

Visual Object Tracking and Interception in Industrial Settings

Ahmet Denker, and Tuğrul Adıgüzel

Abstract—This paper presents a solution for a robotic manipulation problem. We formulate the problem as combining target identification, tracking and interception. The task in our solution is sensing a target on a conveyor belt and then intercepting robot's end-effector at a convenient rendezvous point. We used an object recognition method which identifies the target and finds its position from visualized scene picture, then the robot system generates a solution for rendezvous problem using the target's initial position and belt velocity. The interception of the target and the end-effector is executed at a convenient rendezvous point along the target's calculated trajectory. Experimental results are obtained using a real platform with an industrial robot and a vision system over it.

Keywords—Object recognition, rendezvous planning, robotics.

I. INTRODUCTION

SEVERAL industrial applications aim to achieve sensing a target and reaching it for grasping. From the pioneering works of early seventies to the present day, efforts in combining vision and robotic applications are too numerous which can be found in literature [2,3,4,5]. Using a visual set-up, for robotic manipulation when working with targets whose position is unknown, provides substantial advantages to solve these problems [1]. A depiction of robotic manipulation platform utilizing visual system is shown in Fig.1.

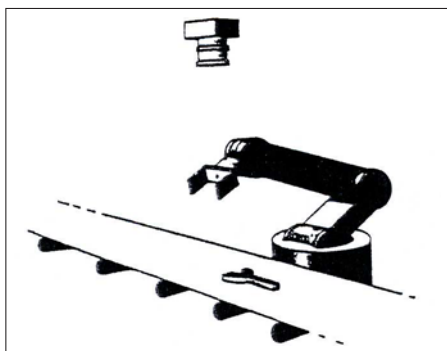


Fig. 1 Manipulation platform using vision system

The problem considered in this work is identifying a target object on a conveyor belt with a vision system, and planning a rendezvous between object and robotic manipulator. The approach to the problem can be split in two main parts as

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visual object identification and interception. The approaches for these considered problems will be presented in the following sections.

II. TARGET IDENTIFICATION

In this paper the proposed object recognition method utilizes corner information, which is obtained by using an 8-directional chain code, as features of the target object, and Kohonen's self organizing maps as classifier[6]. The method operates in three steps; pre-processing, feature extraction and classifying.

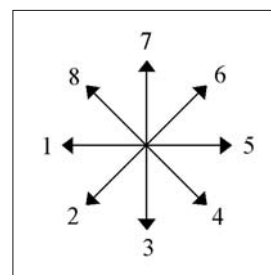


Fig. 2 8-directional chain code

Firstly, edge detection process is applied to the object's captured image and edge information is encoded in accordance with 8-directional chain code as shown in Fig.2. This code is obtained by determining the direction and number of 1's in a binary image. The chain code vector, $\mathbf{c} = [c_1, c_2, \dots, c_n]$, is subjected to two transformations to obtain a new vector \mathbf{d} , which carries information that is independent of rotation and size. The following two transformation algorithms are implemented to obtain \mathbf{d} from \mathbf{c} .

Algorithm 1: [First transformation]

```

for i=1 to n
    if  $c_i = c_{i+1}$  then  $c_{i+1} = 0$ 
    else  $c_{i+1} = c_{i+1} - c_i$ 
end
    
```

Algorithm 2: [Second transformation]

```

j=0, k=0
for i=1 to n
    if  $c_i \neq 0$  then  $k = k + c_i$ 
    if  $c_{i+i} \neq 0$  and  $k \neq 0$  then  $j = j + 1$ 
     $d_j = k$ 
     $k = 0$ 
end
    
```

Using **c** and **d** vectors, a characteristic vector **v** with eight elements for each object class, is obtained.

$$\mathbf{v} = [v_0, v_1, v_2, \dots, v_7]. \quad (1)$$

The elements of the characteristic vector have the following definitions.

- v_0 : number of corners,
- v_1 : ratio of the longest side to the shortest side, rounded off to integer,
- v_2 : number of angles between 0 and 45 degrees,
- v_3 : number of angles between 46 and 90 degrees,
- v_4 : number of angles between 91 and 135 degrees,
- v_5 : number of angles between 0 and -45 degrees,
- v_6 : number of angles between -46 and -90 degrees,
- v_7 : number of angles between -91 and -135 degrees.

