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Integrated Maintenance Logistics Monitoring System for High Speed Rail, Based on Internet of Things Technology

Alhossein Mohamed[1], Peng Qiyuan[2], Malik Muneeb Abid[3*], Muhammad Iqbal [4]

[1]PhD Scholar, School of Transportation and Logistics, Southwest Jiaotong University, Chengdu 610031, China, Email: mhmdhosentem@hotmail.com
[2]Professor, School of Transportation and Logistics, Southwest Jiaotong University, Chengdu 610031, China, Email: qiyuan-peng@swjtu.edu.cn
[3,] Assistant Professor, Department of Civil Engineering, College of Engineering and Technology, University of Sargodha, Pakistan, Email: muneeb.abid@uos.edu.pk, malik.muneeb.abid@hotmail.com*
[4] Assistant Professor, Department of Computer Science, Bahria University, Karachi, Pakistan, Email: miqbal.bukc@bahria.edu.pk

Abstract

This paper presents the structure of a new Integrated Maintenance Logistics Monitoring System for High-Speed Rail (IMLMS–HSR), adopting internet of things technology and using Matlab simulation and field testing centring on the critical technical problem for the monitoring system, i.e., reader–reader collision. While IMLMS–HSR, which is based on IoT technology, incorporates work from disparate areas, three central advantages have been isolated through radio frequency identification (RFID), including how to manage IMLMS–HSR, anticipating and mitigating RFID tag-reader collision, and prevention of reader–reader collision. In the paper, means of managing IMLMS–HSR is described. Second, potential RFID tag–reader collisions can be avoided or resolved using the Manchester algorithm patrol. This paper proposes a power-control scheme based on a probabilistic power control (PPC) algorithm, embedded in reader transmission power-to-control the read range of a system to resolve reader–reader collisions. The results show that for an IMLMS–HSR (provided with less than five readers using the PPC algorithm) a range exceeding 3.5 m can be monitored with favourable effect by relying on embedded software, thereby affirming the feasibility of the maintenance system or urgent repair orders, including an order allowing for the commencement of construction work on HSR tracks.

Keywords: High Speed Rail (HSR); Internet of Things (IoT); maintenance logistics monitoring; Matlab simulation

1. Introduction

The Chinese railway industry is increasingly reliant on scientific and technological innovation following the integration of smart transportation systems created by internet of things (IoT) and communication technologies (Fraga-Lamas, Fernández-Caramés and Castedo, 2017). Extended total and operating lengths of Chinese high-speed railways

(HSRs) demands to design and implement an IMLMS–HSR that is embedded with IoT technology. Essentially, the design of an IMLMS–HSR using IoT technology is oriented to enhance the supervision of the construction and security of occupied HSR lines following railway construction. This system allows effective supervision of construction workers, materials and tools along the given HSR line. Scientific and technological innovations have transformed rail infrastructure and moderated its life-cycle cost, and it has been found that HSR operations are predisposed toward three main issues: a flexible catenary, a wheel–rail and signal system, and an extensive maintenance force (Wang, 2011). Management of maintenance safety on HSR is particularly important. Chen (2012) concluded that Japan, France and Germany prefer a hierarchical management structure of two or three levels, namely, the railway administration, the regional bureau and the integrated maintenance depot. China, however, applies a heuristic of separation management, inspection and maintenance. At present, information networking, internet and IoT technologies have allowed information to be widely shared and used as the basis for control and decision-making through the acquisition, transmission, processing and sharing of data (Jo, Kim and Kim, 2017). Information-based maintenance management systems can reach real-time maintenance management by integrating IoT technology into the management of engineering, electrical and power supply systems (Gao, 2009). The design of an IMLMS–HSR based on IoT technology is therefore geared towards ensuring real-time monitoring of the occupation status of HSR lines by providing for logistical disposal of construction materials and workers after construction, thus guaranteeing HSR safety. The developed IMLMS–HSR based on IoT technology covers diverse fields. The use of radio frequency identification (RFID) in the development of IMLMSs is increasing with as readers are developed to read data from tags or input data into them via using RF signalling (Memon et al., 2018). Three main issues have been isolated with the use of RFID, namely, management of IMLMS–HSR, RFID tag-reader collision, and reader–reader collision (Li et al., 2015). In this study, models are proposed for use in addressing reader–reader collisions in the IMLMS–HSR with IoT technology. The management of IMLMS–HSR is been discussed below in section 3.1. RFID tag–reader collisions can be resolved by Manchester algorithm patrol (Zhang, 2011). Currently, the synergetic planning and power control algorithms are proposed to account for reader–reader collision (Cha et al., 2008), but a PPC algorithm is used to resolve reader–reader collision in this paper.

