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Study of Shearing Line Traces Laser Detection System

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ABSTRACT
A set of laser detection system for shearing tools is developed, By holding breakage of the cable, firstly, using single-point laser displacement sensors to pick up surface features signal of line trace, then wavelet decomposition is used to reduce the noise, and the signal after noise reduction is obtained. After that, the threshold based sequence comparison method is used to achieve matches of similar coincidence for trace features, and then using a gradient descent method to getting the minimum cost of cost function value through continuous iterative, and finally realizing the fast traceability of corresponding shearing tool.

KEY WORDS: Line trace, Shearing tools, Threshold based sequence comparison, Machine learning.

1 INTRODUCTION

IN recent years, frequent theft of cables along the high-speed railways has resulted in huge losses of state property and has caused interruption of railway signals and communication equipment power supply in China. This has forced failure of the respective systems leading to several railway accidents, significant loss of lives, and diminished safety of property.

Statistical data show that criminals use wire cutters, cable cutters, destroy pliers, and other large shear tools to sever cables. Line traces, which are scratches on the surface of the body, can be caused by the pressure of the line-shaped deformation and line traces of the broken ends on the surface are frequently found at the scene. Thieves use tools that cause load on the trace-bearing body, which form local material changes on the contact part. Moreover, thieves use tools to cut the cables, which form local material changes on the contact part. The tool traces reflect the external morphological structure of the contact area, and provide clues to the investigation based on the analysis of the tools used in the criminal act, thus narrowing the scope of the investigation. It possesses characteristics that are difficult to destroy or disguise, frequently occurring, and possess high identification value for investigators to determine the nature of the case and the tools used in the criminal act. These characteristics are important to confirm suspects.

Compared with the traditional methods of observation and comparison, the nonlinear shear trace quantitative examination in image recognition and 3D scanning technology. However, these detection methods are complicated because of the randomness at the crime scene. The structure of the algorithm is not well suited to engineering. The pictures and size of 3D files are too large, increasing the difficulty and making the above method unsuitable as the first approach to handling the case, which greatly reduces its practical value.

The single-point laser displacement test has advantages that include an undamaged surface of the measured object, a light-free environment; high precision, small data file size, and good frequency response characteristics. However, Nan Pan, et. al. (2015) have proposed that problems like signal noises reduction, signal matching and tool inference are encountered when this method is applied to analysis the traces of actual sheared scene:

1) Laser leveling: the actual difference of shearing angle will lead to its uneven surface, just to make the test data consistent, first, to ensure that the laser sensor and the surface of the vertical angle consistent decapitation, that is automatically leveling;

2) Optical path interference: The laser detection need to synchronize the surface of the joint precision shooting to ensure that the detection position is correct,

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but the laser displacement sensor and micro-camera could not be installed vertically (to avoid mutual occlusion), It is necessary to design a light path system, to make the laser can penetrate the cross section and return, does not affect the test results, but also to reflect the cross section of the astigmatism, so that the microscope can capture a clear mirror cross section.

3) Signal noises reduction: The displacement picked up by the signal laser sensors is often mixed with many background noises restricted to the actual test environment and the difference between the broken ends of the cable itself. This type of noise arises from the mechanical error of the test equipment itself and external disturbances. To this end, the method requires maximum noise interference reduction and improvement of the quality and accuracy of the follow-up work based on the accuracy of the signal.

4) Signal Matching: There is a wide range in the shapes of the actual sheared traces. Despite the use of the same cutting tool, the broken ends will differ with respect to the number of directions and displacement deviations upon being severed. The lengths of the match signals and the signals to be matched are not the same. At the same time, the two trace detection signals are likely to coincide at only one part. In reality, the detection signal cut by the same tool cannot directly acquire its similar characteristics in the time domain; therefore, the data need to be converted to the transform domain for processing.

5) Tool inference: Due to rampant criminal activity, the scene of the incident may have hundreds of shear broken ends. The shear surface morphology of the cutting tool cannot be fully reflected in the broken ends of cables, except the part of the shear surface (an incomplete mark) that remains on the individual trace-bearing body. When comparing every data point, the computation involved in the algorithm will greatly increase, lowering the contrast efficiency. To do this, a fast comparison of the characteristics of a plenty number of trace laser detection data points by a dynamic time warping algorithm is required to implement the traceability inference of the cutting tool traces further.

