

Particle Swarm Based Arc Detection on Time Series in Pantograph-Catenary System

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Abstract—Pantograph-catenary system is the most important component for transmitting the electric energy to the train. If the faults have not detected in an early stage, energy can disrupt the energy and this leads to more serious faults. The arcs occurred in the contact point is the first step of a fault. When they are detected in an early stage, catastrophic faults and accidents can be avoided. In this study, a new approach has been proposed to detect arcs in pantograph-catenary system. The proposed method applies a threshold value to each video frame and the rate of sudden glares are converted to time series. The phase space of the obtained time series is constructed and the arc event is found by using particle swarm optimization. The proposed method is analyzed by using real pantograph-videos and good result have been obtained.

Keywords—pantograph-catenary system; image segmentation; time series; phase space; arc detection; particle swarm optimization.

I. INTRODUCTION

Railway transportation becomes more and more popular with the production of modern trains. The energy is transmitted from pantograph-catenary system to the train. So, the quality of the current collection depends on the health of the interaction between pantograph and catenary system [1]. The contact wire draws a zigzag over the pantograph strip. The pantograph strip will damage over the time because of wearing, aging or bad weather condition. The pantograph strip is replaced with new one before the wearing of it has not reached its limit. This process is an important maintenance to avoid risks because there is not a measure for useful life of pantograph strip [2]. The quality of the current is based on a continuous contact between pantograph and overhead wire. On the other hand, poor contact causes burst of arc and wear.

The analysis of interaction between pantograph and catenary system is an active research area and breakdown of this system causes huge economic losses. The researchers has been tended to automatic approaches based on computer vision and signal processing methods. The vibrations of the catenary is analyzed to detect the catastrophic faults between pantograph and catenary system [3]. Hough transform and edge detection of thermal images were used for examination of the pantograph strip. The condition of pantograph strip was determined by

using the heat exchange at contact point [4]. The condition of the pantograph-catenary system monitored by using accelerometer signal and good results obtained [5]. Phototube or photodiode sensors used to detect the arcing condition by using ultraviolet emissions. The wavelet analysis was applied to phototube and DC current signals collected from train and the quality of the current was evaluated [6].

Boguslavskii et al. [7] proposed a computer vision based method to recognize the pantograph model. The system uses the edge detection and geometric model of the pantograph. The method was tested on three pantograph models and good results were obtained. Li et al. [8] combined Hough transform and wavelet analysis to obtain the edges in the image. The obtained results are used to detect the wears on the pantograph strip. The wear of the pantograph strip was detected by extracting the edges of the pantograph image and photoelectric sensors [9]. Arc faults were detected by using current and voltage signals [10]. A model was constructed to obtain the current and voltage signals and arc faults were successfully detected by processing these signals. The arc faults were modelled by using Mayr arc model and the signals obtained from this model was used to detect arc faults [11]. A contactless method was proposed to monitor the interaction between pantograph and catenary system. For this purpose, the line sensors were mounted to catenary poles and a scan area was constituted. A computer vision based control system was proposed to adjust the pantograph height in active pantograph system [12]. The height of the pantograph was found by using Hough transform and edge detection algorithms and a PID controller was applied to control the pantograph height. The position of contact wire was tracked by using mean-shift algorithm and the disorder in contact point was determined [13]. The edge detection based method was applied to pantograph videos and the position of contact wire was determined in each frame [14]. This knowledge was used to analyze the contact point.

In literature, the limited studies have been proposed to detect the arc. The proposed methods need other equipment's mounted on the roof of locomotive out of a camera. This increases the cost of condition monitoring process. In this study, a new method has been proposed to detect the arc faults

in pantograph-catenary system. The proposed method takes a video sequence and applies a threshold value for segmentation of the image. The rate of the shining is recorded as a sample of a signal for each frame and the phase space of this signal is constructed. The size of the arc is determined by analyzing the cluster of phase space with particle swarm optimization and the arc events are determined. The proposed method is cheaper than other algorithm and it has a simple structure. An arc event is determined in an early stage.

