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Object's Orientation and Motion for Scene Understanding

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Abstract

Here in the present paper, A methodology for understanding scenes which includes moving objects in it, in the framework of notion of concepts. First by conceptualizing, understanding an object which is an element of a scene will be described. Then how to know the direction to which that object is heading will be discussed. Further, the methodology proposed, for understanding conceptually the motion of an object will be described utilizing the above knowledge of direction.

1.Introduction

Smooth communication between humans is possible by sharing the same context in the level of image with each other. So many an event are experienced by a human, and by making an image of an event, a human can posses concepts in a systematic manner. In a man-machine system, by introducing such a system that utilizes concepts and a way for concept formation to an interface which bridges human and a machine(s) makes the man-machine system free from skill (less human load).[1] There are visual and auditory information, etc. for humans sensation. Visual information will be conceptualized, and a way for understanding motions of conceptualized images.

2.Image Processing

Visual information needs memorizing in some compact manner. Making an image of an object will be desribed, first. To make an image here is to extract features of an object as figure, and that figure's outline will be employed. This procedure is broken down into two part. The first procedure is preliminary processing for feature extraction; tracing contour and then linearizing. The second part is categorization which follows the linearization.

2.1 Preliminary Processing

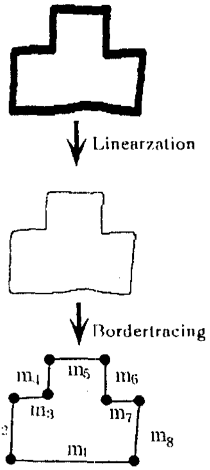


Fig.1 Feature extraction of figure

Tracing contour is to follow the edge of an object's contour as a closed line. The closed line obtained by this procedure is linearized. Linearization decomposes the original closed line into a set of line segments. This set of line segments together with the successive-connection relation "Line segment x lies next to Line segment y." is a totally ordered set M with respect to that successive-connection relation. This is shown schematically in Fig.1.

$$M = \{ m_i \mid i = 1, 2,.. 8 \} \cdots(1)$$

Each m_i denotes a line segment which is a member of linearized contour, and it is a line segment from the node i to the node i+1. Thus a totally ordered set M is obtained.

2.2 Categorization

On the totally ordered set M obtained for a specific object, features of that figure is extracted, by using various relations. Relations to be employed here are successive-connection relation from m_i to m_{i+1}, satate-of-connection relation (concave-convex relation), and relation of connection angle. [2,3]

2.2.1 Representation Matrices of Relations

a)Representation matrix for connection relation Let R_c on the set M denote the relation " m_{i+1} is next to m_i." The arrangement of line segments which constitutes the linearized contour of an object can be described by this relation R_c, where $1 \leqq i,j \leqq n$, $i \neq j$; n is the number of line segments. Checking whether $m_iR_cm_j$ or $m_i\tilde{R}_cm_j$ with respect to every pair of the set M determines the representation matrix $P_c=(M,R_c)$. This representation matrix P_c consists of c and blank as its (i,j)-elements according to whether $m_iR_cm_j$ or $m_i\tilde{R}_cm_j$, respectively.

$$P_c=\begin{array}{c|cccccccc|} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\ \hline 1 & & c & & & & & & \\ 2 & & & c & & & & & \\ 3 & & & & c & & & & \\ 4 & & & & & c & & & \\ 5 & & & & & & c & & \\ 6 & & & & & & & c & \\ 7 & & & & & & & & c \\ 8 & c & & & & & & & \end{array}$$

Fig.2 Representation matrix of connection relation

b)Representation matrix for state-of-connection relation State-of-connection relation or concave-convex relation R_1 viewed from inside the contour determines the representation matrix, which is defined as follows:

(1) $m_iR_1m_j$: m_i and m_j are in concave relation.

(2) $m_i\tilde{R}_1m_j$: m_i and m_j are in convex relation.

In the above definitions, $\tilde{R}$ denotes the negation of R.

In the case in which $\tilde{R}$ holds, the symbol "+" is placed at the (i,j)-element, in the case of R, "-" The matrix P_1 for the figure in Fig.1 is shown in Fig.3

$$P_1=\begin{array}{c|cccccccc|} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\ \hline 1 & & + & & & & & & \\ 2 & & & + & & & & & \\ 3 & & & & - & & & & \\ 4 & & & & & + & & & \\ 5 & & & & & & + & & \\ 6 & & & & & & & - & \\ 7 & & & & & & & & + \\ 8 & + & & & & & & & \end{array}$$

Fig.3 Representation matrix of concave-convex relation

c)Representation matrix for acute-obtuse relation Applying the following relation to connection angle determines the representation matrix to denote acuteness, obtuseness, and rectangle of connection angle.