2. System Structure Design

The IMLMS–HSR describes a set of complete monitoring systems for line maintenance logistics with a computer core, encompassing a combination of hardware and software applications. According to the design published by Zhang (2011), the system is composed of equipment tags (a passive RFID tag and a quick response [QR] code), an electronic packing case for small spare parts, access control identifiers for service passage and warehouse outbound, hand-held terminals (HHTs), long-range passive RFID tag readers, repeaters, data transmission channels, transmission interfaces and the relevant monitoring software applications.

Following the main operating principle of this system, the master computer transmits maintenance and/or urgent repair work orders to HHTs and provides access control identifiers for service passage and warehouse outbound. Warehouse outbound information is relayed to permitted track workers, and quantities of materials (through passive RFID tag or QR code identification) are identified for the maintenance work on the tracks.

Track workers, materials, tools and instruments are all equipped with passive RFID identification tags. This allows them to be automatically logged as they pass through the access control identifiers for warehouse and service passage or through an HHT. The identifiers upload all the information received to the master computer for recording and sound an audible and visible alarm in case of any discrepancy of data from that sent by the master computer. The electronic access doors are powered and controlled with access control identifiers for passage and can only be opened and closed where the user data are identical.

HHT has QR codes stored for access control identification, and these can separately operate the electric door. In addition, HHT can record the path that the track workers follow, which can be used to monitor any materials remaining on the tracks after work is complete. The access control identifier for service passage is provided with two long-range passive RFID tag readers to identify the direction. The master computer and access control identifiers for warehouse and service passage can communicate with each other.

Last, using IMLMS–HSR with IoT technology, dispatching offices, railway stations, public security departments and HSR maintenance departments within the jurisdiction of a railway administration can monitor the status of workers, materials and tools in real-time over an interconnected public communications network.

3. System Function Design

The development of a logistics monitoring system requires the integration of management processes, in this case, those of the monitoring of the integrated maintenance logistics of HSR, RFID and transmission technology, barcode technology, embedded software, electronic circuitry and management software for logistics monitoring.

3.1 Logistics monitoring management

Cha et al. (2008) explored the concept of management systems and their relationship to railway maintenance and concluded that the management of the monitoring of integrated maintenance logistics for HSR encompasses the following processes:

1) A maintenance order or urgent repair order, such as an order requiring the commencement of construction work on HSR track.
2) This order goes through the dispatching offices of the railway administration. Quantities of track workers and materials are determined, and workers are requested to check and confirm the contents.
3) The order is transmitted to HHT, and access control identifiers for service passage and warehouse outbound are sent. Information on warehouse outbound, permit to work on track (a passive RFID tag or a QR code), specific track workers and quantities of materials are given.

