# Speed Prediction of High Speed Mobile Vehicle Based on Extended Kalman Filter in RFID System

Yupin Huang(✉), Liping Qian, and Anqi Feng

College of Information Engineering, Zhejiang University of Technology, Hangzhou 310023, China
yphuang_zjut@163.com, lpqian@zjut.edu.cn, aqfeng_zjut@163.com

**Abstract.** The traditional speed prediction generally utilizes GPS and video images, and thus the prediction accuracy is heavily dependent on environmental factors. To this end, through using RFID (Radio Frequency Identification) data, this paper proposes a vehicle speed prediction algorithm based on Extended Kalman Filter (EKF). Specifically, the proposed algorithm works as follows. First, the RFID reader equipped in the vehicle acquires the state information of tags deployed on the road. Second, The data processing module equipped in the vehicle demodulation and decoding these information. At the same time, the RFID reader sends information to the RFID label after the current information is encoded and modulated. Third, the vehicle predicts the vehicle speed based on the EKF through establishing the state space model with acquired state data. The simulation results show that the proposed algorithm can effectively predict the vehicle speed at 0.6 s.

**Keywords:** Radio frequency identification · Speed prediction
Extended Kalman filter

## 1 Introduction

With the rapid development of society and economy and the improvement of people's living standards, vehicles have become indispensable means of transport for people's daily travel. Traffic congestion and traffic accidents have become more and more common, and meanwhile traffic environment has also gradually deteriorated. The paradigm of intelligent transportation system (ITS) has been proposed as a promising solution to cope with the increasingly serious traffic problems. The ITS can effectively integrate information, data transmission, electronic sensing, computer and other technologies into the entire ground transportation management system to achieve real-time, accurate, efficient, large-scale and comprehensive traffic intelligence management. Among them, tracking and predicting the speed of vehicle ahead is indispensable, and has been widely used in the design of vehicle control plane. The speed prediction of vehicle ahead can


L. Meng and Y. Zhang (Eds.): MLICOM 2018, LNICST 251, pp. 52–59, 2018.
https://doi.org/10.1007/978-3-030-00557-3_6

make the driver acquire more informed judgments and actions, and increase the driver's warning time and greatly reduce the probability of a traffic accident. Therefore, it is very important to track and predict the speed of vehicle ahead accurately in real time.

At present, most speed prediction methods are based on the video image speed measurement. In [1], the author proposes a new virtual loops of video speed detection method, which has the ability to judge the type of vehicle according to the characteristic curve and advantage of this method is the processing time shortened. The work [2] systematically designs a novel license plate detection method based on a texture classifier specialized, which has the ability to capture the gradient distribution characteristics of character strokes that make the license plate letters.

In recent years, although the accuracy of video velocimetry has become higher and higher, there are still limitations. For example, the video velocimetry depends largely on the camera's resolution and the corresponding image processing algorithms. At the same time, the high cost of the camera renders it not be widely used in roads.

As environmental factors have less impact on radio frequency identification technology, and its convenience and low cost have also been widely used in daily life. Some scholars do a lot of research on radio frequency identification. RFID technology has been used in the railway industry which can track the trains moving on the same track to prevent head on collisions as well as rear end collision [3]. In [4], the RFID tag system was proposed for bicycle deployment, and the label installation method and label content setting are specifically described. The authors in [5] analyzed the influence of the relative position of readers and tags on the read error and the read rate through experiments, and proposed a method of calculating the range of the readable area of the RFID reader on the pavement. To reduce the cost of RFID system safety certification, the authors in [6] propose a lightweight RFID mutual authentication protocol with cache in the reader (LRMAPC), to store the recent visited key of tags, so that recent visited tags can be authenticated directly in the reader.

Based on the above research, in order to improve the speed tracking accuracy and fast effectiveness, this paper designs an algorithm based on RFID EKF to track the speed of high-speed mobile vehicles. The simulation shows that this method can reduce the system cost to a great extent under the RFID environment, also can predict the speed of target vehicle fast and effectively, ensures the vehicle running safety, and reduce the probability of traffic accidents.

