Tridimensional Visual Servoing

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Abstract: This paper presents a tridimensional visual servoing that gives the information of the position, height and orientation of several objects presented in the working area of a robot manipulator. With this information, the robot manipulator's effector can pick and place objects to a specific position. A pair of stereo camera produces the feedback obtaining a particular position of the effector of robot. The servoing implemented is based on vision stereo lateral model. This servoing system is tested experimentally in real time on a Scara Manipulator, including the stereo cameras and image processing using Matlab.

Keywords: Visual Servoing Systems, Robotic Manipulators. Stereo vision, Kinematics control.

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1. Introduction

Flexible Manufacturing Systems (FMS) utilizes robotics manipulators in its Flexible Manufacturing Cells to perform different task as pick and place materials, parts or products, assembly a products, and quality control. These tasks require speed and precision, to have some economical advantages and good engineering. Conventional robot manipulators have limited accuracy in positions and need time to perform task.

A servoing system provides these requirements. A servoing system uses a visual system to control the position of a robotics manipulator. This visual servoing does not need to know a priori the coordinates of the work piece and could not need a robot teaching, allowing having not repetitive tasks, especially in assembly. The vision feedback control loops have been introduced in order to increase the flexibility, the speed and the accuracy of robot system [1], [2] - [5].

Vision-based robot control is classified into two groups [6]: position-based and image-based control Systems. In a position-based control system, the input is computed in the three-dimensional Cartesian space (3-D visual servoing) [7]. The position of the target with respect to the camera is estimated from image features corresponding to the perspective projection of the target in the image. There exits several methods to recover the pose of an object, all of them based on the knowledge of a perfect geometric model of the object and the calibration of the camera to obtain unbiased results. In an image-based control system, the input is computed in the 2-D image space (2-D visual servoing) [8]

An image-based visual servoing is robust with respect to camera and to robot calibration errors. However, its convergence is theoretically ensured only in a region around the desired position. Except in very simple cases, the analysis of the stability with respect to calibration errors seems to be impossible, since the system is coupled and nonlinear.

A new approach is called 2-1/2-D visual servoing since the used input is expressed in part in the 3-D Cartesian space and in part in the 2-D image space [9].

There exist several techniques to extract 3D information. Some of them, called direct sense, estimates the distance to an object based in the measurement of the time of the transmission and reception of a wave, known the propagation media. This can be done by laser, ultrasound and radar. The disadvantage is that can measure one point at a time. Other technique is to use the shadow to compute the depth of the object [8]. A method for determining depth from focus [10] relates the distance from camera to objects out of focus, needing two images. The technique using encoded light pattern, the objects are illuminated from one point, in a plane, or a mesh of points through a projector with a position and orientation known respect to the camera [11].

Another technique uses two perpendicular cameras in specific positions obtains two images to compute the space information of the object.

Stereo Vision utilizes two cameras focusing the same object from different views and then to determine from the differences of the images, the distance of the objects by triangulation. There are several models for Stereo Vision as Lateral Model, Axial Model, and Generalized array of stereo cameras [12].

A previous work of the authors, is related with a Servoing System using one camera applied to a pick and place task [13], [14].

In this paper presents a visual system that gives the information of the position, height and orientation of several objects presented in the working area of the robot manipulator. With this information, the robot manipulator's effector can pick and place objects to a specific position. A pair of stereo camera produces the feedback obtaining a particular position of the effector of robot. The servoing implemented is based on vision stereo lateral model. This servoing system is tested experimentally in real time on a 5 degrees-of-freedom Scara Manipulator, including the stereo cameras and image processing using Matlab.

2. The 3-D Visual Servoing

The system has a stereo vision with two web cameras, based on vision stereo lateral model, that is to say both cameras separated by a horizontal displacement and perpendicular to objects. The cameras are mounted as shown in Figure 1, including illumination system (two lights of 100 W).

