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AN OPTIMAL RADAR VEHICLE RANGING ALGORITHM AGAINST VELOCITY MUTABILITY

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Abstract. *There exists the strong velocity mutability in the process of vehicle running and the research on accurate vehicle ranging algorithms is paid attention to widely. However, it is still difficult to use dynamic model to describe the mutability and to use the conventional frequency sampling based on computer visual signal to guarantee more complete acquisition of signal mutation. In order to avoid the defects above, this paper puts forward an optimal radar vehicle ranging algorithm against velocity mutability. The optimal algorithm carries out the acquisition of vehicle ranging frequency modulation signal by radar. It uses the nonlinear filtering method to carry on denoise processing, attains the accurate intermediate frequency signal, and provides the accurate data base for vehicle ranging. And the intermediate frequency signal emission frequency is calculated to eliminate the dynamic error so as to realize the vehicle ranging. The experimental results show that the optimal algorithm can effectively improve the accuracy of vehicle ranging when velocity mutability happens, and satisfactory effects have been obtained.*
Keywords: Radar ranging, Velocity mutability, Dynamic error, Nonlinear filtering

1. **Introduction.** In the process of vehicle running, it is necessary to measure the running range accurately, so as to provide reference for the driver [1]. With the continuous improvement of automobile manufacturing technology, the requirements for vehicle performance have also become higher and higher [2]. Therefore, some hot issues on the vehicle ranging algorithms are discussed in the research field of the vehicle and there is a very broad development space and practical value. At present, the vehicle ranging algorithms mainly include the vehicle ranging algorithm based on laser reflection, the vehicle ranging algorithm based on computer vision, and the vehicle ranging algorithm based on image segmentation [3], in which the vehicle ranging algorithm based on computer vision is used most commonly. [4-6] used visual ranging technology, and it had the strong adaptability for accuracy, velocity, intelligence, etc., which was mainly used in vehicle intelligence. [7-9] used ultrasonic and infrared range, and its characteristic was with a relatively short detection range, which was mainly used in reverse control system. [10-12] used laser and microwave radar range, and it had the advantages of distance measurement and high accuracy, which was widely used in vehicle active safety control system.

There exist different running velocities for different vehicles, and different accelerations for different vehicle models. The most difficult condition is that the strong velocity mutability happens in the running process of vehicles, such as the accidental braking and the machine fault. It is hard to describe the velocity mutability by dynamic model. And the ranging result distortion is resulted in, which reduces the accuracy of vehicle ranging. To avoid the drawbacks above, an optimal radar vehicle ranging algorithm against velocity mutability is put forward in this paper. The radar is adopted to acquire the vehicle ranging frequency modulation signal, and the nonlinear filtering method is used to denoise the signal, which improves the accuracy of vehicle ranging and provides the accurate data base for vehicle ranging. The intermediate frequency signal transmission frequency is calculated so as to realize vehicle ranging. The experimental results show that this algorithm can effectively improve the accuracy of vehicle ranging when the velocity mutation happens, and satisfactory effects are achieved.

The remainder of the paper is organized as follows. The conventional vehicle ranging algorithm based on computer vision is reviewed and analyzed in Section 2. Then, the optimal radar vehicle ranging algorithm against velocity mutability is presented in Section 3. In Section 4, the experimental results on contrastive data from both the algorithm of this paper and the conventional algorithm are demonstrated. Finally, conclusions are given with the importance and the practical value of the optimal algorithm.

2. **Conventional Vehicle Ranging Algorithm Based on Computer Vision.** For the conventional vehicle ranging algorithms, the computer vision algorithm is used most commonly. And the road vehicle is chosen to illustrate the computer vision algorithm. Set the computer visual image number of vehicle running road as N, the vehicle image edge area pixel number as n, the vehicle running initial velocity as V_0, the running velocity change parameter as η, and the data set consisting of the vehicle edge area pixel as $\{a_1, a_2, \ldots, a_n\}$.

Using Formula (1), the pixel gray mean of vehicle running track image is calculated as follows

$$\upsilon = \frac{\eta(V_0 - a_i)}{|N^2 - n|} \tag{1}$$

Using Formula (2), the running ranging is calculated as follows

$$\omega = \frac{\upsilon\sqrt{V_0 - 1}}{a_i^2 - a_1^2} \tag{2}$$

By the method above, the vehicle ranging is calculated so as to provide reference for the driver.

In the running process of vehicles, there is the strong mutability for vehicle running velocity, and it is difficult to describe the mutability by the dynamic model. As a result, there is the obvious error in visual image of vehicle ranging, which reduces the accuracy of vehicle ranging.

According to Formula (1), the vehicle velocity change parameter increases, which makes the pixel gray mean of running track image increase. According to Formula (2), the pixel gray mean of vehicle running track image increases, which causes the vehicle running range to increase. So the vehicle ranging accuracy is reduced. Furthermore, in the experiments of Section 4, it is proved that the computer vision algorithm is applied to the condition with smaller absolute value of uniform velocity or accelerated velocity.

