Image-Based Visual Servo Control of a Robotic Arm by Using Cellular Neural Networks

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Abstract: *An image-based visual servo control of a robotic arm with two degrees of freedom using a video camera to follow a moving object is presented. The proposed algorithm includes only elementary CNN (Cellular Neural Networks) template operations. Hence, it is possible to implement this algorithm on a CNN-Universal Chip (CNN-UC). In this way, between two successive acquired input images, by complete parallel processing with cellular neural networks of two-dimensional signals all the necessary processing are performed in real-time.*

Keywords: *image-based visual servo control, cellular neural networks (CNN), CNN-Universal Machine, CNN-Universal Chip*

I INTRODUCTION

The widening of the application field of robots by the growth of their abilities, as a consequence of the integration of sensors in their structure, represents a fundamental issue nowadays. Among the sensors used in robotics, the visual sensor or video camera occupies a special place, because its use allows the contact-less evaluation of the work space [1], [2]. Using a visual sensor and processing the information contained in the acquired images allow controlling the position of a robot's actuator or to guidance a mobile robot towards a target object. To improve the precision, mostly the visual sensor, which is the extraction of the information from the image, the looking part, and the actual control of the position, the moving part, are included in a visual feedback loop, and called generally visual servo control (visual servoing) [1]. In Figure 1, a structure "look and move" type, based on images for visual servo control of a robot is presented. The video camera is fixed on the robot arm (so called "eye in the hand").

In this case, the visual system is situated in the superior hierarchical order of the system's structure, i.e. the visual system provides the reference for the servo system of the kinematic joints. This configuration uses internal joint angle sensors for attaining the prescribed position of the robot.

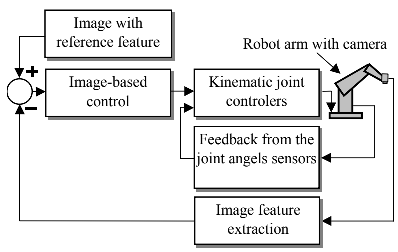


Figure 1
Image-based look-and-move structure

One of the most important advantages of the image-based servo control towards the position-based one is that the precision of the system positioning is less sensitive to the calibration errors of the video camera. Another advantage is the reduced processing time.

In order to implement the real-time visual servo control, a high computing power is needed, especially for the high speed and robust processing of an image.

II CELLULAR NEURAL NETWORKS

The cellular neural network (CNN) is an analog processor with two-dimensional or multi-dimensional structure, that includes identical nonlinear analogue circuits, regularly positioned, called cells, which locally interact each other based on some templates that determine the processing result. CNN supercomputer (CNN-Universal Machine, CNN-UM) are high speed devices for analog signal processing, which can be an advantageous alternative to the serial digital computers or to other specialized hardware for parallel processing. It have been proved that cellular neural networks (CNN) are very efficient tools in a wide spectrum of applications like modeling of biological phenomena, image processing, cryptography, etc.; others CNN's applications include specific image processing tasks, that can be used in visual control of an industrial robot, or for mobile robot navigation with obstacles avoidance [6] [8]. The major advantage of using CNN is their high speed of data processing, which allows to control in real time the process. This advantage can be fully exploited if the application is implemented on a CNN Universal Chip (CNN-UC).

Designing a CNN application means the design of the corresponding templates. However, by performing only one processing step, with a single template on a CNN chip can solve a small number of problems. In the most applications a template is nothing else but an elementary instruction, and the CNN application design is transformed actually in CNN programming, with the aid of several elementary instructions or subroutines, based on templates available in a template library [9].

III THE EXPERIMENTAL ROBOTIC SYSTEM

A simplified experimental model is proposed in Figure 2, based on the structure outlined in Figure 1. The system has a single visual sensor placed on the arm of an industrial robot with two degrees of freedom and having rotating kinematic joints (JA and JB); the positions of the joints are characterized by θ1 and θ2 angles.

