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Microprocessor Technology and Programmable Logic Controllers in New Generation Railway Traffic Control and Management Systems

M. KORNASZEWSKI
UNIVERSITY OF TECHNOLOGY AND HUMANITIES IN RADOM, Faculty of Transport and Electrical Engineering, Malczewskiego 29, 26-600 Radom, Poland
EMAIL: m.kornaszewski@uthrad.pl

ABSTRACT
An application of modern microprocessor technique and more effective microprocessor systems has a large influence on development of devices railway transport and railway automation systems. Functioning new generation railway traffic control and management systems is largely based on Programmable Logic Controllers (PLC), which allow the designers to exploit self-control mechanisms, events registration, technical diagnostics, remote control and fault detection). Railway traffic control and management systems belong to safe technical railway transport solutions, it means that they have to meet the fourth safe integrity level CENELEC (SIL-4), what implies, that the configuration principles and software installed have to satisfy CENELEC EN 50 128 and EN 50 129 standards.

KEYWORDS: transport, safety, systems control of railway traffic, Programmable Logic Controllers

1. Introduction

From the beginning of the railway existence, devices were used to provide safe move on railway tracks. The development of these devices took place every single day. The requirements, needs and users' expectations grew, however, the basic objectives of using these devices remained unchanged, i.e. safety and efficiency of railway traffic. It is possible to implement presented goals by means of the railway traffic control devices. These devices have gone through gradual evolution from mechanical, electrical devices to microprocessor ones.

The technology, which is basis of the railway traffic control system execution, should allow introducing new elements in place of the old ones during the operation of the system. It should be done in such way to not disturb the system's basic functions. Functional system blocks should be equipped with appropriate diagnostic outputs and status indicators. The external connectors should be easily accessible for servicing and testing devices. The durability of railway devices should not be less than 20 years [10].

2. The implementation of Programmable Logic Controllers to railway transport

The Programmable Logic Controllers PLC applied in railway transport systems are microprocessor devices designed to control the railway executive devices operation. PLCs must be adjusted to the particular railway system and to its configuration by introducing a proper operation algorithm to the memory. PLCs are industrial computers that implement the devices control algorithm under the real-time operating system control, e.g. in the railway traffic control system. The controller is equipped with an appropriate quantity of input elements collecting information about the system status (e.g. railway sensors) and its service requesting. It also includes selected output elements connected with executive devices (e.g. railway barrier at level crossings), signaling devices (e.g. semaphores of automatic block signaling) or data transmission [7, 8, 15, 16].

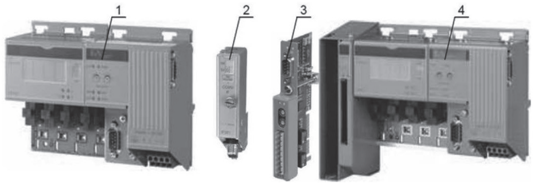


Fig. 1. An example of MINICONTROL PLC controllers used in SPA-5 signaling by Bombardier Transportation production [11], where: 1 – central unit (for configurations with EOC train sensors); 2 – transmission module RS-485; 3 – transmission module CAN; 4 - central unit (for configurations with ELS wheel sensors)

2.1. The structure of typical PLC controller

The internal structure of typical PLC controller is shown in Fig. 2. The central processor is composed of a microprocessor and several specialized processors which are connected to each other by a logical network. These processors perform specified by the control system instructions in a very short time. The system determines a program which coordinates the work of the PLC controllers. It is located in the EPROM or PROM controller memory and ensures appropriate service of the controller's internal operating functions. In addition, it is responsible for execution of the algorithms stored in the program's memory.

PLC controller operation is based on continuous observation of analogue and digital inputs. It includes also making decisions based on the operation algorithm and proper control of its outputs [5, 6, 8, 15, 17].

