Hot Box Detection System Design for Railway Vehicle Safety

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Abstract: - This study aims at designing a smart hot box detection system by using infrared technology to maintain safe transportation on the railways. An infrared detector array was used in this measurement system aimed so as to measure the heat emitted from the faulty beds. This system includes a hot box detector, a CANBUS communication line and a computer terminal. The hot box detector includes infrared detection cards, placed on both directions of the railway, and two trigger keys, one of which is placed near the cards and the other at a remote point.

Key-Words: Multi-infrared detector, railway safety, hot box detector, contact-free temperature measurement

1 Introduction

Side bearings are one of the components of railway vehicles which are prone to heavy loads. Frequent incidents of breakdowns occur in such railway components. Such failures push up the friction between the parts. As friction increases, a temperature increase is observed in the entire side bearing box. Moreover, another problematic factor contributing to an increase in heat in such components is defective wheel bearing beds or insufficient greasing. An increase in heat would cause several problems such as melting of the metals and degrading of the grease in the wheel bearing beds, which lead to derailing of the wagons and overturning of the vehicle. Detecting the failure beforehand can prevent possible accidents; hence it could also be possible to prevent losses of lives and material loss. The system made both time and cost saving possible due to prediction. Furthermore, data recorded onto the database enables us to see the updated information regarding the lifetime and maintenance of the railway vehicles. Hence the hot box detectors are widely used in many European countries like Germany, Switzerland, and Finland to prevent derailments [1]. Most of the studies related hot box design and application to the railways can be classified into three groups: risk analysis and probabilistic hot box modeling [2], [3], hot box modeling in transient and steady state operation of trains [4], and hot box applications for railway operation in Europe [5].

Along with the advanced technology, hot box detectors have gained a significant role in preventing relevant accidents. Accordingly, a hot box detector was designed in this study to detect the rising temperature beforehand, to prevent possible accidents, to identify the maintenance periods of the vehicles and to ensure uninterrupted flow of traffic in the meantime. Accidents that had happened on railways were studied before the hot box detector was designed. At the same time, the factors leading to the accidents were identified. The detector which could be used in the system was studied primarily since determining the model to detect the temperature was the top priority in the system design. The velocity of the detector to be selected proved to be crucial as the components of the railway vehicle would be measured during a period

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when the vehicle was moving. It is necessary to use detectors with high costs so that accurate measurements can be performed at higher velocities. It is possible to attach more than one detector onto the detector card designed. Having more than one detector on single card ensures scalability, which enables one to adjust the system costs according to the relevant need. It also enhances the precision of the measurement values. All these factors would enhance the availability and reliability of the system. Another significant parameter that has an impact on the measurement rate of the hot box detector is the rate of communications between the detection circuits. CANBUS protocol was used to ensure the communications between the infrared detection cards. This study was, to authors' knowledge, the first time when CANBUS protocol played a role in the design of the hot box detector. The system identifies the temperature by measuring the infrared energy emitted from the railway vehicle components, such as brake housing, gear box and side bearing box, which are particularly exposed to heat. The system is placed on both directions of the railway based on the height of the box to be measured. In addition to the measurement system, two trigger keys are placed within certain distance, which enables one to have access to the velocity data of the vehicle (Fig.1). Velocity data of the vehicle is transmitted to the system, thus this makes the system become prepared for the measurement beforehand. Power supply circuit sets the supply voltage according to the relevant requirements of microprocessor and other units. Infrared detectors transmit the temperature values they read to the microcontrollers via the I^2C communications module. Data received from all detectors is transmitted to the computer terminal via CANBUS and presented to the user at terminal interface [6].

2 Design of Detector System

The designed system is able to measure overheating of some components of railway vehicles in a contact-free and continuous way, and can transmit data to the user directly. The system is comprised of three parts (Fig.2), which are: hot box detection circuits, CANBUS communications line, and the computer terminal. The algorithm behind the measurement system is shown in Fig.3. First of all the system is activated, making the infrared detectors ready. The system starts waiting the information from the trigger key that a railway vehicle is approaching. As the signal is received the information conveying the data that the vehicle is approaching is relayed to all the infrared detection cards.

