Design and Implementation of a Control, Monitoring and Supervision System for Train Movement Based on Fixed Block Signaling System with AVR Microprocessor

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Abstract. Railway signaling and control systems are vital for the safe control of transport processes in rail traffic. Today, industry uses many processes, such as railway signaling systems, that must be controlled. Manufacturers of such systems have tried to update their products in line with modern industrial control technologies. In this paper, the possibility of using the common industrial automation equipment for signaling systems are investigated. Different parts of the signaling system, including wayside equipment, field element controls (interlocking and object controller) and supervision systems were specified. Then, the interlocking logic was extracted based on a fixed block signaling system. Control, monitoring and supervision systems were designed with an AVR microcontroller and then implemented on printed circuit board. Finally, the outputs of the system and its results with various railway lines, based on chosen layout, were analyzed and its applications identified. These applications include wayside equipment monitoring, the training of traffic control operators, and movement safety tests of the line before setup of the main system.

Keywords: Signaling System, Supervision System, Interlocking Logic, AVR Microprocessor

1. Introduction

With the advent of science and technology, industrial control systems are also being optimized. Today, there are many industrial processes that we need to control. To control an industrial process by automatic control or automation, the controller first receives the status of inputs and values set by the operator and uses the logic of the program to issue output commands and obtain feedback from that output [1]. By using automation in a process, processes and functions that were previously performed by humans are now implemented automatically and with minimal operator intervention. This can improve the safety, reliability, and various other factors.

Industrial controllers may be electrical and/or non-electrical controllers. Non-electrical controllers can be further divided to mechanical, pneumatic and hydraulic controllers. In the category of electrical controller we have two types: controllers based on hardware and those controllers based on both hardware and software. Hardware-based controllers, such as control deck plates, auxiliary contactors, and counters have been used primarily in distribution networks for electrical energy. Some of the defects of this approach are as follows:

❖ Strict design and timing for large processes
❖ Troubleshooting is difficult and restricted in terms of time
❖ High maintenance costs and high depreciation
❖ Energy dissipation and heat generation
❖ The difficulty of changing the control logic due to wiring
❖ Insufficient response time
❖ High and severe noise generation
❖ Unable to register events.

Another type of electrical controller is based on both hardware and software applications. This type of controller also has several variants [2]. One of the variants of electrical controllers is the microprocessor. Various microcontrollers, such as 8051, Z80 and AVR, are used in large industrial automation projects for their low noise levels, low level of programming, and reduced elasticity. They are chiefly used in security systems, mobile phones, automatic door locks, remote controls, music accessories, light controllers, pagers, digital cameras, home appliances, gadgets, microwaves, computers, photocopiers, laser printers, mobile phones, faxes, ECU engine fuel control, airbags, ABS systems, alert systems and entertainment accessories. The second category contains numerical controllers. Numerical controllers and CNCs are used in metal cutting machines. With software such as AutoCAD, the piece is designed and that design is delivered to the machine, which undertakes fabrication automatically.

The programmable logic controller (PLC) is the next type within this category of controller; PLCs are the most common types of controller in industry, and the following companies can be named as the famous creators of this group: Siemens, Schneider, Texas Instruments, Omron, ABB, LG, AEG, Mitsubishi and Allen Bradley.

The next category is about monitoring. As well as controlling the process, controllers must display the status of monitor values and written and visual AVR’s for operators. In addition, in some processes, such as SCADA, in the transmission and distribution lines the controller is not allowed to issue automatic commands. In this case, the following methods are used to monitor the process [3]:

❖ PC base: Analog and digital input/output (I/O) modules are placed on the motherboard of the industrial computer as an internal memory card slot. In this system both controlling and monitoring are performed by the PC. To prevent damage to I/O cards and PCs, isolated cards that contain relay modules are used. Manufacturers of the software that makes this feature include Advantech, Citect, LabVIEW. The LabVIEW cycle time is much less than PLC, for example, AI cards are sampled 400 times every second. IPCs or industrial computers usually have modular plug-ins, anti-dust and anti-noise boxes, and are expensive.