II. THE PROPOSED METHOD FOR ARC DETECTION

The proposed method takes image sequences from a camera mounted on the roof of the locomotive. The proposed method consists of two stages for detecting the arc events. The first stage is based on the segmentation of an image sequence by applying otsu method. The image is converted to a binary image and the ratio of white pixels to black pixels are taken as a sample of the signal for the current frame. After the overall image sequences have been read, the phase space of the obtained signal is constructed and particle swarm based method detect the arc events in the phase space. The general framework of the proposed system is given in Fig. 1.

In Fig. 1, one sample of the time series is obtained by applying otsu threshold method to each frame. After all frames has been read, the phase space of the obtained time series is constructed and the particle swarm based method is applied to phase space in order to detect arc events.

A. The construction of time series by using otsu method

Otsu method is a thresholding method that has been used in many image processing applications. This method obtains the best threshold values by taking into consideration the pixel values. Pixel values are classified according to determined threshold values. If the pixel values in an image are separated to K classes, it should be determined $K-1$ thresholds. The number of pixels, which belong to a pixel value, is taken into consideration and the threshold value is found. Zero order cumulative moments are calculated as in (1).

$$\omega_k = \sum_{i \in C_k} P_i = \frac{1}{N} \sum_{i \in C_k} f_i \quad \text{for } k=1,2,\dots,K \quad (1)$$

In (1), f_i is the number of pixels that has a pixel value C_k . P_i is the probability of i th pixel whether it is on the image or not. The total number of pixels is represented as N . First-order cumulative moments are given in (2).

$$\mu_k = \frac{1}{N\omega_k} \sum_{i \in C_k} if_i \quad \text{for } k=1,2,\dots,K \quad (2)$$

The average intensity of all images is given in (3).

$$\mu = \sum_{k=1}^K \omega_k \mu_k \quad (3)$$

Threshold value between classes are given in (4).

$$\sigma_B^2 = \sum_{k=1}^K \omega_k (\mu_k - \mu)^2 = \left(\sum_{k=1}^K \omega_k \mu_k^2 \right) - \mu^2 \quad (4)$$

The threshold values, which has the best σ_B^2 , is taken as a threshold value for current frame. The proposed otsu threshold method is given in Fig. 2.

In Fig. 2, the method takes one frame in each step and found the threshold value. The pixels in the image changes as 0 or 1. The ratio of arc occurred region to whole region is taken as a sample for time series. This time series is used to detect the arc events.

