Proceedings of the 11th
KACC, October 1996

RESOLVING AN ENTANGLED CORD BY CONSISTENT LABELING

○Yuyo NOGAMI*, Seiji ISHIKAWA**, Kiyoshi KATO*

*Kyushu Institute of Technology
Department of Electric, Electronic and Computer Enginnering
Sensuicho 1-1, Tobata, Kitakyushu 804, JAPAN
Tel: (+81) 93 884 3208, Fax: (+81) 93 871 5835, E-mail: nogami@ishi.comp.kyutech.ac.jp

**Kyushu Institute of Technology
Department of Civil, Mechanical and Control Engineering
Sensuicho 1-1, Tobata, Kitakyushu 804, JAPAN
Tel: (+81) 93 884 3183, Fax: (+81) 93 861 1159

Abstract This paper proposes a technique for analyzing mutual relation of an entangled cord by consistent labeling. Cords are often entangled unexpectedly and sometimes they even produce knots. The purpose of this study is to provide an algorithm to resolve such entangled cords automatically. It may as well have applications in future to recognizing the structure of tree branches, angiography, abdominal intestines, etc.

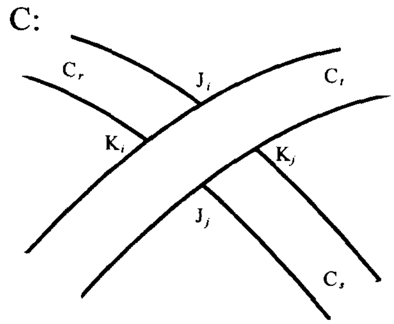
Keywords cords, knots, image processing, consistent labeling

1. INTRODUCTION

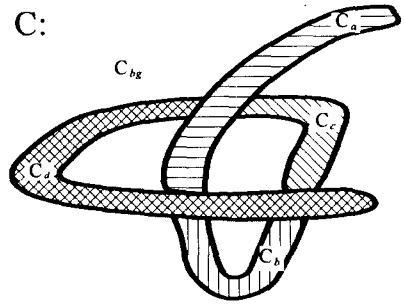
Entangled cords or knots of cords are physical phenomena often observed in our life. Since man is often aslced to make entangled cords in order or to undo knots, these abilities should as well be possessed by a future intelligent robot which may deal with various jobs in a flexible manner. In spite of its importance, automatic entangled cords analysis has not yet been tackled by the reserchers in the image analysis field. In this paper, a technique is proposed for analyzing mutual relation of an entangled cord by consistent labeling[1]. A given cord is separated into several regions on its edge image and assigned labels. Connection and separation among these regions are analyzed and described in terms of consistent labeling[2]. Solutions of the consistent labeling problem give candidate connection orders[3].

2. DEFINITIONS AND ASSUMPTIONS

Some definitions are given here. In Fig.1(a), the cord location where two cord segments cross



(a)



(b)

Fig.1 Junctions and cord areas

each other is called *a cross point*. By tracing edges on a cord, *junctions* such as J_i and K_i are found. They are called *a junctions pair*. A series of pixels between this junctions pair are called *common edge pixels*, since they are shared by the region of one side and that of the other side of the pixel series. Junctions are the first and the last pixel of the common edge pixels.

The areas surrounded by cord edges are given labels C_λ (λ=a, b, c, ..., l) as well as the background C_{bg}(See Fig.1(b)). This image is called *a labeled cord image* and each of the labeled areas *a cord area.*

The following assumptions are given to the procedure:

(a) A single cord with a certain width is taken into account;
(b) A cord crosses itself only once at the same position, in other words, the degree of each cross is two;
(c) Each cross is mutually separated at least twice of the cord width;
(d) The angle which two cords make at a cross point is larger than a certain threshold value.

3. METHOD

The whole procedure is devided into two main parts (See Fig.2). In the first part, the gray image of a cord is differenciated, binalized, and thinned to yield a line drawing image of the cord. The areas surrounded by the cord edge is then given labels as well as the background to yield a labeled cord image.

In the second part, local connection/disconnection information between adjacent areas is extracted from the labeled cord image and the information is described in terms of a consistent labeling problem. By solving the consistent labeling problem by tree search, candidates for possible link relation among the areas on the cord are obtained.