## 2 System Model Design

### 2.1 Model Architecture

In this paper, we propose a EKF-based vehicle speed prediction algorithm by using RFID. The proposed algorithm works as follows. First, the RFID reader equipped in the vehicle acquires the state information of tags deployed on the road. Second, the data processing module is equipped in the vehicle demodulation and decode these information. At the same time, the RFID reader sends information to the label after the current information are encoded and modulated. Then, the vehicle predicts the vehicle speed based on the EKF through establishing the state space model with acquired state data. Among them, the model shown in Fig. 1.

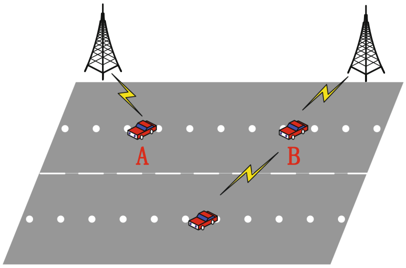


**Fig. 1.** RFID system model

In Fig. 1, the RFID tag (white point and passive tag) is deployed on a straight road. Part of the label memory is fixedly stored with its own information, traffic information and road speed limit information. The other part stores the status information of the vehicle, and the status information includes the current speed and the current time of the vehicle. Own status information encoding Modulation by the vehicle reader through the 24-bit EPC code to write the label. RFID reader installed in the middle of the front bumper of the vehicle, when the vehicle passes the label, each vehicle will first read the information in the label, and then the vehicle will replace their status information in the label status information. Considering the limitation of storage capacity of the RFID tag, the tag store only the most recent vehicle status information. As shown in Fig. 1, $A$ car now stores the status information in the RFID tag, and the $B$ car reads the status information and overwrites its own status information (i.e., $V_k$ and $T_k$). In addition, $V_k$ and $T_k$ are the speed and time the vehicle passes the $k^{th}$ label, respectively. Among them, we focus on speed prediction in this paper, so we assumed that there will be no communication interference between vehicles and the state demodulation and decoding will be completed in an instant.

### 2.2 System Modeling

The RFID system model mainly includes high-speed vehicles, RFID tags deployed at the same road distance, and RFID readers mounted on the bumper of the vehicle. The design criteria of our model are stated as follows [7]: (1) Each RFID tag should be covered by no more than one RFID readers read area at any instant of time. (2) Each RFID readers read area should cover no more than one tag at any instant of time. (3) If a vehicle is in a lane, the vehicle should be able to read tags that are deployed in the lane. (4) If a vehicle can read a tag, at least half of its body should be in the lane where the tag is deployed. (5) If less than half of a vehicle is in a lane, the vehicle should not be able to read any tag in the lane. (6) The label spacing is set to 3 m.

RFID systems can be set up in tunnels, overpasses and other harsh environments. Considering that the change of historical speed determines its future state to a great extent, we only need to collect the historical information of speed and track the speed of vehicle A. Therefore, the state equation and observation equation of the vehicle speed in the RFID system are as follows:

$$\begin{cases} x_k = g(x_{k-1}) + w_{k-1}; \\ z_k = H(x_k) + v_k. \end{cases} \tag{1}$$

In Eq. (1), $x_k$ is the state vector of the system at time $k$, which indicates the true speed of the vehicle at the $k$ time; $g(x_{k-1})$ and $H(x_k)$ are non-linear functions; $w_{k-1}$ is the system noise; $z_k$ is observed value of the system at time $k$, which represents the measured speed of the vehicle at time $k$; $v_k$ is the measurement error. Here, $w_{k-1}$ and $v_k$ are both Gaussian distributed white noise with mean zero.

