

# Intelligent electronic embedded systems for the protection of railway transport from accidents

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## ABSTRACT

The paper considers an intelligent electronic embedded system for the protection of railway transport from accidents, its compatibility with the existing railway control system, principles of its components interoperation and control algorithms.

The paper gives the definitions of the functions performed by the system considered and its mathematical description applied to the realization of the control algorithm.

The process of the device prototype testing is described with the obtained results, advantages and further prospects

**KEYWORDS:** embedded systems; intelligent control, railway transport

## 1. Introduction

The railway transport experiences the tendency towards increasing the routing speed and movement intensity of this type of transport. At the same time this fact encounters a lot of problems the reason of which is a high motion speed. One of these problems is the level of safety that should be sustained at the same or even higher level than it was so far [1].

Therefore, keeping it in mind, intelligent embedded systems are developed being aimed at the protection of trains from accidents and able to solve at least a part of the problems in the industry of railway transport.

The implementation of a new system into operation each time requires a preliminary development of a mathematical model and prototype, a detailed analysis and testing that recognizes drawbacks of the equipment and ways of their overcoming. The testing process often

discovers the problems that are difficult or impossible to find during a theoretical analysis.

Thus the paper analyses the devices that are applied in a general safety control system of a locomotive and in a system using the global positioning system and a wireless communication system providing the basic functions of the device operation: the defining of the moving object location in time and the data exchange between objects.

The application of programming logic controllers in turn solves the complex tasks of the railway transport control.

## 2. Purpose and tasks

The main aim of the authors is to analyze the operation algorithm of an intelligent embedded system control and to realize the testing of the of the system equipment under the conditions of real work.

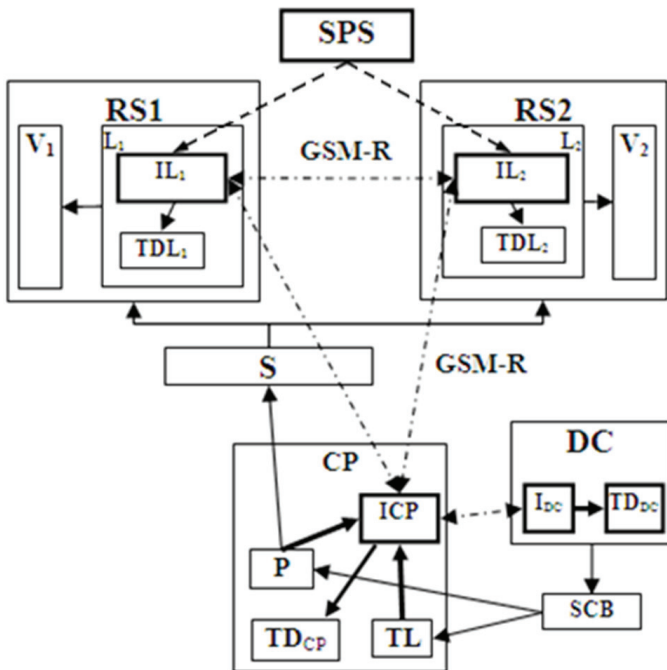


Fig. 1. General structure of the system

The main objectives are:

- To describe the main operation principles of an intelligent embedded system where new devices protecting from accidents are applied [3].
- To define the functions realized by the protecting devices.
- To develop a mathematic model and algorithm for the equipment control.
- To carry out laboratory tests of the main functions performed by the equipment.
- To test the prototype under real operation conditions and to analyze the obtained results.

## 2.1 Operation principles of the control system

As it was mentioned above the main task of an intelligent embedded protective device is to improve the safety of the railway transport routing without changing the present control system of trains. Therefore one of the most important objectives is to integrate this device with the general control system without decreasing the functionality of the present control system and safety level that is of top importance.

Two types of the device are proposed – a locomotive device [4] and a track-section device [5]. The locomotive device is installed in the locomotive and connected to its emergency braking system to stop the train when necessary.

The track-section device is installed in the outside traffic light control enclosure and is connected to the supply and relays of traffic light signals control and railway point control. It controls the light and railway point conditions.