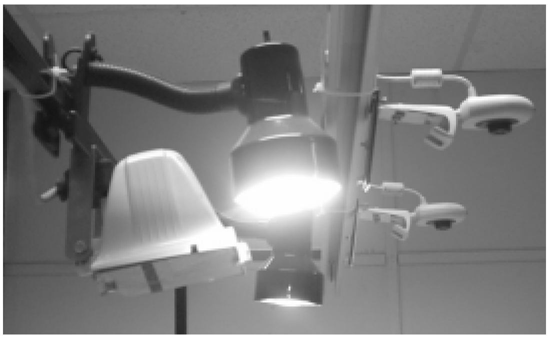


Figure 1. Camera systems and the illumination.

A computer's program control the images capture, the image processing, computes the pose of the objects in the scene, and the control of the robotic manipulator

The robotics manipulator is an IBM 7547, Scara type. in the Laboratorio de Robótica, Inteligencia Artificial y Automatización Avanzada that belongs to Escuela de Ingeniería Eléctrica de la Pontificia Universidad Católica de Valparaíso, Chile. See Figure 2.

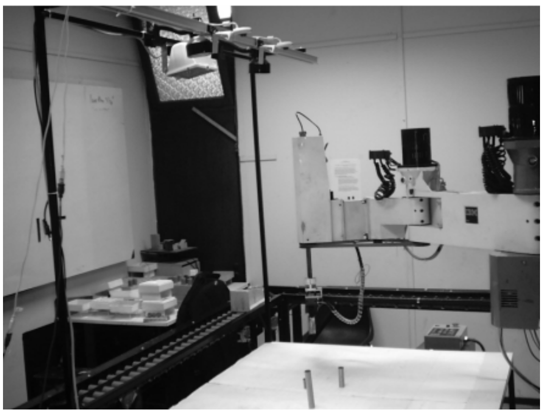


Figure 2. Complete system

In the next Figure 3, a lateral plane of the system can be observed. The work space is restricted to the common vision of the two cameras. The position and height of the objects can be computed.

the scene. The gray image is transformed to a binary image as shown in Figure 4, where the black colors are objects and white pixels are background. This mean that the image is matrix with each cell has a '0' or '1' value

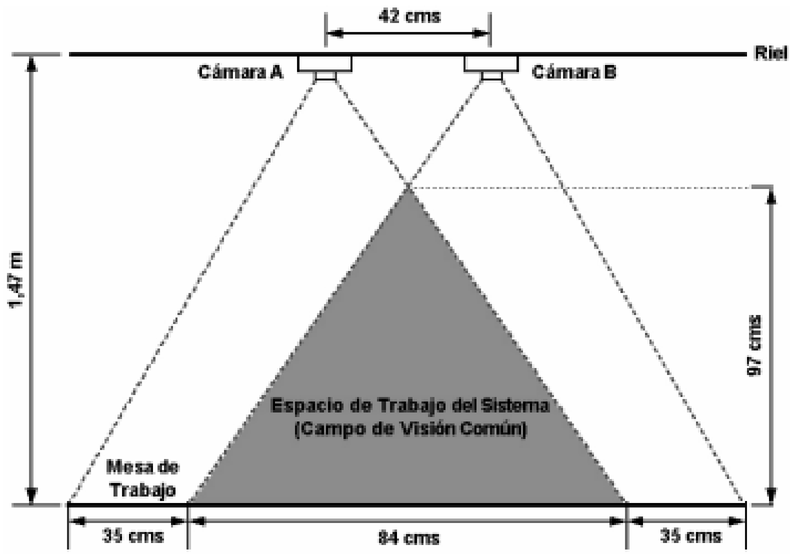


Figure 3. Work space

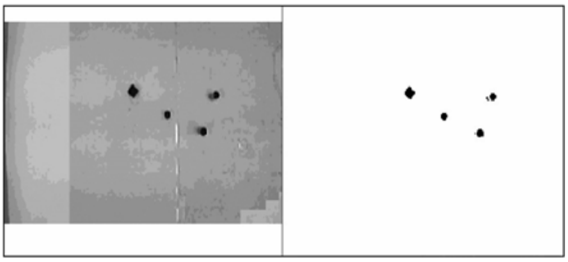


Figure 4. Gray scales Image and binary image.