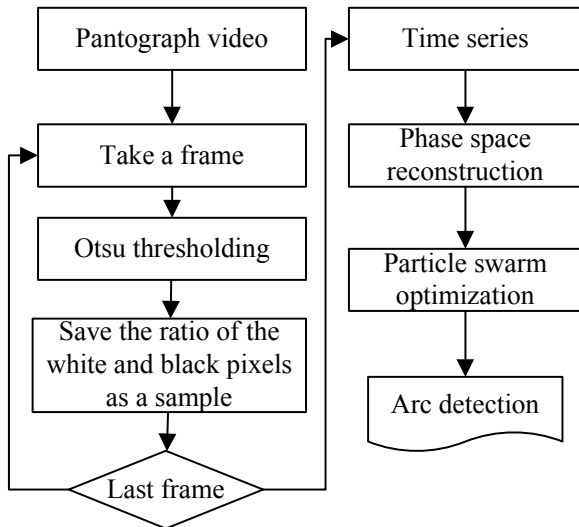


Fig. 1. The general framework of the proposed method

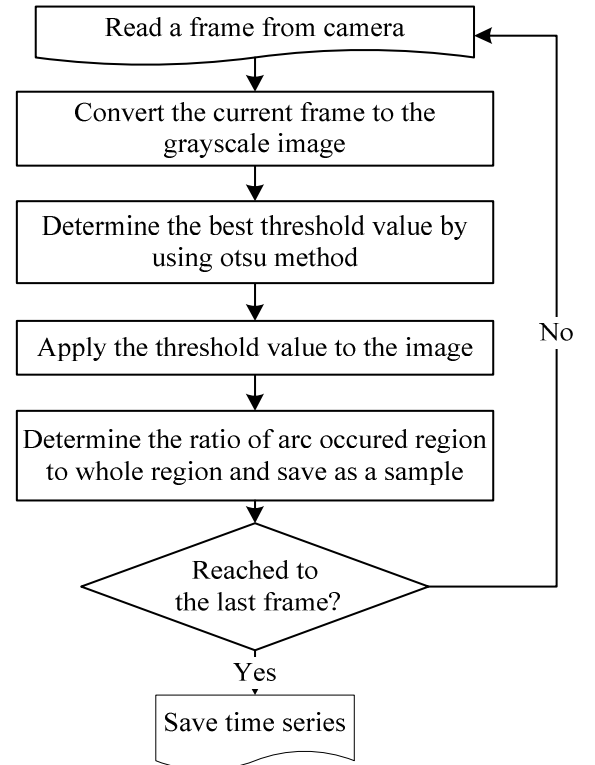


Fig. 2. Otsu threshold method and time series generation

B. Particle swarm based arc detection in time series

After the time series is constructed, the arc events will be determined. First the phase space is constructed. The phase space method analyzes a time series at least two dimensions [15]. This method is based on nonlinear time series analysis. A time series is mapped to different dimensions. The phase space of an $x[k]$ signal is calculated as shown in (5).

$$P = \begin{bmatrix} x_{1+(d-1)\tau} & \dots & x_{1+\tau} & x_1 \\ x_{2+(d-1)\tau} & \dots & x_{2+\tau} & x_2 \\ \vdots & \vdots & \vdots & \vdots \\ x_N & \dots & x_{N-(d-2)\tau} & x_{N-(d-1)\tau} \end{bmatrix}_{(N-(d-1)\tau) \times d} \quad (5)$$

Where P is the phase space matrix and each row of this matrix shows a point in the phase space. Each column is a delayed version of the original time series with an embedding dimension d and time delay τ [16-17]. The phase space is constructed after the time series has been obtained from otsu method. The arc in the time series is taken as an event. An event is defined as an important occurrence. In this study, the arc is taken as an event.

For detection of arc events, an event characterization function should be defined. In this study, the event characterization function determines whether an arc occurs in the next step of the time series or not. This objective function is also used in [18] to detect the earthquake events. This function is given below.

$$g(x_t) = x_{t+1} \quad (6)$$

The objective of our optimization problem is to find a temporal pattern cluster. The members of this cluster defines an event that occurs in the next step. A temporal pattern cluster is represented as P and the cardinality of P is calculated as follow.

$$c(P) = \sum_{i=1}^N 1, \quad \text{for all } x_i \in P \quad (7)$$

In (7), N is the number of samples and $c(P)$ is the sum of ones for all x_i that are inside the cluster P . The cardinality is calculates as follow for all x_i that is outside of the P .

$$cn(P) = \sum_{i=1}^N 1, \quad \text{for all } x_i \notin P \quad (8)$$

The average eventness of the phase space points, which are in and not in the temporal pattern cluster P , are given in (9), respectively.

$$\mu_P = \frac{1}{c(P)} \sum_{i=1}^N g(x_i), \quad \text{for all } x_i \in P \quad (9)$$

$$\mu_{Pn} = \frac{1}{cn(P)} \sum_{i=1}^N g(x_i), \quad \text{for all } x_i \notin P$$

In (9), the average values are found for points of cluster P and other points. The variances for each condition is given (10).

