Design of Tram Collision Prevention System Based on Infrared Ranging and Kalman Filtering

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Abstract: Since the route of tram operation is set on a specific orbit, pedestrians or vehicles may enter the orbit during driving. In order to avoid such traffic accidents caused by collisions, a set of infrared ranging fusion is designed. Kalman filtering algorithm for tram anti-collision system. Considering that the obstacles in front may have moving speed, the real-time information obtained by infrared ranging is used as the data basis, the prediction model is established according to the current relative distance and relative speed, and the Kalman filtering algorithm is used to accurately predict the relative speed, and then the relative vehicle is used. Calculate the distance warning threshold from the information and relative speed to eliminate the calculation error and improve the accuracy of the relative real-time distance information. The theoretical test shows that the method can greatly improve the accuracy of detecting the real-time distance of the tram during driving.

1. Introduction
Tram has the characteristics of low cost, large volume, convenient and fast, and its status in the city is between the subway and the bus. It is a new type of transportation. Trams have pedestrian crossings in the driving line, sharing road rights with social vehicles in some sections, and this driving situation is prone to collisions. Therefore, in order to reduce the probability of accidents, an anti-collision warning system for ensuring traffic safety of trams is designed. Because the speed of the tram itself is slow, the speed value will not change suddenly. Therefore, when designing the anti-collision warning system for the tram, the real-time distance information collected by the infrared range finder can establish the prediction model [1]. Based on this prediction model, Kalman filtering algorithm predicts the distance information of adjacent acquisition data cycles, and measures the relative vehicle speed to achieve accurate warning.

2. Overall system design
2.1. System frame design
The design includes several parts for information acquisition, data processing and alarm braking. The real-time data detected by the infrared range finder, including the current driving speed and the distance from the obstacle, transmits the data to the single-chip control unit, and obtains the accurate relative distance and relative vehicle speed through the Kalman filtering algorithm to determine whether to send a signal. Sound and light alarm and automatic brake braking. Figure 1 shows the schematic diagram of the system framework.
2.2. System hardware design

The system hardware consists of STM32F103ZET6 single-chip microcomputer, infrared transmitting circuit, infrared receiving and amplifying circuit, shaping circuit, alarm module and power supply circuit. The STM32F103ZET6 microcontroller is the core control unit. The 12-bit ADC is a successive approximation analog-to-digital converter with up to 18 channels that can measure 16 external and 2 internal sources [2]. The analog signal detected by the infrared range finder is converted into a digital signal by high-speed A/D conversion inside the STM32 microcontroller. The circuit diagram of the power module is shown in Figure 2.

2.3. System software design

After the initialization of the MCU, the subroutine is repeatedly called, and the MCU judges each signal cycle to determine whether the infrared sensor receives the reflected signal of the reflected infrared ray. During the running of the tram, set S to the distance between the train and the obstacle in front. To avoid collision traffic accidents, set the safety distance of the infrared distance measurement result S to 8m and the dangerous distance of S to 5m. The data obtained by the MCU through the Kalman filtering algorithm determines the current relative distance. If the relative distance is greater than or equal to 8m, the program enters the loop detection; if the relative distance is less than 8m and greater than 5m, the single-chip sends a signal for sound and light. Alarm; if the relative distance is less than or equal to 5m, the MCU will directly send an automatic brake signal to perform emergency braking. The main control program flow chart is shown in Figure 3.
3. Infrared ranging combined with Kalman filtering algorithm prediction process

3.1. Infrared ranging principle
The infrared range finder continuously transmits infrared rays with a frequency of 40 kHz to the direction of the tram. If a signal reflected from the obstacle is detected, the reflected signal is received by the infrared sensor, and after being converted by the single-chip microcomputer, after being programmed, By multiplying the signal transmission period T by the number of signal transmissions n, the time difference t between the transmitted and received signals can be obtained, as in equation (1).

\[ t = Tn \quad (1) \]

\[ S = \frac{1}{2} Ct \quad (2) \]

In equation (2), C is the propagation speed of infrared rays. By default, the propagation speed is equal to the speed of light, which is \(3 \times 10^8\) m/s; n is the value of the signal pulse, and T is the period of the signal pulse.