2 HARDWARE DESIGN OF DETECTION SYSTEM

2.1 Design of the multifunctional stage

FOR the purposes of ensuring the precise measurement of the necessary stability conditions, all parts of the detection system are installed in the vibration table, the vibration table is mainly composed of the base and shock absorber board, can make the instrument in the precise operation to reduce the interference caused by external shock.

By translation, rotation and lifting, to achieve a rapid spatial position adjusting and positioning the carrier on a stage. Electronically controlled angular displacement table can be adjusted in ± 15 ° tilt angle in any direction. By controlling the microscope apparatus main laser displacement sensor with high accuracy and precision electric stage, detection and feature extraction cross-section of minute marks. In the horizontal direction can be around the fast moving adjustment, and can do 360 ° rotation, in the vertical direction can lift the height of the adjustment stage. Its main role is to make the stent on the measured truncated fast space position adjustment and positioning to meet the measurement needs.

2.2 Design of the motion control subsystem

The motion control subsystem is mainly composed of horizontal electronically controlled angular displacement table and longitudinal electronically controlled angular displacement table and is arranged vertically to each other so that the vertical axis can be rotated within ± 15 ° to adjust the angle and realize the angle A plane in ± 15 ° tilt angle adjustment in any direction. The main role is to carry the object to be detected, and accurately adjust the detection cross-section and high-precision laser displacement sensor to maintain parallel to the plane.

2.3 Design of the laser detection subsystem

Laser detection subsystem models using CD33-L50-422 precision laser displacement sensor trace feature detection, which detects the distance of 47.3mm, the detection range is ± 5mm, a resolution of 2.5μm. High-precision laser displacement sensor installed in the vertical electric slide, so that it can be moved in the vertical, the detection of small traces of the cross-section, and quantitative data back to the host computer for analysis.

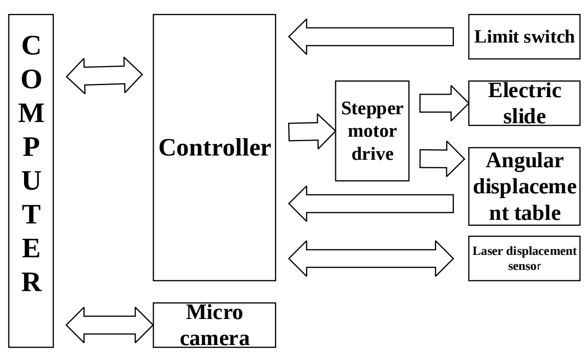

Figure 1. Schematic of detection system.

3 SIGNAL CHARACTERISTIC MATCHING

3.1 Variable length and partial overlap problem

PRIOR to the matching the similarity of trace signals after noise reduction, the following two issues must be addressed:

Variable trace length. Each collection of trace detection signal length is not the same. Most of the length of the matching signal data and the signal to be matched is different. Simultaneously, the similarity of two discrete sequences can't be directly measured using Euclidean distance and correlation coefficients. Thus, point-to-point operations become meaningless.

2) Parts overlap. This means that two detection signal traces may only overlap at some part by coincidence. This condition can cause significant interference to the calculation of the final coincidence.

Therefore, the problem of variable length and overlap can be optimized through a computing algorithm capable of matching. The basic steps are as follows:

1) Setting the input data of A and B, which are data that satisfy the above requirements.

2) Setting a match to the minimum length L. The two coincidences must meet the minimum overlap length by selecting the longest length to the shortest part from A and to compare with B, that is equivalent to choosing a different location for some matches.

3) Iteratively executing each position's contrast. Each comparison should be compared to the variance size of differences degree of the two corresponding positions. The current state is recorded if the variance size is the minimum.

4) If the function of 3) is completed, the role of A and B is exchanged, followed by completion of steps 2) and 3).

5) Calculating the variance of minimum difference degree and outputting the matching result.

The process of signal matching is shown in Figure 2.

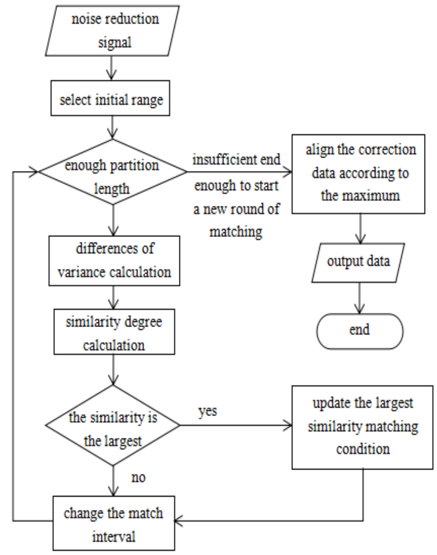

Figure 2. Signal matching flowchart.

