult to understand. Fuzzy logic has had great success in running machinery that is computer operated. For instance, fuzzy systems used to formulate the human's knowledge. Fuzzy set theory and fuzzy logic have evolved into powerful tools for managing uncertainties inherent in complex systems(Bender ,1996) (Zhang et al., 1999) (Alexander ,1996). In general, building a fuzzy system consists of three basic steps: structure identification (variable selection, partitioning input and output spaces and choosing membership functions), parameter estimation, and model validation. Fuzzy systems create a systematic process for replacing one knowledge base with a nonlinear mapping. Because of this, we will be able to use systems according to knowledge fuzzy system in engineering applications(Wang ,1997).. The area of correlation points is divided to four parts as shown in Fig. 4.

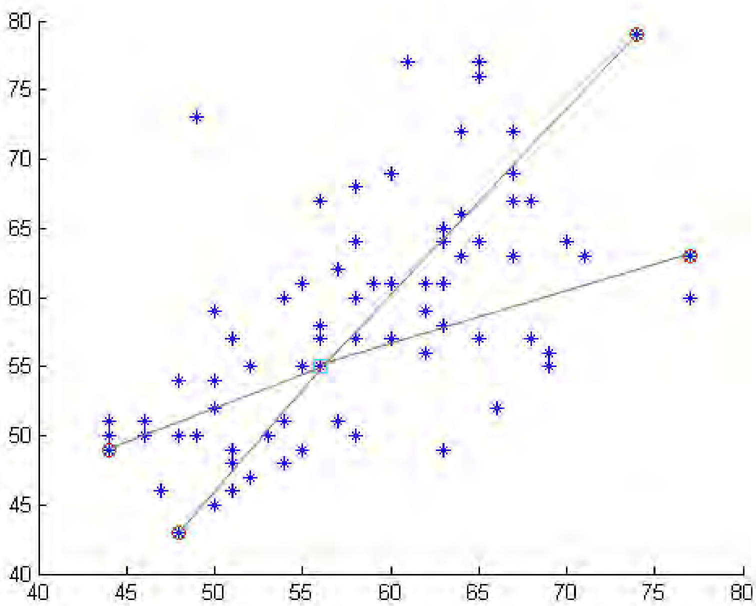

Figure 4. The partions of correlation area

4.2.1 Fuzzification

The computational technique of inputs of fuzzy system is demonstrated in Fig.5. The distances of the centers of images from best point are d_1 and d_2, respectively. The triangular membership functions have been used. Four inputs in the fuzzy system are the distances of center of each area from the images (Fig. 5).

The fuzzy controller employs four inputs by using Euclidian distance, shown in Eq. 9, of each point at each partition of correlation area from the image center. This fuzzy controller has only one control output.

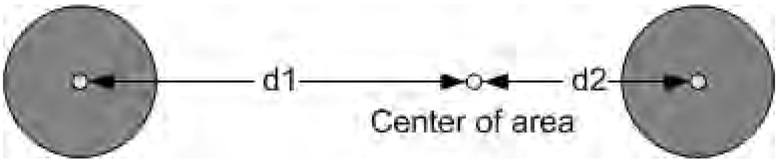

Figure 5. Distances of the centers from best point of images (heuristic method)

4.2.2 Fuzzy Rule Base

The IF part of rule bases include the ratio of the distances of central point in each area from the image center. The THEN part of these rules is suggested for the center of correlation area:

IF input $r = \frac{d_1}{d_2} \succ 1$ THEN output is center of area (1) or center of area (2).

IF input $r = \frac{d_1}{d_2} = 1$ THEN output is center of correlation area.

IF input $r = \frac{d_1}{d_2} \prec 1$ THEN output is center of area (3) or center of area (4).

The above rules can be dedicated for each area. It means the total number of rules is 12.