3. **Radar Vehicle Ranging Algorithm.** The radar vehicle ranging algorithm is the core issue in research field of vehicles. The conventional vehicle ranging algorithm based on computer vision cannot avoid the velocity mutability of vehicle running, which causes the construction failure of the accurate visual image range dynamic model and reduces the accuracy of vehicle ranging. Therefore, this paper proposes the optimal radar vehicle ranging algorithm against velocity mutability.

3.1. **Frequency modulation signal filtering processing.** Radar can adjust the frequency modulation signal to satisfying the output requirements by means of the grid adjustment installment. The frequency modulation signal is a set of linear transformation signals which reflects on the vehicle. The reflected signal and the initial signal are operated by differential to get the intermediate frequency signal in the process of frequency modulation. And the running range is calculated according to the signal. Because the frequency modulation signal can be interfered by a variety of external factors and cause the low accuracy of the signal, it is necessary to carry on the nonlinear filtering processing, so as to improve the accuracy of frequency modulation signal.

Using Formula (3), the frequency modulation signal is denoised and the high-frequency modulation signal noise is removed, which is shown as follows

$$B(k,l) = \frac{\sum\limits_{(u,v)\in U_{p*q}} r(k+u,l+v)i(k+u,l+v)}{\sum\limits_{(u,v)\in U_{p*q}} r(k+u,l+v)} \tag{3}$$

where, $i(k,l)$ is the characteristic parameter of frequency modulation signal, $r(k,l)$ is the weight value of characteristics, and $(u,v) \in U_{p*q}$ is the data set of all reflected signal characteristics.

Using Formula (4), the low-frequency modulation signal is denoised and noise can be effectively removed, which is shown as follows.

$$h(k,l) = \frac{\sum\limits_{k}\sum\limits_{l}(i(k,l) - i(k,l+1))}{M} + \frac{\sum\limits_{k}\sum\limits_{l}(i(k,l) - i(k+1,l))}{M} \tag{4}$$

where, i is the result of weighted process, h is the nonlinear filtering result, and M is the operation result of characteristic difference.

By the method above, denoising is carried out in the frequency modulation signal, so as to improve the accuracy of frequency modulation signal and provide the accurate data base for radar vehicle ranging.

3.2. **Vehicle range measurement.** In the optimal radar vehicle ranging process against velocity mutability, the intermediate frequency and vehicle range are in positive proportion relationship. Therefore, the intermediate frequency signal frequency is the data base of radar vehicle ranging. In frequency measurement process, the dual frequency measurement method is used, which needs to measure the time base and the signal frequency at the same time. By calculating the mean of more intermediate frequency signal emission cycles, the reciprocal is got, and thus the frequency mean of intermediate frequency signal is obtained. Then, the starting time of two counter units is consistent with each other. And the intermediate frequency signal is dealt with waveform transformation processing; the actual starting time of measurement is controlled by the processed result so that the actual starting time of measurement becomes integer times of intermediate frequency signal cycle.

Set the counting starting time of intermediate frequency signal frequency as U, the measurement result of intermediate frequency signal frequency in counting unit as P_y, the measurement result of clock signal in counting unit as P_0, and the two results are described by Formulas (5) and (6), which are expressed as follows.

$$P_y = Ug_{JG} \tag{5}$$

$$P_0 = Ug_0 \tag{6}$$

Value of g_{JG} is calculated by Formula (7), which is described as follows.

$$g_{JG} = \frac{P_y}{P_0} g_0 \tag{7}$$

In radar vehicle ranging process, the gate open time and the intermediate frequency signal measurement initial time are the same. Therefore, there are not errors in the intermediate frequency signal frequency calculation process. Set the frequency interval of radar emission frequency modulation signal to be described by Formula (8).

$$T_U(u) = B_U \sin[\psi_0(u)u + \vartheta] \quad 0 < u < T \tag{8}$$

where, ϑ is the space location parameter of oscillator, $\psi_0(u) = 2g_0(u)$, and $g_0(u)$ is the output frequency of modulation signal, which is calculated by Formula (9).

$$g_0(u) = g_j + v_u \quad 0 < u < U \tag{9}$$

where, $v = \frac{C}{U}$ is the velocity of signal transmission, U is the time interval of signal transmission, and C is the bandwidth of signal transmitted. The space position of output frequency modulation signal is calculated by Formula (10).

$$\varphi_0(u) = \int_{-\infty} \psi_0(u)du = 2\pi g_j u + \pi v_y^2 + \vartheta \tag{10}$$

The frequency modulation signal from the radar transmission is reflected by the vehicle, and the reflected signal parameters are attained, which is shown by Formula (11).

$$T_S(u) = T_U(u - u_e) \tag{11}$$

where, $u_e = \frac{2S}{d}$ is the signal transmission lag time, d is the electromagnetic wave transmission velocity and S is the vehicle running range, which usually satisfies $u_e = U$.