(1)$m_iR_2m_j$: The angle between m_i and m_j is acute($\alpha_{ij} \leqq \pi/2+\zeta$).

(2)$m_i\tilde{R}_2m_j$: The angle between m_i and m_j is obtuse($\alpha_{ij} \geqq \pi/2+\zeta$).

In the above definitions, α_{ij} denotes the connection angle between m_i and m_j, $0 < \alpha_{ij} < \pi/2$, and ζ denotes rectangle with small allowance which a human recognizes as rectangle. Representation matrix P_2 for R_2 is filled with "1" at the (i,j)-element for $m_i(R_2 \setminus \tilde{R}_2)m_j$, "-1" for $m_i(\tilde{R}_2 \setminus R_2)m_j$, where $R \setminus S$ denotes that R holds while S does not holds. The relation $R_2 \cap \tilde{R}_2$ indicates that m_i and m_j are in rectangle. For this case, "0" is placed at the (i,j)-element. As described above, the features of an object in the level of contour can be represented in the form of matrix by defining various relations on the set M.

$$P_2=\begin{array}{c|cccccccc|} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \\ \hline 1 & & 1 & & & & & & \\ 2 & & & -1 & & & & & \\ 3 & & & & -1 & & & & \\ 4 & & & & & 0 & & & \\ 5 & & & & & & 0 & & \\ 6 & & & & & & & 0 & \\ 7 & & & & & & & & 1 \\ 8 & -1 & & & & & & & \end{array}$$

Fig.4 Representation matrix of acute-obtuse relation

2.2.2 Categories

Classification of objects by utilizing the above representation matrices will be described. A sequence of symbols, which denotes a category *C*, is deduced by applying the following operation to pairs of elements of those representation matrices:

$$C = \mathrm{E} \times \mathrm{P} \quad \cdots(2)$$

The operation E x P is a symbolic operation, defined as follow:

$$C = (c_1, c_2 \cdots c_n),$$
$$c_j = 1\mathrm{x}p_{1j} + 1\mathrm{x}p_{2j} + \cdots + 1\mathrm{x}p_{ij} + \cdots + 1\mathrm{x}p_{nj},$$
where
$$1 \times p_{ij} = \begin{cases} \text{null string}, \text{ if } p_{ij} = \text{blank} \\ p_{ij}, \text{ otherwize;} \end{cases}$$
$$\mathrm{E} = (1\ 1 \cdots 1); \quad \cdots(3)$$

The operation of a+b for any pair of strings a and b indicates yielding the string ab.For example, in the case of $P=P_1$, C_1 is the following matrix:

$$C_1 = \mathrm{I} \times P_1 = [+++-++-+] \quad \cdots(4)$$

The corresponding category C_1 is the string of the elements of C_1 in the original order in C_1 :

$$C_1 = +++-++-+ \cdot\cdot\cdot(5)$$

This convex-concave category C_1 is the conceptualized object, and the object of the same string of + and - is identical to each other in the level of convex-concave category. A acute-obtuse category C_2 is obtained from P_2' in the same manner as the case of C_1. For the figure in Fig.1 is:

$$C_2 = -11-1-10001-1 \cdot\cdot\cdot(6)$$

In these categories, only relative locations of each symbol to the rest of symbols, and which symbol comes first in the string as a category does not matter. That is, for example, the following categories are identical:

$$\left.\begin{array}{l} C'_1 = ++++-++- \\ C''_1 = -++++-++ \end{array}\right\} \cdot\cdot\cdot(7)$$

To classify convex-concave category in more abstract level, the notion of simplified category is introduced. To obtain the simplified category of a convex-concave category, a succession of a unique symbol is represented by a single same symbol. The category of a single + represents a circle which is regarded as the infinite number of small line segments connected in a convex manner at every connection of two succesive line segments. The simplified category may classify objects of different length of category into a unique category. In this sense, the simplified category classifies objects in the level of the most basic characteristic of figure.

