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ScienceDirect

Underground Space 2 (2017) 210–219

www.elsevier.com/locate/undsp

Smart monitoring of underground railway by local energy generation

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Received 5 July 2017; received in revised form 18 October 2017; accepted 27 October 2017
Available online 2 December 2017

Abstract

The objective of this study is to develop a prototype for smart monitoring of underground rail transit by local energy generation. This technology contributes to powering rail-side devices in off-grid and remote areas. This paper presents the principles, modeling, and experimental testing of the proposed system that includes two subsystems: (1) an electromagnetic energy generator with DC-DC boost converter (2) a rail-borne wireless sensor node with embedded accelerometers and temperature/humidity sensors and (3) a data processing algorithm based on the Littlewood–Paley (L-P) wavelet. Field testing results, power consumption, L-P wavelet transform methods, and feasibility analysis are reported. One application scenario is described: the electromagnetic energy harvester together with the DC-DC boost converter is used as a local energy source for powering the sensor nodes of a Wireless Sensor Network (WSN), and the abnormal signals of out-of-round wheels are identified based on the measured rail acceleration signals and L-P wavelet analysis.

Keywords: Condition monitoring; Energy harvesting; Electromagnetic; Underground rail transit; Wavelet

Introduction

Motivation

Underground rail transport in China has been experiencing a rapid increase in the last decade. As of early 2016, China had 3195.6 km of subway lines (Hodge, O'Keefe, Weeks, & Moulds, 2015). With the development of underground rail transport in China, the market requirement for rail-side monitoring equipment and sensors has dramatically increased (Wikipedia, 2017a). Both wired and wireless rail-side monitoring devices require external power supply. Wired monitoring equipment need a large investment in the electricity infrastructure, whereas their wireless counterparts utilize rechargeable batteries, implying high maintenance costs. It is, therefore, necessary to develop a new energy strategy to use alternative renewable energy sources (Gao, Wang, Cao, Chen, & Liu, 2016; Lee, Correia, Lee, Neilan, & Gregor, 2014; Wang, Wang, Gao, & Wang, 2017).

Review of the State-of-the-Art

The existing energy harvesters in the railway industry can be categorized from the perspective of track-borne and bogie-borne mechanics. In track-borne mechanics, the energy harvester can be rigidly connected to a rail foot (Nelson, Platt, Albrecht, Kamarajugadda, & Fateh, 2008), attached to a rail web (Gao, Wang, Cao, Chen, & Cai, 2017), mounted onto a tie (Pourghodrat, Nelson, Hansen, Kamarajugadda, & Platt, 2014; Wang, Penamalli, & Lei, 2012), or buried beneath a sleeper (Yuan, Yang, Song, & Liu, 2014). The specified harvester in track-borne mechanics can be an inductive voice coil

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https://doi.org/10.1016/j.undsp.2017.10.002
2467-9674/

(Nelson et al., 2008), a cantilevered piezoelectric beam (Gao et al., 2016), a rotationally electromagnetic generator (Wang, Penamalli, & Zuo, 2012), or in the form of a piezoelectric drum transducer (Yuan et al., 2014). In bogie-borne mechanics, based on the application objective, the energy harvester can be located on a brake beam (Socie & Barkan, 2008) or installed on a coach (Pasquale, Soma, & Zampieri, 2012). The harvesting principle of bogie-borne mechanics is normally achieved with a magnetic suspension (Pasquale et al., 2012) and leaf-spring resonator (Socie & Barkan, 2008).

Although various energy harvesters have been proposed and investigated in the railway industry, only a few studies have discussed their integration and application in a self-sustaining railway monitoring system. Bischoff, Meyer, Enochsson, Feltrin, and Elfgren (2009) established a Wireless Sensor Network (WSN) for strain monitoring of a truss railroad bridge by using solar energy harvesting to power sensors. Sekula and Kolakowski (Sekula & Kolakowski, 2012) proposed a weigh-in-motion (WIM) system using piezoelectric strain sensors powered by photovoltaic modules. Solar power is highly dependent on the weather conditions, and solar panels must be cleaned frequently to maintain the optimal performance (Gruden, Westman, Platbardis, Hallbjorner, & Rydberg, 2009). However, there is no sunlight available for a railway transit through a tunnel and metro rail transit (Wikipedia, 2017b).

