Application of Image Processing For Solving Numerical Puzzles Using A 3 DOF Robot

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Abstract: The robot introduced in this paper is designed to solve numeral puzzles. Its control is totally by computer and has vision capability which leads its arm to certain places. In the control loop of the arm for identifying the top of the arm, image processing technique is used. Because of its polar movement on the plane, the design of the robot is considered an optimized one. The control orders are given to robot by a parallel port which obtains image from a camera through USB port. For numerical recognition a simple algorithm with the capability of learning new patterns is used. Noting that different conditions have not been given to the robot, therefore the robot is highly considered intelligent. Some of the robot characteristics include recognizing numbers by camera, 3 degree of freedom, polar movement of the plane, locating the arm of robot with the use of camera, and capability of learning simple numerical pattern.
Such a system can be helpful as a benchmark in testing and performing image processing algorithms. An arm with 3 degrees of freedom as effector and a webcam as vision sensor has been used in the system. Processing of images should be done using a personal computer.

Keword: Image processing, vision feedback, pattern recognition, adaptive control

1 Introduction

With the increasing need of production system to increase productivity, most industries are adapting flexible manufacturing system and automation. To this extent, robots are becoming most popular every day [1]. About %35 of robot applications are in welding car body pieces in automobile industries [2].

%25 of robots in automobile industries are used to handle materials and %20 of robots are utilized in feeding, load and unloads materials. Other important industries such as electronics, heavy industries, plastic, food, chemical, etc are also benefiting from robots [3, 4].
Advanced industries such as aerospace and marine use robotics very widely. These robots are utilized in drilling aluminum sheet, connecting pieces and setting them for riveting processes [5].

On the other hand, development of software for robots has made offline programming possible which increases the flexibility of production line.

In other term, any change in product or its related operation without setting robot individually becomes possible.

A schematic diagram of a simple vision system that is used for assembly line of a factory is illustrated in figure 1.
Vision system primarily takes an image from the component and then determines whether the part has desired properties or not.

Finally a proper control signal based on the acquired feedback from image processing, is produced and sent.

Equipments required for vision system include light sources, camera and processing unit (Fig1).

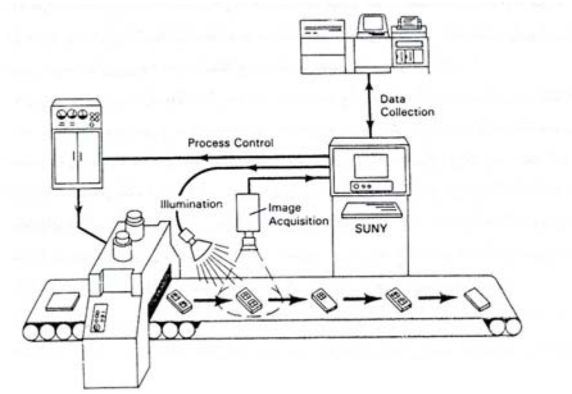

Fig1. A Typical Industrial Vision System

The offline programming system has progressed based on computer graphics in such away that a robot can be programmed without action to it [6].
In the shadow of this need a Puzzle Solver Robot is designed so it can solve different problems in industry.

2 Robot Design and Fabrication

As a new experience, this robot was made in order to be a image processing benchmark or use in different industries. Different functions of the robot include Mechanical system, electronic unit, and computer system (fig2).

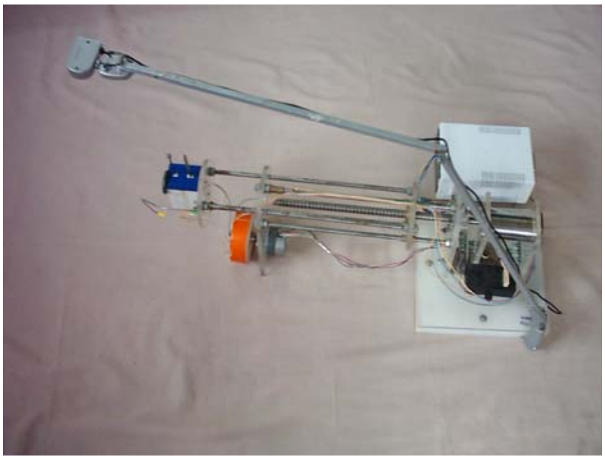

Fig2. PSR Picture

3 Mechanical System

The robot has a telescopic arm with a 3 degree of freedom (figure3).
Each point in the plane is addressed by polar system. The design of the robot is optimized using the mentioned addressing system. The power transmition of the robot uses a worm gear system.