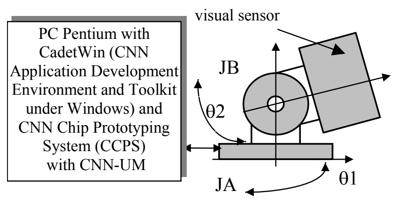


Figure 2
The experimental robotic system

In this application we will take into consideration that the original images are captured with the camera at discrete time instances t_0+kT, where t_0 represents the initial moment, T is the sampling time step and k is a natural number.

In the first step we select an object in the image plane from the acquired image. In order to determine the position of this object, a Cartesian reference system (xOy) is attached to the image plane of the camera, having the origin in the center of the image (as shown in Figure 3).

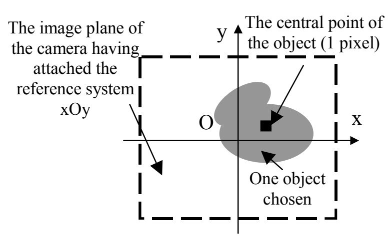


Figure 3
Image plane of the camera

The position of the object in the image plane is given by a single point P(x,y,kT) (this point will be called in the following the central point of the object). Here, x denotes the horizontal co-ordinate, y is the vertical co-ordinate and kT is the time instance the image has been captured.

Thus, the determination of the position of an object in the image plane can be considered as a method, through which only the central point (only a single pixel) have to be identified, without knowing this point's co-ordinates in the attached Cartesian reference system. Please observe that the central point of the object is located at half of the distance to the most distant points of the object, both on x and y directions.

In this application it is presumed that at the initial moment t_0, the central point or at least a random point of the designated object is situated in the origin of the reference system attached to the image plane. This condition will be accomplished practically by setting the kinematic joint angles to the reference $\theta1_0$ and $\theta2_0$.

In principle, any other criterion for object selection can be used; for example, we can select a single moving object at a given time. The algorithm presented in the following still keeps its validity.

The described robotic system must assure that, after selection of an object, the camera would follow the selected object regardless of its movement in working space. For this purpose, the position of the robotic arm must be modified so that after the system reaches the stable position, the central point of the object should be found in the origin of the reference system xOy.

The proposed objective is to increase the processing speed, to assure a real-time functioning of the system. For this reason, the CNN cellular neural networks will be used in as many processing steps as possible. For this purpose, all the signals being used, no matter of their nature, are interpreted as images. In this way, from the current image acquisition up to the determination of θ1 and θ2 reference angles, the processing take place in a CNN environment, in order to minimize the total processing time. As a result, all the necessary data processing are can be done between two images samples, acquired successively, as is imposed by a real-time functionality of the robot.

If the processing speed is high enough, even in the case of a positioning error, the robot's control system will be able to correct the current position, before it "loses" the selected object "from sight".

IV DESCRIPTION OF THE ALGORITHM

To follow moving objects, the proposed algorithm uses a binary input image that results from the acquired gray-scale image after elementary processing steps. The value of the pixels in the gray-scale images are in the interval [-1, 1], known as the standard domain in CNN. For binary images, these values could be only +1, for the black pixels (pixels belonging to the followed object) and –1 for white pixels.

The proposed algorithm has the following steps:

- Designation of the initial moment and automatic selection of the object that will be followed, at each image acquisition.

To designate an object in the image plane, at the initial moment t_0, at least one point of the object must be brought to the origin of the reference system attached to the image plane. After that, the designated object at the moment t_0 has to be automatically selected for each moment of time (t_0+kT). This way, at the end of this step, the output image will contain only the designated object at t_0, but in the current position. For an automatic selection of the designated object in a binary image, using CNN processing, the template follow.tem [9] was used. Thus, the processing time depends upon the input image type, the selected object's dimensions and the difference between the positions of the object in two successive acquired images.

- Determination in the image resulted after the first processing step, of the position P(x,y,kT) of the central point belonging to the selected object.

Again, the algorithm does not specify the numeric coordinates of the central point relative to the reference system attached to the image plane, only identifies it. To find the position of the central point of the object, we can use the template center.tem [9] or a CNN algorithm special designed for this purpose [8].