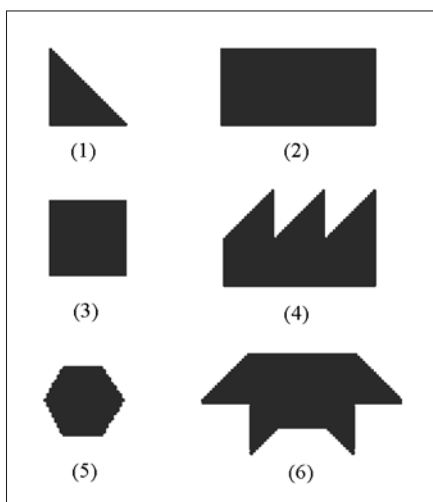


Fig. 3 Object classes to be recognized

The characteristic vector obtained this way is used as the input to the self organizing map. The characteristic vectors, for the objects used for training in Fig.3, are in the following table.

TABLE I
CHARACTERISTIC VECTORS ASSIGNED TO OBJECTS

Object No.	Characteristic Vector
1	[3,2,0,1,2,0,0,0]
2	[4,2,0,4,0,0,0,0]
3	[4,1,0,4,0,0,0,0]
4	[6,2,0,6,0,0,0,0]
5	[6,4,1,3,1,0,1,0]
6	[8,3,1,2,3,0,0,2]

The cells of the network are tuned to various input signals through learning process. The spatial location of a cell in the network then corresponds to a particular object. The magnitude of the similarity between the input signal and the cell provides information about the object.

Self organizing network is trained to recognize the features by using the following algorithm.

Algorithm 3: [Training]

Step 1. Attribute a random weighting vector to each node. Set up a radius for neighbourhood.

Step 2. Apply the input characteristic vector.

Step 3. Use the following formula to calculate the Euclidean distance d_j between the input vector and each output vector j .
 $d_j = \sum_{i=1}^N (x_i(t) - m_{ij}(t))^2$ where N is the number of nodes, $x_i(t)$ is the characteristic vector of the i^{th} object at time t , $m_{ij}(t)$ is the weighting vector of the j^{th} node under the i^{th} input and at time t .

Step 4. Choose the node j which has the minimum d_j .

Step 5. Update the weighting vectors of the node j and its neighbours, in the neighbourhood N_j . Using a gain term $\alpha(t)$ which is selected as $(0 < \alpha < 1)$ and decreases in time

$$m_i(t+1) = m_i(t) + \alpha(t)[x_i(t) - m_i(t)] \forall i \in N_j(t)$$

$$m_i(t+1) = m_i(t) \forall i \notin N_j(t)$$

Step 6. Repeat by going to Step 2 until the termination conditions are satisfied. After training using this scheme, the system has been particularly successful in recognizing the object of interest in cluttered environments.

III. ROBOTIC INTERCEPTION

After identifying the target object and obtaining its initial location by using visual system, the second phase of this study is executing robotic interception process at a convenient rendezvous point. For intercepting objects traveling along predictable trajectories, Prediction, Planning and Execution (PPE) methods are well suited [7]. In a PPE strategy, the motion of an object through a robot's workspace is predicted. Robot motion to intercept the object is then planned and executed [8]. Here, the solution to the rendezvous problem is considered on planar coordinates. The initial position of the target is determined by visual system. The target is moving along with conveyor at a constant speed and robot manipulator is at a location over the conveyor belt, thus movement at third direction can be omitted. Under definite initial conditions of the manipulator and the target, trajectory for robotic interception at a rendezvous point on the conveyor is planned and analytically calculated.

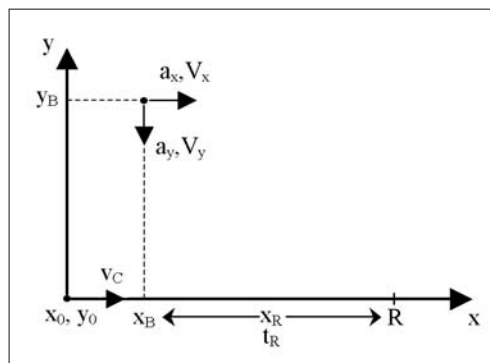


Fig. 4 2-D reference diagram

The initial position of end-effector (x_B, y_B), visualized target position located as the origin(x_0, y_0), and planned rendezvous point (R) are shown in Fig.4.

V_c, V_x, V_y and t_R denote speed of the target, end-effector's average speed on x and y directions, and time required for the end-effector to arrive to the rendezvous point, respectively.

$$t_R = \frac{y_B}{V_y} \quad (2)$$

$$\begin{aligned} x_R &= V_x t_R \\ x_B + x_R &= V_c t_R \\ x_R &= V_c t_R - x_B \\ \frac{V_x}{V_y} y_B &= V_c \frac{y_B}{V_y} - x_B \\ V_x &= V_c - x_B \frac{V_y}{y_B} \end{aligned} \quad (3)$$

V_y determines both of the V_x and rendezvous time, thus firstly V_y is determined utilizing the velocity diagram in Fig.5.