Scope of paper

The objectives of this study are to solve the power supply problem of rail-side sensor nodes and to construct a smart monitoring system for underground rail transit. The system consists of self-sustaining rail-mounted sensor nodes with the ZigBee protocol stack and a local energy harvester for railway condition monitoring. Compared with a WSN system powered by solar energy, the proposed solution is independent of the weather conditions and can be used for both railway transit through a tunnel and urban rail transit. Furthermore, it is favorable to achieve direct defect identifications through the wavelet transform of the measured raw signal, which is highly suitable for the engineering community.

Fig. 1 depicts the proposed approach for smart monitoring of underground railway. It includes three subsystems: (1) an electromagnetic energy generator with a DC-DC boost converter; (2) a rail-borne wireless sensor node with embedded accelerometers and temperature/humidity sensors, and (3) a data processing algorithm based on the Littlewood–Paley (L-P) wavelet. The rail-side sensors are connected to the ZigBee end device and powered by the track-borne energy harvester. The data can be transmitted to the ZigBee coordinator and accessed through a webpage on the internet with cloud computing technology. The serial port of a WiFi adapter can be used to allow the ZigBee nodes to communicate with any secure or open wireless network or access point. Data can be transferred over TCP/IP (Transmission Control Protocol/Internet Protocol), UDP (User Datagram Protocol), or HTTP (Hyper Text Transport Protocol) using 802.11b/g/n infrastructure or through ad hoc mode (Simple AP/Station Mode) networking. Once the collected data from the ZigBee nodes are available over the WiFi, Internet-based computing (cloud computing) can enable access to a shared pool of configurable computing resources (i.e., computer networks, servers, and storage). The collected data can be analyzed

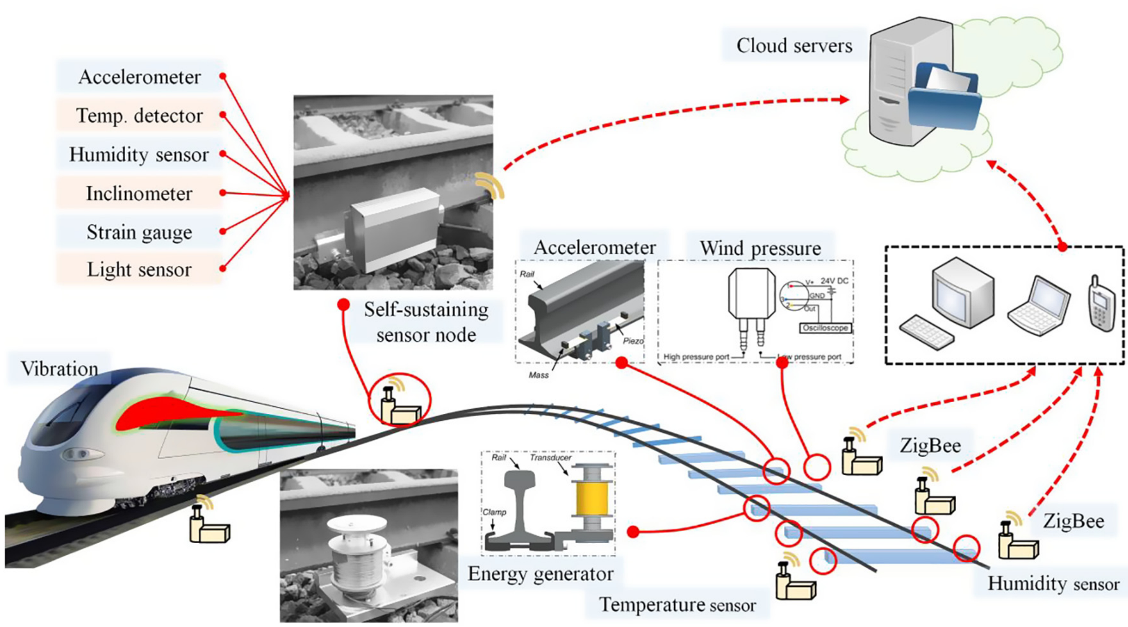

Fig. 1. Illustration of the proposed solution for smart monitoring of underground railway.