4.2.3 Defuzzification

The Eq. 10 is applied to defuzzify the fuzzy control rules in the defuzzification step. The defuzzifier which is applied is the center of gravity.

$$y^* = \frac{\sum_{l=1}^{M} \bar{y}^l w_l}{\sum_{l=1}^{M} w_l} \tag{10}$$

5. Algorithm

The diagram belongs to our approach is demonstrated in this section. All the processes described before are shown as an algorithmic approach in Fig. 7.

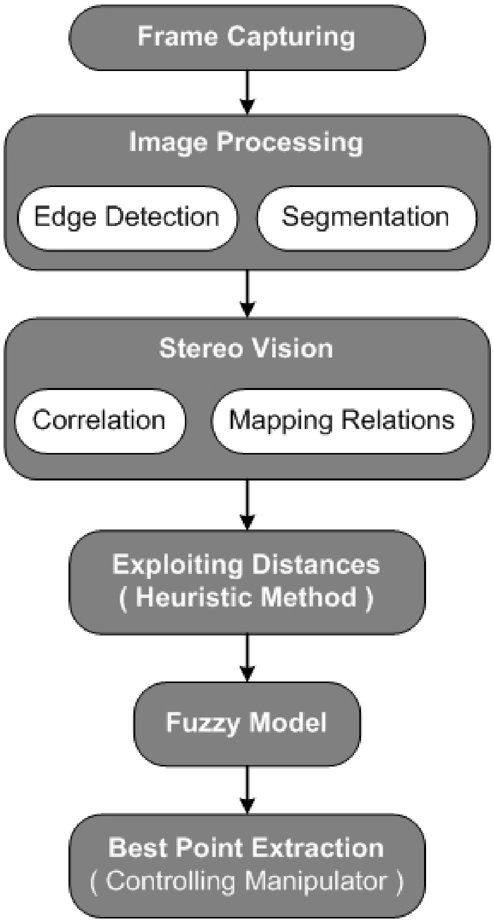

Figure 7. The Processing Diagram

6. Testing Irregular Objects

This method has been used for an unformed object. The edges of images and correlation of images is demonstrated in Fig.8 and 9, respectively.

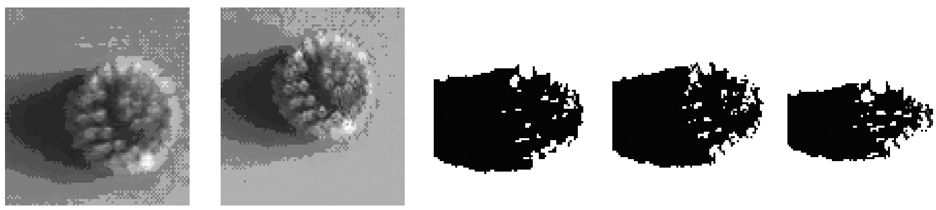

Figure 8. (Left to right) images of: camera 1, camera 2, and binary images: 1, 2, and correlation of images

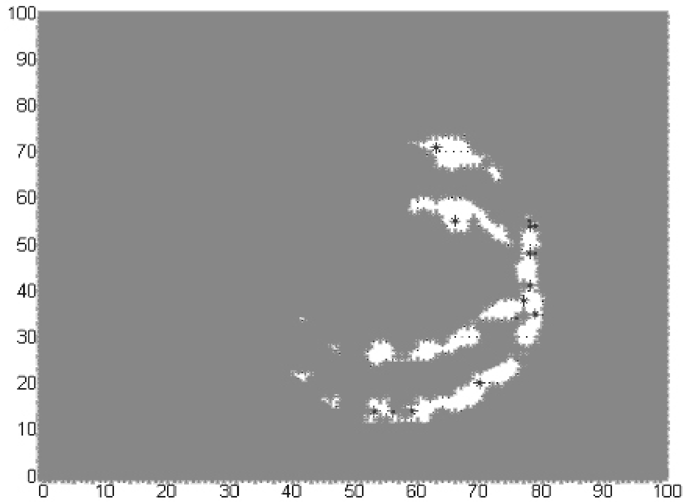

Figure 9. Exploited points of an irregular object

7. Simulation

At first, the implemented software captures two images from two existing cameras belonging to the robot. Then the correlation algorithm gives a set of points to be used in next processing steps. Then, the heuristic method achieves all its necessary data as the correlated points of the correlation process and determines four extreme points to compute available distances. The fuzzy method is also used to find the best point in this case. Fig. 10 demonstrates the steps to get the correlation points. Finally the best coordinates are accessible (Fig. 11).

