RFID Data-Driven Vehicle Speed Prediction Using Adaptive Kalman Filter

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Abstract. This paper focuses on the design of radio frequency identification (RFID) data-driven vehicle speed prediction method using adaptive Kalman filtering. First of all, when the vehicle moves through a RFID tag, the reader needs to acquire the state information (i.e., current speed and time stamp) of the last vehicle across the tag, and meanwhile transmits its state information to this tag. Then, the state space model can be formulated according to the acquired state information. Finally, the adaptive Kalman filtering algorithm is proposed to predict and adjust the speed of vehicles. Adaptive Kalman filtering algorithm achieves the adaptive updating of variable forgetting factor by analyzing the error between the expected output value and the actual output value, so as to achieve the online updating of the prediction model. The numerical results further show that compared with the conventional Kalman filtering algorithm, the proposed algorithm can increase the speed prediction accuracy by 20%. This implies that the proposed algorithm can provide the better real-time effectiveness for the practical implementation.

Keywords: Speed prediction · RFID · Data acquisition · Adaptive Kalman filter

1 Introduction

Nowadays, with the increasing popularity of vehicles, the vehicle driving is suffering serious traffic problems, such as traffic road congestion, road traffic collision and road traffic incidents, et al. At present, drivers often rely on personal driving experience and visual responses evaluate the driving state of the front vehicle, but there is still visual blind area and experience error phenomenon. In order to alleviate traffic pressure and reduce the incidence of accidents, it is of practical importance to improve the driving safety by accurately predicting the speed of vehicles.

Currently, the main way to get the running speed of vehicles is based on laser velocity measurement [1], radar speed measurement [2], ultrasonic speed measurement [3–5], visual speed measurement [6], or GPS speed measurement [7,8]. All of the above methods are performed in the context of wireless communication. They are mainly applied to traffic intensive areas, traffic accident

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prone areas, urban central areas, parking lots, and crossroads. In these places, the speed of vehicle is predicted in real time through wireless sensing to avoid traffic accidents. However, when applied to complex terrain roads (e.g., U/Z shaped roads), there will be a lot of prediction errors. In the U/Z-shaped Road, there will be no vehicle in front of the rear vehicle to be scanned in the turn, and thus the wrong judgment leads to the occurrence of traffic accidents. Also, in the complex terrain roads, it is unrealistic to make the network stable communication. This implies that in some roads, vehicle communication may be delayed or even fails. To this end, a method based on radio frequency identification (RFID) is proposed in this paper.

As a new wireless communication technology, the RFID system consists of three parts: the RFID tag, the reader and the antenna. When the vehicle runs in the RFID environment, the wireless radio frequency method is used to carry out non-contact and bidirectional data transmission between the reader and the tag, in order to achieve target identification and data exchange. At present, RFID technology has been applied in many fields, such as automatic train identification management [9], automatic identification, sorting, transport management of aviation passenger baggage [10], highway toll and intelligent transportation system [11], taxi management, bus hub management [12] and railway locomotive identification system etc [13]. With the rapid development of RFID technology, the traffic management, traffic flow and vehicle safety have been guaranteed.

In different traffic scenario, different communication systems and modeling methods will make the speed prediction results diverse. The authors in [14] proposed a method of measuring and maintaining vehicle road distance based on RFID system. The simulation results show that the system can achieve high safety level while maintaining the comfort of the driver. A tracking and location algorithm of wMPS system based on small multiplier Kalman filter was proposed in [15], which reduced the nonlinear error and improved the accuracy of tracking and positioning in motion. According to [16], a vehicle speed prediction method based on Fuzzy Markovian model and autoregressive model was proposed to solve the vehicle fuel control design problem. This method poses some advantages in state recognition mapping, resolution elimination, dimensionality reduction, and improvement of prediction accuracy.

This paper focuses on the design of RFID data-driven vehicle speed prediction method using adaptive Kalman filter for inferior or complex roads, such as tunnels, caves and high bridges. The method combines the known environmental characteristics and equidistant distribution of data in a certain number of data acquisition points, that is, RFID tags. The RFID tags are placed on the surface of the road to store vehicle status information (i.e., current speed and times tamp). Then, the vehicle reader uses radio frequency to read the vehicle information from the tag and feedback its state information to the tag. Finally, the vehicle uses adaptive Kalman filter with variable forgetting factor to update the vehicle speed estimation. Adaptive Kalman filtering algorithm achieves the adaptive updating of variable forgetting factor by analyzing the error between the expected output value and the actual output value, so as to achieve the online updating of the prediction model. Through the simulation analysis, it can be seen that compared with the conventional Kalman filter method, the proposed method is better to reduce the error and improve the accuracy.