The second part proceeds in detail in the following way:

(i) Each single labeled area on a cord is represented in a list of successive pixels which compose its edge;
(ii) The positions where two cord parts cross are extracted on the list of pixels by looking for the pixels that are shared by two cord areas;
(iii) The cord area is separated into three subareas at each cross.

Connection/disconnection information between two areas/subareas on the cord is obtained from the following criteria:

(1) If two areas/subareas share common pixels on their edges, they are disconnected.
(2) Successive subareas are connected.

The first disconnection relation is transformed into connection relation and merged into the second information so as to be described as a consistent labeling problem. Actually the above information is written in the form of unit-label constraint relation in which 'unit' is an order of labels and 'label' is the labels assigned to cord areas.

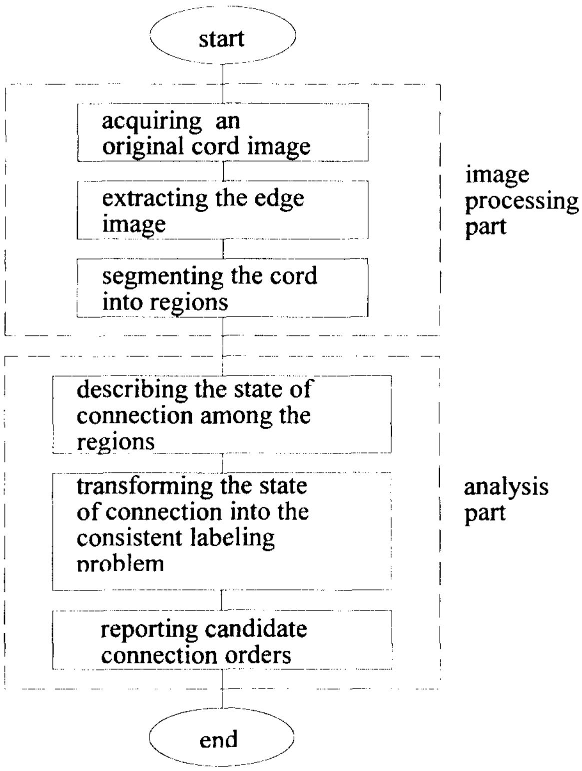


Fig.2 Flow of the analysis

4.EXPERIMENT

An experiment is performed employing real cord images. Figure 3 shows the original cord image and its respective image processing stages. The original cord given in Fig.3(a) is illuminated from four different directions and the four images of the different contrast are taken by a fixed video camera. Each of the images are applied Gaussian Laplacian filter to extract cord edges and the four edge images are merged into a single edge image as shown in Fig.3(b). The edge image is thinned and given labels as shown in Fig.3(c).

Employing aformentiond connection/dis-connection criterion (1), following disconnection relation is obtained from the labeled cord image (Fig.3(c));

$$\begin{array}{l} \neg(a,b2),\neg(a,c1),\neg(a,c2),\\ \neg(b1,c1),\neg(b1,c2),\neg(b1,d),\\ \neg(b2,a),\neg(b2,c2),\neg(b2,d),\\ \neg(c1,a),\neg(c1,b1),\\ \neg(c2,a),\neg(c2,b1),\neg(c2,b2),\\ \neg(d,b1),\neg(d,b2) \end{array} \quad (1)$$

Here ¬(p,q) represents that p is not connected to q.

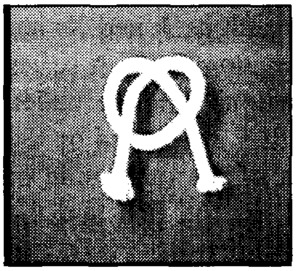
The above dissconnection relation (1) is then rewritten into connection relation, which yields

$$\begin{array}{l} R : \{ (a,b1),(a,d),\\ \quad (b1,a),(b1,b2),\\ \quad (b2,b1),(b2,c1),\\ \quad (c1,b2),(c1,c2),(c1,d),\\ \quad (c2,c1),(c2,d),\\ \quad (d,a),(d,c1),(d,c2) \} \end{array} \quad (2)$$

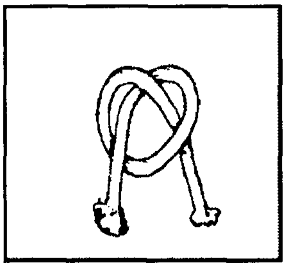
This provides the unit-label constraint relation and, by solving thisemploying tree search, the solution

a-b1-b2-c1-c2-d

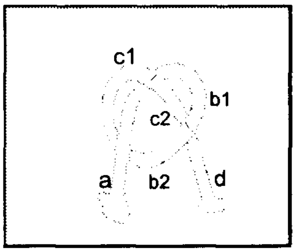
is obtained, which gives an exact path from one end to the other end of the cord. Note that p-q means the area labeled p is connected to the area labeled q in this order.