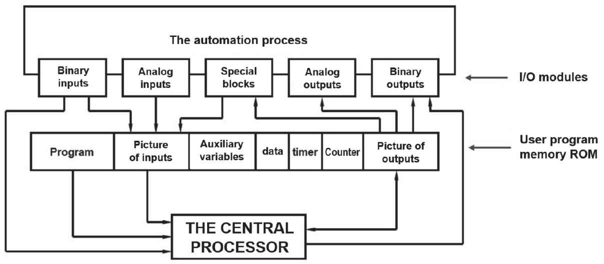


Fig. 2. The basic components occurring in the standard PLC solution [6]

3. The safety of railway control and traffic management devices

Nowadays, the speed of data processing as well as convenient and clear presentation of controlled transport processes on monitors are carried out by modern computers for applications in railway control and traffic management systems. The first solution was a replacement a relay control panel by a computer panel with the presentation of movement situation shown on the monitor. The introduction of more advanced techniques in terms of railway traffic control processes management required complete replacement of the relay automation – by microprocessor technology [2, 3, 4, 14, 16].

The basic feature of safe solutions in railway transport control systems is the „fail-safe" principle, which generates the fact that a single failure or a single disruption of the system operation cannot lead to a dangerous situation. This is possible assuming that the probability of multiple damage is negligible. In addition, it is assumed detection of individual errors in a relatively short time and appropriate (safe) system behavior in the event of damage detection [2, 4, 18].

The development trends of microelectronics and programming have forced the necessity of unifying technical standards which refer to devices intended for the safe railway systems implementation. The equipment and software, which are used to creation of systems responsible for safety, are a subject of high quality and reliability requirements. As a result of long-lasting work of European Committee for Electrotechnical Standardization CENELEC, the algorithms were developed and implemented in terms of creation, checking and commissioning of safe railway applications (Tablele 1). They have been included in the relevant CENELEC standards of EN 50 128 and EN 50 129 [12, 13, 14, 18].

Tablele 1 lists ones of the most important railway traffic control systems with various functional assignments and tasks in the railway traffic control process with assigned security levels to them. It is recommended by CENELEC European Committee for Standardization of Electrical Engineering.

Tablele 1. The safety levels of selected railway transport systems according to CENELEC recommendations [6, 13]

No.	The name of the railway system	Safety level
1	Control devices at the railway traffic station	4
2	Line system block	4
3	Train control devices	4
4	Track occupancy control systems	4
5	Automatic crossing signaling	4
6	Remote controls traffic train	4
7	Train continuity control device	3
8	Automatic train composition marshalling devices	2
9	Traffic guidance device	2

3.1. The methods of ensuring a high-level safety of railway traffic control systems made in the microprocessor technology

The issues of safety and reliability in the field of microprocessor railway traffic control systems should be considered in two aspects: the technical devices that create system infrastructure and system software.

The system must be composed of at least two computers that are linked together in an appropriate structure to meet a high safety requirements. This structure is create to enable data processing in a safe way, mutual control etc. There are also alternative systems based on one computer unit. The second computer is used as a hot reserve to achieve the required safety conditions.

The appropriate program operations are performed to achieve the safety of single-channel systems. They consist in data coding and processing of two programs on one unit testing each other.

The multi-channel systems, usually two or three-channel systems, are characterized by ensuring security by hardware and software redundancy. In these solutions the results are compared from the source of two computers. The condition for safe operation of the "2 out of 2" system is full compliance with all of the results obtained from the active channels outputs. The occurrence of any error will result in a safe reaction of the entire system. In the "2 out of 3" system, a negative result from two computers will cause as an activation of the third computer. For further processing, the same result from two computers is taken into account [1, 4, 6, 7].

