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Position computation models for high-speed train based on support vector machine approach

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ABSTRACT

High-accuracy positioning is not only an essential issue for efficient running of high-speed train (HST), but also an important guarantee for the safe operation of high-speed train. Positioning error is zero when the train is passing through a balise. However, positioning error between adjacent balises is going up as the train is moving away from the previous balise. Although average speed method (ASM) is commonly used to compute the position of train in engineering, its positioning error is somewhat large by analyzing the field data. In this paper, we firstly establish a mathematical model for computing position of HST after analyzing wireless message from the train control system. Then, we propose three position computation models based on least square method (LSM), support vector machine (SVM) and least square support vector machine (LSSVM). Finally, the proposed models are trained and tested by the field data collected in Wuhan-Guangzhou high-speed railway. The results show that: (1) compared with ASM, the three models proposed are capable of reducing positioning error; (2) compared with ASM, the percentage error of LSM model is reduced by 50.2% in training and 53.9% in testing; (3) compared with LSM model, the percentage error of SVM model is further reduced by 38.8% in training and 14.3% in testing; (4) although LSSVM model performs almost the same with SVM model, LSSVM model has advantages over SVM model in terms of running time. We also put forward some online learning methods to update the parameters in the three models and better positioning accuracy is obtained. With the three position computation models we proposed, we can improve the positioning accuracy for HST and potentially reduce the number of balises to achieve the same positioning accuracy.

1. Introduction

The high-speed railways (HSRs) have been recognized by the world because of its obvious advantages in high-speed, punctuality and energy-saving [1]. In recent years, HSRs have experienced a rapid development around the world. Furthermore, there are many countries in the world that have developed HSRs to connect major cities, such as Japan, Germany, China, etc. [2].

The first HSR, Tokaido Shinkansen, went to commercial operation with the speed of 210 km/h in 1964 in Japan [3,4]. E5 series trains were introduced to commercial operation with a speed of 320 km/h on March 2011 in Japan. Currently, the length of HSR network in Japan reaches 2387.7 km [5]. In Germany, the third generation of Inter City Express(ICE) was tested at the speed of 350 km/h in 2006, but with a service speed of around 330 km/h at present [6,7]. In 1999, China started to construct the first HSR line. On August 1st 2008, the Beijing-Tianjin Intercity HSR was opened in time for the Beijing Olympic Games with a distance of 117 km [8,9]. Moreover, with a operation speed of 350 km/h, it has set the record for the fastest high-speed train(HST) in the world at that time. On December 26th 2009, Wuhan-Guangzhou HSR (WG_HSR), connecting two major cities in China, was put into commercial operation at the speed of 350 km/h. And the total length of WG_HSR is 1068.8 km, which was the fastest and longest HSR in the world at that time. At the end of 2011, China has the world's longest HSR network with a length of 8358 km, which is expected to reach 32,000 km by the end of year 2015 [10,11].

As the operation speed of HST increases, positioning accuracy is becoming more and more important for the train control system. On one hand, high-accuracy positioning of HSR is a key point for ATP (Automatic Train Protection) in calculating protective curves to guarantee the safe operation of the train. On the other hand, the accuracy of positioning partially determines the minimum distance between adjacent HSTs, which greatly affects the operation

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efficiency of HSR. At present, the real-time positioning of HST mainly relies on track circuit along the railway line and on-train speed sensors [12,13]. Positioning accuracy is very low based on track circuits only, the existence of speed sensors is able to obtain continuous position. However, there is still a big accumulated error resulting from wheel idling and slipping in this positioning method. In Ref. [14], the authors proposed an algorithm to detect and compensate the accumulated error.

To eliminate the accumulated positioning error, balise, a positioning device installed between two tracks, is added to the train positioning system to correct the accumulated error by providing the accurate position stored in it when a train is passing it. Shortening the distance between adjacent positioning balises is an effective way to improve the positioning accuracy. However, more balises employed will increase the cost of train positioning system [15]. Generally speaking, a positioning system for HST should have reliable performance, high positioning accuracy and low-cost. Therefore, in order to reduce the positioning error, balises together with speed sensors are introduced to the positioning system of HST. Positioning error of train goes to zero when the train is passing through a balise. However, positioning error between adjacent balises increases as the train moves away from the previous balise.

At present, methods for improving positioning accuracy between adjacent balises are mainly based on adding extra equipment, such as radar or GPS receivers. It is clear that this method greatly increases the cost and, the extra equipment introduced has the potential of adding complexity and unreliability for the train control system. In this paper, we focus on applying advanced computing methods to increase the positioning accuracy for HST with balises and speed sensors only. The advanced methods include least square method (LSM), support vector machine (SVM) and least square support vector machine (LSSVM).