A DC motor coupled with a gear box moves the arm (radius).

Rotation of arm (angle) is obtained by a stepper motor mounted on the arm. Puzzle pieces can be grabbed and handled by a magnet attached to arm.

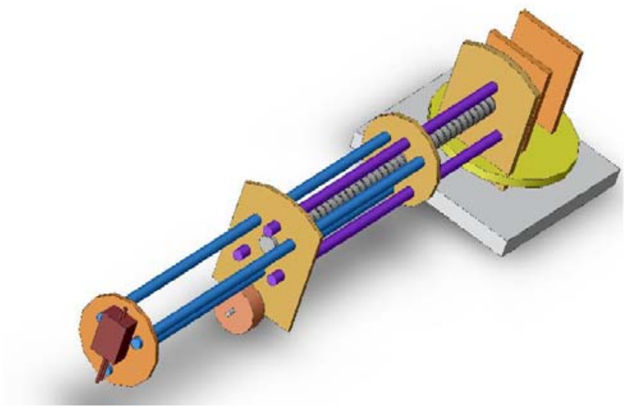

Fig3. PSR Schematic

The solid parts of robot are made of 8mm plaxy glass connected by aluminum rods.
The pivot arm is fixed in place by a heavy piece of polyethylene plate on which the control unit and the camera are installed.

4 Electronic Unit

As explained in the previous section, in total two DC motors and one stepper motor (200 steps) must be controlled. A computer is utilized for image processing and control of the robot. The control commands are issued through a printer port of the controlling computer.

The computer takes images by a web camera through USB. Based on the designed control algorithm, the necessary commands trough parallel port is passed to the interface.
The two controllers of DC motors provide left and right motor rotation. A powerful push-pull movement for controlling motors is provided. So the robot can withstand unpredictable loads.

In order to protect the pieces during handling, the speeding up of the puzzle pieces must be limited. This action is done by Pulse Width Modulation (PWM) wave. So, speeding up or down of the gripper is controllable.

It is necessary to allocate four bits to step motor, two bits for each drivers of DC motors and one for turning the magnet off and on.
So, in total nine controls bits are necessary. Also printer port is used to control circuit.

5 Computer Programming and Image Processing

The robot's control program is written by Delphi7 with a total of 1600 lines of programs. The Program's GUI is shown in figure 4.

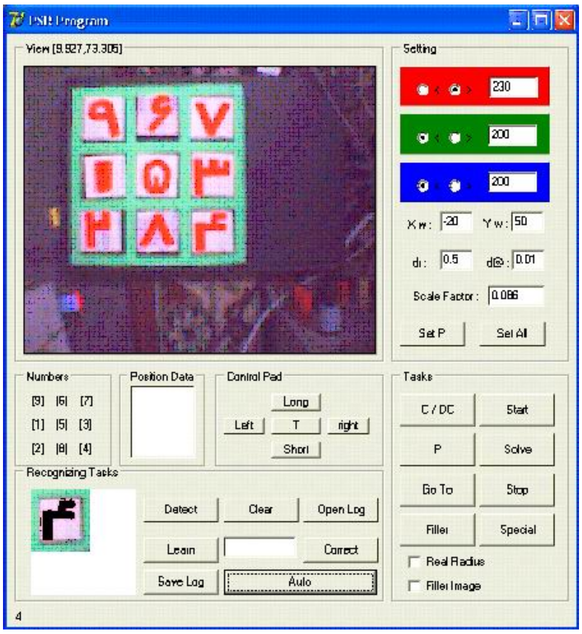

Fig4. The program's GUI

Different sections of the Program are as follows:

5.1 Device Driver

This section consists of sub-programs written in assembly language for hardware control and access to the printer port.

Note is made that Delphi has an internal assembler so; there is no need to link the main program to other control sections.

5.2 Image Capturing

To capture images Video for Windows (VFW) technique is used.

The Tscap32 component is used to get data from camera driver through VFW. This is a free component on the internet.

The images are given as 352*288 matrix in RGB format and pass to image processing section.