## 3 Vehicle Speed Estimation Algorithm Based on Extended Kalman Filter

The core of EKF algorithm is to linearize the nonlinear system. Specifically, the nonlinear function is expanded by Taylor and first order linearization is truncated, ignoring the rest of higher-order terms, so that the nonlinear problem is transformed to linear. Second-order truncation [8] can reduce the estimation error caused by linearization and greatly increases the number of iterations of the data. Therefore, this paper selects the EKF algorithm under first-order truncation.

The EKF algorithm must first be linearized preprocessing, let $g(x_{k-1})$ Taylor expand at $\overline{x}_{k-1|k-1}$, $H(x_k)$ Taylor expand at $\overline{x}_{k|k-1}$:

$$\begin{cases} g(x_{k-1}) = g(\overline{x}_{k-1|k-1}) + A_{k-1}y_{k-1} + \Delta t_1; \\ A_{k-1} = g'(x_{k-1}); \\ y_{k-1} = x_{k-1} - \overline{x}_{k-1|k-1}; \\ H(x_k) = H(\overline{x}_{k|k-1}) + C_k(x_k - \overline{x}_{k-1|k-1} + \Delta t_2; \\ C_k = H'(\overline{x}_{k|k-1}). \end{cases} \tag{2}$$

Here, $A_{k-1}$ and $C_k$ are Taylor coefficients at the $\mathrm{k}-1$th moment and Jacobian matrix at the kth moment, respectively, $\overline{x}_{k-1|k-1}$ is the optimal estimation of the state at the $k-1$th moment, $\overline{x}_{k|k-1}$ is the predicted value of state at the

$k$th moment, $y_{k-1}$ is estimation error at the $k-1$th moment, $\Delta t_1$ and $\Delta t_2$ are higher-order infinitesimals, and $y_k$ is the error between the measured and a priori values at time $k$.

Ignoring higher-order infinitesimals, and Take Eq. 2 into Eq. 1:

$$\begin{cases} x_k = g(\overline{x}_{k-1|k-1}) + A_{k-1}y_{k-1}; \\ z_k = \overline{H}_{k|k-1} + C_k(x_k - \overline{x}_{k-1|k-1}) + v_k; \\ A_{k-1} = g'(u_{k-1}). \end{cases} \tag{3}$$

The EKF algorithm will have little difference in form from Kalman filtering (KF) after linearizing the nonlinear system. The EKF algorithm is also divided into the forecasting process and the updating process. The EKF algorithm [9–11] is as follows:

Calculate the prior predictive value $\overline{x}_{k|k-1}$ at time $k$:

$$\overline{x}_{k|k-1} = f(\overline{x}_{k-1|k-1}) \tag{4}$$

Calculate a priori error covariance matrix $P_{k|k-1}$

$$P_{k|k-1} = A_k P_{k-1|k-1} A_k^T + Q \tag{5}$$

Calculate the approximate optimal Kalman gain $K_k$

$$\overline{K}_k = P_{k|k-1} C_k^T (C_k P_{k|k-1}^T C_k^T + R)^{-1} \tag{6}$$

Calculate the optimal state estimate $\overline{x}_{k|k}$ at time $k$

$$\overline{x}_{k|k} = x_{k|k-1} + \overline{K}_k(z_k - H(\overline{x}_{k|k-1})) \tag{7}$$

Calculate the a-posteriori error covariance matrix $P_{k|k}$ of the best estimate at time $k$

$$P_{k|k} = (I - K_k C_k) P_{k|k-1} \tag{8}$$

Where $I$ is the identity matrix. Theoretically, $A_{k-1}$ and $C_k$ are Jacobian matrices for solving $g(x_{k-1})$ and $H(x_k)$ respectively. Considering the difficulty of actual calculation, Taylor's first-order truncation approximation, so the approximate Kalman gain is obtained; Since the distance between RFID tags is set at 3 m, the time between two labels passing through a high-speed vehicle (20 m/s or more) is relatively small, In reality, few people change acceleration many times in a very short period of time, which is good for suppressing the divergence of EKF linearization.

