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A Method of Resolving an Entangled Cord

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Abstract

We often see entangled cords in our daily life. Entangled cords need to be resolved and put in order to handle them conveniently or to keep their quality in a good situation. In order to resolve an entangled cord, mutual relation must be made clear in advance among areas of the cord. In this paper, a technique is presented for analyzing mutual connection among the areas of an entangled cord. A given image of a cord is separated into cord areas and each of the areas is represented by a list of edge pixels. The lists are analyzed to find a unique path from one end of a given cord to the other end. Experimental results employing real cord images are shown.

1. Introduction

We often come across entangled cords or knots of a cord in our daily life. Knots are usually made with a purpose, whereas cords are unexpectedly entangled which may cause inconvenience in handling. When we come to the idea that it is almost our routine to untie knots or put entangled cords in order, this ability should as well be implemented on a future intelligent robot. In spite of its importance, however, automatic entangled cord analysis has not yet been dealt with in image analysis. A computer graphical approach is seen in [1] which shows a way of undoing a cord visually on a display and not of analyzing how it is connected as a whole. A method employing consistent labeling is reported [2,3]. They employ dis-connection relation among cord areas and represent it in terms of a consistent labeling problem to find a solution.

In order to resolve an entangled cord, mutual relation must be made clear in advance among areas of the cord. In the technique proposed here, a given image of an entangled cord is separated into each cord area and the cord area is described by a list of the pixels which compose the edge of the cord area. Employing the lists, the given entangled cord is analyzed to find a unique path from one end of the cord to the other end. Performance of the proposed technique is experimentally evaluated.

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2. Definitions and Assumptions

Some definitions and assumptions are given. Suppose a line drawing of a cord is given as shown in Fig.1(a). Each distinct area separated by edges of the cord is called *a cord area* and given a label $C_\lambda(\lambda$=a, b, c, ..., l). The background is also given a label C_{bg}. They are also called *a cord label* and *a background label*, respectively. The entire image with labeled cord areas are called *a labeled cord image*.

When three cord areas meet at a position as shown in Fig.1(b), the position is called *a cross point*. By tracing edges on a cord, *junctions* having three labels around it (such as J_i and K_i) are known. The two junctions are also called *a junctions pair*. They are referred to as a pair because they bound a series of pixels on the edge shared by two cord areas. This series of pixels are called *common edge pixels*.

The followings are assumed in the procedure:

(i) A single cord with width $W(W>0)$ is considered;

(ii) The degree of each cross point is two, *i.e.* a cord crosses itself only once at an identical position;

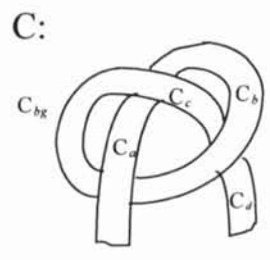
(iii) For angle θ which two cord segments make at a cross point, $\theta_0 \le \theta \le \pi/2$, where θ_0 is a positive constant.

3. Method

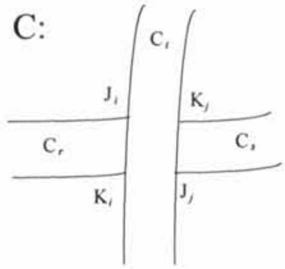
The entire procedure is composed of two main parts. An acquired image is processed in the first part to yield an edge image and the image is separated into cord areas and the background area by tracing the edges. They are also given labels and a labeled cord image is obtained. Each cord area of the labeled cord image is represented by a list of successive edge pixels.

In the second part, all junctions pairs are extracted by tracing edges of cord areas. Every pair of the junctions pairs are examined their match to find partners such as [Ji, Ki] and [Jj, Kj] in Fig.1(b) to recover continuity of the cord.

This proceeds in the following way.



(a)



(b)

Fig.1 Cord areas and junctions

A cord C is composed of cord areas $C_{\lambda_i}(i=1,2,\ldots,n)$. A cord area C_t is represented by list L_t using pixels $P_{t_i}(i=1,2,\ldots,n_t)$ on its edge. It is simply written as

$$C_t = \left(P_{t1}, P_{t2}, \ldots, P_{tn_t}\right).$$

List L_t is an array. It contains these series of edge pixels and their labels.