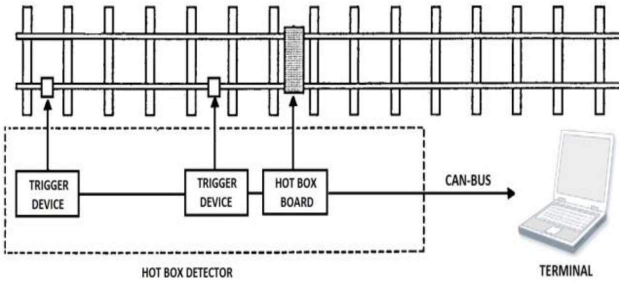

Fig.1: Block diagram of the detector system design.

After receiving this signal measurement is initiated. This procedure is repeated for each of the vehicle component to be measured. Completion of measurement is perceived by the help of a timer, which is reset as the measurement starts. The counter of the timer goes up from the last measurement to the predetermined time-out period. Following this, data about the completion of measurement is relayed to the terminal software. Then data regarding the heat is compiled from all the infrared detection cards. The measurement results are compared with threshold values determined previously. In case of detecting any hot box, the user is warned accordingly. Thus, a possible accident can be prevented by informing employees in charge.

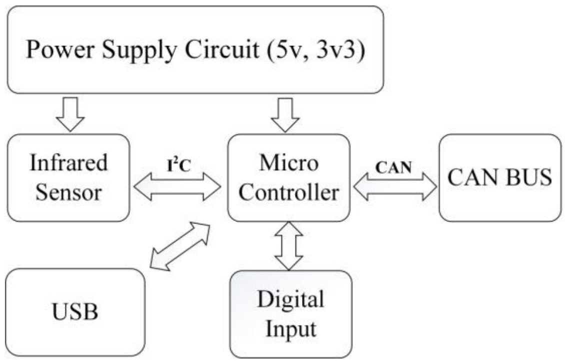

Fig.2: Flowchart of the system.

2.1 Features of IR Detection

Recall that infrared (IR) is an electromagnetic radiation across the visible light and microwave. Infrared radiation reaches the detector through a transmission medium. All bodies emit a kind of infrared energy even if their energy levels vary.

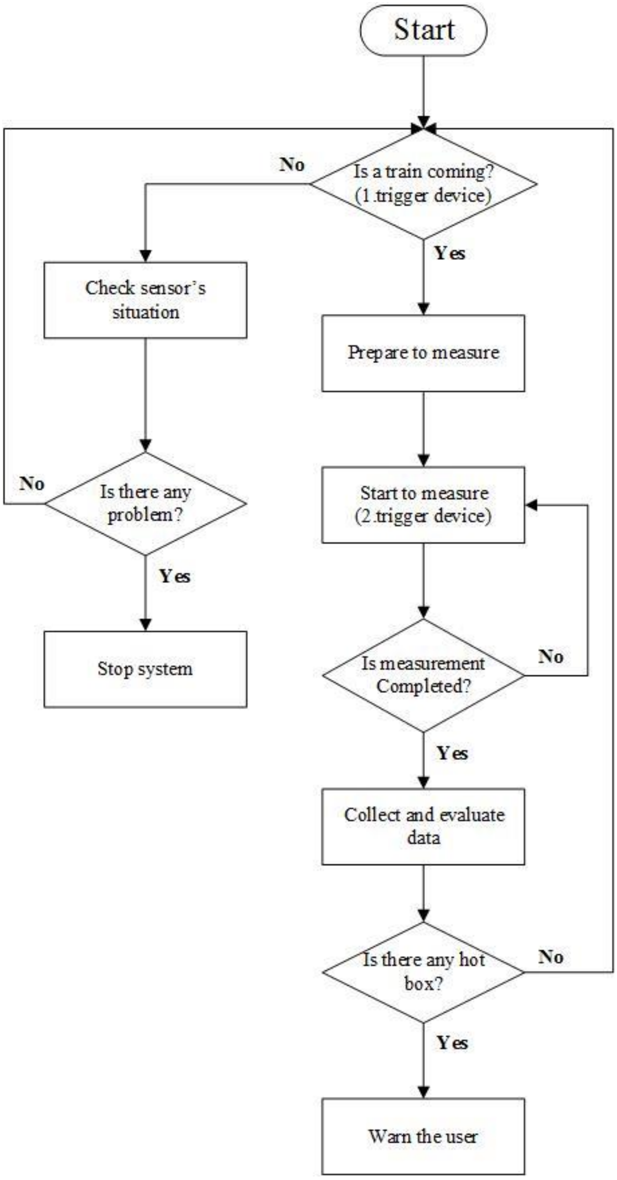

Fig.3: Block diagram of the detector subsystem.