The scheme of interoperation of the embedded safety system elements is given in Fig. 1.

The existing railway system contains the following elements [6]:

rolling stock – RS1, RS2; locomotives –  $L_1$ ,  $L_2$ , wagons  $V_1$ ,  $V_2$ ; railway points CP; signalling, centralization and interlocking system SCB; dispatching centre DC; traffic lights TL; shunts P and rails – S.

The new embedded safety devices include: locomotive equipment –  $IL_1$ ,  $IL_2$ , equipment of railway points ICP containing receivers of satellite positioning system SPS, wireless communication devices at locomotives  $IL_1$  and  $IL_2$  and railway point CP; information output displays –  $TDL_1$ ,  $TDL_2$  at the locomotives and railway point TDCP.

GSM-R network serves to provide a wireless communication channel. As it is seen from Fig.1, both embedded control devices are equipped with the aerial of satellite positioning system, that allows defining the coordinates, the height above the sea level for the locomotive at any moment.

## 2.2 The realised functions of the system

The following functions are defined for the train safety protective device:

- Establishment of connection between two devices (traffic lights and train);
- Greenwich Mean Time for the IL;
- Train location latitude, longitude, altitude for the IL;
- Traffic lights location latitude, longitude, altitude for the ICP;
- Obtaining the signal from a traffic light from its control device;
- Obtaining the signal from a railway point from its control device
- Sending the traffic light signal to the locomotive device IL;
- Sending the railway point signal to the locomotive device IL;
- Warning the train driver on the necessity of emergency braking start if the risk of accident exists;
- Start of train emergency braking.

A great attention is paid to the control of locomotive and visual representation of different variable parameters using light indicators or messages that are displayed at the train driver place. That provides the driver with the information on the device operation stability, the accuracy of the obtained information and the obtaining of warning signals.

The main task of the device is to warn the driver on the necessary routine or emergency braking and to complete the necessary operations for protection of the train from accident decreasing the speed.

In the case when the locomotive driver does not complete the necessary operations at a particular moment the emergency braking system is operated stopping the train in front of the place of traffic lights with a stop signal.

### 3. The formulas applied in the calculation algorithm

The following functional relations define the mathematical model of the device operation:

The total braking way (m):

$$S_{Br} = S_{Sag} + S_{real} \quad (1)$$

where  $S_{sag}$  is a preparation braking way (m):

$$S_{Sag} = \frac{V_0 \cdot t_{sag}}{3.6} \quad (2)$$

where  $t_{sag}$  - the preparation time, assuming that the train contains less than 200 axes (s):

$$t_{sag} = 7 - \frac{10 \cdot i_c}{b_T} \quad (3)$$

$S_{real}$  - the real braking way (m):

$$S_{real} = \sum \frac{500 \cdot (V_0^2 - V_{beig}^2)}{\xi \cdot (b_T + \omega_{ox} + \omega_i)} \quad (4)$$

where  $V_0$  - initial speed of braking, (km/h);  
 $V_{beig}$  - finishing speed of braking, (km/h);  
 $\xi$  - braking of the train while rolling in the opposite force operation (for cargo wagons  $\xi = 120$ );  
 $b_T$  - the specific braking way of the train;  
 $\omega_{ox}$  - the specific basic opposite force to the train movement;  
 $\omega_i$  - the specific opposite force according to the profile of the way.

The specific braking force of the train  $b_T$  is defined from the formula:

$$b_T = 1000 \cdot v_p \cdot \varphi_{kr} \quad (5)$$

The braking factor  $v_p$  is defined from formula (1), but the braking shoe factor  $\varphi_{kr}$  is as follows:

$$\varphi_{kr} = 0.27 \cdot \frac{V + 100}{5 \cdot V + 100} \quad (6)$$

The specific basic braking force opposite to the train movement  $\omega_{ox}$  is defined from the formula:

$$\omega_{ox} = \omega_0'' + \omega_x \quad (7)$$

The basic braking force opposite to the locomotive movement is defined from the formula:

$$\omega_x = 2.4 + 0.011 \cdot V + 0.00035 \cdot V^2 \quad (8)$$

The basic braking force opposite to the wagon movement is defined from the formula (cargo wagons):

$$\omega_0'' = 0.7 + \frac{3 + 0.1 \cdot V + 0.0025 \cdot V^2}{q} \quad (9)$$

Where  $q$  - the pressure on one axis of wagon, (t).