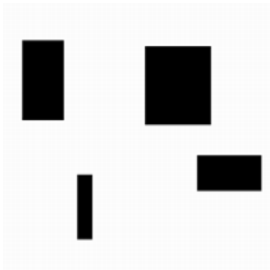
The restriction is considering only the objects in the common work space of the stereo vision. Pixels outside of that space are colored to avoid them.

3. Images Processing

Images captured by cameras are in RGB format, where each pixel is a combination of blue, red and green colors. The RGB image is transformed to a grey scale image and the color information is now bright information. With this kind of image the objects are contrasted with the background, obtaining two frequencies of gray level. Then, it is possible image segmentation using a threshold chosen according to the illumination, the objects and the colors along depend on if a black or white pixel. The resolution used is 288*352 pixels, with a matrix of 288 rows and 352 columns.

The next step is to eliminate the noise using and appropriate threshold. The noise is due to errors in image capture and problems in the work area.

For objects identification, it is used the tag technique assigning a number to each one in the image, from left to right and up to down, searching cells with "1" value in the first set of cells, the next set tag is "2" and so on, until "n" that is the object number. The result is presented in the Figure 5.



0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 1 1 1 0 0 0 0 3 3 3 0 0 0
0 0 1 1 1 0 0 0 0 3 3 3 0 0 0
0 0 1 1 1 0 0 0 0 3 3 3 0 0 0
0 0 1 1 1 0 0 0 0 3 3 3 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 4 4 4 0
0 0 0 0 0 2 0 0 0 0 0 4 4 4 0
0 0 0 0 0 2 0 0 0 0 0 0 0 0 0
0 0 0 0 0 2 0 0 0 0 0 0 0 0 0
0 0 0 0 0 2 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Figure 5. Object's tags.

An algorithm utilize Tag's object to compute the object centroid and its (x, y) position. To find centroids, the image matrix is taken, store extreme positions of all elements different from "0", obtaining the length and width, and then dividing them. The algorithm gets the centroids without considering the orientation of the objects. The result, for the objects in Figure 4, is shown in the Figure 6.

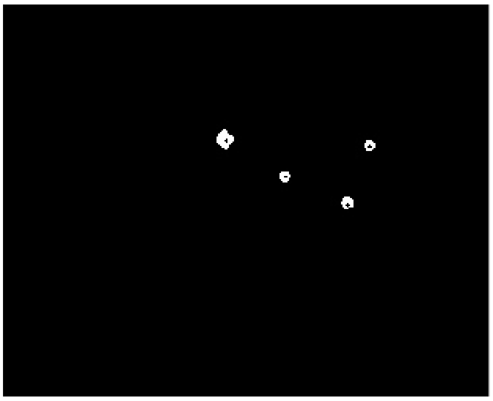


Figure 6. Object's Centroids.

The object orientation is necessary to compute, to know the rotate angle for the effectors of the robotics manipulator can pick the object. The algorithm uses the centroid of the object to determine the distance to every contour point of the object, choosing the minimal distance, that is to say the orientation of the object. The orientation angle θ is the argument of a complex number in the corresponding quadrant. Figure 7 presented how is the plane complex origin centered in the centroid of the object and the θ angle.

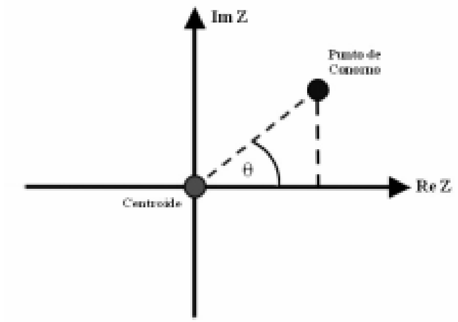


Figure 7. Object's Orientation.

Procedure is repeated for every object.

4. Coordinates of the Robotics Manipulator

4.1 Computing (x, y) Coordinates

The coordinates of the centroids of the objects within the common work space, is expressed as a row and column of the pixel of the object in the image matrix. However, this information is not sufficient to have (x, y) coordinates for the manipulator can pick the object. It needs a relationship between image coordinates and the manipulator coordinates. As this relationship is not the same in the whole work space, this space is divided in segments with different relationships between the two coordinates. Each segment has 5 measurements of centroid points and the coordinates that the robotics manipulator has to have to pick objects. The relationship between the column of the centroid pixel and the X coordinate of the robotics manipulator, are in Figure 8.