The specific algorithm of speed prediction in this paper is as follows:

**Algorithm 1. Speed prediction specific algorithm**

Initialize variables and $k = 1$.
According to the formula 2∼3, the EKF algorithm pretreatment.
Read the initial status flow ($V_{k-1}$ *and* $T_{k-1}$) in the RFID tag.
**if** the vehicle does not travel out of the deployment of the RFID system of the road **then**
  Calculated to $A_{k-1}$, $y_{k-1}$,$C_{k-1}$,$K_k$ and other variables.
  According to the formula 4  5,Calculate $\overline{x}_{k|k-1}$ and $P_{k|k-1}$.
  According to the formula 6  8,Calculate $K_k\overline{x}_{k|k}$ and $P_{k|k-1}$.
  Vehicles to the next RFID label.
  K=K+1.
**end if**

# 4 Simulation

## 4.1 Simulation Settings

In order to test the practicality and effectiveness of this tracking system, we simulated the deceleration mode. The deceleration mode means that the vehicle A moves with a speed at 25/m, then it decelerates with an acceleration at $a = -3\,\text{m/s}^2$. In order to more intuitively determine the effectiveness and rapidity of the system, set the vehicle B from 20 m/s to start tracking vehicle A. And set the initial distance of vehicles A and vehicles B to 1000 m to prevent vehicle collision.

The simulation experiment in this paper adds the real speed information plus Gaussian random noise with mean zero and variance 1 as the velocity observation, and adds the real time information to Gaussian random noise with mean zero and variance 0.5 as the time observation. The tool used in the simulation experiment is MATLAB R2016a.

## 4.2 Simulation Results Analysis

The mean square error of speed is introduced as the evaluation index. The mean square error is defined as follows:

$$MSE = \frac{1}{N}\sum_{k=1}^{N}(X(k) - \overline{X}(k))^2 \tag{9}$$

Where $N$ is the number of simulations; $k$ is the $k$th simulation; $X(k)$ is the true state value of the target at the $k$th moment; and $X(k)$ is the state of the filtered estimate at the $k$th moment.

Since the deceleration process is more important than the acceleration process while the vehicle is traveling, we only consider the deceleration process. On the other hand, the acceleration process can be seen as the opposite of the deceleration process. When there is a special situation in front of the vehicle,

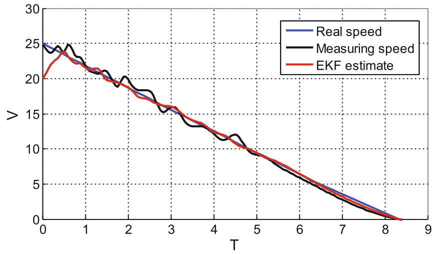


**Fig. 2.** Speed comparison chart

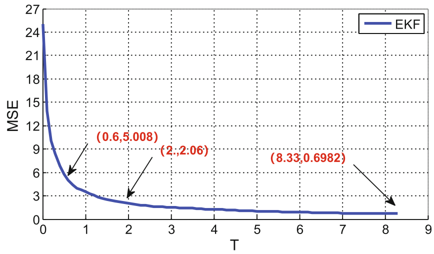


**Fig. 3.** RFID system model

the vehicle should quickly decelerate to ensure safety. Simulation diagram shown in Figs. 2 and 3.

From Fig. 2 it is clear that the extended Kalman filter algorithm can track the target vehicle speed from the initial velocity of 20 m/s in about 0.6 s. Then, even if there is a measurement error in the status information, the speed tracking target can be corrected well. On the other hand, since the label spacing is fixed and the vehicle speed varies, the sampling time in the simulation is not fixed, which results in a longer sampling period during deceleration. The specific formula is as follows.

$$\begin{cases} D_{tag} = v_{b,i} t_i + \frac{1}{2} a t_i^2; \\ a = \frac{\sum F}{m} \end{cases} \tag{10}$$

Where $D_{tag}$ is the spacing of labels; $v_B$ is the speed at which vehicle B reaches the $i$th label; $t_i$ and $a$ are respectively the sampling time and acceleration of the vehicle B from the $i$th tag to the $(i+1)$th tag; $m$ is the mass of the vehicle, set to 1.5 tons.