The rest of this paper is organized as follows. In Sect. 2, we describe the system framework and model establishment. Speed prediction algorithm based on adaptive Kalman filter is presented in Sect. 3. The simulation results and analysis are presented in Sect. 4. Finally, Sect. 5 concludes the paper.

2 System Framework and Model Establishment

2.1 System Framework

The RFID system is deployed on the pavement of tunnels, caves and bridge roads that GPS signals cannot cover. It consists of three parts: the RFID tag, the reader and the antenna. The corresponding RFID system model is shown in Fig. 1.

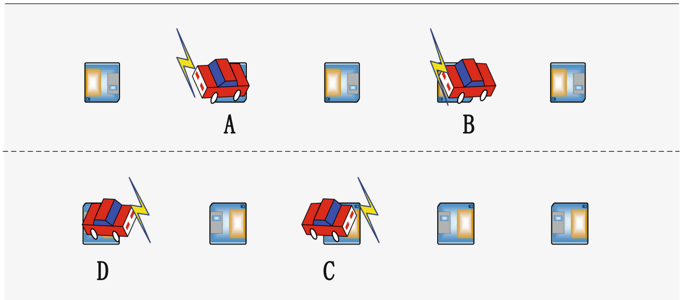

Fig. 1. RFID system model (Color figure online)

In Fig. 1, the block on the road is the RFID tag, which identifies the vehicle attached to it and stores the related state information of the vehicle. The vehicle front bumper equipped with the reader (two pieces of red blocks in front of the car), which is used to read the state information from the tag, and write the own state information to the tag. Antenna (yellow lightning) is used to achieve target recognition and data exchange, so that drivers can know the relevant state information of vehicles ahead of time, and better take safety measures.

The speed prediction of vehicles based on adaptive Kalman filter in RFID environment works as follows: ① the vehicle uses the logo of the RFID tag as well as the reading and writing of the reader to effectuate the data collection; ② the speed of vehicle is predicted by adaptive Kalman filter algorithm; ③ the velocity prediction value is corrected to make the velocity prediction close to the true value.

2.2 System Modeling

The RFID system consists of high-speed vehicles and a number of RFID tags (passive tags) deployed by a large line equidistant. Considering the RFID system set up on the roads, tunnels and bridge roads, the speed of vehicles basically the same, so the formula for displacement and speed are denoted by:

$$x_k = x_{k-1} + v_{k-1}\Delta(t) \quad (1)$$

$$v_k = v_{k-1} \quad (2)$$

Where x_k denotes the displacement of the vehicle at k time, $\Delta(t)$ denotes sample time interval, v_k denotes the vehicle speed at k time. In the static RFID system, the high-speed vehicle as the research target. When the vehicle arriving at the X_k of each state, each tag can establish relatively efficient data transmission with it [17]. After the completion of the data transfer, we can obtain the vehicle speed v_k and sample time t_k. Then, the above calculation formula (1) (2) are transformed into a state space model. Therefore, the equation of state and the measurement equation in the RFID system can be expressed as:

$$X_k = AX_{k-1} + \omega_{k-1} \quad (3)$$

$$Z_k = CX_k + \epsilon_k \quad (4)$$

Where X_k represents the state vector of system at the k time, A and C are state transition matrix, ω_{k-1} refers to the systematic error, Z_k represents the state observational values for k time systems, ϵ_k denotes the measurement error. Note that, ω_{k-1} and ϵ_k refer to the white noise of Gauss distribution, which are subject to $N(0, Q_{k-1})$ and $N(0, R_k)$, respectively.