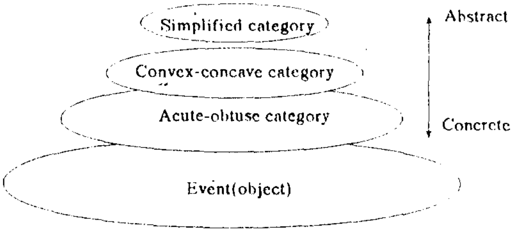


Fig.5 Hierarchy of image category

2. 3 Procedures for Classifying Figures

Classification of figures is performed through the following four procedures:

Procedure(1)symbol-string matching in the level of simplified category.

Procedure(2)symbol-string matching in the level of convex-concave category.

Procedure(3)symbol-string matching in the level of acute-obtuse category.

procedure(4)matching in the level of connection angle and segment-length ratio.

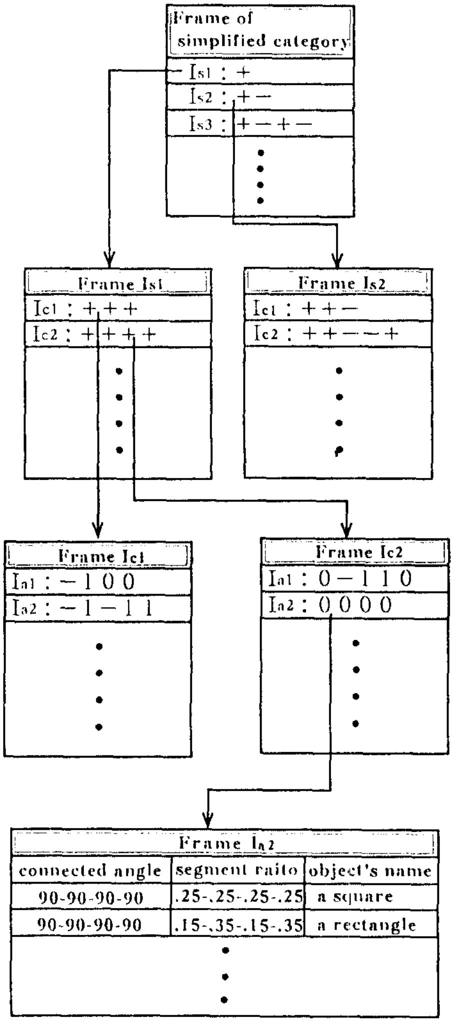


Fig.6 Hierarchy of category

Inputted objects are, first, processed by the procedure described in the previous sections, and the simplified, the convex-concave and the acute-obtuse categories are generated.The category obtained through the above four procedures is compared with categories stored as the past experience in the framework of the hierarchy of category. Recognition of the inputted object is to find a consistent category with one of those in the hierarchy of category. The procedure is as follows. To start with, the item of simplified category I_{si} must be found, which includes the category of the object in question. Then, seeking is continued to find the item I_{ci} within the frame of convex-concave category C_{si} which lies in the subordinated level of the item I_{si}

, and so forth to the level of Procedure(4) in which connection angle and segment-length ratio are used for identification sotred in the frame of convex concave category concerned. The segment-length ratio is the ratio of a specific segment length to the overall length of contour which is the total length of all the segments of a linearized figure. Letting the length of segment m_i be denoted $\|m_i\|$, the segment-length ratio of m_i is given by:

$$L_i = \frac{\|m_i\|_2}{\sum_{k=1}^{n}\|m_k\|_2} \quad \cdots(8)$$

Connection angles and segment-length ratio are utilized to find the item which is most akin to those of the inputted object. The name of the object is thus determined. The whole process described above makes it possible to understand the given scene from the objects which consistutes that specific scene. The present procedure can also deal with an object which consists of multiple closed lines as its contour in the same manner as above.

3. Understanding Plane Figure's Orientation

Here, how to understand which direction the object concerned is heading will be described, with respect to plane figures.[4]

3.1 Direction Understanding

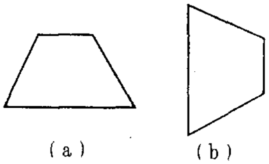

(a) (b)

Fig.7 Orientation of figure

As shown in Fig.7, the orientation of a figure indicates an arrangement of its features distinguishing from among other possibilities of the same figure. As a method to give an answer to this question, a direction-index point is defined to judge the figure's direction utilizing the features of the figure. By using this direction-index point, a figure is understood the figure's orientation. From the viewpoint here, the figure shown in Fig.7(a) can be given a judgement that "The figure is upward." and the one in Fig.7(b), "The figure is rightward." Further, the change in figure from Fig.7(a) to7(b) is understod as "The figure turned clockwise." In understanding such a situation, some index for figure "direction," is necessary. This index will be called direction-index point. It is not possible to find a direction-index point for all figures in a unique manner. So, a way for the determination of the orientation of a figure will be described, depending on its features. Since a direction is represented by a vector, direction-index vector will be employed, which is determined using direction-index point. To do this, the existence of direction-index point is necessary. Direction determination without using direction-index point will be discussed after describing the way by using direction-index point. Direction angle shown in Fig.8 is used for direction-index vector.