As shown in Fig. 3, the initial tracking speed of the vehicle is 20 m/s. With the EKF algorithm, the mean square error of speed drops sharply in 0.6 s and slowly decreases in 0.6 s to 2 s, which shows that the algorithm can predict the target speed quickly and effectively.

## 5 Conclusion

In this paper, For the phenomenon that the GPS signal cannot work normally because of the environment, an RFID road system based on extended Kalman filter for tracking and predicting high-speed moving vehicles is established in this paper. The results show that the EKF algorithm can predict the vehicle real-time status and parameter changes through the established vehicle driving model. Specifically, the algorithm effectively predicts vehicle speed at 0.6 s as the vehicle decelerates.

**Acknowledgement.** This work was supported in part by the National Natural Science Foundation of China under Project 61379122, Project 61572440, and Project 61502428, and in part by the Zhejiang Provincial Natural Science Foundation of China under Project LR16F010003, and Project LR17F010002.

## References

1. Liang, W., Junfang, S.: The speed detection algorithm based on video sequences. In: 2012 International Conference on Computer Science and Service System, Nanjing, pp. 217–220 (2012)
2. Luvizon, D.C., Nassu, B.T., Minetto, R.: A video-based system for vehicle speed measurement in urban roadways. IEEE Trans. Intell. Transp. Syst. **18**(6), 1393–1404 (2017)
3. Malakar, B., Roy, B.K.: Survey of RFID applications in railway industry. In: 2014 First International Conference on Automation, Control, Energy and Systems (ACES), Hooghy, pp. 1–6 (2014)
4. Penttila, K., Sydanheimo, L., Kivikoski, M.: Performance development of a high-speed automatic object identification using passive RFID technology. In: Proceedings of 2004 IEEE International Conference on Robotics and Automation, ICRA 2004, vol. 5, pp. 4864–4868 (2004)
5. Lee, E.K., Yoo, Y.M., Chan, G.P., et al.: Installation and evaluation of RFID readers on moving vehicles. In: International Workshop on Vehicular Ad Hoc Networks, Vanet 2009, Beijing, China, DBLP, pp. 99–108, September 2009
6. Li, C.T., Lee, C.C., Weng, C.Y., et al.: Towards secure authenticating of cache in the reader for RFID-based IoT systems. Peer-to-Peer Netw. Appl. **11**, 1–11 (2017)
7. Cheng, W., Cheng, X., Song, M., Chen, B., Zhao, W.W.: On the design and deployment of RFID assisted navigation systems for VANETs. IEEE Trans. Parallel Distrib. Syst. **23**(7), 1267–1274 (2012)
8. Yang, S., Baum, M.: Second-order extended Kalman filter for extended object and group tracking. In: 2016 19th International Conference on Information Fusion (FUSION), Heidelberg, pp. 1178–1184 (2016)
9. Zeng, C., Li, W.: Application of extended Kalman filter for tracking high dynamic GPS signal. In: 2016 IEEE International Conference on Signal and Image Processing (ICSIP), Beijing, pp. 503–507 (2016)
10. Jiang, K., Zhang, H., Lin, J.: $NH_3$ coverage ratio estimation of diesel-engine SCR systems by a dual time-scale extended Kalman filter. IEEE Trans. Veh. Technol. **67**(4), 3625–3629 (2018)
11. Jiang, Z., Zhou, W., Li, H., Mo, Y., Ni, W., Huang, Q.: A new kind of accurate calibration method for robotic kinematic parameters based on the extended Kalman and particle filter algorithm. IEEE Trans. Ind. Electron. **65**(4), 3337–3345 (2018)