This paper is organized as follows. In Section 2, we formulate a mathematical model based on the analyzing of wireless message from the train control system to better illustrate the position computation problem. In Section 3, LSM, SVM, and LSSVM models are employed to compute the position of HST based on the model introduced in Section 2. In Section 4, we define six indexes to evaluate the performance of the three position computation models proposed. The first two indices are commonly used in regression problem while the rest of the indices are for this position computation problem in particular. Furthermore, we propose parameter updating method for each position computation model. In Section 5, the three models are compared with ASM model and analyzed in details using field data collected in WG_HSR. Conclusions and future research directions are summarized in Section 6.

2. Mathematical model for HST position computation

2.1. Brief introduction of CTCS-3 system

CTCS is the abbreviation for Chinese Train Control System. CTCS is divided into five application levels, where CTCS-3 system (level-3 CTCS system), is designed exclusively for the HSR and HST. The CTCS-3 system consists of two parts, on-board equipment and ground equipment. Compared with CTCS-2 train control system, CTCS-3 implements bidirectional information transmission based on GSM-R (GSM for railways) [11]. The On Board Unit (OBU) reports the current speed, the location, the running direction and some other data to Radio Block Center (RBC) (a ground equipment) by wireless message via GSM-R. RBC sends the line data, the temporary speed limit information, driving license, and some other data to the OBU under its jurisdiction in return [16,17].

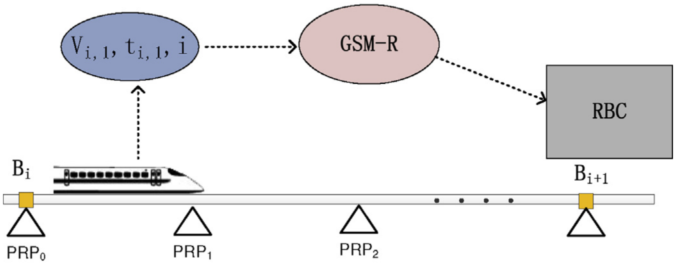

Fig. 1. The main process of position reporting information.

2.2. Mathematical model for HST

As mentioned in Section 2.1, the OBU sends the current information of the train to RBC via GSM-R. The current information is also known as position reporting information, which includes the speed of the train, reporting time, the last related balise number, etc. Fig. 1 shows the delivery process of the position reporting information via wireless message. The PRP0 (Position Report Point 0) in Fig. 1 implies the first position reporting point between bailises i and $i+1$, denoted as B_i and B_{i+1}, respectively. The time interval between adjacent PRPs is typically a few seconds (no more than 7 s).

Based on position reporting information at each point, we propose a mathematical model for computing the position of HST, which is shown in Fig. 2. From Fig. 2, it is not difficult to see that there are total of $(n_{i,i+1}+1)$ PRPs between B_i and B_{i+1} (including the PRPs at B_i and B_{i+1}). L_i and L_{i+1} is the kilometer marks of B_i and B_{i+1}, respectively. $L_{i,i+1}$ is the length from B_i to B_{i+1} and is calculated by Eq. (1) as follows.

$$L_{i,i+1} = L_{i+1} - L_i \tag{1}$$

$(V_{i,0}, V_{i,a}, \cdots, V_{i,n_{i,i+1}})$ and $(t_{i,0}, t_{i,1}, \cdots, t_{i,n_{i,i+1}})$ denote the speed of HST and reporting time at each PRP, respectively. $(D_{i,1} \cdots D_{i,n_{i,i+1}})$ is traveling distance between two adjacent PRPs. Thus, we can obtain the position of train at each PRP as:

$$P_{i,j} = L_i + \sum_{j=1}^{n_{i,i+1}} D_{i,j} \tag{2}$$

In engineering practice, average speed method (ASM) is used to calculate the traveling distance $D_{i,j}$, defined as $D_{i,j}^{asm} = V_{i,j-1} + V_{i,j}/2 * (t_{i,j} - t_{i,j-1})$. Generally speaking, there is a difference between $\sum_{j=1}^{n_{i,i+1}} D_{i,j}^{asm}$ and $L_{i,i+1}$. We define the difference error as e_i.

$$e_i = L_{i,i+1} - \sum_{j=1}^{n_{i,i+1}} D_{i,j}^{asm} \tag{3}$$

After testing ASM using the field data collected from WG_HSR, we find that the maximum error e_i can reach 80 m, which is too big for accurate positioning of HSR. Therefore, it is necessary to develop new approaches for computing $D_{i,j}$ to reduce the error e_i.

3. Three models for position computation

3.1. Hypothesis for estimating accurate traveling distance

As we mentioned earlier, there are many positioning balises installed along the HSR line, which can correct positioning error by using precise location data stored in them. However, it is difficult to get the accurate position for HST running between adjacent balises. In this paper, we assume that the positioning error e_i for each traveling distance is proportional to its value $D_{i,j}^{asm}$. Through