4) Small tools and materials are packed and given passive RFID tags for identification according to the information received by HHT and are confirmed by HHT scanning.
5) Workers, large materials, various tools and instruments and tool kits are added separately with passive RFID tags. These have automatic login as they pass through the access control identifiers for the warehouse or through HHT as they leave the workshops and warehouses in work districts. All information is transmitted to the long-range terminal for recording. When nonconformity with the order in the master computer is detected, the access control identifier for the warehouse sends an audible and visible alarm.
6) The access control identifier for service passage scans the permit to work on the track that is stored in HHT. The access door is then opened only if the information that is presented is correct. The information recorded on the workers and materials is then transferred to the access control identifier for service passage. When incoming materials are found not to be logged by the warehouse access control identifier, the service-passage access control identifier for service passage gives an alarm. The access control identifier for service passage is provided with long-range readers A and B, such that the service doors can only be opened in the sequence A then B.
7) The access control identifier for service passage gives audible and visible alerts when work time is complete, provides a separate alarm when workers and materials do not depart from the track within the required time, and automatically logs out the departing workers and materials, or they are logged out by HHT. All information is transmitted to the long-range terminal for recording. In In the event of nonconformity with provided log data, the access control identifier for the service passage gives an audible and visible alarm. The access control identifier for service passage is provided with long-range readers C and D, such that the service doors can only be opened in the sequence C then D.
8) Workers, large materials, various tools and instruments and tool kits with RFID tags are automatically logged out as they pass through the access control identifier for the warehouse or are logged out through HHT as they leave the workshops and warehouse in the work district. Likewise, all information is transmitted to the long-range terminal for recording.
9) The travel path is tracked and recorded using the GPS positioning function of HHT.
10) A single operation is completed.

3.2 Analysis of logistics monitoring management software

IMLMS–HSR is a computer-oriented system that relies on RFID technology and combines relevant hardware and software applications to perform real-time tracking and intelligent management of all integrated maintenance logistics of an HSR (Zhang, 2011). Its main function is to coordinate information sharing, beginning with the issuance of a maintenance order to the completion of the maintenance actions. In Fig. 1, the basic functions of the system are shown. The function modules of the management software for HSR integrated maintenance logistics monitoring using IoT include the modules of system management, tag management, identifier management, alarm processing, dispatch and command management, and online logistics management, as well as access control of inbound and outbound items, as well as arrival at and departure