The space position of intermediate frequency signal is got by calculating reflection signal differential, which is shown as follows.

$$\varphi_G(u) = \varphi_0(u) - \varphi_0(u - u_e) = \pi\left(2g_j u_e + 2v_{u_e} \cdot u - v_{u_e}^2\right) \tag{12}$$

Using Formula (13), the transmission frequency of intermediate frequency signal is calculated as follows.

$$\begin{cases} \psi_{JG}(u) = \frac{u\varphi_{JG}(u)}{du} = 2\pi g_{JG}(u) = 2\pi v_{u_e} \\ g_{JG}(u) = v_{u_e} \end{cases} \tag{13}$$

Substitute $u_e = \frac{2S}{d}$ to Formula (13) and the vehicle running range is got, which is shown as follows.

$$S = \frac{g_{JG}d}{2v} = \frac{dU}{2C}g_{JG} \tag{14}$$

According to the method above, the vehicle ranging frequency modulation signal is acquired, and then the nonlinear filtering method is adopted to denoise the signal, which can improve the accuracy of vehicle ranging frequency modulation signal and provide the accurate data base for vehicle ranging. The transmission frequency of intermediate frequency signal is calculated so as to realize vehicle ranging.

4. **Experimental Results and Analysis.** In order to validate the superiority of the vehicle ranging algorithm of the paper, the contrastive experiments are carried out. The experiments are set as follows. On the road selected, the range scale is dimensioned as 0-1000m respectively, the same vehicle moves on the road from 0-meter scale to 100-meter scale for many times, the velocity change number for each time increases from 1 to 20 times successively, the conventional vehicle ranging algorithm based on computer vision and the vehicle ranging algorithm of the paper are adopted, and the vehicle is ranged three times for every 10m distance, and the measurement is carried out by the two algorithms at the same time. The error mean of vehicle ranging of the two algorithms is shown in Figure 1.

By analyzing Figure 1, it can be observed that the error mean curve of the algorithm of the paper is below that of the conventional algorithm in general, which indicates the optimal radar vehicle ranging algorithm against velocity mutability can improve the accuracy of the vehicle ranging. And it can be found that under the circumstances of the frequent change of vehicle running velocity, the dynamic error of vehicle ranging using the algorithm of the paper is the nearly same to the dynamic error without frequent change of vehicle running velocity, in which the accuracy of vehicle ranging of the algorithm of the paper cannot be interfered by velocity mutability.

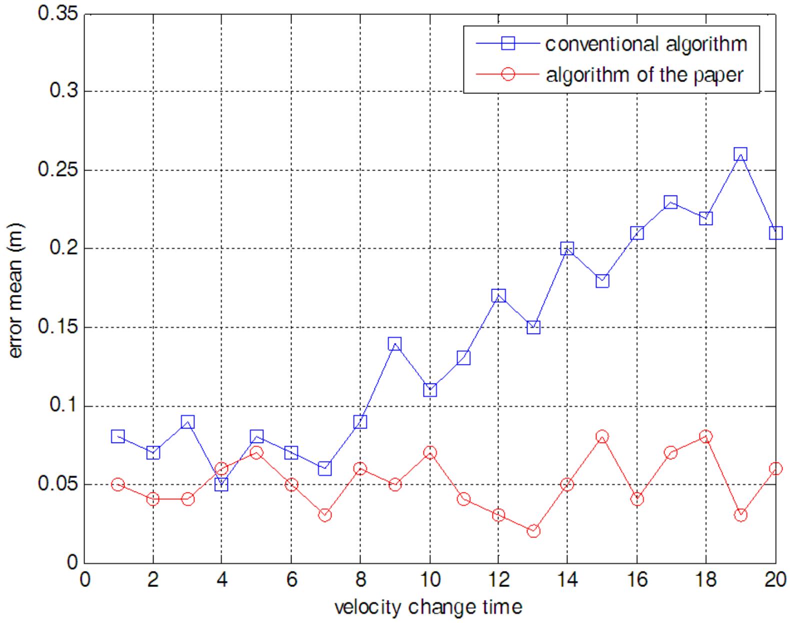

FIGURE 1. Experimental results of error mean

5. **Conclusions.** In this paper, the optimal radar vehicle ranging algorithm against velocity mutability is proposed, which carries out the acquisition of vehicle ranging frequency modulation signal and uses the nonlinear filtering method to denoise the signal in order to improve the accuracy of vehicle ranging and provide the accurate data base for vehicle ranging. And the transmission frequency of the intermediate frequency signal is calculated so as to realize the vehicle ranging. The experimental results show that the algorithm of the paper can effectively improve the accuracy of the vehicle ranging as well as the ability against velocity mutability. Further research of the optimal algorithm will be carried out especially on its comparative analysis. The optimal algorithm will show more important and practical significance in the future.

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