$$\sigma_P^2 = \frac{1}{c(P)} \sum_{i=1}^N (g(x_i) - \mu_P)^2, \quad \text{for all } x_i \in P \quad (10)$$

$$\sigma_{Pn}^2 = \frac{1}{cn(P)} \sum_{i=1}^N (g(x_i) - \mu_{Pn})^2, \quad \text{for all } x_i \notin P$$

The objective function can be defined by using previous equations as follows.

$$f(P) = \frac{\mu_P - \mu_{Pn}}{\sqrt{\frac{\sigma_P^2}{c(P)} + \frac{\sigma_{Pn}^2}{cn(P)}}} \quad (11)$$

This objective function is useful for identifying temporal patterns that has a high average eventness. After the objective function has been defined, the particle swarm based optimization can be used to find the center points of temporal pattern cluster. The cluster radius is taken as a constant value. The main steps of particle swarm based arc detection are given in Fig. 3.

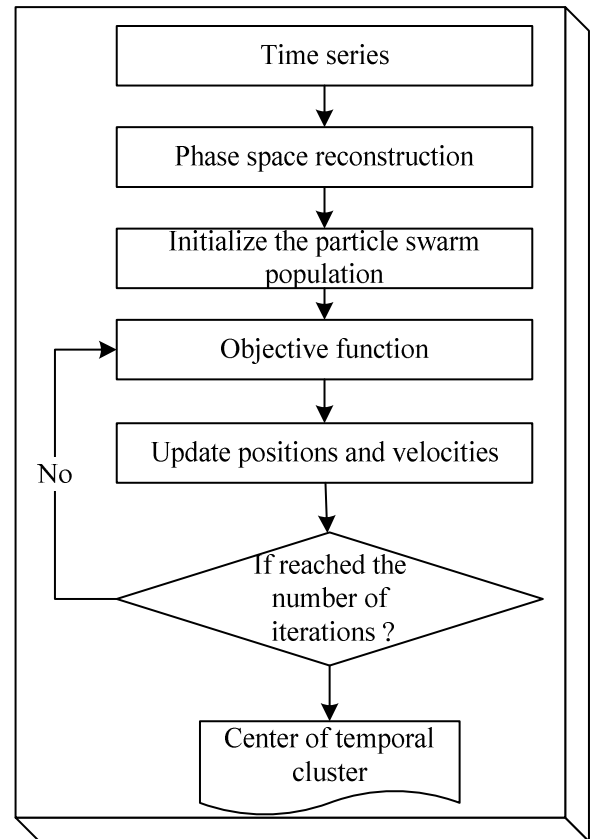


Fig. 3. Particle swarm based event detection

In Fig. 3, the time series, which is obtained from a video sequence, is taken and the phase space of it is reconstructed. The particle swarm optimization is initialized in two dimensional phase space. The aim of the particle swarm optimization is to find the center of the best temporal cluster center that predicts an event occurrence in the next time. The algorithm is iterated until the number of iterations.

III. EXPERIMENTAL RESULTS

The detection of the arc events gives useful information regarding the quality of collected current. If the occurrence of an arc increases, the friction will damage the pantograph strip. This arc causes a loss of the contact between the pantograph and the contact wire. The proposed algorithm is applied to a real pantograph's video. The sequences of images are acquired from a camera, mounted on the roof of the locomotive. The video of the pantograph system is saved for a determined time. While the camera captures a frame, the algorithm applies otsu method in order to determine the ratio of change. The experimental setup of the proposed algorithm is given in Fig. 4. The parameters of the PSO algorithm is given in TABLE I. The pantograph videos have been taken in three different conditions. Each video has 1000 samples. While the first video has a minimum arc, the arc increases in the second video. In the last video, the arc covers a big part of the image. Three frames taken from videos are given in Fig. 5.