Figure 1. Control and monitoring via PC
PLC base: PLC base monitoring controls the process and the main processing in PLC and monitoring by HMI or PC. First, the input logic of the outputs is downloaded to the PLC control program. It is then possible to monitor the process and set up the required items by programming the HMI or PC. This kind of monitoring is possible depending on the need for the following two methods;

- Using the Human Machine Interface (HMI) hardware interface: the HMI is a kind of industrial monitoring that can be connected to the PLC by observing the process of executing parts of the process or adjusting some of the variables, that is, the interface between human and machine. Some of these monitors are touch screen. The HMI and PLC connections are performed by a variety of ports, and the HMI is usually scheduled from the same port. This method is used when the monitoring interval to the PLC is low, and there is not enough space available to use larger monitoring equipment. For example, HMIs installed on the door of electrical distribution boards.

- PC base remote monitoring: in this method, the main processing of the control is done in the PLC, and the display of the field-layer equipment and alert messages are graphically monitored and stored on the PC and can be traced. This method is appropriate when the industrial network is disassembled or the monitoring interval and the controller are large [4], [5].

The other type of electrical controller is based on artificial intelligence (AI). This eliminates or compensates for complex process algorithms automatically, so that in case of failure of each component of the process, the output will not change.

Distributed or extended control systems are the next category. One of the most important methods for controlling industrial processes is the DCS control system. Here, the process is divided into groups, related to each other and the various work areas, and to control and monitor each area there is a local controller containing software and routines related to the same part of the process. Then, all of the controllers are connected to the network and monitored and managed by the central control software at the command center. However, while new PLCs are equipped with better equipment to keep up the process while there are major faults. In such projects, for each part there is an independent controller, to limit the adverse effects of problems that may occur in other parts of the process [6], [7].

As control technology continues to grow, the control and monitoring of trains is evolving and being constantly updated in light of experience. As result, the railway signaling system uses another type of electrical controller [8], [9].
2. Implementation of a signaling system by PLC industrial controller

Each kind of control system is designed for a primary purpose or set of purposes, such as process improvement, production, quality improvement, and in general, to increase the safety and efficiency of the system. Programmable logic controllers comprise one of the most important and most frequently-used tools for automation in modern industries. Virtually all new machines and lines of production use PLCs. In fact, this flexible equipment has become widely used as a complete controller in various industries, so that with the advancement of technology and the presence of automation in the entire industry, the use of old command circuits is obsolete, and in most industrial centers, PLCs have been used.

In the scheme presented in this section, a SIMATIC S7-400 programmable logic controller (SIECEM) was used for the control and protection functions for the signaling system of two sample stations. In addition to covering interlocking control tasks, this controller can perform some functions and operations automatically and without operator intervention. Of course, today, more powerful programmers with much greater capabilities are produced and marketed by other manufacturers, which are now used in many modern control systems in the world. But what is important is familiarity with the process and how to deal with the control system of a process in choosing or replacing a control system appropriate to that process. With advances in science and technology, industrial control systems are also being upgraded.
For two metro stations, as described in Figure 4, we used two 300 series PLCs (Siemens), one of which was selected as the object controller, and thus responsible for collecting data and transferring interlocking commands. The relationships of the controllers with each other and the upper hand controller, which was responsible for interlocking, is assumed by the Profibus industrial network. Using a computer, it is also possible to create a local command center at the station. For interlocking, the PLC Series 400 was used with WinCC software for monitoring. In order to increase the reliability coefficient, the voting method in the interlocking section can be used.

In this way, the three controllers covered programming and different duties (OC) and processed parallel data independently and sent output to interlocking. Then, based on the number of votes, the interlocking controller generated the final output. This method can be implemented by the PLC to achieve an applicable level of safety integrity.

This example specifies that although manufacturers of separate signaling systems have separate departments for industrial control products, it is possible to use industrial controllers to implement the signaling system and its components including ATO, ATS, ATC, and ATR.