The infrared emission circuit first emits infrared rays in the forward direction of the train. After encountering the obstacle, the infrared radiation is reflected. The infrared receiving and amplifying circuit receives the reflected signal for the first time. At this time, the infrared sensor sends a pulse signal to the single chip microcomputer, and the integrated counter of the single chip microcomputer starts counting work; After the receiving amplifier circuit receives the reflected signal for the second time, the MCU performs the Kalman filtering algorithm to predict the processing, the data is latched, and the data is displayed on the LCD display through the MCU, and then it is judged whether the alarm should be performed or the alarm and the brake are performed. The schematic diagram of infrared ranging is shown in Figure 4.

![Figure 4. Schematic diagram of infrared ranging](image-url)
3.2. Kalman filtering algorithm and establishment of prediction model

3.2.1. Kalman filtering algorithm

Kalman filtering theory is an algorithm for linear minimum variance error estimation of dynamic system state sequences. It describes the system through dynamic state equations and observation equations. It has the characteristics of small computation and real-time calculation [3]. In this system, this algorithm is applied to estimate the moving speed of the obstacle in front of the train. After the algorithm predicts, the system will generate a reliable estimate for the obstacle, and then retrieve it within a smaller threshold, and finally filter effect.

3.2.2. Improvement of Kalman algorithm prediction model

The application of conventional infrared ranging in automotive anti-collision systems is described in [4]. The single-chip microcomputer relies on the infrared transmission and reception time interval as the counting start signal, and directly processes it through the single-chip microcomputer to obtain the time difference, and obtains the measurement distance by using \( S = \frac{1}{2} C t \). Since this calculation method lacks an optimization algorithm for data, it introduces optimization of data. According to the actual situation of the tram operation, there are two improvements to the Kalman algorithm A and B:

A. In order to derive the equation of the real-time state of the system, \( t_k \) and \( t_{k+1} \) are introduced into two arbitrary adjacent acquisition data moments, and \( S(k) \) and \( S(k+1) \) are respectively two trams and front obstacles. The distance of the object, where \( k \) takes a positive integer; the set \( T \) is the sampling period time of the infrared ranging, where the value is 0.1 s; \( S(k) \) is the relative distance between the tram and the obstacle ahead at \( t_k \); \( S(k-1) \) is the relative distance between the tram and the obstacle ahead at \( t_{k-1} \). \( z(k) \) is the relative speed change between the tram and the front obstacle between two adjacent periods. Get the following formula:

\[
S(k + 1) = S(k) + TS(k) \quad (3), \quad S(k) = S(k - 1) + z(k)
\]

Substituting equation (3) into equation (4) can be obtained:

\[
S(k + 1) = S(k) + z(k)T + W(k) \quad (4)
\]

In the equation, \( W(k) = \frac{z(k)T}{\sum} \), and the state vector is \( X(k) = [S(k) \; (k - 1)]^T \), then \( X(k + 1) = [S(k + 1) \; (k)]^T \), from which the system state equation is derived as:

\[
X(k + 1) = \varphi(k)X(k) + G(k)W(k) \quad (6)
\]

Where \( X(k) \) is a two-dimensional target state vector; \( \varphi(k) \) is a one-step transfer matrix of the target state; \( G(k) \) is a noise one-step transfer matrix; \( W(k) \) is a system state noise, and its covariance matrix is \( R_1 \);

B. In order to reduce the error of the measurement results, the measurement equation is introduced to obtain the final calculation formula. Let \( Y(k) \) be a two-dimensional measurement vector; \( H(k) \) is a state measurement matrix; \( V(k) \) is measurement noise, and its covariance matrix is \( R_2 \).

\[
Y(k) = H(k)X(k) + V(k) \quad (7)
\]