3 Speed Prediction Algorithm Based on Adaptive Kalman Filter

In this paper, the adaptive forgetting factor μ_k is introduced on the basis of the time updating of the conventional Kalman filter algorithm. It changes the value of the error covariance matrix $\overline{P}_k$ when the time updated, thus enhancing the influence of the current data and keeping the data in the latest state. At the same time, according to the state equation and the measurement equation, an improved Kalman filter algorithm, namely the adaptive Kalman filter algorithm [18,19], is established. The improved Kalman filter algorithm:

(1) Time update (prediction stage)

① The state value $\overline{X}_k$ of the k time is predicted by the modified state value X_{k-1} of the $k-1$ time

$$\overline{P}_k = AX_{k-1} \quad (5)$$

② The error covariance matrix $\overline{P}_k$ of the k time is predicted by the modified error covariance matrix P_{k-1} of the $k-1$ time

$$\overline{P}_k = \mu_k A P_{k-1} A^T + Q \quad (6)$$

(2) Measurement update (correction stage)
① Calculation of Kalman gain K_k based on the error covariance $\overline{P}_k$ of the k time prediction and the measurement noise R

$$K_k = \overline{P}_k C^T (C\overline{P}_k C^T + R)^{-1} \tag{7}$$

② Introduce the state observation value Z_k of the system, then obtain the optimal state value X_k of the current time with using the state value $\overline{X}_k$ of the k time prediction.

$$X_k = \overline{X}_k + K_k(Z_k - C\overline{X}_k) \tag{8}$$

③ Update the error covariance, get the P_k value, prepare for the new error covariance at the next time.

$$P_k = (I + K_k C)\overline{P}_k \tag{9}$$

where the defined parameters [20] are shown in Table 1.

Table 1. Variables used by adaptive Kalman filter algorithm

Q	Covariance matrix of system noise
R	Covariance matrix of measurement noise
$\overline{X}_k$	The priori estimate of state at k time
X_k	The posterior estimate of state at k time
$\overline{P}_k$	The priori estimated error covariance matrix for k time
P_k	The posterior estimated error covariance matrix for k time
Z_k	Observation sample value at k time
K_k	Kalman gain at k time
A, C	State transition matrix
I	Unitary matrix
μ_k	Adaptive forgetting factor

In the RFID environment, the dynamic requirement is very high for the high-speed vehicles. Therefore, when the parameters change little, we use a larger adaptive forgetting factor μ_k to increase the intensity of the prediction. When the parameters vary greatly, the small adaptive forgetting factor is used to enhance the identification accuracy. The formula for the adaptive forgetting factor is used in this paper as follows:

$$\mu_k = \max\{1, tr(G_k)/tr(H_k)\} \tag{10}$$

$$G_k = M_k - CQC^T - R \tag{11}$$

$$M_k = \begin{cases} 0.5 e_k e_k^T, & k = 1 \\ \frac{\mu_{k-1} e_k e_k^T}{1+\mu_{k-1}}, & k > 1 \end{cases} \tag{12}$$

$$e_k = Z_k - C\overline{X}_k \tag{13}$$

$$H_k = CAP_{k-1}A^T C^T \tag{14}$$

With the increase of driving distance, the new error e_k becomes bigger and bigger. While introducing the adaptive forgetting factor μ_k, it can reduce the error between observation value and prediction value. At the same time, $\overline{P}_k$ value satisfies symmetry and positive definite, improving the dynamic performance of the system. The process of speed prediction operation for high-speed mobile vehicles based on adaptive Kalman filter in the RFID environment as follows:

Algorithm. The steps of vehicle speed prediction based on adaptive Kalman filter

1: **Initialization:**
Initialize state transition matrix A and C.
Initialize covariance matrix P_{k-1}, Q, R.
Initialize adaptive forgetting factor μ_{k-1}.
2: **Collect initial data** v_{k-1} **and** t_{k-1}
3: **Update adaptive forgetting factor** μ_k
4: **Time update:**
Calculate the state prediction value $\overline{X}_k$.
Calculate the error covariance matrix $\overline{P}_k$.
5: **Measurement update:**
Calculate Kalman gain K_k for the first moment.
Introduce the state observation value Z_k.
Calculate the optimal velocity X_k.
Update the error covariance matrix P_k.
6: **Next sample:**
let $K = K + 1$, repeat the above operation step 2.3.4, until the vehicle driven out of the RFID system.

4 Simulation Results

In this paper, the simulation experiment is carried out by using MATLAB. The simulation environment is set to a tunnel road with a length of 0.5 km, as well as 75 linear isometric distribution of RFID tags on the surface of the road. According to the national standards of highway tunnel speed and safe distance, the safe distance is set to 100 m. At the same time, according to scientific knowledge: The nerve response time of normal people is 0.3–0.5 s; The effective time of braking is 1.2–1.5 s [21,22]. So it is set in the vehicle speed relatively constant to 80 km/h forward, and in the course of the driving process every 0.3 s to carry out a communication with RFID tag, to achieve data exchange. It is assumed that the initial state of the iterative estimate is $(0, 80/3.6)^T$.