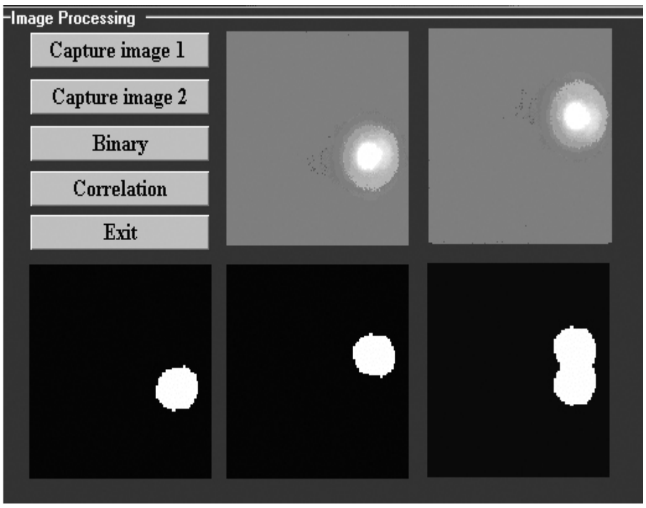

Figure 10. Correlation computin

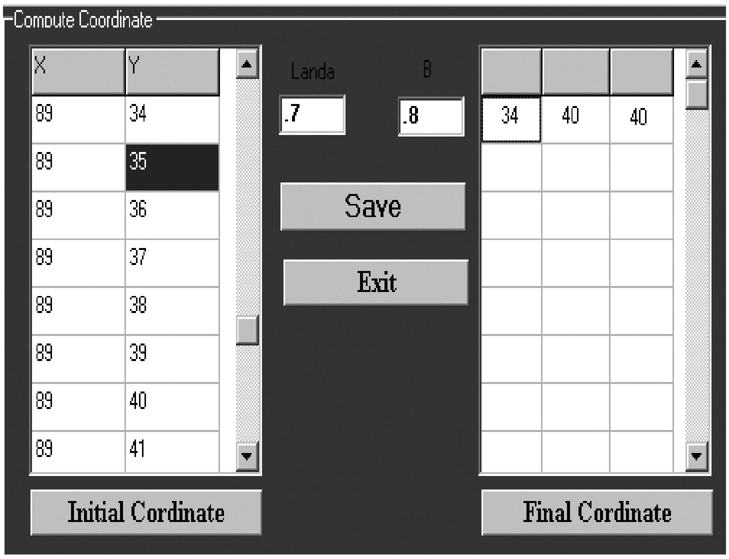

Figure 11. Computation of the best point

8. Experimental Results

In this study, the accuracy of our approach was compared with other approaches based on neural networks on 3P robots (Lopez & Plat, 2000) (Wang, 1992) (Hahnel et al., 2001).which contains some errors according to the structure and foundation of neural networks. Table.1 compares neural network and fuzzy methods on stereo vision for a 3P robot. It demonstrates that the fuzzy method is more reliable.

Type of Object	Circle	Cylinder	Cubic Rectangle	Cubic Square
Neural Network	98.3%	98%	97%	97.2%
Fuzzy System	100%	100%	100%	100%

Table 1. Comparison of neural network with fuzzy system in 3p robot

9. Conclusions

Here, applying a fuzzy model in stereo vision of a 3p robot is presented. According to the simulation results, correlation error is reduced where the best result in a 3p robot applying neural networks is about 97% of correctness, but using a fuzzy approach, let us to achieve up to 100%. It is obvious that all these results are achieved by simulated software and different kinds of errors could be occurred in real environment. Some of them are discussed in(Korayem et al., 2001).This fuzzy model can be applied to a large class of robotic manipulators.

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