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Recursive filtering for communication-based train control systems with packet dropouts☆

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ABSTRACT

Accurate information about the train position and velocity is critically important for Communication-based Train Control (CBTC) systems. However, it is practically difficult to obtain the precise information of such information due mainly to the “inaccurate measurements” induced by the measurement noises and the “unreliable communication” caused by the wireless train-ground communication. In this paper, a recursive filtering algorithm is proposed to generate the estimates of the train position and velocity for CBTC systems subject to the measurement noise and packet dropouts. Firstly, the dynamics of a train is modeled based on the Newton’s motion equation. Then, a Bernoulli distributed sequence is introduced to describe the packet dropout phenomenon of the wireless communication. The purpose of the problem addressed is to design a recursive filter such that there exists an upper bound for the filtering error covaSix Talent Peaks Project for the High Level Personnelriance. Subsequently, such an upper bound is minimized by properly designing the filter parameter recursively. The desired filter parameter is obtained by solving two Riccati-like difference equations that are of a recursive form suitable for online applications. Finally, an illustrative example is given to show the effective of the proposed filter design scheme.

1. Introduction

With experiencing fast economic growth, population expansion and urbanisation in worldwide, especially in some major developing counties, the demand for a safer, more efficient and comfortable mass transit system is very urgent [22]. Railway system is a good choice for either urban commuting or intercity transport, as they meet the increasing needs for low emissions and high capacity. In railway systems, it is particularly important to ensure that train control systems could obtain the data from trains including the locations, velocities, identities and other operation information. In early years, railway systems tended to apply the track circuits to realize the communication between trains and the train control center. Such kind of train control systems are known as Track-circuit Based Control (TBTC) systems. TBTC systems would give rise to low detection resolution, which finally leads to long operation headway for trains in order to guarantee there is no possibility for potential collisions. In other words, track-circuit based technology would probably result in low operation efficiency. In recent years, by utilizing modern wireless communication technology, Communication-based Train Control (CBTC) systems have been developed to meet the rapidly increasing demand on efficiency and safety. Compared with the TBTC systems, the CBTC systems could dramatically increase capacity and lower the unreliability in operation.

CBTC systems are automatic train control systems. A typical CBTC system structure is shown in Fig. 1, which contains five subsystems, namely Automatic Train Protection (ATP), Automatic Train Operation (ATO), Automatic Train Supervision (ATS), Computer-based Interlocking (CI) and Data Communication System (DCS). ATP is the most significant subsystem of CBTC systems. The main task of ATP is to trigger the braking when emergencies happen so as to protect the train from dangers. ATO is the driving part of the operation which is utilized to automatically operate trains. ATS is

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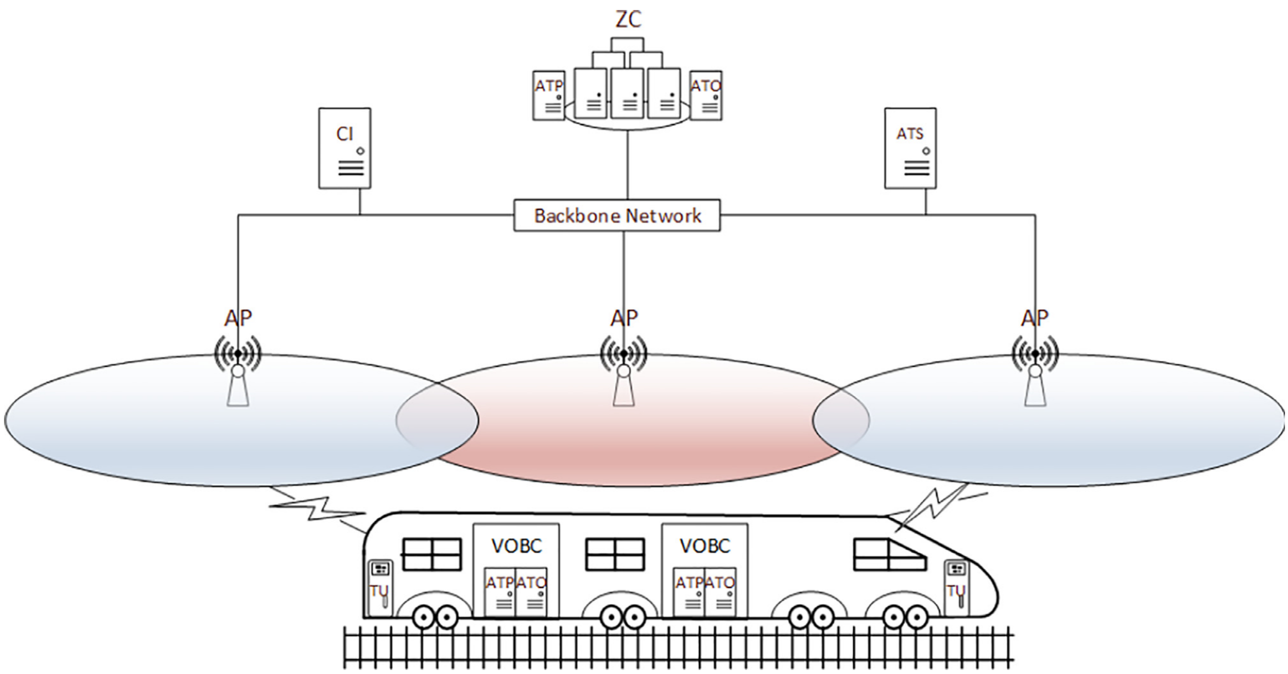