(a) Original image

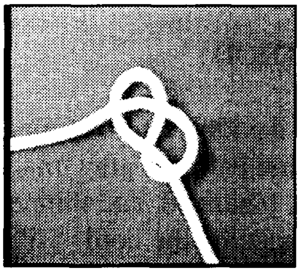


(b) Edge image

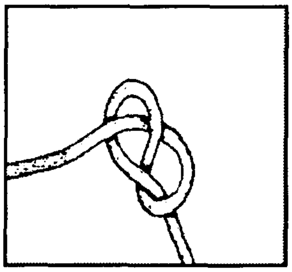


(c) Label image

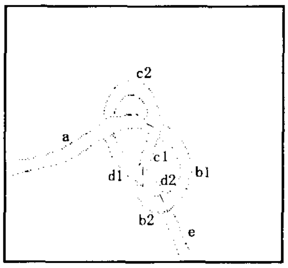
Fig.3 Cord image 1.



(a) Original image



(b) Edge image



(c) Label image

Fig.4 Cord image 2.

Another experimental result can be seen in Fig.4. In the same way as in Fig.3, Fig4(a) is the original image, (b) is its edge detected image, and (c) is the labeled image. In this case, the unit-label constraint relation is given by

R : { (a,b1),(a,b2),(a,d2),(a,e),
(b1,a),(b1,b2),(b1,d1),
(b2,a),(b2,b1),(b2,c1),(b2,c2),
(c1,b2),(c1,c2),(c1,e),
(c2,b2),(c2,c1),(c2,d1),(c2,d2),(c2,e),
(d1,b1),(d1,c2),(d1,d2),(d1,e),
(d2,a),(d2,c2),(d2,d1),(d2,e),
(e,a),(e,c1),(e,c2),(e,d1),(e,d2) } ,

and its solutions are

a-b1-b2-c1-c2-d1-d2-e
a-b1-b2-c1-c2-d2-d1-e
a-b2-b1-d1-d2-c2-c1-e
a-d2-d1-b1-b2-c1-c2-e
a-d2-d1-b2-b1-c2-c1-e .

Although the solutions are not unique, they contain the exact solution a-b1-b2-c1-c2-d1-d2-e.

5.DISCUSSION

As the result of having applied the proposed technique to real cord images, the exact solution was obtained for the first image (Fig.3(a)), where as candidate solutions were reported for the second image (Fig.4(a)). Since only two criteria are employed for analyzing connection/dis-connection relation, the size of R is still large which may cause a set of solutions.

Employment of some other heuristics is within the scope of our study such as smoothress of edges at junctions or the minimum length of the connected path. The former contributes to reducing the size of R, while the latter may be able to choose a single solution which satisfies the criterion.

One of the immediate applications of this study is to recognize and resolve entangled cords by a manipulator (or manipulators). A hand-eye system employing this technique might even untie knots of a cord in future. Other applications may include recognizing the structure of tree branches, and, as for medical image understanding, recognition of an-giographic images and abdominal intestines images.

6.CONCLUTION

A technique was proposed for analyzing the connection relation of an entangled cord by consistent labeling. Performance of the technique was shown by experiment employing real cord images. Although the consistent labeling can find a correct solution, further heuristics need be emloyed in the technique in order to speed up the serch for finding a single solution.

REFERENCES

[1]Haralick. R.M., Shapiro. L.G.:"The consistent labeling problem: Part1", IEEE Trans. Pattern Anal. Machine Intell., PAMI-1, 2, 173-184(1979).

[2]Nogami. Y., Ishikawa. S., Kato. K.: "Considering about analyzing connection of cords", Record of 1995 joint conference 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", The 14th SICE Kyushu Branch Annual Conference, 425-426(1995). (in Japanese)