Removing spike noise from track alignment irregularities measures using an iteration filter

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Hang Zhang, and Yongjian Wu

Removing Spike Noise from Track Alignment Irregularities Measures Using an Iteration Filter

Hang Zhang[a)] and Yongjian Wu[b)]

Institute of information science and engineering, Central South University, Changsha 410075, China.

[a)]zhang22@csu.edu.cn
[b)]yjwu1992@163.com

Abstract. This paper describes an algorithm based on the smooth characteristic of track online for the real-time detection and removal of spike noise. Spike noise is caused by random events, including the shake of the frame of the trolley, detection or transmission errors within the measuring systems. Its effects are extremely undesirable because they can generate erroneous alerts for relevant, which can influence the results of safety and reliability. Due to the variable characteristics, and the measurement is operated in dynamic and turbulent conditions, the real-time detection of spike noise is difficult. By using the smooth characteristic of track online, we develop a filtering algorithm that is able to perform spike noise removal in real time. The proposed algorithm is validated on a set of experimental results, which include a comparison with other algorithms. The results confirm the effectiveness of the filtering algorithm, which have been implemented on our developed trolley modeled GJY-T-CSU-4.

Key words: A real-time filter; impulse noise; the smooth characteristic of track online; track maintenance; spike noise.

INTRODUCTION

With the demand for safety and reliability growing, the automation of measuring railway track alignment irregularities is becoming increasingly urgent. In general, railway track alignment irregularities include the horizontal alignment irregularity and vertical alignment irregularity parameters [14]. As a routine measuring tool for railway works department, trolley is generally used for railway track alignment irregularities monitoring for their remarkable performance especially in low price, simple structure and short work cycle. Essentially, based on chord measurement method, the measuring hardware system mounted on the trolley can acquire the irregularities data of the basic chord (1.25m) and calculate the track direction of 10m chord and versine of 20m chord using a corresponding algorithm. In particular, "sporadic" and inherently unpredictable disturbances often cause the occurrence of impulsive "spike–like" noise, which heavily contaminate the acquired data. There are several known reasons that may generate this type of phenomenon, e.g. the shake of the frame of the trolley, detection or transmission errors within the measuring system, singular parts of tracks (switches, level crossings) hiding the rail profile. Its presence is particularly undesirable since it can cause erroneous alerts for relevant defects, which must be necessarily detected for safety and preventive maintenance. A large amount of filtering algorithms has been proposed in the past few years, to remove the spike noise in many other contexts (e.g., digital signal processing [2], process control [7], audio signal processing [6], and image processing [11]). Using linear filtering techniques, including average filter and Kalman filter, analyse the measured data damage by spike noise. Moreover, a filtering approach that revises all the measured data is highly undesirable by using the high accuracy of measurement systems. Integrating the knowledge and experience of experts of railway measurements, a fuzzy filter online has been developed to cope with such a disturbance in paper [7] in which spike noise is able to identified by analyzing the measured parameters in particular patterns. But how to change experience of experts to fuzzy-rule is even more challenging. Moreover, the real-time processing performance of this method is also one of considerations, which is

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limited by the monitoring speed. By using the smooth characteristic of track online, a real-time filter to remove the spike noise online is presented in this paper [15]. The effectiveness of the algorithm is analyzed by a comparison with other spike noise detection and restoration approach on a large number of rail test experiments.

OVERVIEW OF RELATED LITERATURE

The parameters of track irregularity condition, which typically including gauge, super elevation, track alignment, versine, track profile, twist and other geometric shape and position parameters, will be used to check the track disease, guide track maintenance for ensuring traffic safety, and are also essential for modern management of the track status. In recent years, many researchers have done a lot of work to detect the status of the track irregularity. Compared to the large track inspection car, trolley is preferred to be used for railway track alignment irregularities ordinary monitoring due to the low price, easy to use and the short work cycle. Measuring systems are mounted on trolley running on the tracks powered by human, which can get and store vast volumes of track irregularity data. The speed of the trolley is far as 8km/h. Meanwhile the acquired track irregularity data are often heavily contaminated by impulsive "spike–like" noise. The spike noise is very similar to random uncertainties occurring in many engineering fields. The literature suggests a large amount of different filtering methods to deal with this noise. Classic smoothing filters include mean filter, Gaussian filter, median filter [7], non-iterative smoothing filter [4], neighborhood filter [5], bilateral filter [6], etc. These standard linear filtering techniques are inappropriate in track irregularity data processing because they invariably alter the frequency content without differentiating between the contribution of spike corrupted samples and that of uncorrupted samples. The regularization approach has been attracted by many researchers in signal restoration, which can take advantage of the priori knowledge about the signal [8]. In the design of anisotropic diffusion equation regularization, a lot of "edge-stopping" functions have been introduced to improve the automatic stopping of the diffusion [9-10].

