A Novel Signal Similarity Evaluation Algorithm and its Application in Irregular Shape Recognition

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Abstract. Irregular shape recognition has been a tough problem in image understanding field. One type of feature extraction techniques involves transforming shapes into signals through certain process, and thus the shape recognition problem becomes comparing similarity between signals. This paper proposes a novel signal similarity evaluation scheme that may classify signals into different categories to fulfill the shape recognition task. Experiments on pavement guide marks recognition are conducted to study the potential of the proposed method. Results demonstrate its ability in irregular shape recognition applications with higher accuracy and faster speed.

1. Introduction
Pavement guide mark recognition has been playing an important role in the Intelligent Driving System. However due to the convexity-concavity characteristics of the boundaries, the recognition of guide marks becomes a big challenge and existing methods cannot meet the requirement. With the combination of data processing theory, transformations that convert shapes into signals have been applied and therefore corresponding signal similarity evaluation techniques are keys to solve the problem.

Pavement guide marks are one of the most commonly seen transportation signs for drivers. Their shapes are well-defined but with both convex and concave points along their borders. Therefore the automatic recognition of guide marks is a difficult task faced by many researchers. The paper chooses guide marks recognition as its goal and leads to the study of a novel approach of signal similarity evaluation scheme. Beginning with the projection to a guide mark boundary to complete the shape transformation into signals, the signal centroid is then calculated and fused into the original signal to form a new signal for the final similarity measurement. Conclusions are made based on the similarity of whether the unknown shape is one of the guide marks.

All experiments in the study are run in natural scenes with different sorts of real pavement status. The results demonstrate the potential of this new similarity comparison algorithm in irregular shape recognition applications.

2. Signal Centroid And Similarity Evaluation
Centroid is a notation originally derived from Physics. It is introduced in this work to describe one of characteristics of a signal and believed to be able to distinguish different signals under certain circumstances. If a signal is considered as a mass point system, the definition of the signal centroid can be written as follows:
Where $\{S(i)\}_i = 1, 2, \cdots, N$ is a random signal, and $(x_c, y_c)$ is its centroid. To make a decision on whether two signals are similar, the distance between two signal centroids are calculated. The smaller the distance is, the closer two signals are.

$$\text{Dis} = \sqrt{(x_{tc} - x_{rc})^2 + (y_{tc} - y_{rc})^2}$$ (2)

Where $(x_{tc}, y_{tc})$ and $(x_{rc}, y_{rc})$ are centroids of the unknown signal and the reference signal respectively.

3. Algorithm Design

The centroid based signal similarity evaluation method demonstrates its good performance in random time series signals. However, in the pavement guide marks recognition applications, guide marks are both irregular and well defined. On one hand, they have convex and concave points along their boundaries, and on the other hand, guide marks themselves show similarities to some extent. Below is an example.

Given facts above, a new signal comparison scheme must be presented to distinguish shapes or signals as shown in Figure 1. By introducing centoid, the paper proposes a novel approach to reform the projection signal by adding its centroid at the end. Suppose $\{S(1), S(2), \cdots, S(N)\}$ is the original
projection signal of a guide mark and \((x_c, y_c)\) is its centroid. According to the new scheme, firstly a new signal \(\{N S(1), S(2), \ldots, S(N), x_c, y_c\}\) is formed. Then the similarity between an unknown signal \(NS_u\) and the reference signal \(NS_r\) is calculation based on the linear combination of the Euclidean distance and Chessboard distance:

\[
\text{Sim} = \alpha \text{Sim}_E + \beta \text{Sim}_C
\]  

(3)

Where \(\alpha\) and \(\beta\) and two weights,

\[
\text{Sim}_E = \sqrt{\sum_{i=1}^{N+2} (NS_u(i) - NS_r(i))^2}
\]  

(4)

is the Euclidean distances between \(NS_u\) and \(NS_r\), and

\[
\text{Sim}_C = \max_{1 \leq i \leq N+2} |NS_u(i) - NS_r(i)|
\]  

(5)

is the Chessboard distance between the two.

4. Experimental Results

Pavement guide marks under tested in this paper are all obtained from the camera mounted on the moving vehicle in real scene. In addition to the complexity in shape, negative effects such as weather, light and other natural factors are unavoidable and therefore make the guide marks recognition even more difficult. The study adopts area projection in both vertical and horizontal directions as two signals representing a guide mark to conduct proposed signal similarity evaluation.

(Figure 2) Straight and right turn mark

Given a \(h \times w\) binary image contains a straight and right turn guide mark as shown in Figure 2(b), it can be represented as

\[
B(x,y) = \begin{cases} 
1, & \text{foreground} \\
0, & \text{background}
\end{cases}
\]  

(6)

The projection of \(B(x,y)\) onto the \(X\) axis is defined as \(hp(x)\), and the projection of \(B(x,y)\) onto the \(Y\) axis is defined as \(vp(y)\)

\[
\begin{align*}
hp(x) &= \sum_{y=1}^{h} B(x, y) \\
vp(y) &= \sum_{x=1}^{w} B(x, y)
\end{align*}
\]  

(7)

From (7), \(hp(x)\) is the accumulation of all foreground in each column and \(vp(y)\) is the sum of white pixels in each row. In order to calculate the similarity between a tested signal and the reference, normalizations in both axes of signals must be finished firstly. Both \(hp(x)\) and \(vp(y)\) have to be rescale into the same length \(k\), and signal magnitude have to be limited within \(0~1\) through the following procedures:
Applying the new signal comparison scheme, two new signals with $k + 2$ as their lengths are formed for both $H_P$ and $V_P$ respectively and are written as $NH_P_{k+2}$ and $NV_P_{k+2}$. According to (3),(4) and (5), similarities between unknown shapes and a reference guide mark are calculated separately as $Sim_{H_P}$ and $Sim_{V_P}$. The final decision on whether the unknown shape is the reference guide mark is made based on

$$Sim = \sqrt{Sim_{H_P}^2 + Sim_{V_P}^2}$$

Four tested images are given in Figure 4 and Table 1 is the similarity evaluation of those 4 with respect to 9 references.

It can be seen from Table 1, all unknown targets can be classified into the right group. Large experiments have been run and results have demonstrated the proposed method shows promising irregular shape recognition potential in both accuracy and speed.
5. Conclusions
Irregular shape recognition has been one of the most difficult tasks in the image understanding area. It becomes tougher when dealing with convex-concave shapes. This work transforms shapes into signals firstly and then introduces a novel signal similarity evaluation scheme to fulfill the task. Experimental results have proven its advantages in pavement guide marks recognition and it may be used in other shape recognition applications as well.

6. Acknowledgment
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7. References
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Table 1 Similarity Evaluation of 4 Unknown Targets With Respect To References

| Target references | Target 1 | Target 2 | Target 3 | Target 4 |
|-------------------|---------|---------|---------|---------|
|                   | 2.61    | 12.38   | 19.61   | 21.92   |
|                   | 9.43    | 7.51    | 4.4     | 6.35    |
|                   | 8.99    | 7.08    | 5.1     | 4.69    |
|                   | 8.21    | 4.83    | 8.29    | 8.01    |
|                   | 8.43    | 2.16    | 11.29   | 11.29   |
|                   | 6.21    | 8.43    | 10.83   | 11.78   |
|                   | 9.51    | 7.31    | 5.32    | 2.08    |
|                   | 9.19    | 4.82    | 9.51    | 10.24   |
|                   | 8.10    | 7.45    | 7.74    | 6.82    |
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