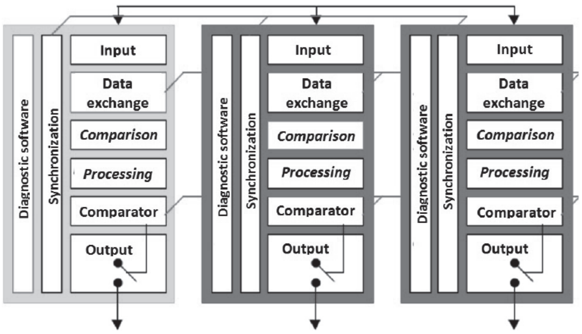


Fig. 3. The "2 out of 3" rule used in the SIMIS-W control system at railway traffic station [10]

Fig. 3 shows an example of the safety rule "2 out of 3" application in the SIMIS-W microprocessor control systems at the railway traffic station. The SIMIS-W control system includes two identically constructed control channels, where the same data is compared to each other at the inputs. Both control channels continually perform the same tasks. The commands issued to peripheral devices through both channels must be identical. Otherwise, the comparators switch the channel output gateways to a safe state. The configuration of SIMIS-W „2 out of 3" is based on presented principle but the third channel remains in standby mode. It results in higher availability of the system [10].

The basic methods of achieving the required safety level of railway traffic control systems made in the microprocessor technology are [6, 8, 10, 11]:

- hardware redundancy – there can be distinguished two independently operating channels for power systems, PLC controllers (Fig. 4), I/O systems and others in the control system. Regardless of the quantity and type of railway devices, they are allocated to both channels so that in the case of failing one of the channels, the other one could provide sufficient system protection;
- differentiation of programs steering in both channel – programs for PLC controllers in individual channels are developed by independent programmers' teams. The most common programs are written in assembly language used at the processor level or ladder diagram;
- synchronization of the control channels operation – PLC controllers of both channels are connected mostly by a serial interface where information can be exchanged between them. The purpose is to determine the compliance action of the railway traffic control system decision layer even if one of the channels is turned off;
- real-time testing of the operation correctness of modules and railway traffic control devices – the control programs additionally contain the procedures testing the operation correctness of the supply systems, I/O devices, individual modules as well as procedures and mechanisms of the control systems self-testing;
- real-time testing of the control program by means of procedures checking the correctness of each program cycle realization and the correctness of the current railway traffic control system parameters.

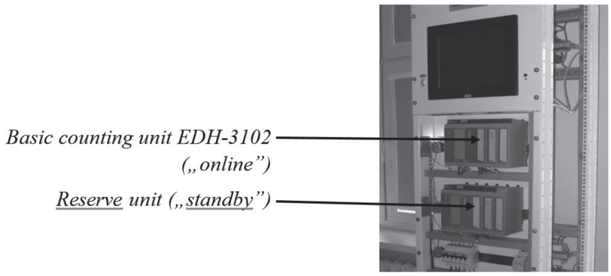


Fig. 4. An example of structure redundancy of control devices in the SOL-21 train's wheel sensor system (Laboratory of Railway Traffic Control Systems at the University of Technology and Humanities in Radom) [own study]

4. The analysis of selected Programmable Logic Controllers and microprocessor technology applications in railway traffic control systems implemented in Polish railways

4.1. The industrial controllers 2005 series Bernecker & Rainer in axle train's counter system SOL-21 type

The SOL-21 train axle counter system, produced by Bombardier Transportation, consists of wheel sensors located in the field and the EAS-4 internal equipment cabinet located in the signal box. The EYM-41 is an independent manipulator device placed in the room of the station master. The whole is connected by power and transmission cables [11].

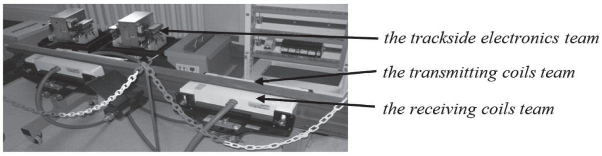


Fig. 5. The location of the SOL-21 system's basic elements in the Laboratory of Railway Traffic Control Systems at the University of Technology and Humanities in Radom [own study]

The internal devices (EAS-4 cabinet) of the SOL-21 system include the following elements [11]:

- basic counting unit EDH-3102 („on-line"),
- reserving counting unit EDH-3102 („stand-by"),
- event recorder EZE-12,
- uninterruptible power supply UPS,
- electronic interface to the Ebilock 950 system,
- relaying interface ECH-6302 (optional),
- FSK concentrator ECH-6304 (optional),
- additional elements such as: power supplies, power supply and transmission surge protection circuits, modems, etc.