Studies of spike-noise-corrupted signal focus on fuzzy filter based on fuzzy reasoning [7], which can not only detect the every spike noise, but also reconstruct the signal with the spike removed by a recursive filtering algorithm [17]. By synthesizing the basic measured data with these recent research attempts in regularization approach and recursive filtering algorithm, we developed an innovative dynamic iteration filter in which the filtering action is graded by means of smoothing regularization approach. Section III elaborates the details of the iteration filtering algorithm.

ITERATION FILTER AND THE MEASURING MODEL FOR TRACK ALIGNMENT IRREGULARITIES

The measuring noise and new dynamic iteration filter

The aim of track alignment irregularities measure is to get track alignment irregularities in 10m and 20m chord through the trolley's running in the track. In the measuring track alignment irregularities, trolley only can acquire the irregularities data in the basic chord (1.25m) due to the limit of the body of trolley. We select the trolley's vertical axis as the basic chord length of measurement noted as M (M=1.25m in this paper). In the middle of running the trolley in the tract, through the linear displacement sensor mounted on the middle of the vertical axis to measure the relative displacement between the sensor's head and the trolley's body, track alignment measured data $h(i)$ can be acquired. i respects the sampling point number. We used a mileage encoder mounted on the trolley's vertical axis to measure distance of the trolley traveled and use equidistant sampling model to trig sampling.

But there exist switches, level crossings and rail joints in the railway in-service tract, which make the linear of tract being broken lines and not smoothing surves. Additionally, manufacturing error for the trolley, the shake of the frame of the trolley in the running process, detection or transmission errors within the measuring system can make the spike noise enter into the acquired data $h(i)$. So it is necessary to research the effective and real-time filtering algorithm. Essentially the filtering algorithm is such an operator, by which the undesirable component in the raw data will be filtered out and the desirable component be remained. The whole data processing is shown as fig 1.

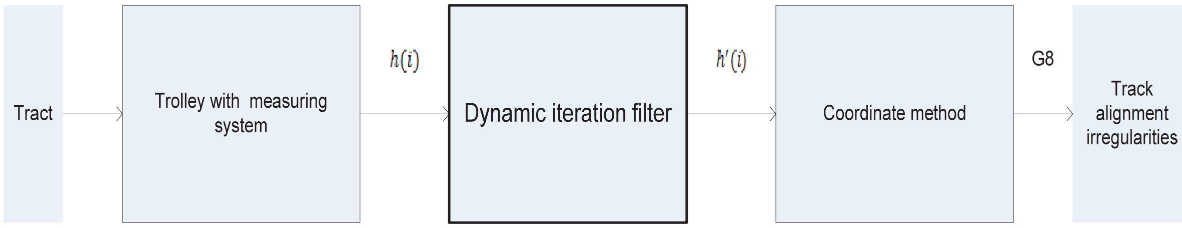

FIGURE 1. The whole data processing

$h^{'}(i)$ respects the filtering results for raw measured data h(i).

The basic principles of the proposed filtering technique can be summarized as follows.

While the trolley is running on the track, the measuring system is continuously acquiring the irregularities data in the basic chord (1.25m), ie raw measured data $h(i)$, through equidistant sampling.

How to select the sampling step T is important for improving the calculation results. But From the practical experience, the shorter the sampling step, the better calculation results. But the selection of the sampling step is determined by the real-time processing performance of the measuring hardware. Moreover, through the experiments for many different sampling steps, we can select 0.125m as the best the sampling step in in practice using (T = 0.125m), so $i = \text{int}(distances/0.125)$.