3.2 Noise reduction

The type of wavelet must be selected prior to noise reduction. The original signal has to be decomposed into several layers in the actual noise reduction process. When more layers are decomposed, the details of data processing will also increase, leading to more details being erased to eliminate more noise. Therefore, a balanced decomposition layer must be determined.

For the trace of the current detection, the approximate signal expansion of hierarchy 1 still has more glitches. The approximate signal expansion of hierarchy 2 has been greatly improved compared to the development of hierarchy 1. Most of the glitches have been improved, while the approximate signal of hierarchy 3 improves this phenomenon further and has been very close to the desired pattern from the graphical feedback. Therefore, only the development of hierarchy 3 is necessary in general.

According to the formula:

$$f = a_n + \sum_1^n d_i \tag{1}$$

In addition to the approximate signal, detailed data are still needed. Although the approximate data are very close to the wave style according to the naked eye at hierarchy 3, signal details are still lacking because a significant amount of low amplitude noise is lost; therefore, it can only represent the general trend but cannot accurately show the traces. The signal should be filtered and de-noised for every detail by setting a threshold:

$c_i = \begin{cases} 0, |c_i| < r \\ c_i, |c_i| \geq r \end{cases}$, c_i represents the i th decomposition of the wavelet coefficients.

IA threshold needs to be set and all data under the threshold must be removed to eliminate the noise in the detail. Given that general noise exists in high-frequency irregular pattern, the value is small, which is converted to the detail part. The signal should be filtered and de-noised by setting a threshold for every detail.

$$f' = a_n + \sum_1^n d'_i \tag{2}$$

Among them:

d'_i is the detail of the data after the threshold noise reduction.

f' is the trace data after the noise reduction.

3.3 Matching strategy based on threshold sequence

The most common way to match the similarity of the two signals is to calculate the difference between the two and to accumulate all the differences. The larger the final result, the greater the degree of deviation and the lower the similarity. Considering the existence of errors in the actual detection, and too small differences can generally be ignored, you can add a threshold on this basis, two sections of the signal in a certain position within a certain range, can be considered to be equal, and in the beyond the scope of the need to be included in the deviation.

The similarity based on the threshold difference can be calculated in this way under different variations. It is possible to find a transformation of the least degree of difference within a given transformation range.

At this time, it is assumed that the traces detection signals A and B are intercepted and the converted inputs are:

$\mathrm{I}_1 = \{i_{11}, i_{12}, \ldots, i_{1m}\}$, $\mathrm{I}_2 = \{i_{21}, i_{22}, \ldots, i_{2m}\}$.

The degree of difference is calculated as:

$$Difference = \frac{\sum_{k=1}^{m} g(i_{1k} - i_{2k}) * context(k)}{m} \quad (2)$$

$$g(x) = \begin{cases} 0, |x| \le c \\ cost(x), |x| > c \end{cases}$$

c is the given threshold $cost(x)$is a cost function, and $cost(x) > 0$.

$context(k)$ is a combination of the previous match the weight of the situation, which is mainly to consider the position k before the match.

Considering the difference in the value of each of the two inputs, if the difference between the two values is within a certain range, that is, within the threshold, regardless of the difference value, if the difference is greater than the threshold, then calculate a difference based on cost function $cost(x)$, and finally accumulate to the final result. If the result is 0, then it is exactly the same, and the larger the value, the greater the difference.

3.4 Sample library establishment

As the fundamental basis to identify the tools of trace signals, the quality of the sample library and the build mode directly affect the final results.

Its establishment usually follows the following steps:

1) Determine the types of tools, scope, and type that needed to identify. Each tool should be numbered by the uniform rules and the detailed parameter information should be recorded.

2) A single broken trace must be checked at least twice to eliminate the coincidence of detection. When the degree of coincidence between the two signal data points is more than 99%, the data can be regarded as qualified. The same broken trace is recommended to record different data at multiple locations, where each position should use the method given previously. The manual correction is allowed when necessary, as well as all means that are conducive to improve the quality and representation of the trace sample.