The basic braking force opposite to the wagon movement is defined from the formula (passenger wagons):

$$\omega_0'' = 1.2 + 0.012 \cdot V + 0.0002 \cdot V^2 \quad (10)$$

Using the described basic formulas the logic controller program used in the locomotive device includes the corresponding program implemented for the calculation of braking distance.

The following algorithm is used to define the distance between the objects. At the beginning the distance SABO in degrees between station A (locomotive) and station B (traffic light or locomotive) without accounting the height above the sea level (Fig. 2). The calculation applies the Pythagorean Theorem assuming that the difference of width and longitude is a cathetus but the distance between the stations is the hypotenuse.

Then the distance between stations A and B in meters is obtained from the distance in degrees using the obtained results of the previous step. We assumed that one degree is 111,120 (m), 1 minute is 1,852 (m), 1 second is 30.87 (m). Knowing the height of the station above the sea level H, applying the Pythagorean Theorem it is possible again to define the distance between the objects including this value  $S_{AB}$ , that results in more precise calculation of the given value (Fig. 3).

Wherewith the distance in meters between stations A and B is obtained including the height above the sea level. In the same way the distance between the objects is obtained applying the geographic locations of these objects.

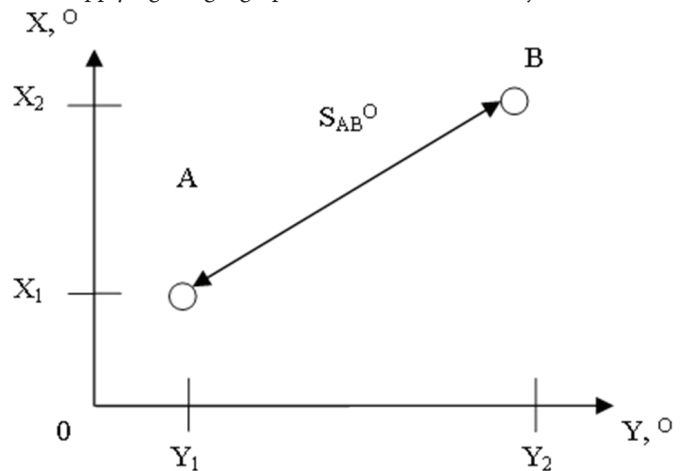


Fig. 2. Defining of the distance between the objects in degrees

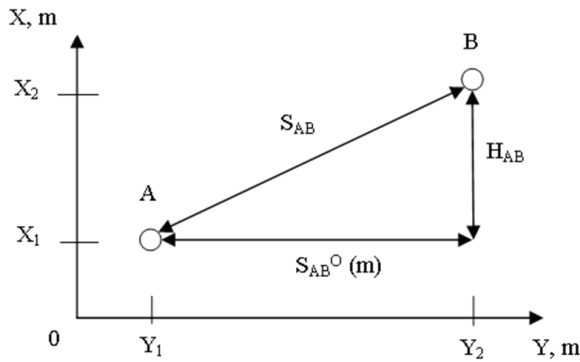


Fig. 3. Defining of the distance between the objects in meters

### 4. The algorithm of the device control and its implementation

This section defines the new control algorithm for the embedded accident protective device and its implementation with a programmable controller.

The block-scheme of the algorithm is given in Fig. 4.

List 1 presents a fragment of the program that notes the processing from GSM-R aerial obtained information and data sending to the locomotive device.