Let us consider a discrete series of samples *h(i),* where $i = 0,1,2, \ldots$ is the sampling point number and *h(i)* represents a track irregularity parameter of the basic chord, measured using the linear displacement sensor and affected by spike noise. The goal of the algorithm is to detect the occurrence of every spike, and to reconstruct an estimate of the signal with the spike removed $h^{'}(i)$. By using the following equation, we can compute the filtered signal:

$$h^{'}(i+1) = h^{'}(i) + k(i) * [h(i) - h^{'}(i)] \tag{1}$$

From (1), it is easy to infer the following three rules.

• If $K(i) = 1$, $h^{'}(i+1) = h(i)$, the output of the algorithm is identical to the measured variable. This condition obviously occurs whenever no spike is detected.

• If $K(i) = 0$, $h^{'}(i+1) = h^{'}(i)$, the algorithm retains the output of the filter at the previous step. This is a reaction to a detected spike. It is removed by replacing it with the previous measured sample.

• If $0 < K(i) < 1$, the output of the filter is obtained by a weighted average of the value to filter and the last filtered value. In this case a spike is detected but only partially scaled.

How to select the parameter $K(i)$ plays an important role in our algorithm. But it is no impossible to detect precisely when and where the spike occurs. In fact, the parameter $K(i)$ is seen as a probability where a spike is detected. From existing experiences, the detection of spike noise in the railway measured data is usually performed offline by experts of railway measurements. Moreover, there is a priori knowledge that track in using must have smoothness within some distance in order to ensure traffic safety, that means measured data should have no have spike signal. Considering the track is connected by many certain length rails, we can select 5m as the smoothness length, or filtering widen-window L=5m/0.125m=40. In order to achieve continuous measurement tasks, we select dynamic iteration filter as filtering algorithm. the filtered output is computed by applying filtering widen-window iteratively as follows when the measuring distance is larger than 5m:

For i=(start-point+1) : (end-point-L)

$$h^{'}(i+1) = F(h(i), h(i+1), \cdots h(i+L), h^{'}(i)) \tag{2}$$

Where start-point=0; end-point $= \text{int}(\dfrac{entmileage - startmileage}{0.125})$,end-mileage and start-mileage come from the mileage encoder mounted on the trolley.

The key issues for our algorithm are how to decide the function F, shown as fig2.

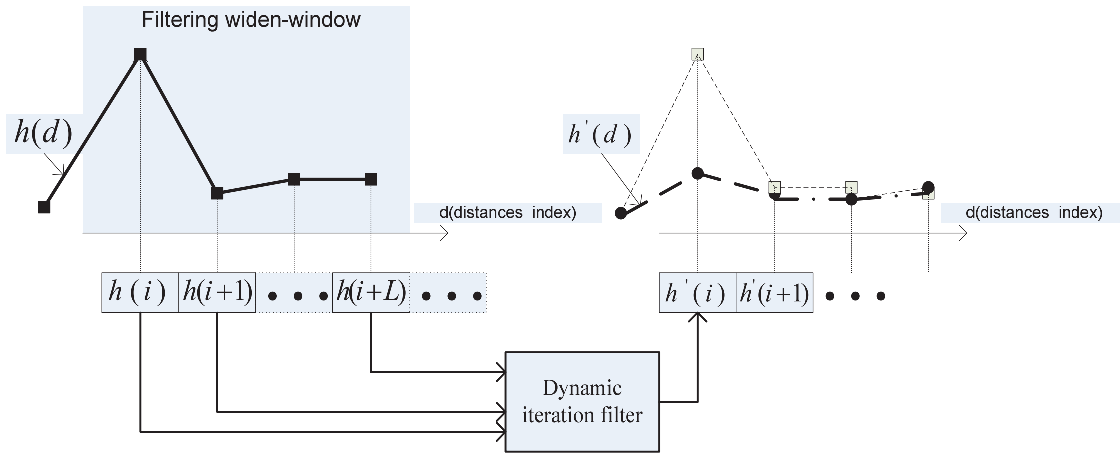

FIGURE 2. Dynamic iteration filter

To do so, in this paper, on the one hand we introduce the concept "edge-stopping" function which has been successfully used in edge detection in image processing [9,10,12-13]. And among the different "edge-stopping" functions, we select Gauss "edge-stopping" function as the description for the parameter *K*(*i*).