In other words, infrared radiation is a heat transfer between the objects at different temperatures. Thermal energy forming during this transfer is transmitted at infrared wavelength. Infrared detectors view the energy transmitted at infrared wavelength as spectrum. Note that thermal radiation spectrum and its amount are closely related to the surface temperature of the object. As temperature goes up, so does the intensity of infrared radiation. Infrared detectors have different sensitive and measurement capacity. They work at certain wavelengths. Emissivity coefficient relatively signifies the capability of a body to spread the energy on a body surface through radiation. Bodies radiate based on their temperature and physical properties. This ratio of radiation is called emissivity. Each body has a different emissivity coefficient. Emissivity coefficient of most bodies is above 0.8 (Table 1). Note that, bodies whose emissivity coefficient is below 1 are known as gray bodies. If the emissivity coefficient is also dependent on temperature and wavelength, then these ones are defined as non-gray bodies [7].

Table 1: Emissivity coefficients by materials

Material	Emissivity coefficient
Aluminum	0,05
Brick Mortar	0,93
Concrete	0,54
Glass	0,92
Water	0,98

The output of the infrared sensor is proportional with absolute temperature of the chip. This requires the information of the core temperature so as to compute object temperature recognized by each pixel on the sensor.

Table 2: EEPROM addresses to compute T_a

EEPROM address	Cell info	Stored as	Refers to
0xDA	V_{TH}_L	Two's complement	Threshold voltage at absolute zero
0xDB	V_{TH}_H		
0xDC	K_{T1}_L	Two's complement	Temperature coefficient
0xDD	K_{T1}_H		
0xDE	K_{T2}_L	Two's complement	Temperature coefficient
0xDF	K_{T2}_H		

Ambient temperature (T_a) in (1) for the absolute temperature of the sensor (V_{TH0}) in (2) is computed by the temperature coefficient (K_{T1}) of the threshold voltage value in (3) and the temperature coefficient (K_{T2}) of the threshold voltage value in (4). All the data are stored as two's complement on the chip. The EEPROM address informations of the absolute temperature and temperature coefficients are given on Table 2.

$$T_a = \frac{-K_{T1} + \sqrt{K_{T1}^2 - 4K_{T2}\left[V_{TH}(25) - PTAT_{data}\right]}}{2K_{T2}} + 25\,[^{o}C] \quad (1)$$

$$V_{TH}(25) = 256V_{TH\_H} + V_{TH\_L} \quad (2)$$

$$K_{T1} = \frac{256K_{T1\_H} + K_{T1\_L}}{2^{10}} \quad (3)$$

$$K_{T2} = \frac{256K_{T2\_H} + K_{T2\_L}}{2^{20}} \quad (4)$$

In order to compute the temperature of the object (5) is used to determine temperature value recognized by each pixel on data matrix.Here, $V_{IR}(i,j)\_balanced$ stands for each balanced pixel without a disturbance, and α(i,j) is for the pixel sensitivity factor stored in EEPROM.

$$T_{o(i,j)} = \sqrt[4]{\frac{V_{IR(i,j)\_balanced}}{\alpha_{(i,j)}} + \left(T_a + 273{,}15\right)^4} - 273{,}15 \text{ [°C]} \quad (5)$$