List 1. Obtaining the data from a GSM-R aerial.

```
// Block 1.
LD SM0.0 // always complete the following operations,
CALL WDC_INIT:SBR6, INIT_own_
stationnmb:VW1982, // station number is initialized,
&INIT_IP_Address:&VB1800, &INIT_
Dest_Port:&VB1820, // server IP address is initialized,
&INIT_Modem_Name:&VB1826, // title of the modem is
initialized,
&INIT_Modem_PW:&VB1834, &INIT_SIM_PIN:&VB1844, &INIT_
APN:&VB1852,
&INIT_APN_User:&VB1880, &INIT_APN_User_PW:&VB1890,
&INIT_DNS:&VB1900, &INIT_Clip_Numbers:&VB1940, INIT_Busy
// Block 2.
LD SM0.0 // always complete the following operations,
CALL WDC_RECEIVE:SBR8, 0, // data sending block is
called,
RECV_AreaStart:VW1984, RECV_
AreaLenght:VW1986, // data sending volume is defined,
RECV_Received_From:VW1792, // initial defining of the
data sending range,
RECV_Rcvd_DataStart:VW1794, RECV_Rcvd_DataLengt:VB1981,
RECV_NewTime_Rcvd:V1780.7.
// Block 3.
LD SM0.0 // always complete the following operations,
```