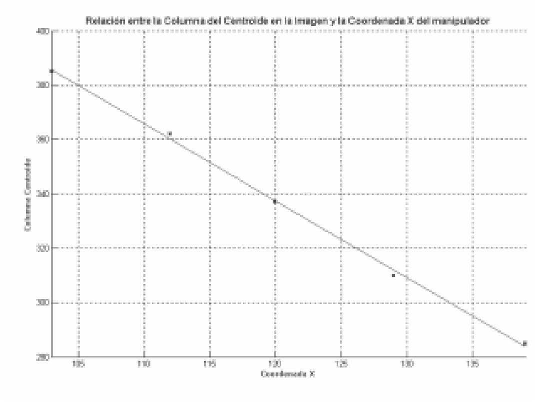


Figure 8. Relationship between centroid column en the image and X coordinate of the robotics manipulator

From Figure 8, a linear relationship is found, and it is possible determine X from equation (1) using linear progression.

X = -2.8282904 * (Column of Centroids) + + 676.89183 (1)

Equation (1) transforms the information of column of centroids pixel of the object, in the X coordinate to send to robotics manipulator. Equation (1) is valid only in the segment that is jeans it has to have equation for each segment.

To obtain the Y coordinate and to send to robotics manipulator, a relationship between X and Y coordinates is put in a Figure 9.

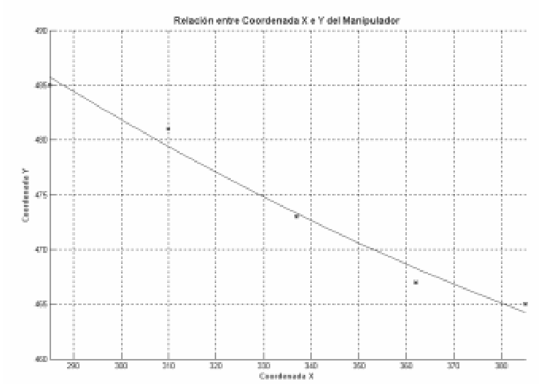


Figure 9. Relationship between X & Y coordinates of the Manipulator.

The Relationship between X and Y coordinates are related using quadratic progression to obtain a second grade polynomial in equation (2).

$Y=5.203*10^{-4}*(X)^2$ - 0.5636046*(X) + 604.126309 (2)

Equation 2 determines Y coordinate to send to robotics manipulator. The same procedure is used to obtain the equation in each segment with corresponding data. The row and column of the centroids permits to identify the segment in the work space where the objects are and then to assign the right equation, to compute (x, y) coordinates for the robotics manipulator.

To reduce errors due to perspective distortion, the coordinate measurements are done using the image nearest of the object. The second image is employs to determine the depth, the Z coordinate.

4.2 Computing the Z coordinate

The equations (3), (4) and (5), from Stereo Vision Lateral Model, computes Z coordinate.

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = I \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} \Delta x \\ 0 \\ 0 \end{bmatrix} \quad (3)$$

$$\frac{x_0}{x_L} = \frac{y_0}{y_L} = \frac{\lambda - z_0}{\lambda} \quad (4)$$

$$\frac{x_0 + \Delta x}{x_R + \Delta x} = \frac{y_0}{y_R} = \frac{\lambda - z_0}{\lambda} \quad (5)$$

Find the value of z_0 from the preceding equations; it is the equation (6).

$$z_0 = \lambda \cdot \left(1 - \frac{\Delta x}{\Delta x + x_D - x_I} \right) \quad (6)$$

Where:

x_D and x_i: represent the column coordinate of the pixel of the centroid from image captured by right and left cameras

Δx: represents the distance between cameras along the x axis, equal to 103 pixels.

λ : is focal length of the cameras lens.

z_0 is proportional to height of the object, but it is not the z coordinate of the manipulator.