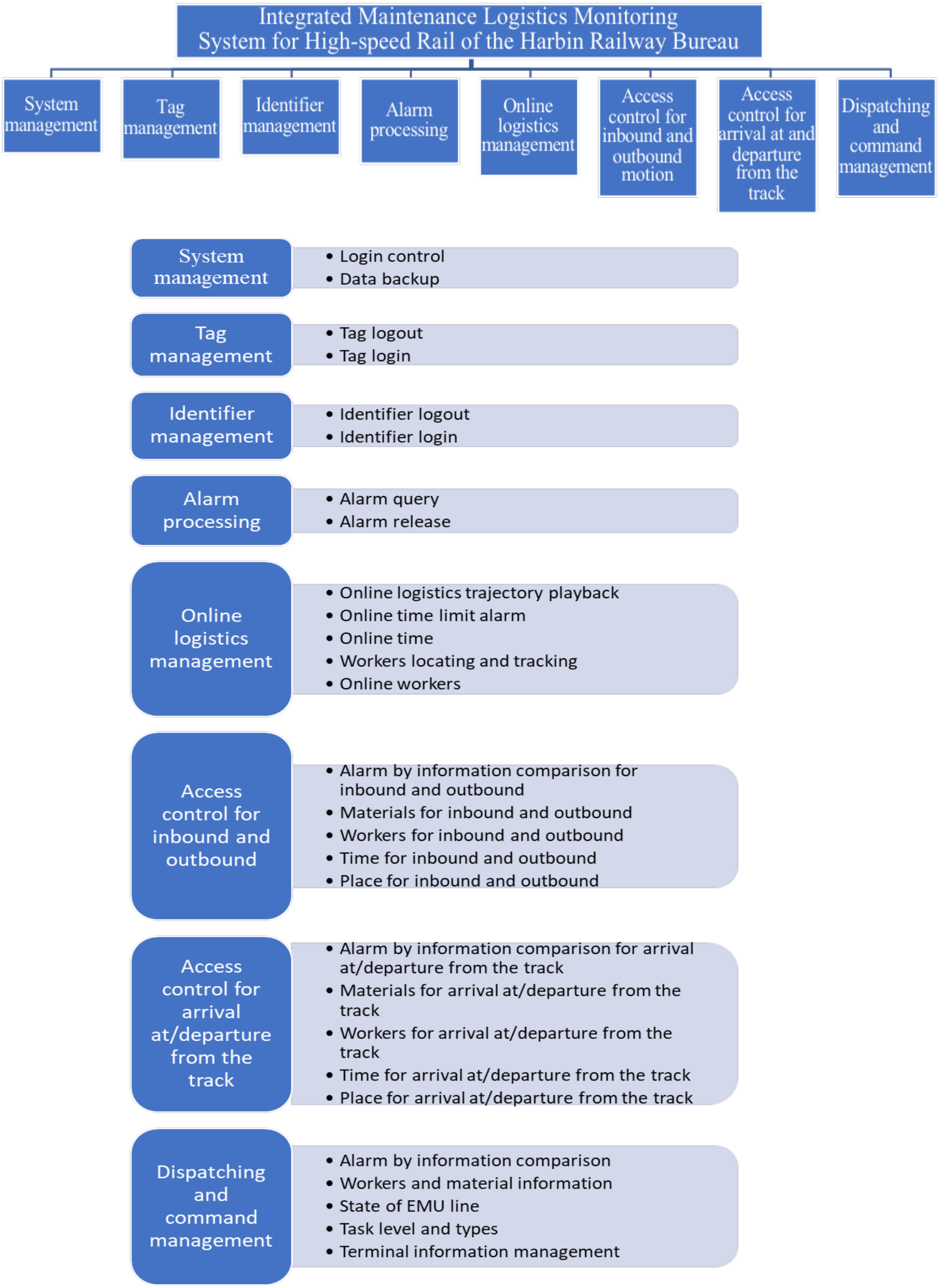

Figure 1 Modules of Monitoring Management Software

from the track. Definitions of the management and process functionalities within the logistics monitoring management system are given below:

- System management: Login control and data backup.
- Tag management: Tag login and logout.
- Identifier management: Identifier login and logout.
- Alarm processing: Alarm query and release.
- Online logistics management: Online workers, worker locating and tracking, online time limit alarm and online logistics path playback.
- Access control for inbound and outbound: Place, time, workers, materials and alarm according to information comparison for inbound and outbound data.
- Access control for arrival at and departure from the track: Place, time, workers, materials and alarm according to information comparison for data on arrival at and departure from the track.
- Dispatching and command management: Terminal information management, task level and type, state of EMU line, workers and material information and alarm by information comparison.

4. Information Reader-Reader Collision

RFID technology is widely used in the identification and collation of data from objects through RF signalling to increase convenience and productivity (Geng et al., 2010). This study extended the application of UHF RFID technology to the design of IMLMS–HSR with IoT to monitor merchandise, employees and railway tracks in the course of the construction and/or repair of HSR. The use of UHF RFID technology is linked to an increased sensitivity, rate and efficiency of data transfer. Even as its use increases in the HST industry, RFID technology is hampered by the low efficiency of tag identification efficiency resultant of tag-reader collision or reader-reader collision. Reader–reader collisions develop as a result of the simultaneous interrogation of a tag by neighbouring readers. Studies have shown that multiple readers require interrogation zones that allow the propagation of a frequency without interference. This is because the power radiated from one reader must be congruent to the tag backscatter signal level if it is to induce interference in its interaction with other readers. This paper proposes a power control scheme, based on a PPC algorithm embedded in a reader transmission power to control system read range to resolve reader–reader collisions.

4.1 Methodology

MATLAB simulation

Previous studies in this area have been limited to examining collision among five or more RFID tag readers. The readers in IMLMS–HSR are mainly located at the HSR line access and are generally found in sets of two to five readers. In this context, a PPC algorithm was simulated in MATLAB for 2–10 readers.