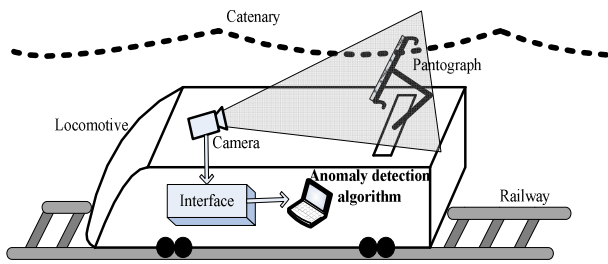
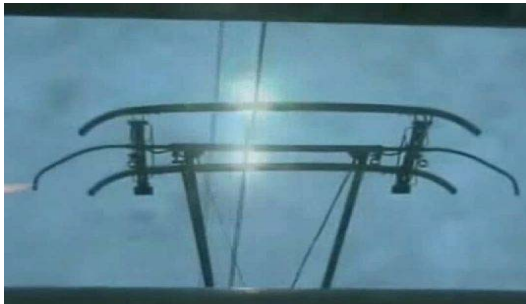


Fig. 4. The experimental setup

TABLE I. PSO PARAMETERS

Parameter	Value
Number of iteration	100
Population size	20
c1	2.05
c2	2.05



(a) Minimum arc



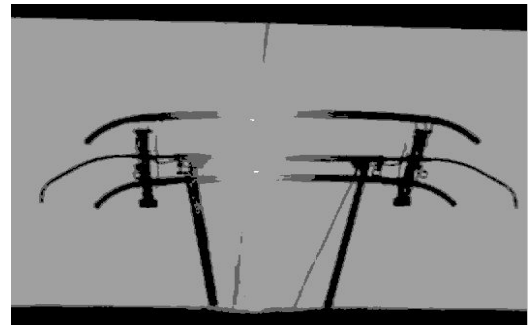
(b) Increased arc



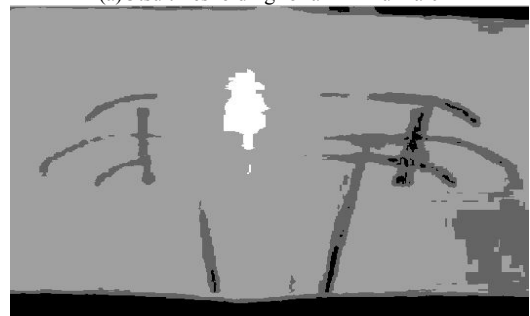
(c) Big arc

Fig. 5. Three different arc occurrence

In each frame, the current image sequence are converted to the gray scale image. Then, a threshold value based on otsu method are applied to each frame. The otsu results are given in Fig. 6 for three frames.



(a)Otsu thresholding for a minimum arc



(b)Otsu thresholding for increased arc



(c) Otsu thresholding for big arc
Fig. 6. Otsu thresholding and segmentation for three frames

As shown in Fig. 6, arc consisting regions according to Otsu method are indicated with white color. White region is quite small in small arc. Moreover, white region is growing in intense arc. White region is calculated according to all regions in the image in order to determine the intensity of the arc. A time series is created for 1000 frame by using this process. The time series of a big arc condition is illustrated in Fig. 7.

As seen in Fig. 7, arc intensity is obtained from 1000 frame image. The normal and big arcs occurs in this time series. After the time series has been obtained, the phase space of the time series should be constructed. The embedding dimension and time delay are selected as 2 and 1, respectively. The obtained result from phase space is given in Fig. 8.