From the equations (5), (6), and (7), the equations can be obtained:

\[
\varphi(k) = \begin{bmatrix} 2 & -1 \\ 1 & 0 \end{bmatrix}, \quad G(k) = \begin{bmatrix} 1 \\ 0 \end{bmatrix}^T, \quad H(k) = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}
\]

3.3. Optimization Process of Kalman Filtering Algorithm

3.3.1. Introduction of prediction formula

In order to reduce the measurement error, the accuracy of the measurement results and the stability and reliability of the experiment are improved[5]. Here \( K(k) \) is defined as the system gain value; \( P \) is the error variance matrix; \( H(k) \) is the state measurement matrix; \( \hat{X} \) is the target state vector prediction value.
Among the various optimization algorithms, the complexity of the Kalman algorithm is low, and it is easy to derive the global optimal solution. The gain formula, variance prediction formula and state prediction formula predicted by Kalman filtering are shown in equations (8), (9), and (10).

\[
K(k) = P\left[\frac{k}{k-1}\right]H^T(k)\left[H(k)P\left[\frac{k}{k-1}\right]H^T(k) + R_2(k)\right]^{-1} H(k)P\left[\frac{k}{k-1}\right]
\]

\[
P(k/k) = P\left[\frac{k}{k-1}\right] - K(k)H(k)P\left[\frac{k}{k-1}\right], \quad P\left[\frac{k+1}{k}\right] = \varphi(k)P(k/k)\varphi^T(k) + G(k)R_1(k)G^T(k)
\]

\[
\hat{X} \left[\frac{k+1}{k}\right] = \varphi(k)\hat{X} \left[\frac{k}{k-1}\right] + K(k)\left[Y(k) - H(k)\hat{X} \left[\frac{k}{k-1}\right]\right]
\]

In this model, the distance difference \(W(k)\) originally measured between adjacent periods is regarded as system noise, and the indirect value can be avoided. The value of \(W(k)\) is not calculated by Kalman filter prediction algorithm. In the process of calculating the conditional error variance matrix, \(P\left[\frac{k}{k-1}\right]\), \(P(k/k)\) and system gain \(K(k)\) do not contain the two-dimensional measurement vector \(Y(k)\), including only \(R_1\), \(R_2\), \(\varphi(k)\) and \(H(k)\) known matrices.

3.3.2. Introduction of error matrix and gain matrix

In order to obtain the initial value of the error matrix[6], the parameters \(P_0\) and \(\varphi(k)\) are introduced as fixed values, and the linear stable constant values are expressed in equation (6), so there is a stable solution to the conditional error variance matrix. It is assumed that starting from the initial value \(P_0\) of the error matrix, when \(K\) approaches infinity, then \(P_k\) is infinitely close to \(P_\text{const}\). It can be seen from the push-down formula that when \(P_k\) is stable to a certain value, the \(K_k\) gain matrix will also stabilize to a value, that is, \(P_\text{const}\) infinitely approaches a certain value, and a certain threshold range is set. Within this threshold range, this can be considered as When the filtering reaches a stable state, the calculation of this method can omit the calculation of \(K_k\) and achieve the purpose of simplifying the calculation process. In the experiment, the covariance matrix \(R_1\) of the system state noise, the covariance matrix \(R_2\) of the measurement noise, and the initial value \(P_0\) of the error matrix can be experimentally determined to their initial values.

\[
R_1 = 0.007, \quad R_2 = \begin{bmatrix} 0.006 & 0 \\ 0 & 0.006 \end{bmatrix}, \quad P_0 = \begin{bmatrix} 0.36 & 0.36 \\ 0.36 & 0.36 \end{bmatrix}
\]

After a number of iterative calculations, the error matrix \(P\) approaches a stable value \(P_\text{const}\), at which point the gain matrix \(K\) also approaches a value \(K_\text{const}\). The values of \(P_\text{const}\) and \(K_\text{const}\) are as follows (11), (12).