$$g_\sigma(s(i)) = e^{-\frac{s(i)^2}{2\sigma^2}} \tag{3}$$

Where $H = average(h(i),\cdots,h(i+L)); s(i) = h(i) - H; \sigma = \sqrt{\frac{(h(i)-H)^2 + \cdots + (h(i+L)-H)^2}{L}};$ Gauss "edge-stopping" function $g:[0,+\infty] \to (0,1]$ is a continuous monotonically decreasing scalar function with $g(0)=1$ and $\lim_{s\to+\infty} g(s) = 0$. So the bigger s(i), the bigger possibility that spike is detected, and the smaller the parameter *K*(*i*), which it can satisfy above-mentioned three rules.

On the other hand, we introduce window-filtering technology. Suppose the filtering widen-window L= 5m /0.125m=40, within the filtering widen-window, we can use following equation:

$$h'(i+1) = h'(i) + \alpha \sum_{j=0}^{L} g_\sigma(s(i+j)) * (h(i+j) - h'(i)) \tag{4}$$

Where α is the weighting factor ($\alpha \in (0,1); \alpha = 0.5$ in this paper.

The measuring principle for track alignment irregularities

The trolley for the automation of measuring track alignment irregularities is based on principle of chord measurement method [3,4] , In the evaluation of tract quality and tract maintaining, track alignment irregularities of the 10m chord are selected as evaluation criteria. So it is necessary to calculate track alignment irregularities of the 10m chord from the acquired track alignment irregularities data of the 1.25m length of chord. In this paper, we select the coordinate method to copy with the calculation track alignment irregularities [11], which can overcome the shortcomings of the chord measurement method lies in that the amplitude gain will change in spatial frequency domain with the change of irregularity wavelength. Following the same processing method, we can get the track alignment of 20m chord, which is important for the evaluation of tract quality in curve section of the tack [16]. So in here, we only take the track alignment of 10m chord for example.The coordinate method is described as follows, meanwhile the mathematical model for coordinate method is shown in Fig 3.

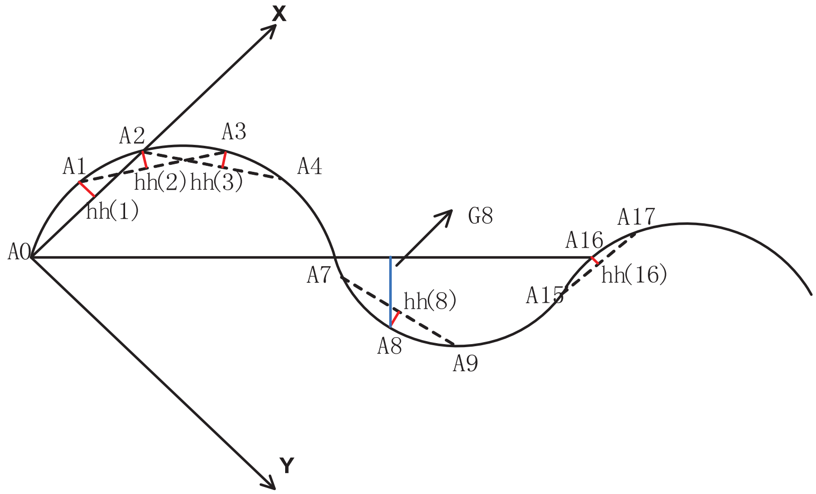

FIGURE 3. Mathematical model in coordinate method

STEP 1: Select the irregularities data $hh(d)$ in calculation points from the acquired data $h^{'}(d)$.

In order to meet the real-time demand, we select 0.625m distance as calculation points step to get our calculation data, or calculation points NN=10m/0.625m=16, marked as A1,A2,…,A16 in figure 3. Where Curve respects the tract that will be measured, so A0A2 respect the trolley's vertical axis whose length is 1.25m, ie A0A2=1.25m. Assuming A0A2 as the X-axis, A0 as the origin, Y-axis perpendicular to the X-axis, connect A0 and A16 forming a straight line, through point A8 make a perpendicular G8 of A0A16, the length of perpendicular G8 is the value of 10m track direction.

STEP 2: Calculating the track alignment irregularities in 10m chord.