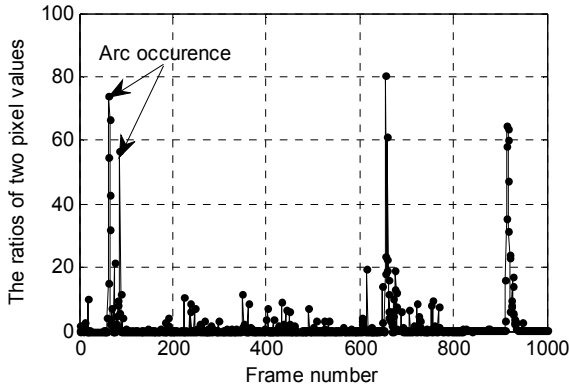


Fig. 7. The time series with big arc condition

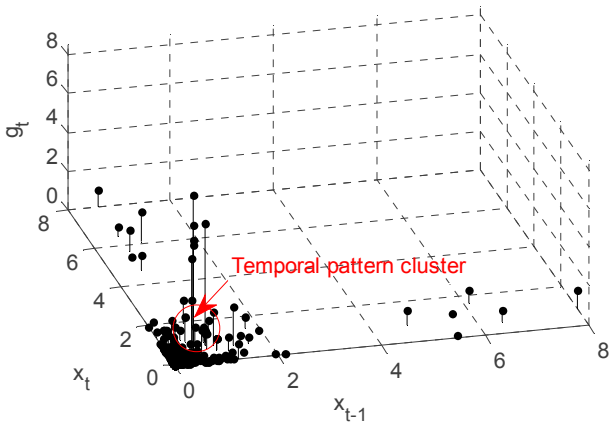


Fig. 8. 3D phase space for time series

The arc events are predicted in phase space by using particle swarm optimization method. The algorithm is iterated until the number of iterations. The convergence of particle swarm optimization is given in Fig. 9.

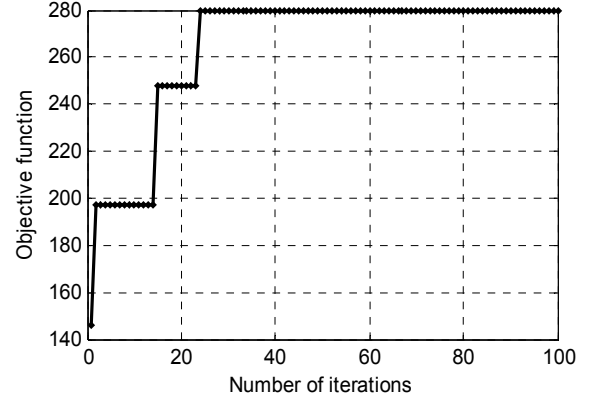


Fig. 9. The convergence of particle swarm optimization

As shown in Fig. 9, the algorithm reaches the maximum value after about 30 iterations. The proposed method is a new approach to detect the arc occurred in a pantograph video. In a pantograph system, many factors affect the interaction between a pantograph and catenary system. However, the serious arc occurs when the pantograph strip damages. The proposed approach is new method for detection of pantograph-catenary system. The proposed method is compared to thermo-vision based method [4]. The comparison results are given in TABLE II for 1000 frames.

As shown in TABLE II, the proposed method is faster than thermo-vision method. The thermo-vision based analysis uses a large portion of the time to find the contact point. So, such an analysis is not appropriate for real-time operation. After the time series has been obtained, the phase space of the time series is constructed and particle swarm optimization is run to find temporal pattern cluster. The particle swarm optimization based method finds the temporal pattern cluster at about 4 seconds. So, overall algorithm takes 16 seconds for 1000 frames.

IV. CONCLUSIONS

There are some factors which critically affect the quality of current transmission to pantograph from catenary in electrical railways. Arc and wear that are consisted of friction in contact between catenary and pantograph can cause dangerous faults. Therefore, detection of arcs and maintenance on location of detected arcs is very important. In this paper, particle swarm optimization based arc detection algorithm using time series obtained from camera images has been proposed for pantograph-catenary systems in electrical trains. The proposed algorithm based on event prediction with particle swarm on phase space obtained from time series has been verified with simulations used healthy and faulty real data. Comparative analysis of proposed approach has been given with simulation results using real data. Obtained results show the effectiveness, high accuracy, and realizability in real time.

TABLE II. COMPARISON RESULTS OF TWO METHODS

Methods	Feature Extraction And Analysis	Average Time (Second)
Thermo vision [4]	Edge detection, Hough transform	200
The proposed method	OTSU thresholding	12

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