Speed Prediction Results Analysis: Figures 2 and 3 shows the vehicle speed prediction results using the conventional Kalman filter and adaptive Kalman filter, respectively. It can be seen that in comparison with conventional Kalman filter (KF), adaptive Kalman filter (AKF) is expected to provide the better real-time effectiveness. The "blue dotted line" denotes the actual running speed of vehicles, and the"red real line" denotes the estimated running speed of vehicles based on the filtering method. According to the comparison of the two lines, the more close the "blue dotted line" and the "red line" position, it shows that the speed of the method is better.

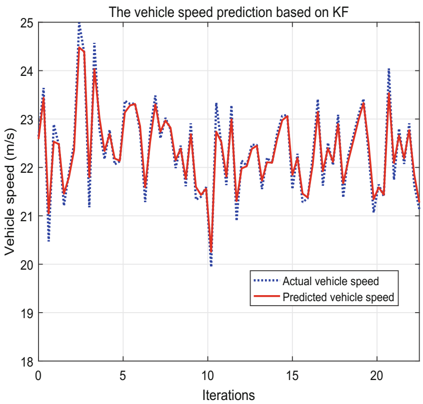

Fig. 2. Speed prediction effect of Kalman filter (Color figure online)

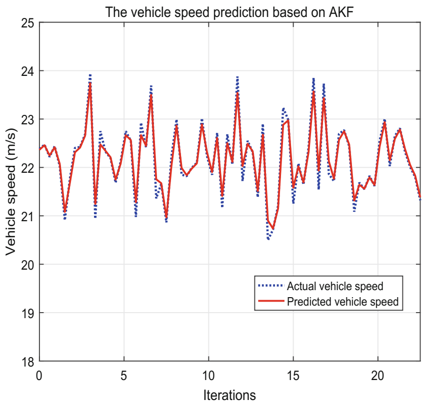

Fig. 3. Speed prediction effect of adaptive Kalman filter (Color figure online)

Speed Error Results Analysis: In the simulation experiment, the actual operation speed of vehicles and the estimated speed are calculated to observe the speed error of the vehicle passing through each RFID tag. Thus, the Kalman filtering algorithm and the adaptive Kalman filtering algorithm are compared to analyze the error results. The vehicle speed error effect as shown in Figs. 4 and 5.

From Fig. 4, we can see that in the whole iteration process, the maximum error between the actual speed of vehicles and the estimated speed based on KF is ± 0.6, and fluctuates on this. From Fig. 5, it can be seen clearly that during the whole iteration process, the maximum error between measured and estimated values of vehicle speed decreased from ± 0.6 to ± 0.4, and the fluctuation range is decreased by 20%, and the convergence effect is improved. Comparison between Figs. 4 and 5, we can know that in the RFID environment, the error based on the AKF is lower than the error based on the KF. The reason is that it introduces adaptive forgetting factor, reduces memory length of filter, makes full use of "present" measurement data, improves dynamic performance of filter, and better reflects real-time validity.

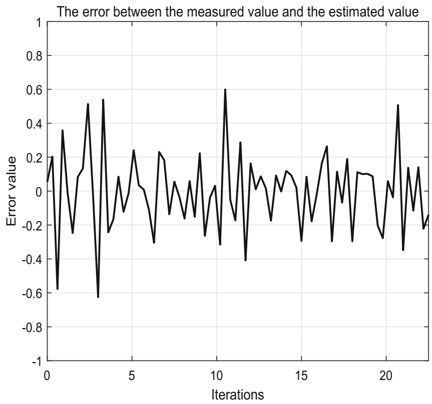

Fig. 4. Speed error effect of Kalman filter

Fig. 5. Speed error effect of adaptive Kalman filter

5 Conclusion

In this paper, a speed prediction method based on adaptive Kalman filter is proposed to predict the speed of vehicles. This method provides a possibility to record and predict the speed of vehicles under harsh environment, bend, downhill and other conditions. The simulation results justify that the speed prediction result based on adaptive Kalman filter is more close to the real value than based on conventional Kalman filter. Meanwhile the convergence effect of the filter improved, the fluctuation range decreased, effectively overcome the adverse effect caused by the process error and measurement error. This implies that the proposed algorithm can provide the better real-time effectiveness for the practical implementation.