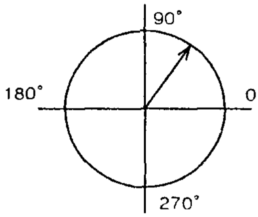


Fig.8 Direction angle of vector

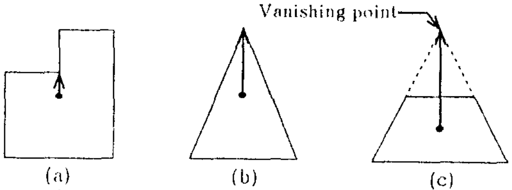
3.2 Orientation Understanding Using Direction-Index Point

Average coordinate of all the nodes' coordinates of a figure is used to represent the location of that figure. This point is called the center of figure. A direction-index vector is defined to be a vector which has its tail at the center of figure and its head, at the direction-index point. A direction-index point is determined by using the knowledge of features in Table 1.

Table.1 Knowlege for finding direction-index point

If a unique "-" exsists.
then the corresponding node is index point. ···(a)
If a unique acute(or rectangle, or obstuse angle) exists.
then the corresponding node is index point. ···(b)
If a vanishing point of line segment exists
then it is the index point. ···(c)
•
•
•

Using this Table, direction-index point is determined first. Then By the corresponding direction-index vector obtained automatically, the direction of the figure is determined. The knowledge in Table I is built by inputting rules for searching a direction-index point according to the figures of a specific figure.

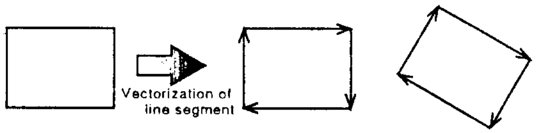


(a) (b) (c)

Fig.9 Figures and direction-index vectors

3.3 The Case with No Direction-Index Point

Figures for which a direction-index point can not be found are those of identical connection angle at every node, such as regular triangle, square, rectangle, etc. For these figures, line segments which constitute the contour are regarded as vectors. The string of the directions of those vectors are utilized in reasoning the direction of a figure presented. Let the orientation of the figure in Fig.10(a)
be its original orientation, then the one in Fig.10(b) is understood to be rotated by 30 degrees clockwise from the original orientation.



180-270-0-90 (a) 210-300-30-120 (b)

Fig.10 Direction angles and orientation of a figure

4 Conceptualization of Motion

Conceptualization of motion is described by using the way for determining orientation discussed in the preceding sections. conceptualization of motion is made through memorizing the feature classification of a specific motion (trajectory). This way of understanding motion is based on the fact that a human understands figure shape by classifying the features of shape and not by memorizing the complete shape. The method of classification for conceptualization of motion may depend on what the objective of motion understanding is. Applying the present method to a simulator of vehicle motion, motion understanding is described in what follows. The shape of vehicle for simulation is shown in Fig.11. Using the above method, the center of vehicle and direction-index point are determined. (This model of vehicle has a direction-index point, as shown in Fig.11.) The direction-index vector is obtained by the two points as is also discussed in the preceding sections. Fig.12 shows a part of the vehicle's trajectory. The vehicle moved from the location i to the location i+1 in the figure. The inner product of the two direction-index vectors of the locations i and i+1, or the difference in argument θ, is the quantity which represents the motion of the vehicle. That is, the following string of Θ's represents vehicle's motion:

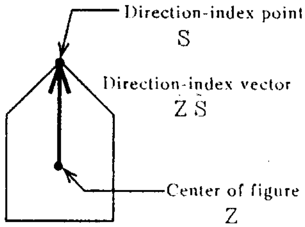
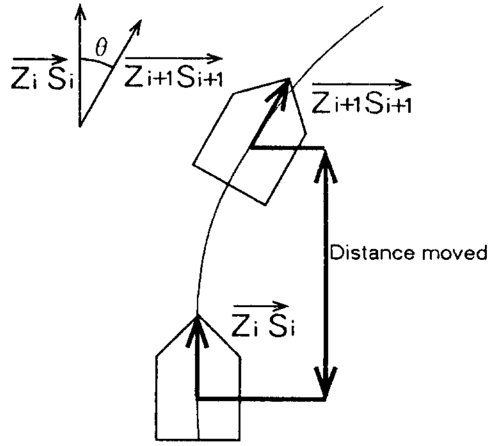