The counting unit is built from the modular components of industrial Programmable Logic Controllers 2005 series manufactured by Bernecker & Rainer. For safety reasons, the counting unit is equipped with two independent data processing channels (processor - memory - operating system - software). Both channels are connected to each other by a system bus, which ensures fast and reliable exchange of information.

The operation of the SOL-21 system consists in controlling the railway tracks sections condition limited by the wheel sensors of the train. The wheel sensor is a device detecting the movement of the train's wheel above the sensor's head. The ELS-95 type wheel sensors are used in the SOL-21 system. Information from these sensors is collected, analyzed and processed by the counting unit. Information about the number of trains axes that have entered and departed from individual parts of railway tracks allow the counting unit to determine the status of these sections. Next, the information is transferred to the dependency system through the relay interface or electronic interface [10, 11].

4.2. The modular processors SCHEIDT & BACHMANN GmbH in the system of level crossing BUES 2000 type automatic signaling

The system of level crossing automatic signaling BUES 2000 (Fig. 6), produced by Scheidt & Bachmann, is one of the most technologically advanced safe solutions of railway traffic microprocessor control systems. BUES 2000 defines new standards for railway level crossing devices. This system is intended for level crossings, in which the management of the safety devices work and control of the signaling work correctness takes place on three levels [6, 9]:

- diagnostic,
- management (control),
- executivem.

The control in the mentioned levels is two-channel. The system of sending information between individual levels and channels at given level is carried out using two data bus systems.

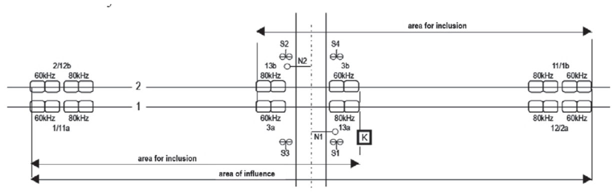


Fig. 6. The standard configuration of devices in automatic signaling of level crossing BUES 2000 type [9]

The level control of crossing signaling BUES 2000 supervises all processes related to level crossing safety function. It consists of three duplicate SCHEIDT & BACHMANN GmbH modular processors: central, light/barrier and track, central program memory and service keyboard. Each duplicated modular processor (Fig. 7) processes real-time independent portions of the appropriate program for a given module. Additionally, the use of safe programs for modular processors ensures required level of safety guaranteed by the system. All modular processors are universal, i.e. they can perform one of the three functions mentioned above, depending on needs. The type of fulfilled function depends on the location in level crossing automatic system and is determined by software [8, 9].

a) b)

Fig. 7. The doubled modular processors and control level service keyboard in BUES 2000 signaling (a); View of modular processor single card (b) [own study]

In the manner specified in Chapter 3.1 in accordance with the "2 out of 2" principle, the control tasks of BUES 2000 signaling are carried out in the case of hardware duplication of modular processors.

The basic element of the modular processor is a microprocessor controller (INTEL CPU 80188EB microcontroller) that works with six controllers CAN *(Control Area Network)* type during the data transfer.

The central module performs general control functions of the devices and supervises all centralized tasks of the railway level crossing safety process. The light/barrier module performs the process of controling warning light and barrier drives work. It also controls the correctness of their operation. The track module is responsible for the use of information received from track sensors and for checking the correctness of their work.

The diagnostic level of BUES 2000 signaling type includes a diagnostic module and a diagnostic center. The diagnostic module ensures the maintenance service with quick access to the information on irregularities in the signaling work. The executing level takes over the proper control of the processes occurring in the railway level crossing devices.

The remote control device is a diagnostic center located in the control room. It is possible to join several dozen railway level crossings located within a dozen kilometers from the railway station on which it is located. The diagnostic center responds to reports sent by railway level crossing signaling. Used software allows to read error messages of equipment on a railway level crossing via a telephone modem. All fault states are registered and trigger an alarm condition in the moment of detection [6, 8, 9].