By calculating the coordinates of each calculation point, finally obtain the value of perpendicular G8. According to the known conditions, the coordinates of starting point A0, A1, A2 are (x[0]=0,y[0]=0), (x[1]=0.625,y[1]=-hh(1)) , (x[2]=1.25,y[2]=0) respectively. Assuming θi is the angle of Chord {A(i-2),A(i)} and X-axis, using the geometric relationship of mathematical model , we can get the expression as follows:

$$\theta_3 = arctan\left(h(1)/0.625\right) + arctan\left(h(2)/0.625\right) \tag{5}$$

$$\theta_4 = \theta_3 + arctan\left(h(3)/0.625\right) + arctan\left(h(2)/0.625\right) \tag{6}$$

$$\theta_i = \theta_i - 1 + arctan\left(h(i-1)/0.625\right) + arctan\left(h(i-2)/0.625\right) \tag{7}$$

i=1,2,…..,n

Assuming the coordinate of A(i) is (X[i],Y[i]):

$$X[\mathrm{n}] = x[\mathrm{n}-2] + 1.25 * cos\theta_n \tag{8}$$

$$Y[\mathrm{n}] = y[\mathrm{n}-2] + 1.25 * sin\theta_n \tag{9}$$

The equation of straight line (A0A16) is y = x*tanθ

$$\theta = arctan\left(\left(y[16] - y[0]\right) / \left(x[16] - x[[0]\right)\right) \tag{10}$$

According to point to the rectilinear coordinate formula:

$$d = \frac{abs(y[8] - \tan(\theta) * x[8])}{\sqrt{1+\tan^2(\theta)}} = abs(y[8]\cos(\theta) - x[8] * \sin(\theta)) \tag{11}$$

$$G_8 = abs((y[8]-\mathrm{y}[0])*\cos(\theta)-(x[8]-x[0])*\sin(\theta)) \tag{12}$$

So, we can get the value of 10m track direction G8. Using the same algorithm can obtain the value of 20m versine. Moreover, coordinate method can application to measure curve radius and curvature [3].

EXPERIMENTAL VALIDATION

The proposed filter has been compared with the median filter (with the same window length) [6], often considered in technical literature as a standard for comparison of impulse noise filtering algorithms. The data comes from the practice line Xiang-Gui one way line in 530319.0-530860.25m, used our developed trolley modeled GJY-T-CSU-4, shown as fig.4.

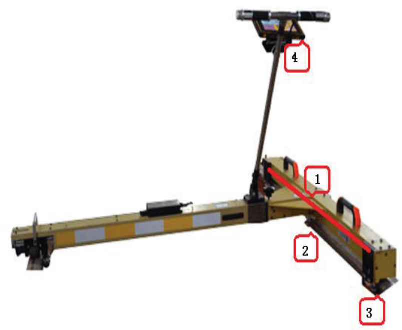

FIGURE 4. The measurement device GJY-T-CSU-4
1—the basic chord; 2-- the linear displacement sensor; 3-- the mileage encoder; 4—the data processing unit