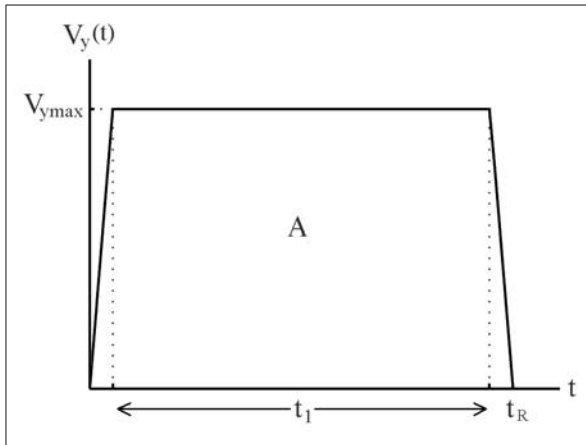


Fig. 5 V_y velocity diagram

Selected acceleration(a) and maximum velocity (V_{ymax}) values determine the variation characteristic of the velocity(V_y). The motion of the end-effector will be determined by using the velocity values. The velocity(V_y) can be formulated as follows:

$$A = y_B$$

$$t_1 = \frac{y_B}{V_y} - \frac{2V_{ymax}}{a}$$

$$\begin{aligned} y_B &= \frac{V_{ymax}^2}{a} + \left(\frac{y_B}{V_y} + \frac{2V_{ymax}}{a} \right) V_{ymax} \\ V_y &= \frac{a y_B V_{ymax}}{a y_B + V_{ymax}^2} \end{aligned} \quad (4)$$

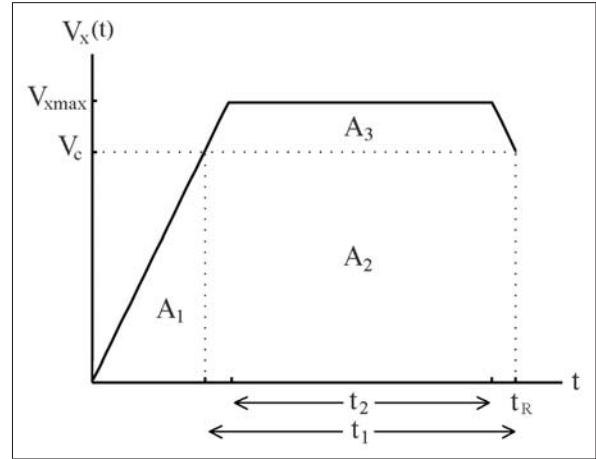


Fig. 6 V_x velocity diagram

Motion of the end-effector on x-direction will be formulated by using Fig.6 as follows:

$$\begin{aligned} x_R &= A_1 + A_2 + A_3 \\ x_R &= \frac{1}{2} \frac{V_c^2}{a} + V_c t_R - \frac{V_c^2}{a} + \\ &\quad \left(t_R - \frac{2V_{xmax}}{a} + \frac{V_c}{a} \right) (V_{xmax} - V_c) + \\ &\quad \frac{(V_{xmax} - V_c)^2}{a} \\ x_R &= -\frac{1}{2} \frac{V_c^2}{a} + V_{xmax} \left(\frac{y_B}{V_y} \right) - \\ &\quad \left(\frac{V_{xmax}}{a} \right) (V_{xmax} - V_c) \end{aligned} \quad (5)$$

Utilizing the position on x-direction equation above, V_{xmax} will be expressed with a and V_y variables. Position equation on x-direction can be expressed as below:

$$x_R = V_c \frac{y_B}{V_y} - x_B,$$

using equation above;

$$V_{xmax} = \frac{-k_1 \pm \sqrt{k_1^2 - 4k_2}}{2} \quad (6)$$

where

$$\begin{aligned} k_1 &= -V_c \\ k_2 &= a \left(V_c \frac{y_B}{V_y} - x_B \right) + \frac{V_c^2}{2} - V_{xmax} \left(\frac{y_B}{V_y} \right). \end{aligned}$$