5.3 Image Processor

Figure5 shows a linear system model of a typical digital image processing system.

Transfer function of each component can be modeled analytically, determined experimentally, or taken from manufacturers' specifications.

The lenses, for example, can be assumed diffraction limited. The computer operation may or may not be linear, but this is the only subsystem in fig4 that is directly under the users' control [7].

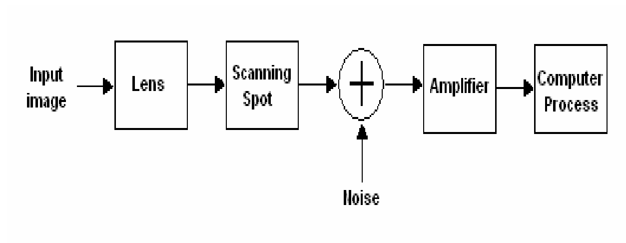

Fig5. The elements of an image processing system

Action related to position finding (TCP) and number recognition for solving the puzzle is done by processing images captured from the camera. The camera used here is a web cam with CMOS technology.

To recognize the image elements, we used a comparison method Between RGB values related to image pixels with the desired red values.

Each of the amounts of R, G and B for a singular pixel can be in the range of 0 and 255. In the beginning the program appropriate amounts of the filter parameters and their application must be given to the program according to a sample frame [8].

For example to identify the yellow color the amount of the R and G must be more than 200 and amount of B must be less than 150.

The color space of this process is shown in Figure6.

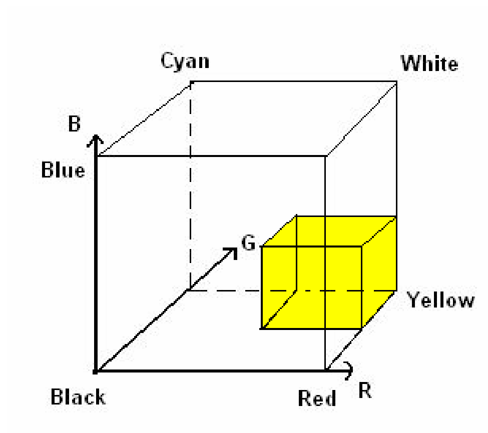

Fig6. Rectangular color space

Therefore, all the color filters are software type. After separating the puzzle, the position of each cell and the number in it, is calculated.

5.4 Low pass filter

In order to eliminate noises in the image, after separating it, based on RGB values the spots that are single and randomly distributed should be omitted.

These spots cause high frequencies in the signal of the image because the amounts of adjacent pixels are significantly different.

In fact, at first the associated number is separated from background, and then it is shown in a separate matrix together with noises, and pixels associated with the separated number are one and backgrounds pixels are zero.

Now we can apply convolution mask of low pass filter. As following:

$$\begin{bmatrix} 1/9 & 1/9 & 1/9 \\ 1/9 & 1/9 & 1/9 \\ 1/9 & 1/9 & 1/9 \end{bmatrix} = \text{LPF Mask}$$

This mask is actually a simple averaging filter. Of course it is possible to use filters with higher dimensions, but in that case processing time would increase.

In Fig7 the image is shown before and after applying low pass filter mask.

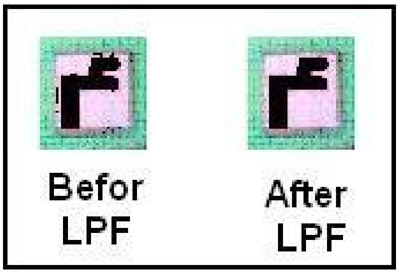

Fig7. Applying Low Pass Filter

5.4 Number recognition

Different patterns of Persian figures are shown in figure 8.

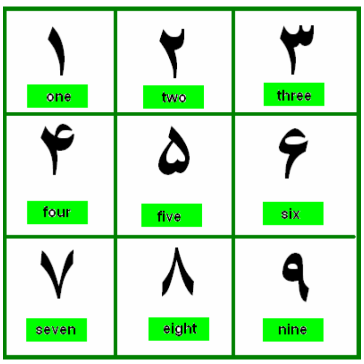

Fig8. Persian figures

After distinguishing the number from the background, the next step is to recognize them.

A novel algorithm is used to recognize numbers using Figure 9 (this is 3 in Persian form), this algorithm is described.