Fig. 1. The typical system structure of CBTC.

a supervision system managing the railway traffic through commanding the CI. DCS is in charge of exchanging the data flow within each subsystems [15]. Most of the DCSs are distributed systems, which are formed by wayside communication system, onboard communication system and radio communication system, respectively. The wayside communication system and onboard communication system are realized through secure wired networks. The radio communication system employs the wireless local area network (WLAN) to exchange data between trains and the wayside access points (APs). Each AP has certain radio coverage. When a train is moving into the coverage of an AP, a bidirectional train-to-wayside wireless connection will be built. When the train is running away the radio coverage of an AP, the connection will be replaced by another one whose radio coverage better covers the current position of the train. Such a phenomenon is referred as the hand-off procedure. In most of the DCSs, the WLAN utilizes the signals with 2.4 GHz industrial, scientific and medical (ISM) band and the IEEE 802.11 family of standards for the media access control (MAC) layer protocol. Obviously, in DCS, APs are very important for the wireless train-ground communication. Continuous data transmissions are carried out between wayside APs and onboard equipment, which enables trains timely receive the moving authorities (MA), speed limit and route data. However, as a radio-based communication technology, the communication performance of such a technology is not always perfect. Packet dropouts might happen and result in operational risks in railway systems.

Due to only a limited spectrum allocated in WLANs and unlicensed ISM band used as the working frequency, the co-channel interference could be the biggest threat for packet dropouts. A main resource of co-channel interference comes from the unwell-planned AP deployment in the DCS. A number of research works have been done on exploring how to decrease the packet dropout rate by planning a more reasonable AP deployment [23]. For example, in [4], a novel AP placement planning method in railway context has been developed. In [16,24] and [8], various AP placement planning strategies focusing on indoor Code Division Multiple Access (CDMA) networks have been discussed. In [9,10] and [12], the planning strategies focusing on WLANs are proposed. To further reduce the affection caused by the co-channel interference, channel assignment in WLNAs is discussed in [2,3], [21] and [13], in which channel assignment has been considered alongside the AP deployment aiming to further improve the DCS system performance in terms of decreasing the packet dropout rate. In addition to co-channel interference, hand-off could be regarded as another important reason of packet dropouts in DCS. In [28] and [7], improved hand-off schemes have been proposed, which have been designed to minimize the packet dropouts when hand-off phenomena happens. However, the aforementioned research results could not eliminate packet dropouts in DCS due to the wireless communication nature, thereby affecting the reliability and Quality of Service (QoS) of CBTC systems. Obviously, packet dropouts would greatly reduce the precision of the train data (e.g. location and velocity) obtained by the Zone Controller (ZC). On the other hand, it is worth mentioning that the train location for most of CBTC systems is measured by the combination of balises and axle counting based speed odometers. In CBTC systems, balises are intermittently placed on the track. When a train runs in the interval between two adjacent balises, train data will be measured by counting the rotations of wheel axel, and when the train passes a balise, the train data will be adjusted. However, due to the unavoidable wheel slip, the estimated train data might be polluted by the measurement noise before the adjustment is made. Accordingly, it is practically difficult to achieve the exact train data under the influence of "inaccurate measurements" and "unreliable communication".

In order to achieve accurate information of the train data, in this paper, a recursive filtering algorithm is developed to generate the estimate of the train data based on the received measurements. The filtering (or state estimation) problems have long been fundamental issues in control and signal processing fields, whose purpose is to derive an estimate of the internal state for a given system based on the obtained measurements. So far, various filtering methods have been reported in the literature (e.g. Kalman filtering [19], Extended Kalman filtering [5], $\mathcal{H}_\infty$ filtering [18,29], set-membership filtering [30]). Considerable effort has been devoted to the filtering problems with different conditions and performance requirements. For instance, in [17], the Kalman filtering problem with intermittent observations has been illustrated where the packet dropouts have been modeled by the general