Two pixels $P_{t,1+k}\left(k=0,1,2,\ldots,[n_t/2]\right)$ and $P_{t,[n_t/2]+1+k}$ are chosen to calculate cord width W_t of cord area C_t by

$$W_t = \min_k d\left(P_{t,1+k}, P_{t,[n_t/2]+1+k}\right),$$

where $d(p,q)$ gives the Euclid distance between pixels p and q on an image and $[x]$ is an integer not more than a real number x. The cord width W is then defined by

$$W = \sum_t W_t / n \ .$$

Junctions are known as those pixels which have three labels around itself. This can be easily found on list L_t. For two arbitrary junctions pairs (Ji, Ki) and (Jj, Kj), following vectors are defined;

$$v_{JK} = vector(J_i K_j), \ \ v_{KJ} = vector(K_i J_j) \ .$$

Cord width is examined first by

$$W - \varepsilon_1 \le (v_{JK} + v_{KJ})/2 \le W/\sin\theta_0 + \varepsilon_2 \ . \quad (1)$$

Here ε_1 and ε_2 are small positive constants.

Similarity of v_{JK} and v_{KJ} are evaluated by

$$\begin{aligned} &\left|\|v_{JK}\| - \|v_{KJ}\|\right| < \varepsilon_3, \\ &\left|1 - (v_{JK}, v_{KJ}) / \|v_{JK}\| \times \|v_{KJ}\|\right| < \varepsilon_4 \ . \end{aligned} \quad (2)$$

Here ε_3 and ε_4 are small positive constants.

A pair of junctions pair (Ji, Ki) and (Jj, Kj) satisfying Eqs.(1,2) are regarded as those pairs corresponding each other at a cross point.

Now suppose (Ji, Ki) is shared by cord areas C_r

and C_t, and (J_j, K_j) by C_s and C_t as shown in Fig.1(b). Since J_i connects to K_j and K_i to J_j, J_i stores information that it connects to K_j of C_s in the form of (K_j, C_s). In the same way, K_i stores (J_j, C_s). Moreover all the common edge pixels between J_i and K_i are eliminated on list L_r. Note that a common edge pixel is known as the pixel having two cord labels and no background label around itself. The same procedure is done with respect to J_j and K_j as well. It is natural that some junctions pairs remain unpaired.

Finally the edges on cord C is traced using the above correspondence information to yield a single closed line which gives a unique path from one end of given entangled cord C to the other end.

The entire procedure is shown in Fig.2.

4. Results

An entangled cord placed on a table is photographed four times employing illumination from four different direction. The images are preprocessed to yield respective edge images, which are merged into a single edge image.