3) Using the data of this sample library as test data, each feature is tested at the same time after completing all the data collection. Test results show that the similarity of every sample data and their group data is significantly higher than other groups. If it is mixed together, the data are invalid, and then steps 1) and 2) are repeated.

3.5 Group identification

The comparison results of the data to be traced and all the samples in the library will be obtained after completing the similar calculation work. These results are the similar degree of a series of samples and input trace. Different types of tools and different locations of the shear will affect the results. Group identification is an effective tool that can aggregate such data and find the best possible data.

Group identification usually follows the following basic steps:

1) Sorting the similarity between the input trace data and the samples in the sample library. Usually, it can only sort the first 10%–20% of the data.

2) Weighting the first 10%–20% of the data. The weighted rule states that the higher the rank of the sequence, the greater the weight. Else, the data is assigned a low weight.

3) Grouping according to the weighting result, and calculating the size of the proportion of each group in the previous 10%–20% data.

4) Sorting the data according to the proportion of each group and selecting the data sorted previously as the result of the derivation.

4 EXPERIMENTAL VERIFICATION

THE effectiveness of this system is verified through the actual shear tool source experiment. The experimental set up is as follows:

Three tools were selected: wire cutters (A), destroy pliers (B), and steel wire clamp (C). A copper bar of 1 cm diameter was cut by shear breakage. All breakage surfaces were tested using the instrument described in the literature [2]. The sample parameter setting involved: a laser pot diameter of 2.5 µm, a subdivided figure for 3200 steps/s, sample frequency pulse of 1000, sampling interval of 50 ms, sampling frequency of 20 Hz, the sampling points being determined according to the cross-sectional area of the broken end. The related algorithms that match the program were written in Python upon verification by Matlab 2016a. The program was run on a PC with Intel Core i7 4.2GHz CPU with 16G DDR4 memory.

Figure 3. Test environment.

The 29 sets of data labeled T16–T45 (T26 and T27 being substantially the same data) were used as test data. There were 1000 data sets containing data on shearing by 10 different tools in the sample library. Excluding the data in the sample library, the results show the first five ranking values.

There were 3 sets of data in T16–T45. T16–T25 were from the traces formed by tool A, T26–T38 were from the traces formed by tools B1 and B2, and T39–T45 were from the traces formed by tool C. B1 and B2 are two tools that belong to the same tool B.

To make the simulation of the data collection in the crime scene more realistic, each group of test data was required to be tested again after shifting from the position based on the benchmark trace data and form the new data. The data in A mainly contained lateral displacement, that is the data moving on a straight line of the original traces. Some data coincided with the original data after the movement. At the same time, the data in A, B, and C, all had U-direction (up) and D-direction (down) movement and had a certain degree of dislocation with the original benchmark traces.

The definitions of tool traceability are as follows:

Successful match: backtrack precisely for the same trace (or tool). There is a certain deviation because of the location of detection, the length of the data, and many others. The sorting is more on the front and it has differentiated between the similarity degree of other types of tools, accurate match rate at 80%.

Fuzzy match: can match to the same tool, but can not accurately indicate the actual corresponding tool, the exact match rate is greater than 60% but less than 80%.

Match failure: Data not associated with the original trace, the exact match rate is less than 60%.

Table 1. The sample matching results by the algorithm proposed in this study

Tool number	Highest matching	Accurate traceability rate	Data description
T16	T17	100%	Group A benchmark data
T17	T16	100%	Group A benchmark data duplicate detection
T18	T20	100%	Group A benchmark data displacement 1/6
T19	T20	100%	Group A benchmark data displacement 1/3
T20	T21	100%	Group A benchmark data displacement 1/3
T21	T20	100%	Group A benchmark data displacement 1/2
T22	T23	100%	With the end of broken A another line
T23	T18	100%	T22 based on the direction D of translation of 1/6 of the other line
T24	T39	20%	T22 based on the direction U of translation of 1/6 of the other line
T25	T41	20%	Dislocation 1/3 and deletion of 2/3 based on T22
T26	T27	100%	Group B benchmark data
T27	T26	100%	Group B benchmark data duplicate detection
T28	T27	100%	Group B benchmark data duplicate detection
T29	T30	100%	Group B based on the direction D of translation of 1/10 of the other line
T30	T29	100%	T29 duplicate detection
T31	T32	100%	Group B based on the direction U of translation of 1/10 of the other line
T32	T31	100%	T31 duplicate detection
T33	T34	100%	Group B similar tools, different ends
T34	T33	100%	T33 duplicate detection
T35	T36	100%	T33 based on the direction D of translation of 1/10 of the other line
T36	T35	100%	T35 duplicate detection
T37	T38	80%	T35based on the direction D of translation of 1/10 of the other line
T38	T37	80%	T38 duplicate detection
T39	T40	80%	Group C benchmark data
T40	T39	80%	Group C benchmark data duplicate detection
T41	T25	60%	Group C based on the direction D of translation of 1/10 of the other line
T42	T43	80%	T41 duplicate detection
T43	T42	80%	T41 duplicate detection
T44	T45	80%	Group C based on the direction U of translation of 1/10 of the other line
T16	T17	100%	T44 duplicate detection

