System Architecture of a Train Sensor Network for Ubiquitous Safety Monitoring

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ABSTRACT—Train safety monitoring and fault diagnosis are critically important because of the disastrous results caused by train collisions and derailments. Train safety protection sensors network is capable of autonomously monitoring the working condition and actively control faults. A number of strategically placed sensors in the vehicles form a network that can monitor various vital parameters and provide real-time prompt to train driver and dispatcher. Designing such networks faces a number of challenging tasks, as one needs to address some conflicting requirements for quick diagnosis, collaborative decision making, achieving high precision and reliability. This paper presents an on-line Train Safety Sensor Network (TSSN) architecture, discusses its hardware and software structure for ambulatory failure status monitoring. The network consists of multiple sensor layers that monitor train's electrical and mechanical activities, a train data center and a ground data analysis server. The server implements fault diagnosis based on a Fault Tree Analysis method (FTA). The results shows that the sensor network contributes to higher train safety guarantee.

Keywords-Train safety, Sensor network, FTA

I. Introduction

Real-time train safety monitoring is a key technology in helping proactive and affordable train healthcare. It allows workers to continuously monitor changes in vital signs and provide feedback to improve maintenance schedule. Recent technological advances in sensor networks enabled the design and proliferation of wireless sensor networks capable of autonomously exerting early control-related parameters under safety thresholds, preventing some otherwise safe cases from "developing" into dangerous ones. The systems can early alert maintenance personnel with a diagnostic procedure via a friendly user interface and optimal supervised recovery adhering to repair standards and guidelines. Critical development in a train sensor network is data acquisition, wireless communication and vehicle reliability analysis. However, train faults resulting in fatal accidents frequently happen in the entire world. Real-time train working condition monitoring and systematical analysis are challenging in a transportation domain.

During the last few years there has been a significant increase in the number and variety of train monitoring devices and systems. However, their acceptance is limited due to the following important restrictions. Traditionally, they are used to collect data only. Data processing and analysis are performed offline, making them impractical for continual monitoring and early detection of degraded components in a train. In addition, their individual sensors often operate as stand-alone systems and usually do not offer flexibility and integration with a networks. At present, train safety network have some applications to multifunction vehicle buses[4]. A navigation and communication monitoring system of space-earth integration for railway safety based on Chinese Area Positioning System (CAPS), can locate a train and communicate its positioning data to the monitoring center [2]. Accidents may stem from decisions and actions taken at times and places quite distant from their final location [1,3,5].

This paper proposes a TSSN architecture. It implements a train-ground wireless on-line tele-monitoring system. It consists of in-train physiological sensors that monitor train health, in-train datacenter and ground server. We describe the hardware and software organization of TSSN. The result of an example shows that the TSSN is practical and meaningful for qualitative and quantitative reliability analysis and useful in practice.

II. System Architecture

A train is a sophisticated mechanical-electrical system many researchers have devoted their efforts to its safety monitoring. It consists of several vehicles. Vehicle faults are the biggest accident source in rail transportation. For example, ill-function of its door system can lead to sudden train braking, thereby resulting derail accident.

Our work intends to conduct train safety monitoring. The monitoring content is composed of the running condition of vehicles and vehicle loading and infrastructure conditions. Each vehicle itself records its working states and stores in vehicle diagnosis node according to a time sequence. Several train data centers send data to Ground Data Center (GDC) by wireless communication channel. GDC synthesizes all of monitoring information based on certain criteria and decision making methods, provides timely diagnosis results to avoid an accident and predicts hidden dangers. The TSSN architecture and decision making process are show in Figure 1.