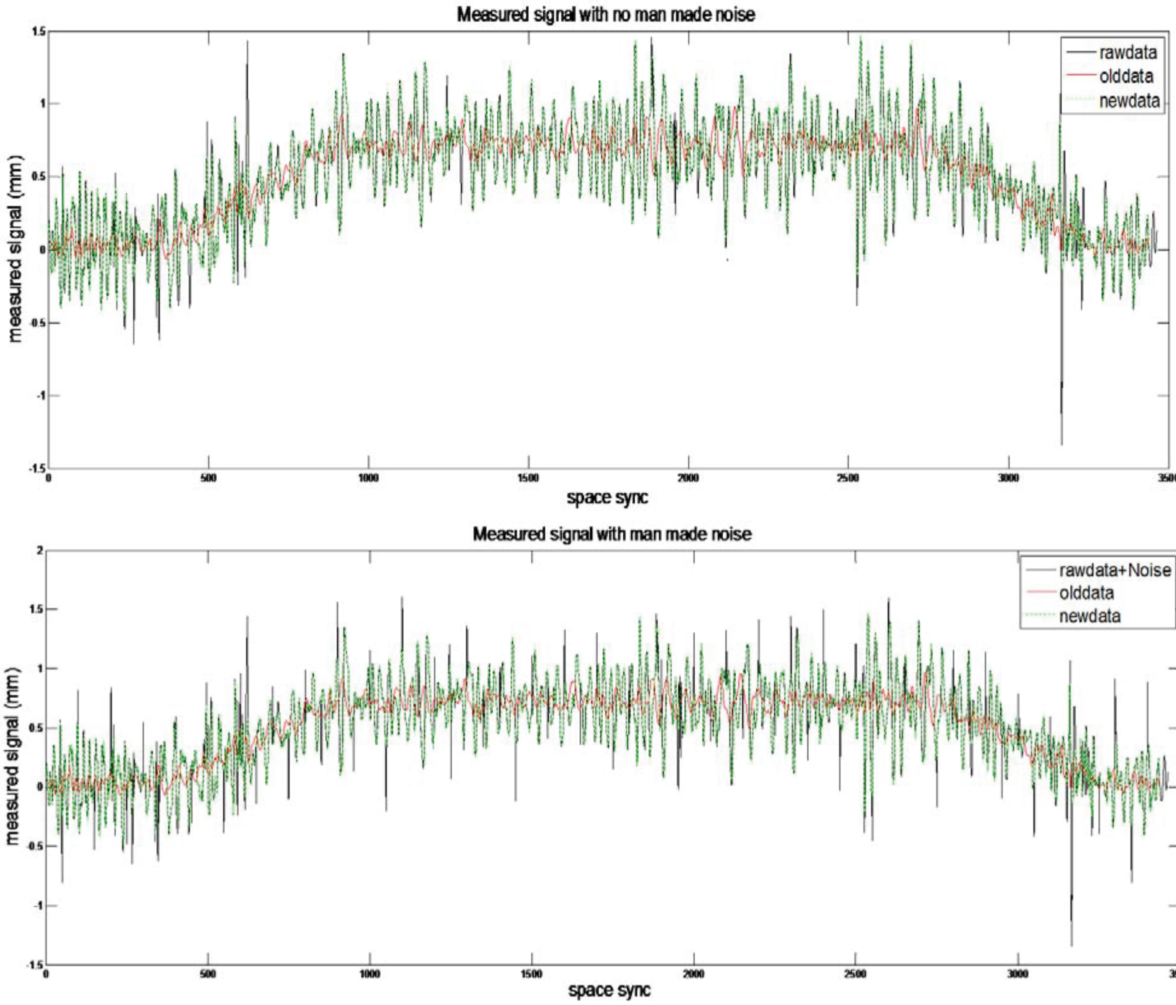

FIGURE 5. Comparison of the Measured signal with no man-made noise and Measured signal with man-made noise.

The first figure of Fig.5 shows the measured signal and the results of measured signal with no man made spike noise. The data which includes 3463 points comes from the practice line track alignment irregularities data of the 1.25m length of chord in 530319.0-530860.25m; meanwhile the artificial noise is to increase the 0.5 sharp noise of the positive and negative direction through every 50 points. In a similar way, the second figure of Fig.5 shows the measured signal and the results of measured signal with man-made spike noise. The raw-data represents the measured signal with our developed trolley modeled GJY-T-CSU-4, moreover we can get the old-data and the new-data by the Median Filter and the Innovative Dynamic Iteration. Through the comparative analysis of two figures, the Innovative Dynamic Iteration has a good performance for disturbance of impulsive spike; meanwhile it can keep the data integrity.