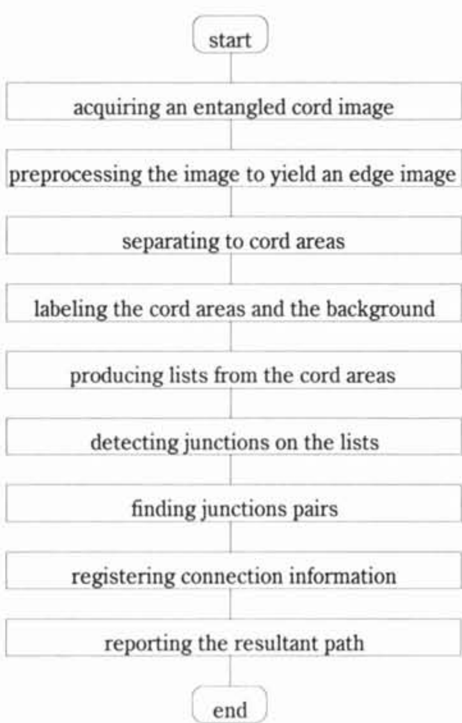


Fig.2 Flow of the entire procedure

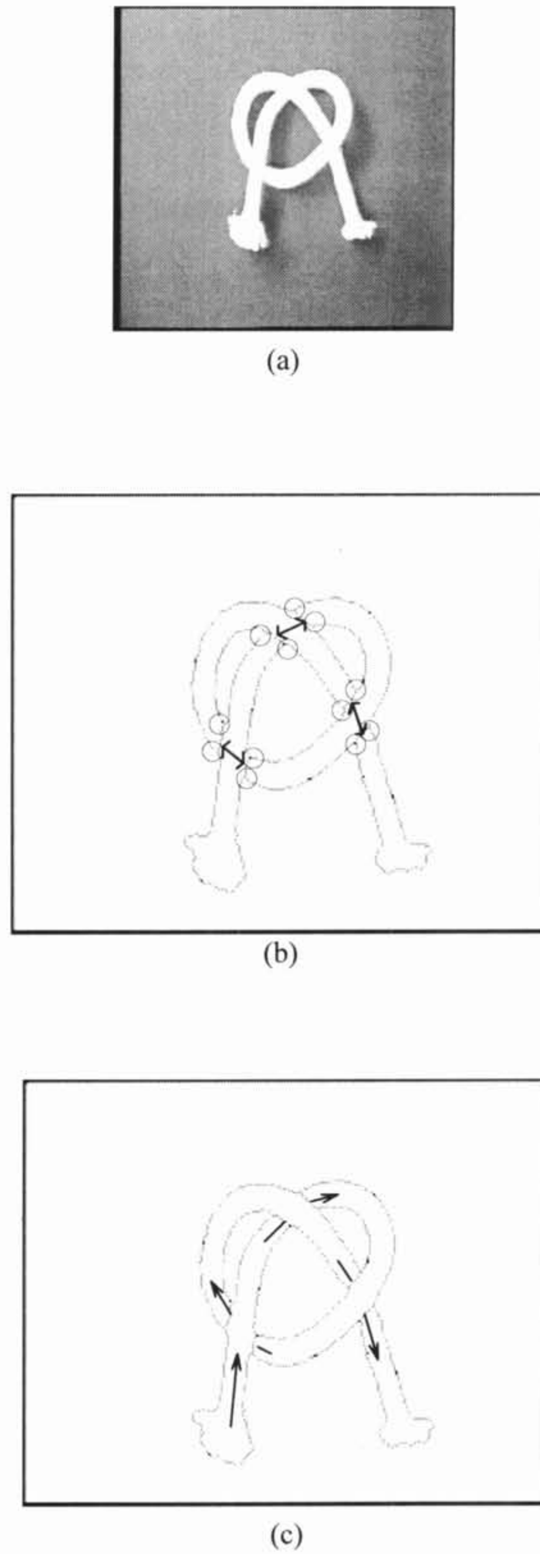


Fig.3 Results: (a) an original image, (b) the edge image with detected junctions, and (c) the resultant path

Results are shown in Fig.3. Fig.3(a) is an original gray scale image and (b) is the edge image with detected junctions where judged pairs are depicted by arrows. Finally the recognized path is given in (c).

5. Discussion

As the result of having applied the proposed technique to entangled cord images, satisfactory results were obtained with loosely entangled cord images. Since there are several particular situations with the figure of even loose entanglement of cords, further refinement with the technique may be necessary in order to take account of them. Application of the technique to more firmly entangled cords is another issue to be investigated.

An immediate use of this study may include recognizing and undoing cord entanglement by a hand-eye system. It may also have potential application to some medical image analysis such as recognition of angiographic images or abdominal intestines images.

6. Conclusion

A technique was proposed for recognizing an entangled cord for the purpose of undoing it. A cord image was represented by lists of edge pixels and the junctions pairs were searched on the lists. A path from one end of the cord to the other end was reported as the result of the analysis. Experimental results were satisfactory. Some more refinements with the technique need to be done to handle with variety of the cord entanglement.

References

[1] Saito, T., Yokoi, S., Toriwaki, J.:"Topology of the 3D digital line figure — an analysis of knot", Technical Report of IEICE, PRU90-83,15-22(1990). (in Japanese)

[2] Nogami, Y., Ishikawa, S., Kato, K.:"On analyzing connection of cords", Proc. of 1995 Joint Conf. of Electrical and Electronics Engineers in Kyushu, 683(1995). (in Japanese)

[3] Nogami, Y., Ishikawa,S., Kato,K.:"Analyzing connection of cords by consistent labeling", Proc. of 14th SICE Kyushu Branch Annual Conference, 425-426(1995). (in Japanese)