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References

1. Yang, M., Dong, B., Wang, H., et al.: Laser radar based real time ego-motion estimation for intelligent vehicles. In: IEEE Intelligent Vehicle Symposium, vol. 1, pp. 44–51 (2002)
2. Floudas, N., Polychronopoulos, A., Amditis, A.: A survey of filtering techniques for vehicle tracking by radar equipped automotive platforms. In: International Conference on Information Fusion, vol. 2, pp. 25–28 (2005)
3. Zamiri, S., Reitinger, B., Grun, H., et al.: Laser ultrasonic velocity measurement for phase transformation investigation in titanium alloy. In: IEEE International Ultrasonics Symposium, pp. 683–686 (2013)

4. Titov, S.A., Maev, R.G., Bogachenkov, A.N.: An ultrasonic array technique for velocity of bulk waves and sample thickness measurement. In: IEEE International Ultrasonics Symposium, pp. 2384–2387 (2010)
5. Kalashnikov, A.N., Challis, R.E.: Errors and uncertainties in the measurement of ultrasonic wave attenuation and phase velocity. IEEE Trans. Ultrason. Ferroelectr. Freq. Control **52**, 1754–1768 (2005)
6. Shen, Q., Ban, X.-J., Chang, Z., et al.: On-line detection and temporal segmentation of actions in vidio based human-computer interaction. Chin. J. Comput. **38**(12), 2477–2487 (2015)
7. Kloos, G., Guivant, J.E., Worrall, S., et al.: Wireless network for mining applications. In: Australasian Conference on Robotics and Automation, Canberra, Australia, December 2004
8. Yoon, J.-H., Peng, H.: A cost-effective sideslip estimation method using velocity measurements from two GPS receivers. IEEE Trans. Veh. Technol. **63**, 2589–2599 (2014)
9. Bhavsar, S.S., Kulkarni, A.N.: Train collision avoidance system by using RFID. In: International Conference on Computing, Analytics and Security Trends, pp. 30–34 (2016)
10. Li, J., Jin, M., Luan, S.: Intriduction radio frequency identification technology. Comput. Knowl. Technol. **6**(15), 4238–4240 (2010)
11. Liu, W., Ning, H., Wang, B.: REID antenna design of highway ETC in ITS. In: International Symposium on Antennas, Propagation and EM Theory, pp. 1–4 (2006)
12. Guo, Y., Zhao, Z.: Design of school bus passengers' identity authentication system based on RFID. In: IEEE International Conference on Communication Problem-Solving, pp. 412–415 (2015)
13. Lee, L.T., Tsang, K.F.: An active RFID system for railway vehicle identification and positioning. In: International Conference on Railway Engineering - Challenges for Railway Transportation in Information Age, pp. 1–4 (2008)
14. Huo, Y., Lu, Y., Cheng, W., et al.: Vehicle road distance measurement and maintenance in RFID systems on roads. In: 2014 International Conference on Connected Vehicles and Expo, pp. 30–36 (2014)
15. Qiong, D., Yang, X., Zhu, J.: Study on tracking algorithm for wMPS based on least square Kalman filter. Chin. J. Sens. Actuators **25**(2), 236–239 (2012)
16. Jing, J., Filev, D., Kurt, A., et al.: Vehicle speed prediction using a cooperative method of fuzzy Markov model and auto-regressive model. In: 2017 IEEE Intelligent Vehicles Symposium, pp. 881–886 (2017)
17. Chen, X., Ling, Y., Chen, M.: Mobile robot localization algorithm based on gaussian mixture consider Kalman filter in WSNs environment. Chin. J. Sens. Actuators **30**(1), 133–138 (2017)
18. Welch, G., Bishop, G.: An Introduction to the Kalman Filter. University of North Carolina at Chapel Hill, vol. 8, no. 7, pp. 127–132 (2006)
19. Sun, Y., Zhang, C.: Research on the detection method of airport pavement joint seeper based on Kalman filter. Chin. J. Sens. Actuators **30**(8), 1204–1208 (2017)
20. Heidari, A., Khandani, A.K., Mcavoy, D.: Adaptive modelling and long-range prediction of mobile fading channels. IET Commun. **4**, 39–50 (2010)
21. Cai, X., Cai, M., Zhang, Y.: Research on driver reaction time in internet of vehicles environment. J. Comput. Appl. **37**(S2), 270–273 (2017)
22. Yang, L., Xing, C., Zhao, H.: Study on driver's reaction time (DRT) during car following. Comput. Technol. Autom. **34**(3), 33–37 (2015)