Power distribution across all readers alters for every time slot, dependent on distribution. Each reader reaches a peak range while sustaining a significant average (Cha et al., 2008). A distribution solution is established by setting a unique probability distribution of power for selection in each time step based on the number of readers within the network. Where reader power adheres to a particular probabilistic distribution, the read range distribution for an individual RFID reader is defined as a function of the power distribution.

$$F(r_i) = f_i(F(P_1),..., F(P_n)) \quad (1)$$

$F(r_i)$ = cumulative density function of reader i read range

$F(P_i)$ = cumulative power density function of reader i

The difference between the PPC algorithm described above and the anti-collision algorithm is in their application, with the latter entailed in the elimination of RFID tag–reader collisions. The theoretical application of the PPC algorithm was verified practically in field testing. The simulation environment was established in Matlab. The power of the reader was set as 30 dB, following ISO standards, and the signal-noise ratio threshold was set to 12 dB. Multiple readers adopted a randomly distributed network topology, with numbers ranging from 2 to 10, and the minimum distance between readers was 3.5 m. The desired reading range for multi-readers was assumed to be 2.5 m. The results of the simulation are shown in Fig. 2.

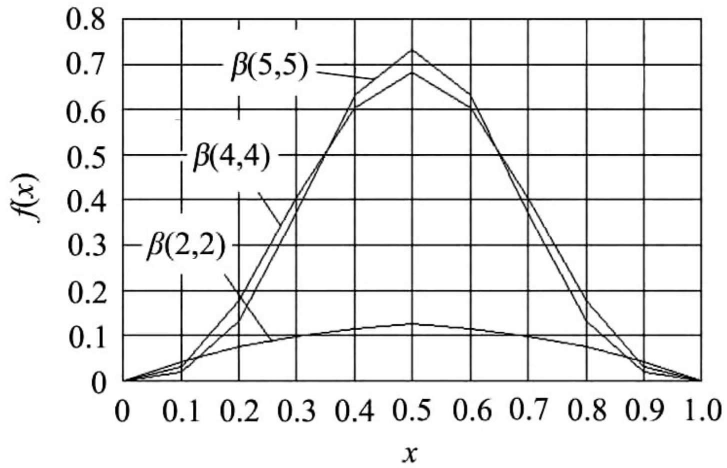

Figure 2 Distribution of Power β of Readers

4.2 PPC Algorithm for 2–10 readers

In adherence to the simulation environment established in Matlab as described above, the results of the simulation are given in Fig. 2. In the figure, the probability density distribution of β is shown. The power distribution can be controlled to obtain a desired distribution of the reading range by changing the α and β parameters, which denote power distribution variables whose cumulative density function ranges from 0% to 100% power.

By altering α and β, power distribution can be controlled, allowing the achievement of the desired read range distribution targets, following the simulation equation above. Where the minimum distance between readers is 3.5 m, the simulation result of the reading distance is shown in Fig. 3.

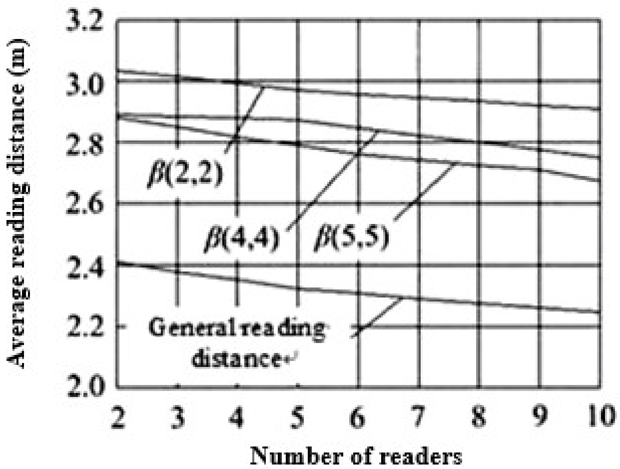

Figure 3 Reading Distance (Minimum Distance between Readers: 3.5 m)

These results show that the reading distance calculated by the PPC algorithm is generally longer than that calculated without use of the algorithm. The results signify an increase in the reading range of the reader. In the same network, the reading power of a given reader is distributed as β (2, 2), β (4, 4) and β (5, 5). The minimum distance between readers is between 2.6 m to 3.2 m when the number of readers is less than five. Therefore, using the embedded software, the readers in use in IMLMS–HSR can effectively monitor a range beyond 3.5 m.