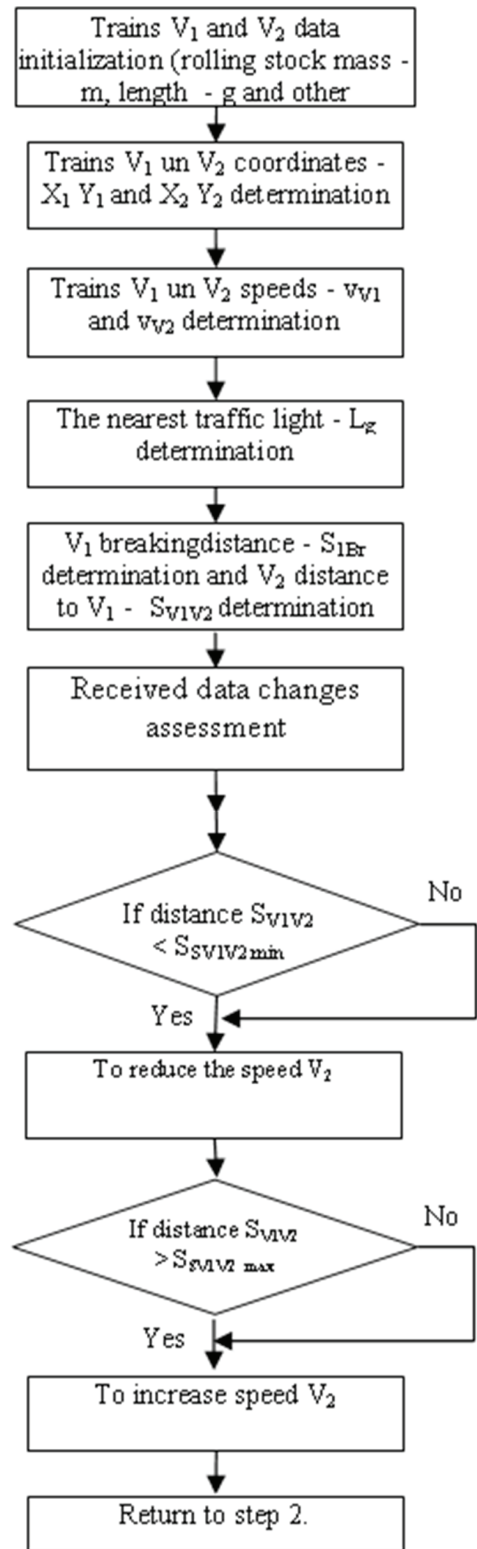


Fig. 4. The block-scheme of the control algorithm

```

= L60.0
LD SEND_CMD_Send:V1780.3
= L63.7
LD L60.0
CALL WDC_SEND:SBR7, L63.7, // data sending operation is
called,
SEND_Target_RS:VW1784, SEND_Data_
Start:VW1786, // starting of data sending,
SEND_Data_Length:VB1980, SEND_Command:VW1788,
&Year:&VB2000, SEND_Busy:V1780.4, SEND_Done:V1780.5,
SEND_Aborted:V1780.6, SEND_Error:VW1790.
// Block 4.
LD SM0.0 // always complete the following operations,
= L60.0
LD CTRL_Act_GPRS:V1781.5 // GPRS regime activity is
checked,
= L63.7
LD CTRL_Act_AT:V1781.6 // AT regime activity is checked,
AB>= counter1:VB2204, 30
= L63.6
LD L60.0
CALL WDC_CONTROL:SBR9, L63.7, L63.6, 30, 900, CTRL_
Operating_Mode:VW1796, CTRL_Busy:V1781.2, CTRL_
Done:V1781.3, CTRL_Aborted:V1781.4, CTRL_Error:VW1798
    
```

The stability of the program operation is checked in different ways:

- Initiating the devices with active sending regime and fixing its sending stability (the data accuracy and its transfer rate);
- Fixing the received coordinates realizing the bulk of the data and analyzing stability.
- Carrying out the switching of different regimes of the locomotive devices and railway points and analyzing the operation stability.

## 5. Stability testing of the proposed electronic embedded system operation

The testing of the device is required to evaluate the functional stability of train safety protective system under real operation conditions and the interoperation of its elements when the devices are the elements of a general control system with a wireless communication channel.

The track section device was tested at a real railway station, being connected to the relay circuit of the control cabinet of the station entry traffic light. Thus the device obtains the signal of the light on supplying control pulses

to the input of the programming logic controller applied in the device.

For a person on duty at the station, who completes combining different routes, different station entry traffic light signals are switched that are instantly doubled by „SAFE-R 4” device displaying the light on at the front panel installed indicator lamps as well as with the help of information window.

This information is sent to the locomotive device that gives the information to the locomotive driver to know the light on signal of the entry traffic light although physically the light is out of the field of vision. This function is provided also at the coded railway sections that for sure is an advantage of the device.

The testing of the locomotive device is made at a workbench, fully imitating the emergency braking starting system, available at a railway station.

After a successful testing at the workbench the experiment was continued at a real station with a real locomotive. The locomotive device is connected to the locomotive M-62 control circuit of electric pneumatic valve (EPV) (Fig. 5). This connection allows controlling the main EPV control coil, i.e. opening its supply circuit initiating this way the process of emergency braking.

The control output of the device is connected to the emergency braking circuit of the workbench. The train motion according to traffic lights is imitated manually,

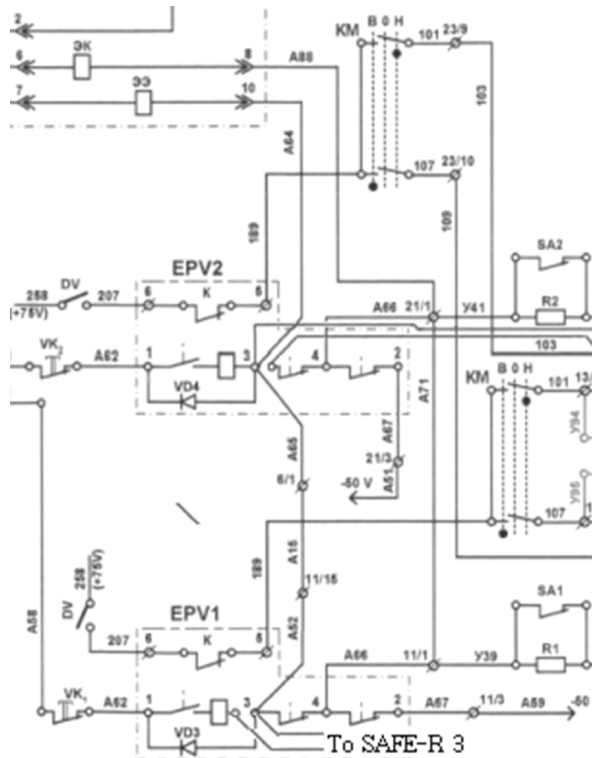


Fig. 5. Circuit of locomotive protective device connection to the system starting the train braking.