2.2 CANBUS Communication

Control Area Network (CAN) is developed in 1983 by Robert Bosch GmbH to reduce the numbers of cable networks inside vehicles in automotive industry. Though, at the beginning it was designed for automotive industry, but today it has been widely used in other industrial control applications due to its high data transmission rate, and cost reduction. In a conventional CAN system, the undetermined computational probability error regarding statistical probability calculations is once in a century. The basic principle that makes CAN different from other communication protocols is that the operation of CAN is a message based, where each message has its unique ID, and messages are transmitted with frames. Thus, the messages flowing in a CAN system are classified into two groups as data and requests. Whereas requests include no data and data messages are transmitted in form of 8 byte at most. The well-known features of a conventional CANBUS system are; priority in message, delay time safety, flexibility in construction, multiple simultaneous admissions, ability to bear with intense data traffic, ability to work for multiple purposes, fault diagnosis and ability to generate fault-related signals, in case of a fault situation in data transmission ability to resend a message automatically when the communication line is available, ability to differentiate temporal and permanent faults ability to shut down the units with permanent faults autonomously. Today the application areas where CANBUS systems are preferred are high speed networks, low-cost multiple cable systems, intelligent motor control, car electronics, intelligent sensors, robot control, and traffic signalization systems. In this study for the communication between detection cards CANBUS is preferred because of its multi-master fashion, reliable communication features and high-speed. CANBUS differs from other protocols owing to definition of the urgency messages to be exchanged over the network in real-time, where commutation is initiated according to the urgency of the situation. Each detector on the system has a unique node address of its own. The procedure of assigning address is enabled through user interface. CANBUS communications rate between the cards is set as 250kbit/s in the system, where CAN messages have 29 bit ID. This module was preferred due to its properties such as message priority, configuration flexibility, lost-time safety, getting the same data from multiple units, eliminating data density in the system, error detection and producing signal for the error and automatically resending the message in case of an error occurring during data transmission. Detectors located in various points on the railway line transmit data to the terminal over CANBUS.

2.3 Computer Terminal

A user interface is required to present the data received from the detector in order to warn the user of a possible problem and to store such data for later analysis. The user can change the parameters of the detector through this interface and can configure it if required. The screen is refreshed each instant when data is received from hot box detector.

Terminal software was developed on Microsoft Visual Studio medium with C# programming language. The user is warned through audio and visual alarm in case out of threshold temperature is detected by the system based on the data received from hot box detector installed on the railway. Once the user gets the data, he is supposed to inform the units in charge, which will prevent a possible accident. The warning signal can provide relevant data regarding when the last measurement was made, how high the temperature was and which component of the railway vehicle this measurement is related to. This data enables employees in charge to identify where the failure has occurred and to take necessary measures.

Temperature measurements, railway vehicle identification number and the time when the measurement has been made are stored on the database. Such data can indicate whether railway components have been exposed to high temperatures or not. Thus, maintenance periods of the vehicles can be determined. In addition, a possible problem regarding the specific part can be prevented by tracking the temperature values, related to the part of the railway vehicle, on the schedule. Hence, the part can be repaired before the problem gets more severe or end-of-life parts can be replaced with the new ones.

3 Experimental Work & Verification

Installing the hot box detectors onto the railway depends on the railway component to be measured. Elements which cause the most common heating problems on railways are the brake lining of the railway vehicle, the gear housings, side bearing housings and brake housings. The distance between the surfaces of such elements to be measured and the hot box detector varies between 200 mm and 400 mm. Before performing the tests sheet metal and iron block, whose temperature would be measured, were kept in the furnace until the desired temperature was achieved. To achieve accurate measurement results, it is significant that the hot box detector perceive only the thermal radiation coming from the surface of the body to be measured. For this reason, the measurement process should be initiated while the body is crossing just opposite the detector.

The initiation of the measurement is realized through the trigger key. Trigger signal for the detecting system comes from the test apparatus. The switching procedure of the hot box detector can be realized through the reed switching element included in the test apparatus. The reed switching element can perform switching through a magnet.

The rotating rod with a magnet on it passes over the reed key and produces a triggering signal when it is just opposite the body detector. Measurement results read from the hot box detector are presented to the users at terminal interface. To verify the measurement results, the thermometer temperature of the same sheet was identified, as can be seen in Fig.5, and comparison was made with the measurement results of the hot box detector.

All measurements were performed at room temperature. As it can be seen obviously from the measurement results, measurements were made just in time thanks to the triggering signal. The temperature values read indicate only the temperature related to the body, which proves that the detector has carried out both accurate and prompt enough measurements.