Fig.11 Shape and direction

$$\Theta = \{\theta_1, \theta_2, \theta_3, , , \theta_i, ,\} \cdots (9)$$

$$\theta_{i+1} = \cos^{-1}\left(\frac{\overrightarrow{Z_i S_i} \cdot \overrightarrow{Z_{i+1} S_{i+1}}}{|\overrightarrow{Z_i S_i}||\overrightarrow{Z_{i+1} S_{i+1}}|}\right) \cdots (10)$$



Thin line shows vehicle's course

Fig.12 Motion of vehicle

How the string is processed is described below. In transforming Θ to a symbolic string, classifications shown in Tables 2 and 3 are used.

Table.2 State of vehicle with θ

$0 \leqq \theta < 5$	Gentle curve
$5 \leqq \theta < 20$	Average curve
$\theta \geqq 20$	Sharpe curve
$\theta \geqq 0$	Anticlockwize turn
$\theta < 0$	Clockwise turn

Table.3 Function of Θ to S

	$0 \leqq \lvert\theta\rvert < 5$	$5 \leqq \lvert\theta\rvert < 20$	$\lvert\theta\rvert \geqq 20$
$\theta \leqq 0$	A	B	C
$\theta > 0$	a	b	c

The transformation here is denoted by the following function:

$$\tau = g(\theta),$$

$$g: \Theta \rightarrow S. \qquad \cdots (11)$$

where $\Theta = \{\theta : \theta \in R\}$; $S = \{A, B, C, a, b, c\}$; $g(\theta)$ is given by Table 3.

In the string $S= \tau_1 \tau_2 \tau_3 \tau_4 \cdots$, if successive two elements are the same, then these are considered to be a single element.

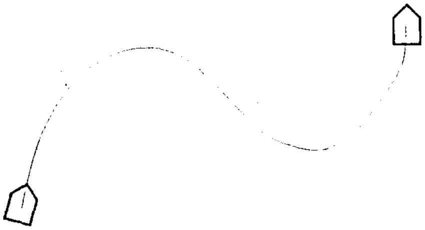


Fig.13 Trajectory of vehicle

Applying this rule yields an abstract representation for the course of a vehicle. An example will be given below. In the case of Fig.13, the string of θ is obtained as:

$$\Theta = \{0\ -4\ -8\ -12\ -15\ -25\ -15\ -25\ -15\ -8\ -4\ 3\ 13\ 26\ 31\ 19\ 13\ 13\ 5\ 5\}. \cdots (12)$$

Applying the function (11) to the above string yields the following string of symbols.

$$S = AABBBCBBAabccbbaa \cdots (13)$$

Further, letting a succession of the same symbol be represented by a single symbol,

$$S = ABCBAabcba \cdots (14)$$

is obtained. By this procedure, The course took by the vehicle in Fig.13 is transformed into the abstract trajectory in Equation(14). The string of symbol in (14) has the following meaning.

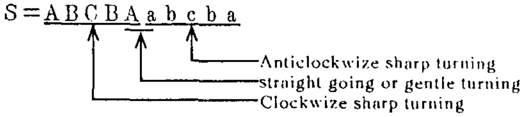
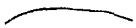


Fig.14 Abstracted trjectory

Table.4 Types of curved lines and the corresponding symbol string

Curved line	Type of string	Shape of line
Sharp curved line	ABA (aba) ABCA (abca), ACBA (acba) ABCBA (abcba)	
Average curved line	ABA (aba)	
Gentle curved line(including straight line)	Aa. A. a	

This string of symbols gives an interpretation that the vehicle took the course like the letter S. The above processing of motion in an abstract fashion provides a systematic classification of motion. That rough classification is shown in Table 4. Utilizing this table, it is possible to understand motion conceptually by assigning a symbol string to a motion. Further, the conceptual treatment of motion provides a method for dealing with motion on the computer globally. Dealing with motion conceptually extends the applicavility of the present method together with the utilization of relations between objects and verbal representation.[5] For example, bilateral translation between words and images makes it possible to operate a vehicle automatically.[6,7] For example, just inputting "turn gently" is understood as choosing typical instance or prototype of the proper conceptual curve from the past experience, which corresponds to the input.

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