4.3. The PLC controllers of the PAC series from GE Fanuc in the track occupancy control system SKZR-2 type

The SKZR-2 system (Fig. 8), manufactured by Z.A. KOMBUD from Radom, is technologically advanced system designed to determine the condition of sections in the controlled area of the railway station track system or a railway open line.

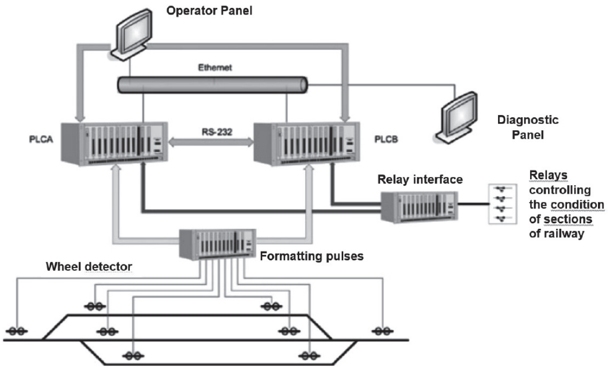
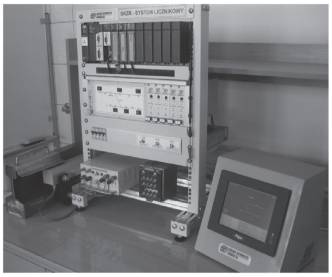


Fig. 8. The standard configuration of the track occupancy control system SKZR-2 type [19]

The SKZR-2 system consists of an internal part and an external part. The internal devices are located in the building of the railway control room, while the external devices are located next to the railway tracks. The system's input circuits cooperate with railway sensors that generate signals for each passing train axis. The axes are counted and in the case of number other than zero, the system decides on confirmation of the railway tracks section occupancy by the train [11, 19].

a)



b)

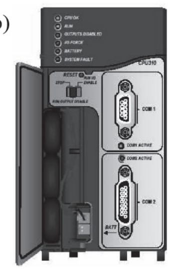


Fig. 9. The view of the GE Fanuc controller placed on a laboratory bench for testing the SKZR system (a); The external view of the central unit module CPU (b) [own study]

The set of information compared independently in PLC controllers of both system channels is the basis for providing information on the track sections status to the station master. In the case of signals about the railway tracks occupation incompatibility, the system is switched into a safe state.

Fig. 10. The cabinet of SKZR-2 system with GE Fanuc PLC controllers and a diagnostic panel [19]

For needs of visualization, service and diagnostics, the SKZR-2 system has a set of commands and reports sent to the operator panel and computer system of the operating position via computer transmission. The SKZR-2 system is equipped with a computer interface for displaying the status of railway tracks controlled sections. The station master receives detailed information about the railway tracks sections. This makes it easier to evaluate the situation in the case of complex actions. Full information about the status of railway traffic control devices is recorded and it reduces the system's diagnostic time in case of a failure [11, 19].

5. Conclusion

The article presents new generation of railway traffic control and management systems made in microprocessor technology and operating on the basis of modern Programmable Logic Controllers. Such systems are currently necessary to ensure adequate control functions in railway transport with the necessary level of safety. Modern railway traffic control systems operate on the distributed computer system with the feature of control decentralization, communicating by the computer networks. In these systems the cooperation between a dispatcher system and a centralized system of dependence with smaller railway traffic control systems is necessary.

The safety of railway traffic control systems made in microprocessor technology results mainly from the use of programmable controllers. It is based on dual channeling, differentiation of control programs in both channels, the possibility of immediate device faults detection, as well as the ability to monitor system operations and record all events. The railway traffic control systems made in this technique are also characterized by: a modular design of software enabling quick adaptation of the system to needs, built-in diagnostic functions, small size, easy installation, continuous at least 24-hour event registration, etc.

The computerization of the railway transport systems should increase their safety by limiting the risk of errors generated by the human factor and automation many of the functions performed so far by humans.

Regardless of the railway traffic control system type (destination, manufacturer, manufacturing technology etc.) and its operation time, the level of safety must be high (in accordance with Table 1).

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