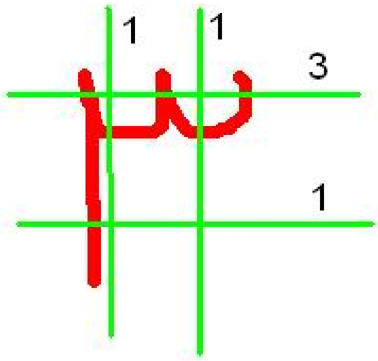

Fig9. Number Recognition Method

As observed in fig.6 the numbers of lines forming a number in different coordinate positions in the number plane are different. This is the key for number recognition in this algorithm. For example for number 3, the number of upper limes are 3, one lines on the bottom, one line on the left and one line on the right is used.

5.5 Puzzle Solving

After determining the order of numbers in puzzle, it is enough to use a free space in the plane for solving the puzzle.

For example, if (8) was not located on its place, we must move the number in the cell outward. After finding and placing number (3) on its place, the outside number moved and placed in the position of (3).

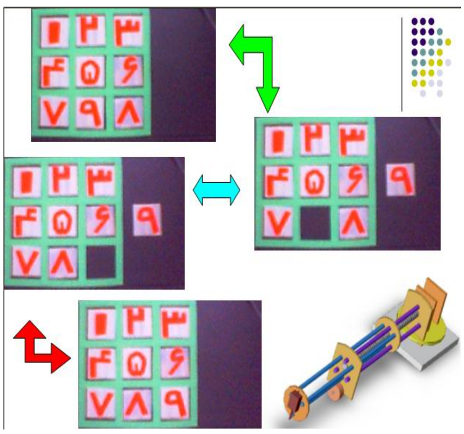

Fig10. Puzzle Solving Method

So after performing this action for several times, the puzzle will be solved. Figure 7 illustrates this algorithm (for replacing (8) and (9) to its certain place).

5.7 Controller

In figure11 a schematic diagram of image processing based close loop controller is illustrated

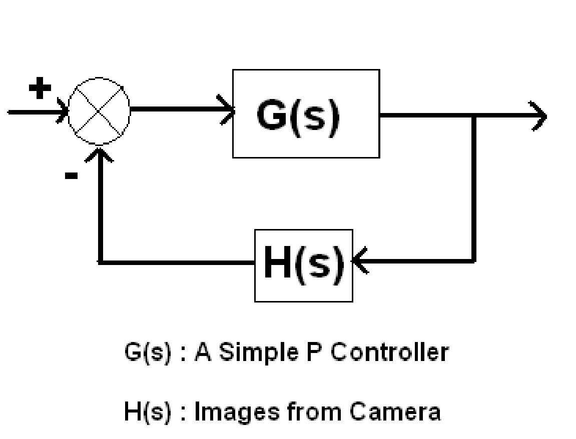

Fig11. Image processing based close loop controller

After number recognition and puzzle solving, all the action that the robot must do in order to organize the puzzle will be determined.

Based on the coordinate of each numbers in the system, this procedure is prepared in the form of a G-code like commands. So, the controller loop based on coordinates will change the position of cell.

The plane is swiped once to finalize TCP. Due to the different between the TCP color and its background, its position will be determined. Now the robot is ready to optimize the movement by considering the TCP point and the intended position. To do this, Firstly radius and then angle of the arm will increase or decrease to become equal to the optimum values of radius and angle.

6 Defining New Tasks

Solving a numerical puzzle doesn't have much application in industry, but robot's capability in employing image processing to solve the puzzle justifies its applicability.

For example, suppose that the robot is to select some components from different conveyor and place them on another conveyor.

In common methods, for proper performance of robot, it is necessary to define coordinates of conveyors for it and to create a method in order to recognize when parts should be grabbed by robot's end effector.

By utilising image processing, an algorithm is developed trough by using which camera can chase the component and whenever the component reaches to the point that end effector is able to catch it, robot grasps the component and moves it.

7 Conclusions

In this paper different part of an intelligent robot capable of solving puzzle is explained.
The coordination between different mechanical, electronics, and computer components, to meet a machine which can do various missions. In this respect, solving an unknown puzzle is considered intelligent. Utilization of image processing to feed a control loop in novel which shows the flexibility of the robot for necessary tasks.

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