\[
P_\text{const} = \begin{bmatrix} 0.0021 & 0.0010 \\ 0.0010 & 0.0009 \end{bmatrix}, \quad K_\text{const} = \begin{bmatrix} 0.707 & 0.207 \\ 0.207 & 0.266 \end{bmatrix}
\]

Based on this data, the distance \(X(k+1)\) between the train and the obstacle in the next signal period can be accurately predicted. Based on the distance parameter, the relative speed is calculated:

\[
v(k) = \frac{S(k+1) - S(k)}{T}
\]

4. Experimental simulation test and analysis

4.1. Experimental simulation test

After designing the hardware module and software module, use keil5 to compile the program and burn it to the single-chip microcomputer. After calculation, the measurement range of the infrared ranging is 5m-150m. For the actual running condition of the tram, set the threshold of the safe distance. It is 8m, the dangerous distance is 5m, and the maximum of the infrared range finder is less than 0.5m. This setting satisfies the measurement range and early warning condition of infrared ranging. The program file was imported using Proteus 7 Professional software, and the simulation was performed. The system was running normally during the experiment, and the sound and light alarm could be performed at the
set threshold of 5 m. The experimental simulation test is shown in Figure 5.

![Figure 5. Experimental simulation test](image)

### 4.2. Analysis of results

In order to increase the accuracy of the experiment and the intuitiveness of the results, a physical model was established in the experiment. Data is generated from the measured relative distance and relative vehicle speed, and the data is uniformly organized to generate a chart, which is marked at each moment during the experiment. Set the tram and the obstacle in front to move in the same direction. Before the start of the experiment, the train and the obstacle are kept at a distance of 20m, and the train travel speed is 4m/s. The train's infrared rangefinder works normally to detect the road condition information. At 8m, the train performs an audible and visual alarm, and the train decelerates at 5m. The reverse acceleration of the train is 3m/s². The data shows that the train stops running within 1.3s. At 3.75s, the relative distance is 5m and the train starts to decelerate. At 5.05s, the train stops completely. The relative distance is 3.4 m, effectively preventing collisions between vehicles and pedestrians or social vehicles. The dynamic experimental results of the obstacle detection are shown in Fig. 6.

![Figure 6. Dynamic experiment results](image)

### 5. Conclusion

The system uses an infrared range finder to detect the front of the tram in real time. Based on the data obtained by the infrared ranging module, the relative distance model is established. Based on this model, the Kalman filtering algorithm is used to calculate the data of the next cycle. Obtaining predictions, calculating relative speeds, making up for deviations in measurement results due to system errors or peripheral environmental influences, and improving the accuracy of early warnings during train
operation. The simulation experiment was carried out by keil5 and Proteus 7 Professional software. The system can perform sound and light warning and automatic braking within the threshold range set in advance, which can effectively prevent the collision during the running of the tram. The feasibility of the system design and the effectiveness of the algorithm.

References:
[1] Lü Xingxing, Wu Botao, Gao Jingfeng, Xue Jinhua. Research on Vehicle Front-end Vehicle Detection and Early Warning System Based on Infrared Ranging[J]. Journal of Highway and Transportation, 2014, 5: 129-130.
[2] Liu Liangping. Research on Network Intelligent Sensor Based on Ethernet Technology[J]. Information Security & Technology, 2011.08:25-27.
[3] Wei Zhiyong. Research on Multi-target Detection and Tracking Algorithm in Intelligent Monitoring System[J]. Enterprise Science and Technology, 2009,22:78-82.
[4] Jin Xiangliang, Zeng Yun, Chen Diping. The establishment of infrared ranging system and its application in automobile collision avoidance system [J]. Infrared Technology, 2001, 3: 43-45.
[5] Chen Xumei, Gong Huibo, Wang Jingnan. Study on BRT Travel Time Prediction Model Based on SVM and Kalman Filter[J]. Transportation Systems Engineering and Information, 2012,12(4):29-34.
[6] Bai Cong, Peng Zhongren. Bus travel time prediction based on dynamic model[J]. Computer Engineering and Applications, 2016,52(3): 103-107, 112.