To compute the real coordinates utilizing a scale factor 'F', transforming the image coordinate z_0 into z coordinate in the real space. In the coordinate system of the robotics manipulator, the z = 0 value is the highest of z axis, and the z = -249 value is the lowest one, however, the minimum value of z = -220, avoid that effectors crushes against the table. It is necessary to have a term that it puts "0" value of z_0 with the zero of the manipulator. This zero adjust term 'T_0' is in the scale factor is included in the equation (6) of the Stereo Vision Lateral Model, obtaining the equation (7).

$$Z = T_0 + F \cdot \left(1 - \frac{\Delta x}{\Delta x + x_D - x_I}\right) \quad (7)$$

λ (Focal length) is included in the scale factor.

Z value is the coordinate sent to robotics manipulator.

To calibrate the system, the term values of zero adjust term 'T0' and scale factor 'F', it is utilized two objects with height known, placed in the same point in the common work space of the system. It computes z coordinate for robotics manipulator used to pick each object. The difference between the columns coordinates of the centroid pixel of the two images (XD – Xi). This data are in the Table 1.

Table 1. Data for 'To' and 'F'

	Object A	Object B
z Coordinate	-219	-135
$X_D - X_i$	93	102

Putting these values in the equation (7) gives the system equation (8).

$$\begin{aligned} T_0 + \left(\frac{93}{103+93}\right) \cdot F &= -219 \\ T_0 + \left(\frac{102}{103+102}\right) \cdot F &= -135 \end{aligned} \quad (8)$$

The values obtaining are: T_0=-1946.6 and F= 3640.9. This values is replace in the equation (7), to obtain equation (9) to compute z coordinate of the robotics manipulator in the segment of the work space, where the measurement are made

$$Z = -1946.6 + 3640.9 \cdot \left(1 - \frac{103}{103 + x_D - x_I}\right) \quad (9)$$

Equation (9) transforms directly the displacement the centroid pixel of the object between each image of the stereo vision system, in the z coordinate of the robotics manipulator. Due to perspective distortion of the object, because of the cameras are not perpendicular to the objects, the equation (9) is valid only in small segment of the work space of the manipulator.

4.3 Computing the Rotation Coordinate

The object orientation is determined by orientation algorithm and then it has to have a transformation to relate algorithm coordinates and manipulator coordinates. The algorithm coordinates considers a positive rotation in the unclockwise, and the positive rotation in the manipulator is clockwise. There exists a difference of 18º between both coordinate systems computed by equation (10).

$$\theta_{Manipulador} = (-1) \cdot \theta_{Algoritmo\ \ de\ \ Orientación} + 18^{o} \quad (10)$$

Finally, the R coordinate is sent to robotics manipulator to have the turn angle of the effector, is equal to the value $\theta_{Manipulado\ r}$ obtained.

The tridimensional servoing systems has been evaluated in a Flexible Assembly Cell with successful results [18]. The cell has a robotics manipulator, a system of vision and a system of automated transport has appeared. The cell performs the assembly of products, with the manipulator, taking the parts and put into other one. Also, the results of this paper was used in in coordination of a visual servoing with camera in the effector of a robotics manipulator. [20]

5. Conclusions

We have presented a visual system that gives the information of the position, height and orientation of several objects presented in the working area of the robot manipulator. This 3D servoing system gives this information, the robot manipulator's effector can pick and place objects to a specific position. A pair of stereo camera produces the feedback obtaining a particular position of the effector of Scara 7475 robotics manipulator. The servoing implemented is based on vision stereo lateral model.

The system has the capacity of identifying the spatial position and the orientation of several objects in steady state, presented in the common work space of stereo vision cameras, then that information is sent to the manipulator to pick and place objects. The (x, y) robotics manipulator coordinates are obtained applying equations based on centroids of the objects. To compute z coordinate is utilized equations of the Stereo Vision Lateral Model, with a zero adjust term and scale factor to coincide the original coordinate system with the manipulator coordinate system. To compute the orientation angle, an algorithm is used.

The stereo vision is evaluated in a Flexible Assembly Cells.

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