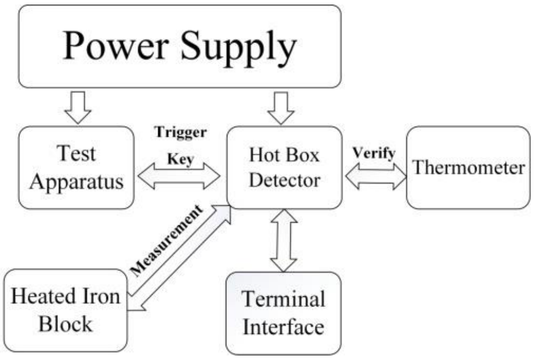

Fig.4: Test environment

The difference in temperature, amounting to a few degrees, between the consecutive measurements is because of the thermal radiation in the environment and due to the fact that the noise in the environment could not be suppressed efficiently by the infrared detector, working at a high pace.

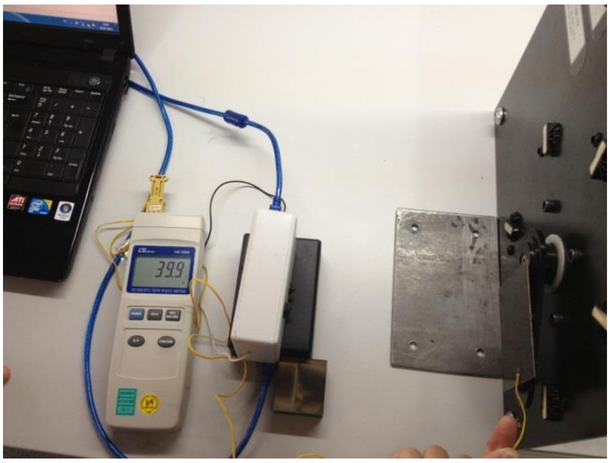

Fig.5: Verification

Tests in which a different body was heated at high temperature levels were repeated. The temperature of an iron block was measured at 92,5°C on the thermometer. Based on the values read through the hot box detector, it was seen that the difference between the lowest and the highest temperature got less as the temperature went up. The reason for this is that the infrared sensor can respond better to high temperature levels.

The test was performed once again by using rusted block (Fig.6). This time, for the trigger signal, a source, independent of the system, producing square wave at 100 ms period was utilized instead of the reed switch on the test apparatus. It was seen that the system had performed an accurate measurement of the body with 82.5 °C on the thermometer.

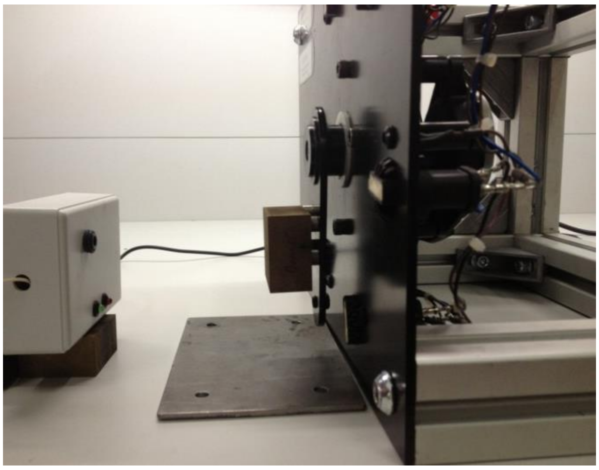

Fig.6: Heated Block

The aim of the test was the display of the relationship between the train velocity and the velocity of the moving body. This test shows that the temperature of the black body can be measurement when it is on the move. The velocity of rotating rod is equivalent to the train velocity of 20 km/h. The calculated results are dependent on the black-body temperature 82.5°C and the frame rate of the sensor. Accuracy levels of 1.5°C when the operating in the 0°C to 50°C range.

4 Conclusion

This study handled the design processes of hotbox detector, which can detect heating components of railway vehicles by making infrared measurement. All features and properties, such as establishing the infrastructure required for the system, choosing the appropriate detecting method, identifying the electronic elements to be used, communications system as well as verifying the user interface and measurement results, which all have an effect on the system design, were explained in depth. Through a further step in this study, it could be possible for the system to receive more prompt measurement by using infrared detectors that can perform measurement at micro second. It could be possible to place more than one hot box detector on a railway, which can perform measurement from various points in a sensor fusion fashion. This would, thus, enhance the precision of measurement, and temperature measurement of various components could be read concurrently at one single interface.

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