The calculation takes 2s, with an 89.7% matching success rate, 3.4% fuzzy rate and 6.9% failure rate.

It shows that the factors such as the angle of cutting off, the angle of laser signal detection, the type of cutting tool, the angle of cutting, the material of broken head and so on have little effect on the final matching result, the error rate is about 2-3%.

To draw a comparison with the technology proposed in this study, the literature algorithm which proposed by Nan Pan, et.al. (2015) is applied using the same 29 sets of data labeled T16–T45. The results are shown in Table 2.

The calculation takes 30 s, with a 72.4% matching success rate, 17.3% fuzzy rate and 10.3% failure rate.

Compared to the method proposed in literature [8], the traceability technique of proposed in this study has obvious advantages in the operation precision and stability order, because the algorithm structure is more simple. The proposed method is more applicable to test the traces data in actual scene detection.

5 CONCLUSION

IN this study, a set of laser detection system for shearing tools is developed. This system consists of motion control subsystem, laser detection subsystem, microscopic imaging subsystem and signal feature matching algorithm. Through actual tests by an expert from the trace testing works in the Ministry of Public Security, the system is proved to be effectively applicable to the shear tools backtrack based on line trace and provide a reliable reference for subsequent identification. To simulate actual working environments more realistically, improve the operation speed of larger magnitude data, and perform comparative and traceability studies of serial criminal offenders in the cross-region faster are avenues for future research.

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Table 2. The sample matching results by the algorithm proposed by Nan Pan, et. al. (2015)

Tool number	Highest matching	Accurate traceability rate	Data description
T16	T17	100%	Group A benchmark data
T17	T16	100%	Group A benchmark data duplicate detection
T18	T20	100%	Group A benchmark data displacement 1/6
T19	T20	100%	Group A benchmark data displacement 1/3
T20	T21	100%	Group A benchmark data displacement 1/3
T21	T20	100%	Group A benchmark data displacement 1/2
T22	T24	80%	With the end of broken A another line
T23	T17	100%	T22 based on the direction D of translation of 1/6 of the other line
T24	T40	0%	T22 based on the direction U of translation of 1/6 of the other line
T25	T19	20%	Dislocation 1/3 and deletion of 2/3 based on T22
T26	T27	100%	Group B benchmark data
T27	T26	100%	Group B benchmark data duplicate detection
T28	T27	100%	Group B benchmark data duplicate detection
T29	T30	100%	Group B based on the direction D of translation of 1/10 of the other line
T30	T29	100%	T29 duplicate detection
T31	T32	100%	Group B based on the direction U of translation of 1/10 of the other line
T32	T31	100%	T31 duplicate detection
T33	T34	60%	Group B similar tools, different ends
T34	T33	60%	T33 duplicate detection
T35	T19	20%	T33 based on the direction D of translation of 1/10 of the other line
T36	T35	80%	T35 duplicate detection
T37	T38	60%	T35based on the direction D of translation of 1/10 of the other line
T38	T37	60%	T38 duplicate detection
T39	T40	80%	Group C benchmark data
T40	T39	80%	Group C benchmark data duplicate detection
T41	T45	60%	Group C based on the direction D of translation of 1/10 of the other line
T42	T43	80%	T41 duplicate detection
T43	T42	80%	T41 duplicate detection
T44	T45	80%	Group C based on the direction U of translation of 1/10 of the other line
T16	T17	100%	T44 duplicate detection

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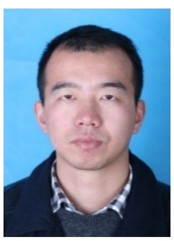
8 NOTES ON CONTRIBUTORS



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