End-effector's equations of motion on x direction at any time t can be found as below:

$$x = \frac{1}{2}at^2$$

$$t \leq t_1$$

$$x = \frac{1}{2} \frac{V_{xmax}^2}{a} + (t - t_1) V_{xmax}$$

$$t_1 < t \leq t_2$$

$$x = \frac{1}{2} \frac{V_{xmax}^2}{a} + V_{xmax} (t_2 - t_1) + \left[V_{xmax} - \frac{a\Delta t}{2} \right] \Delta t$$

$$t_2 < t \leq t_R$$

where

$$t_1 = \frac{V_{xmax}}{a}$$

$$t_2 = t_R - \left(\frac{V_{xmax} - V_c}{a} \right)$$

$$\Delta t = t - t_2.$$

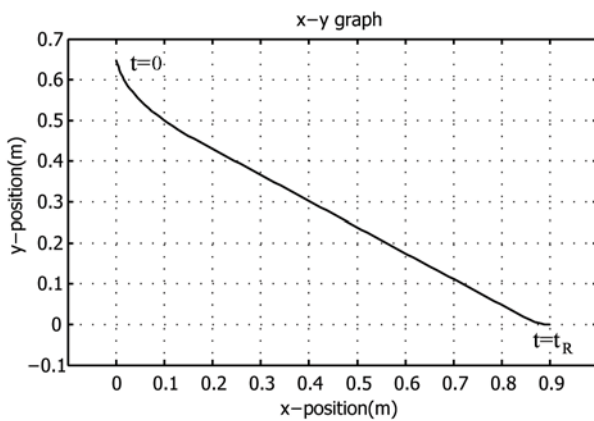


Fig. 7 Simulated end-effector's trajectory

IV. EXPERIMENTAL RESULTS

The resulting planned trajectory obtained by using computer simulation can be seen in Fig.7. The application platform consists of a conveyor, a vision system and a robotic manipulator. Object recognition algorithms and the calculations for the planned trajectory are tested by using this platform. Captured Image of interception with the target object is displayed in Fig.8.

V. CONCLUSION

In this paper we have addressed an assemblage of visual object recognition and rendezvous planning problems for a robotic manipulation system. The objective was to identify a target on a conveyor belt and plan a convenient trajectory for robotic interception and execute these on a real platform. The results of this study shows the potential of using robotic vision for industrial purposes.

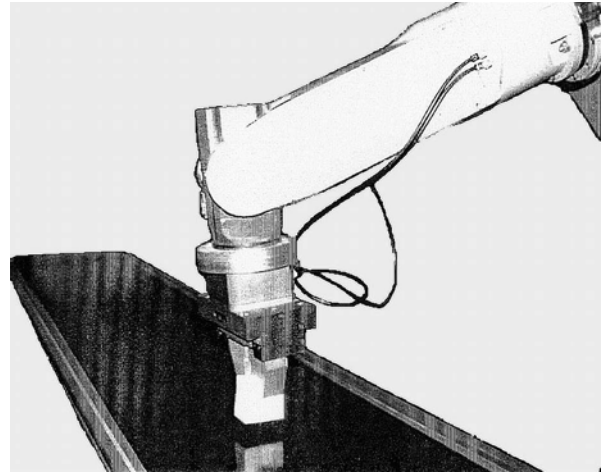


Fig. 8 Implemented robotic interception by using a real platform

REFERENCES

- [1] P.I. Corke, *Visual Control of Robot Manipulators—A Review*, in *Visual Servoing*, edited by K. Hashimoto. World Scientific: Singapore, 1993.
- [2] Y. Shirai and H. Inoue, "Guiding a robot by visual feedback in assembling tasks," *Pattern Recognition*, vol.5, pp.99–108, 1973.
- [3] M. Sitti, M. Ertugrul and A. Denker, "Coordination of two robots using visual feedback," *In Proc. of Int. Conf. on Recent Advances in Mechatronics*, Istanbul, Turkey, 1995, pp.615-620.
- [4] S. Hutchinson, G.D. Hager and P.I. Corke, "A tutorial on visual servo control," *IEEE Trans. on Robot. Autom.*, vol.12, pp.651–670, 1996.
- [5] T. Borangiu, "Visual conveyor tracking for "pick-on-the-fly" robot motion control," *7th International Workshop on Advanced Motion Control*, Maribor, Slovenia, 2002, pp.353–358.
- [6] T. Kohonen, "The self-organizing map," *Proc. of the IEEE*, 78(9), pp.1464–1480, 1990.
- [7] M. Mehrandezh, N.M. Sela, R.G. Fenton and B. Benhabib, "Robotic interception of moving objects using an augmented ideal proportional navigation guidance technique," *IEEE Transactions on Systems, Man and Cybernetics*, vol.30, pp.238–250, 2000.
- [8] D. Hujic, E. Croft, G. Zak, R.G. Fenton, J.K. Mills and B. Benhabib, "The robotic interception of moving objects in industrial settings: strategy development and experiment," *IEEE/ASME Transactions on Mechatronics*, vol.3, pp.225–239, 1998.

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