- Determination of the variations Δθ1 and Δθ2 of the angles towards the actual values of θ1 and θ2 for the rotation kinematic pairs of the robotic arm.

The new reference angles for kinematic joint JA and JB are as follows:

$$\theta 1_{new} = \theta 1_{actual} + \Delta\theta 1, \quad (1)$$

$$\theta 2_{new} = \theta 2_{actual} + \Delta\theta 2. \quad (2)$$

The values of the angles Δθ1 and Δθ2 will be determined so that through the new position of the robotic arm (video camera), the central point of the selected object to be situated in the origin of the reference system xOy, attached to the image plane of the visual sensor. In this case, through positioning the robotic arm, the image error becomes zero, and the proposed control task can be achieved.

The CNN structure, with three identical layers, used for the robotic servo control system is presented in Figure 4.

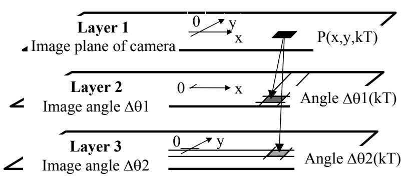


Figure 4
Structure of neural network attached to the robotic control system

Layer 1 represents the actual current input image. By selecting an object and determining the position of its central point, by using elementary processing steps, an image with only one active pixel, (with value +1) will be obtained. All the other pixels are inactive and have the value -1. This image controls than the layers 2 and 3.

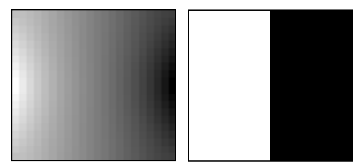
Layer 2 is associated with the "image" of $\Delta\theta 1$. This image defines the reference angle $\theta 1$ and corresponds to the each position on horizontal of the active pixel from layer 1.

Similarly, layer 3 is associated with the "image" of $\Delta\theta 2$. This image is used to determine the reference angle $\theta 2$, which corresponds to the position on the vertical of the active pixel from layer 1. Layers 2 and 3, namely "images" $\Delta\theta 1$ and $\Delta\theta 2$, behaviors like two-dimensional memories which are addressed in position by the active pixel from layer 1.

During creation and selection of the structure of $\Delta\theta 1$ and $\Delta\theta 2$ images, the following aspects have been considered:

- the inverse kinematic transform for a robot arm with rotating kinematic joints and two degrees of freedom;
- the imposed precision and speed for the positioning of the central point;
- the speed of the movement on each axis of the followed object;
- the implementation method for the algorithm in the CNN environment.

In Figure 5 are illustrated two variants of images for $\Delta\theta 1$.



(a) (b)

Figure 5
Examples for image angles

In the simplest situation, the binary images of the angles $\Delta\theta 1$ (Figure 5b) and $\Delta\theta 2$ respectively, serve only to determine the sign of variation of the angles towards the current position, having a constant pre-set value. By using this approximation, the determination of the central point can even be eliminated from the algorithm.

V EXPERIMENTAL RESULTS

Based upon the proposed algorithm for the following of the moving objects, a program was developed using Analogic Macro Code (AMC) [9]. By running this program on the CPS unit [9], the system presented in Figure 2 is capable to track the movement of a projected laser beam and to maintain the laser spot within the surface of the picture. The program processes gray scale images with a resolution of 300*300 pixels and controls in approximately 0.3s, in a closed lop, the position of the video camera.

In Figure 6, a frame from the acquired images is presented.

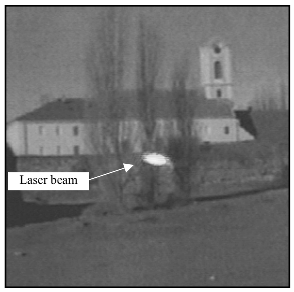


Figure 6
A frame from the acquired images used for testing the laser beam following algorithm

Conclusion

Between two consecutive acquired input images, through complete parallel processing of two-dimensional signals by using CNN, all the data processing can be done in real time. The implementation of the presented algorithm on CNN devices with better performances will improve the results, due to the fact the processing time does not grow proportionally to the image size.

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