Intelligent Design and Algorithms to Control a Stereoscopic Camera on a Robotic Workspace

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ABSTRACT
As a result of the increasingly demands in modern industry, the development of robotic systems with greater flexibility between processes and lower human factor modification and intervention requirements, were necessary. The visual control technology simplifies the process of calibration of a robot with the assistance of visual feedback. The visual inspection of a robot includes the use of industrial cameras and a computer vision system to control its position relative to the work piece. In this paper a system will be designed and constructed, which will be using computer vision to monitor a production line and remove the defective products. For this purpose a stereoscopic camera will be built that will perform and calculate the object's coordinates in its environment. The system controller will make the trajectory planning into the three-dimensional environment, and the control of the robotic arm.

Keywords
Robotic arm, visual recognition, object identification, quality control, movement algorithm, robotic working space

1. INTRODUCTION
The common robotic systems have many limitations when operating in a structured and volatile environment and needs a lot of effort to overcome the problems of accuracy and flexibility. The reason for this, is that the controller in a common robotic system uses an open loop control to determine the position of the end effector in relation with the workpiece. This is done by calculating and controlling each joint separately in a way that the end effector of the robot will be oriented in its environment. With this method, every problem with the orientation or positioning of the end point of the robot, would lead to failure of the procedure. Various, mechanical nature, factors which is affecting the operation of the arm is: the deformation of the links, the efficiency drop of the joints, gaps between the gears as well as problems in the installation. To solve all these problems one have to spent large sums both for regular maintenance of the robot in order for the standards to remain in a strict framework, and for the design of specific components which will ensure reliability and accuracy over time. Alternatively, using visual servoing systems, one can have continuous control of the end effector in real time, always in relation with the workpiece. The visual servoing system utilizes a closed loop control with visual feedback to direct the end-effector without any use of feedback of the joints angle. The purpose of the system is to control the position and orientation of the final element of the robot in relation to the environment, but also with respect to the object being worked.

In summary the advantages of visual servoing technique are:

- Less demands on the hardware of the robotic system.
- The robot accuracy no longer depends on the rigidity and mechanical accuracy of the components of the robot. This allows the use of cheaper materials for in the construction.
- Less demands on customization and training of robots. With the optical vision system, the robot can move and interact with the environment and the objects of interest with more flexibility and autonomy, without the exact design of the trajectory to be necessary.

2. SYSTEM STRACTURE
This section proposes a solution for controlling a robotic arm that performs the sorting process of a production line, using a stable stereoscopic camera. With this arrangement (eye-to-hand) the camera is in a fixed location outside the robot's body, and observes the location of the object relative to the position-motion of the robotic arm. This arrangement have some advantages compared with the eye-in-hand approach. Initially we have a greater amplitude in the foreground, which is important for the current process. Additionally unloads the final arm effector from extra weight and volume, which gives speed, flexibility and less wear on the joints and links. With the process of a productions line object sorting, the element of speed and flexibility is the priority, when the absolute accuracy is not the main issue, as it would be e.g. on a metal welding arm, where the use of eye-in-hand arrangement would be more effective.

For the design of the arm trajectory, the computer vision system must have the calculation capacity of the three dimensions of space. By using any conventional camera we can only capture the two dimensions, since the depth of the space, i.e. the distance of a point from the camera cannot be captured. Therefore it's constructed a stereoscopic camera, where with the use of two individual cameras through appropriate software, is now possible to calculate the coordinates of any point located in the FOV of the camera. All system components placement within the working space of robotic arm can be seen in Figure 1 as schematics and its description is provided below:

- The optical axes of the two cameras are parallel
- The distance b between the cameras is referred to as baseline
- The x-axis is parallel to the baseline
- f is the focal length of the cameras

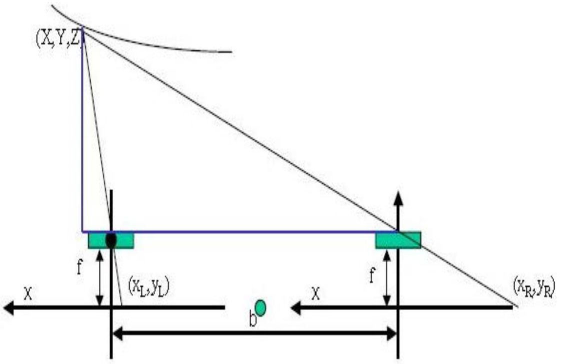

Fig 1: The system's schematics diagram

The general model of the camera system is described by the following equations:

CAMERA1:

$$s \times \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} 634.760 & 0 & 371.474 \\ 0 & 641.519 & 216.801 \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \times \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

Distortion Coefficients:

[1.63549131e^{-01} -1.16144525e^{+00} 3.81926277e^{-03} -3.58756893e^{-02} 4.18116472e^{+00}]

CAMERA2:

$$s \times \begin{bmatrix} u1 \\ v1 \\ 1 \end{bmatrix} = \begin{bmatrix} 612.4115 & 0 & 376.4277 \\ 0 & 619.1765 & 200.8304 \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 & -10 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \times \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

Distortion Coefficients:

[0.20087062 -0.6719277 -0.01130536 -0.02564364 1.24186424]

Given that the cameras are screwed on a solid basis without rotation or differences between the angles, the coefficients in the rotation matrix are zero except the displacement in the X axis, i.e. the distance between the centers of the cameras, which is 10cm.

From the similar triangles of the figure, we see that:

$$\frac{x_L}{f} = \frac{X}{Z}$$

$$\frac{x_R}{f} = \frac{b + X}{Z}$$

Solving the two equations turns out that:

$$Z = \frac{b \times f}{x_L - x_R}$$

Therefore to calculate the distance of a point from real world, with cameras, it is sufficient to know the coordinates of that point on a picture cameras.

If the distance Z is known then the X and Y can be easily calculated.

$$X = x_l \times \frac{Z}{f_y}$$

$$Y = y_l \times \frac{Z}{f_y}$$

$$f_x = f \times c_x$$

$$f_y = f \times c_y$$

where cx and cy, dimensions of the pixel of the camera sensor.

It was observed that the stamping precision of the coordinates of a point mainly depends on the calculation accuracy of Z. The deviation in the calculation of the actual distance of a point from the cameras is represented in the graphs below.

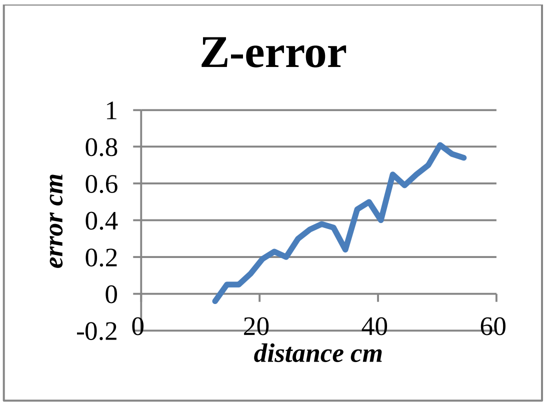

Fig 2: Computed with real distance, point to camera

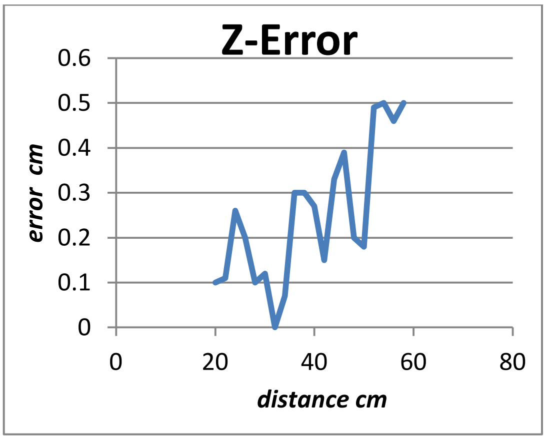

Fig 3: Computed with real distance, point to camera, after software filtering

3. CONTROL ALGORITHM DESIGN

In the previous chapter we generated the coordinates of one or several points of the system's environment, which represent the characteristics of an object. The next issue is to control the arm to interact with this object, according to the conditions of the process. In the developed system, the arm is intended suction of the object-target and removal from the production line. The arm control is done using inverse kinematics, The arm end-effector speed is monitored and controlled by the visual servoing system. The arm control system operates in an open and a closed loop.

3.1 Open Loop Control

The open loop control system is in essence a look-and-move system rather than actual visual servoing. The operation is simple and as indicated by the name, the coordinates that are calculated by the computer vision system, is the robotic arm control command.