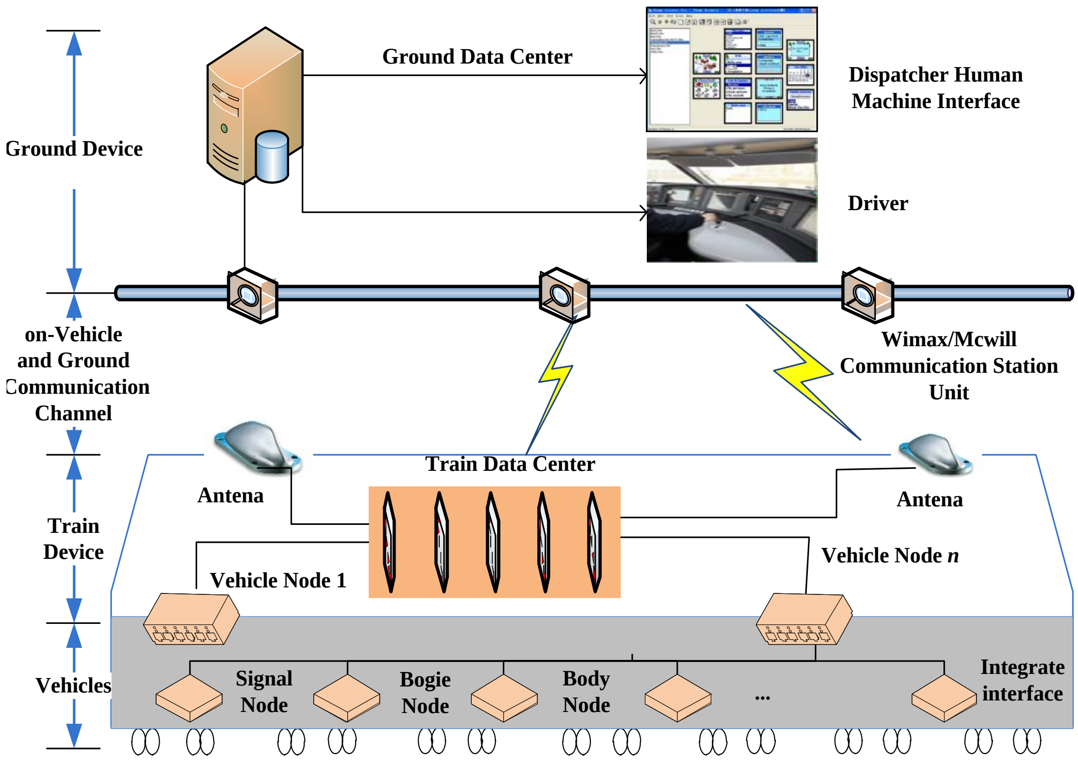

Figure 1. Proposed system architecture

The key technology of TSSN uses distributed sensors to collect online data. TSSN integrates vehicles' information addressing different aspects of inter-vehicle connection, builds an available network structure, a circulation mechanism, a diagnosis data fusion interface.

III. System Reliability Analysis of TSSN

The most important function of TSSN is reliability analysis. For critical components, failure rates of events are calculated via FTA models.

A. *FTA Model and State Transfer Algorithm*

The events in a fault tree model include basic events, intermediate events and top event. All the events have only two states: failure or normal. The corresponding probabilities are a failure rate and a success rate whose corresponding state values are expressed by 0 and 1.

The codes according with the basic events are in Table 1, the Instantaneous Failure Rate data are collected from Shanghai Metro historical maintain records.

Table 1. Failure modes and their characteristics

Code	Name	Instantaneous Failure Rate
T	Door System Open Failure	0.002707089
X_1	Speed Sensor 1	0.001152
X_2	Speed Sensor 2	0.001152
X_3	Speed Sensor 3	0.001152
X_4	Speed Sensor 4	0.001152
X_5	Open / Close Button	0.0005
X_6	EDCU Failure	0.000813

X_7	Open / Close Solenoid Valve	0.000356
X_8	Emergency Unlocking Handle	0.00125
X_9	Unlock Solenoid Valve	0.000749
X_{10}	Unlock Signal	0.000962
X_{11}	Screw / Nut Failure	0.0001
X_{12}	Rail Choked	0.00022
X_{13}	Rubber Pad Damage	0.0004
X_{14}	Motor Failure	0.000058
X_{15}	Coupling Failure	0.00025
W_1	Speed Sensor Failure	7.944E-06
W_2	Unlock Failure	9.362E-07
W_3	Auto Unlock Failure	1.203E-06

B. Statistical Simulation

The simulation process is implemented in C + +. After 10,000 simulation runs, a series of simulation data are obtained. Then the processing results are displayed in Figure2.

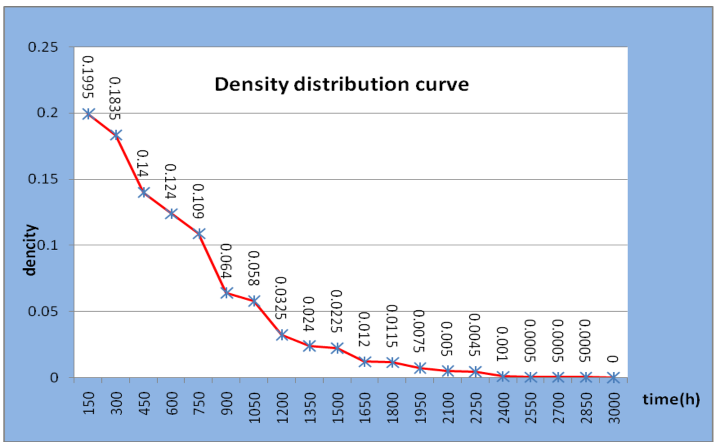

Figure 2. Density curve of failure distribution

IV. Conclusions

In this paper we describe both hardware and software architecture of TSSN. The architecture leverages off-the-shelf commodity computing platforms. The reliability of application and simulation software deployed upon real-time operating system for embedded sensor networks. TSSN promise a ubiquitous monitor vital working condition parameters. It provides a shift from passive failure management toward more proactive preventive accident care and reduces failure occurrence frequency.

Acknowledgment

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