4.3 Test of the logistics monitoring system

A field test of reader–reader collision was performed on the high-speed line access at Shuangcheng North Railway Station within the jurisdiction of the Harbin Railway Bureau, using the devices and software developed for IMLMS–HSR using IoT technology. The PPC algorithm was adopted for the readers.

Test purpose: Testing the reader-reader collision.

Testing devices and system setup: Table 1.

Setup of field test devices: Fig. 4.

Test method:

The distance between long-range RFID card readers was set at longer than 7 m; 20, 30, 40 and 50 special long-range passive UHF-RFID tags were placed in separate packing cases; the workers were divided into four groups, and they passed repeatedly through the service passage and the HSR track 10 times; and the software on the master computer recorded the identification effects of each.

The results showed that there was a zero-misreading rate.

Table 1. Field Test Devices

SN	Description	Model	Qty.	Unit	Remarks
1	Transmission interface		1	Set	Self-made
2	Recognizer		2	Set	Self-made
3	Long-range RFID card reader (Max 6m read range)	AOSID-0702	6	Set	
4	Special long-range passive UHF-RFID tag (Max 8m read range)	AOSID-0835	200	Piece	
5	Industrial RFID hand-held set	AOSID-0813	1	Set	
6	Cable		2000	m	
7	Computer		1	Set	
8	Power extension strip		5	Each	

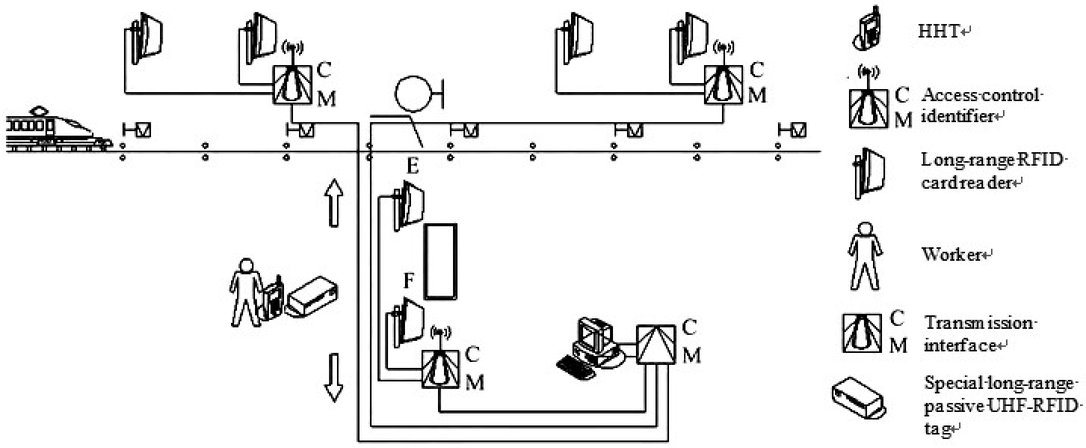

Figure 4 Setup of Devices for Field Test at High-speed Railway Access at Shuangcheng North Railway Station of the Harbin Railway Bureau

5. Conclusion

The paper introduces the management and composition of the monitoring system of IMLMS–HSR, using IoT technology. It provides Matlab simulations and field tests on the critical technical reader–reader collision problem of the system by probing the status quo of the management of integrated maintenance logistics of HSR in China. The results show in cases of less than five readers (using the PPC algorithm) with the minimum distance between reader of 2.6–3.2 m for the IMLMS–HSR, with the embedded software, the readers can effectively monitor a range beyond 3.5 m, indicating the feasibility of the system.

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