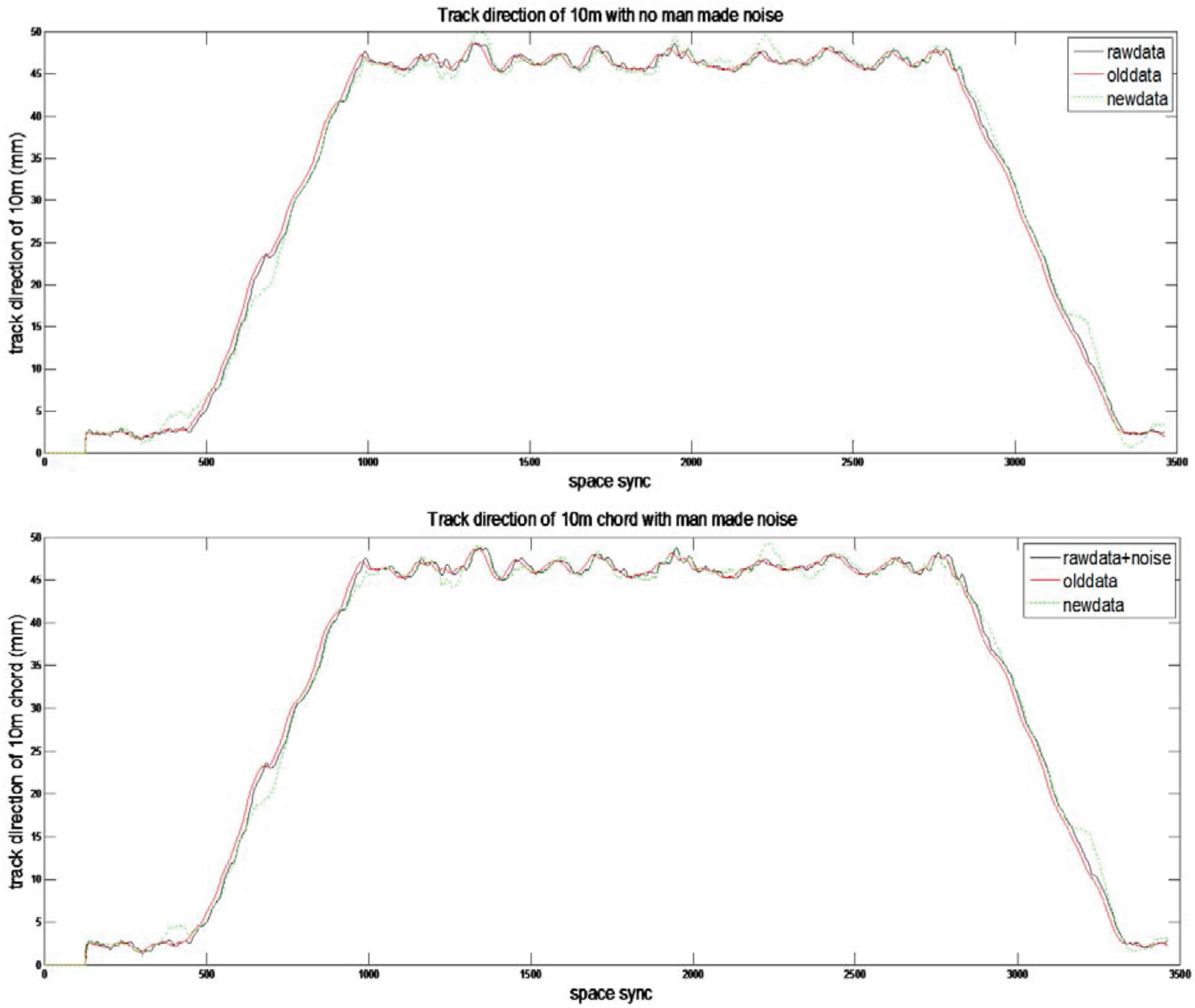

FIGURE 6. Comparison of the Track direction of 20m chord and Versine of 20m chord with man-made noise and no man made noise.

Fig.6 shows the raw data respectively with artificial noise and without noise of the track direction of 20m chord and versine of 20m chord.The old-data is the results by the chord measurement method. The new-data represents the results by the coordinate method. We draw the conclusion that the coordinate method overcomes the shortcomings of the chord measurement method lies in that the amplitude gain will change in spatial frequency domain with the change of irregularity wavelength by the analysis of the four figures.

CONCLUSION

This paper proposed an algorithm based on an innovative dynamic iteration for spike noise detection by our developed trolley modeled GJY-T-CSU-4. The approach is effective and cost low computation, which allows online detection. Moreover, the paper also illustrates that the coordinate method can overcome the shortcomings of the chord measurement method.

By analysis the data come from the practice track alignment irregularities data of the 1.25m length of chord used our developed trolley modeled GJY-T-CSU-4, it can conclude that the innovative dynamic iteration decrease the mistakes of identification and can keep data integrity.

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