To function properly such a system requires an initial calibration on position of the camera system relative to the position of the robotic arm.

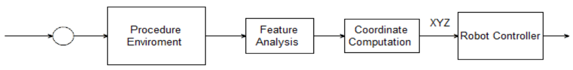

Fig 4: Open loop control scheme

Critical Advantages and disadvantages of such method were then recorded like:

Advantages:

- Low requirements of processing power
- Simplified control system

Disadvantages:

- Low accuracy based on the correct calibration, the correct setting of the camera system and the trustworthiness of the arm
- System sensitive to external interference
- Reduction in systems reliability during time, due to wear of the arm's joints.

3.2 Closed Loop Control

In the closed loop system, except the target object, the computer vision system monitors and calculates coordinates of the end-effector of the arm. The characteristics that describe the specific point of the robot, can as in the case of the object, be either schematically or color. In this work, a red LED or a red tape, had adapted to end- effector. The computer vision system is using the red color to calculate the coordinates of the end-effector relative to the target object and then apply a closed loop system control to zero the error in these coordinates. For zeroing the error was implemented a fuzzy logic control method for the greatest possible precision and smoothness in movement of the arm.

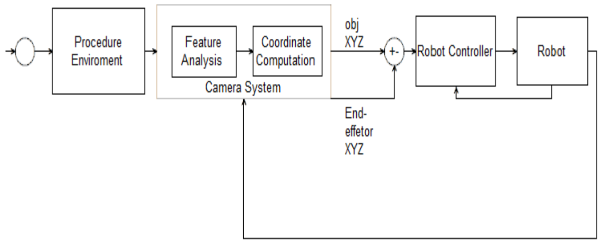

Fig 5: Closed loop control scheme

For comparison reasons the advantages and disadvantages of this method must be recorded, as:

Advantages:

- Greater accuracy and repeatability.
- Greater trustworthiness over time
- Not affected by wear on mechanical parts
- It does not require the calibration of the system

Disadvantages:

- Consumption of more computing power
- Complexity in the control system.

An overall view of the system with both end-effectors and object tracking operations is now provided in the below figure:

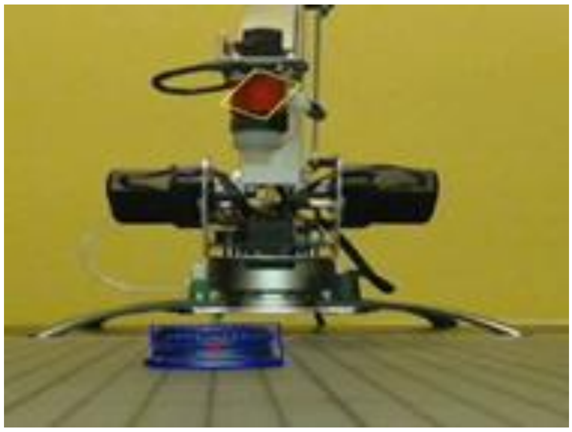

Fig 6: System with both end-effectors and object tracking functions

3.3 Fuzzy Logic Control

In this chapter, it is used a fuzzy logic method for controlling the position of the arm. The aim of this system, as said in the previous chapter, is to decrease the distance error between the object and the interaction element of the arm. The error in each of three dimensions is:

$X_{err} = X_{arm} - X_{obj}$ $Y_{err} = Y_{arm} - Y_{obj}$, $Z_{err} = Z_{arm} - Z\_obj$

The control command to the arm will be Xarm coordinates, Yarm, Zarm (inverse kinematics).

Functions for calculating the control command, are the following:

$$X(f) = \frac{X(f-1) - (x\_err * step_x)}{10}$$

$$Y(f) = \frac{Y(f-1) - (y\_err * step_y)}{10}$$

$$Z(f) = \frac{Z(f-1) - (z\_err * step_z)}{10}$$

$$f = frame$$

$$step_x = [0,10]$$

$$step_y = [0,10]$$

$$step_z = [0,10]$$

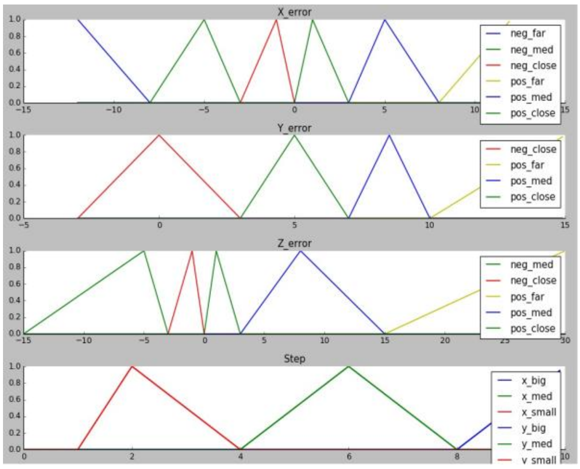

Fig 7: Fuzzy sets for Inputs (x_err, y_err, z_err) and Outputs (step)

Fuzzy Rule example:

active_rule1= **if** *x_err_neg_hi* **or** *x_err_pos_hi* **then** *step_x_big*

active_rule2= **if** *x_err_neg_med* **or** *x_err_pos_med* **then** *step_x_med*

4. CONCLUSIONS

For the challenge of this paper, a visual servoing system was developed, using low cost components, but the methods and techniques that used is common in modern industrial systems. Its purpose is monitoring a production line and removing objects based on specific criteria. The tracking and monitoring system based on a stereoscopic camera that developed for this purpose, which in combination with the algorithm developed yielded good results in terms of accuracy, with a mean deviation in the measurement of the distance + -3mm from the real value. We could achieve better prices using special, for this purpose, industrial cameras. The identification techniques had used, were selected taking into consideration the speed and trustworthiness of the system and with given the limitations in processing power.

In this research project, a visual servoing system of a robot which performs continuous control to the end-effector through specific color or schematic characteristics was implemented. With this method the system show many advantages and great flexibility. The latter no need initial calibration prior to operation, also it's possible for the arm and the cameras to move each other, even during the process.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] S. Hutchinson, G. Hager, and P. I Corke. A tutorial on visual servo control. IEEE Trans. on Robotics and Automation, 12(5):651-670, October 1996.

[2] W. C. Chang. Precise positioning of binocular eye-to-hand robotic manipulators. Journal of Intelligent Robot System, 49(1):219-236, 2007.

[3] E. Malis, F. Chaumette, and S. Boudet. 2-21/2-D Visual servoing. IEEE Trans. on Robotics and Automation, 15(2): 238-250, 1999.

[4] P. I. Corke. Visual control of robot manipulators. World Scientific Series on Robotics and Automated System, 2(1): 8-12, 1993.

[5] D. I. Kosmopoulos. Robust Jacobian matrix estimation for image-based visual servoing. Robotics and Computer-Integrated Manufacturing, 27(1): 82-87, 2011.

[6] J. Feddema, C. Lee, and O. Mitchel. Automatic selection of image features for visual servoing of a robot manipulator. In Proc. Of IEEE International Conference on Robotics and Automation, vol. 2, pp. 832-837, Scottsdale, AZ, May 1989.

[7] P. I. Corke and S. Hutchinson. A new partitioned approach to image-based visual servo control. IEEE Trans. on Robotics and Automation, 17(1): 507-515, August 2001.

[8] W. C. Chang. Precise positioning of binocular eye-to-hand robotic manipulators. Journal of Intelligent Robot System, 49(1): 219–236, 2007.

[9] R. C. Harrell, D. C. Slaughter, and P. D. Adsit. A fruit-tracking system for robotic harvesting system. Machine Vision and Applications, 2(5): 69-80, 1989.

[10] R. Nevtia. Depth measurement by motion stereo. Computer graphics and Image Processing, 5(1): 203-214, 1976.

[11] J. Stavnitzky, D. Capson. Multiple camera model-based 3-D visual servoing. IEEE Trans. on Robotics and Automation, 16(6): 732-739, 2000.

[12] Richard Hartley and Andrew Zisserman. Multiple View Geometry in computer vision. Cambridge University Press, 2nd edition, 2003. ISBN = 0-521054051-8.

[13] D. G. Lowe. Robust model-based motion tracking through the integration of search and estimation. In International Journal of Computer Vision, pages 113–122, 1992.

[14] Gary Bradski & Adrian Kaebler. Computer Vision with the OpenCV Library. O'REILLY Media,2008. ISBN: 978-0-596-51613-0