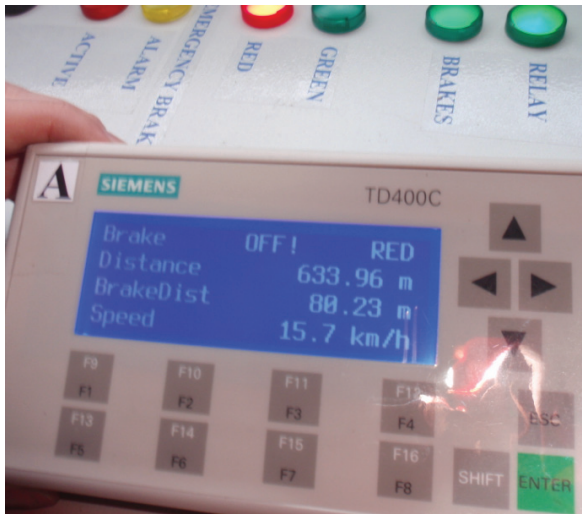


Fig. 6. The information display of the locomotive protective device

entering the location points of the locomotive, which provides the testing process with the necessary distance. Therefore, moving along the planned route, the locomotive is directed to the traffic light that in turn displays the stop signal. At the moment, when the distance between the objects is equal to that necessary for train stopping and preparing the emergency braking system (with warning time delay of 10 sec), the emergency warning signal informs on the forthcoming emergency braking process.

Then, when 10 seconds are counted (the preset time interval), the control relay opens the control relay coil supply circuit connected to the emergency braking EPV activating this way the emergency braking system. Now 7-second time delay starts during which there still is an opportunity to switch the emergency braking off (the present locomotive control system), but the locomotive device blocks this as in this case the braking takes place only according to the absolute necessity when this switching off is not already possible.

## 6. Testing of the system device prototype under real operation conditions

The testing of the device took place at a station of Latvian railway in Riga Bolderaja.

The testing of the prototype consisted of two parts. The first aspect to be tested was whether the device disturbs the work of the driver and warns the driver on the emergency situation. Driving the train to the traffic light with different speeds the driver obtains the information about the red signal of the traffic light but performs the braking manually. During the second testing the ability of

the device to stop the train automatically was examined.

The display of locomotive device during the test displayed different types of information on the speed of the locomotive, the distance to the traffic light and the type of its light and other info (Fig. 6.).

For example, when the locomotive starts its motion from a distance of 998m (according to the data from the device) to the station entry light with a red stop signal it is accelerated up to 35 km/h. The locomotive device displays a warning and the locomotive driver starts the routine braking. As a result the locomotive stops at a distance of 344 m ahead of the traffic light with a stop signal.

During the second stage of the testing the driver „does not mention” the warning of the device. Therefore after some interval the device automatically operates the emergency braking and the locomotive is stopped in all cases ahead of the traffic light with a stop signal.

For example, when the locomotive starts its motion from a distance of 1,503 m (according to the data from the device) to the station entry light with a red stop signal it is accelerated up to 60 km/h [8]. During the warning the routine braking does not take place. As a result the locomotive device automatically starts braking and stops the locomotive at a distance of 432 m from the entry light.

A large distance which can occur between the traffic light and the locomotive after its stop may be explained by the fact that the algorithm calculating the braking distance assumes the corresponding factors defining that the braking system of the locomotive (braking shoes etc) is in a poor condition. As the locomotive braking system under testing was fully in a good condition it allowed stopping the locomotive faster.

## 7. Conclusion

The results obtained during the test prove that the proposed prototypes of the system are able to provide the braking of the train ahead of traffic lights or any other object including level crossings or ahead of another train at a distance large enough from it, improving the safety of the proposed system operation. This function is successfully tested at different motion speeds of locomotives.

The device is able to react timely to an unexpected switching of the traffic light that proves the performance and mobility of the device.

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