3. Implementation of a signaling system by the industrial computer and LabVIEW software

LabVIEW is software used for making virtual labs or virtual tools. LabVIEW is comprehensive programming software and has all the relevant mathematical, logical, fuzzy commands, programming language commands, visual basic, etc. This software was used to program the monitoring section of the train model, which is presented in Table 1.
Table 1. Symbols and the object controller signal list

| Name   | Data type | Address | Visible in HMI | Accessible from HMI | Comment   |
|--------|-----------|---------|----------------|---------------------|-----------|
| ES1    | Bool      | %I0.0   | True           | True                | ESB       |
| ES2    | Bool      | %I0.1   | True           | True                | ESB       |
| ES3    | Bool      | %I0.2   | True           | True                | ESB       |
| ES4    | Bool      | %I0.3   | True           | True                | ESB       |
| T17    | Bool      | %I0.4   | True           | True                | TC        |
| T18    | Bool      | %I0.5   | True           | True                | TC        |
| T19    | Bool      | %I0.6   | True           | True                | TC        |
| T20    | Bool      | %I0.7   | True           | True                | TC        |
| T22    | Bool      | %I1.0   | True           | True                | TC        |
| S20 RED| Bool      | %Q0.0   | True           | True                | RED       |
| S20 GRN| Bool      | %Q0.1   | True           | True                | GREEN     |
| S20 YEL| Bool      | %Q0.2   | True           | True                | YELLOW    |
| S18 RED| Bool      | %Q0.3   | True           | True                | SIGNAL    |
| S18 GRN| Bool      | %Q0.4   | True           | True                | SIGNAL    |
| S13 RED| Bool      | %Q0.5   | True           | True                | SIGNAL    |
| S13 GRN| Bool      | %Q0.6   | True           | True                | SIGNAL    |
| S11 RED| Bool      | %Q0.7   | True           | True                | SIGNAL    |
| S11 GRN| Bool      | %Q1.0   | True           | True                | SIGNAL    |
| S11 YEL| Bool      | %Q1.1   | True           | True                | SIGNAL    |
| P7     | Bool      | %Q1.2   | True           | True                | Point Machine |
| P8     | Bool      | %Q1.3   | True           | True                | Point Machine |
| P7     | Bool      | %I1.1   | True           | True                | PM Feedback |
| FEEDBACK| Bool      | %I1.2   | True           | True                | PM Feedback |
| D1     | Byte      | %QB2    | True           | True                | Dwell Time |
| D2     | Byte      | %QB3    | True           | True                | Dwell Time |

The program writes through the USB port and the serial protocol to the AVR and indicates the position of the train. This software also has the ability to communicate with incoming and outgoing cards and execute commands and commands directly from the operator. With the help of this software, in addition to monitoring, input and output devices can be controlled and defined between components of communication logic.

It is also possible to implement interlocking between components with acceptable accuracy and speed and send the speed values per block to the train. The system is capable of installing on-board the train and supporting a wide range of communication protocols to provide control commands to the TCMS train.

4. Train control system monitoring and modelling

Since the advent of rail transport systems, the safety of traffic and signaling has been crucial for the safeguarding for stock, staff and passengers alike. For the correct operation of this system, the train’s location must first be detected and sent to the control system as the data. After this, local control equipment and an interlocking system, according to the logic, issue the necessary commands to signal lights, needle machines, brake system, etc. Despite this, it is possible to implement a central monitoring system of the train in order to make arrangements in proportion to the number of passengers. By changing the technology of comprehensive control systems, manufacturers and rail specialists have also signaled the signaling technology in line with this change. The history of the signaling system proves this. In this section, using the AVR microcontroller, the safe navigation logic of a model run train was monitored by LabVIEW software. In this kit, with the definition of 12 fixed blocks, the infrared sensors
were used to detect the position of the train and the logic was implemented by the VB software on the microcontroller. With the occupancy of each segment by the train, while the signal of the block was red, it did not allow passing behind it. In this work, the microcontroller played the role of interlocking and LED lights played the role of the LEDs. To send the brake command to the train from the wireless circuit, the open and closed terminals of the train were used to open and close. Finally, using a hardware interface, information about the train’s position was transmitted to the USB port and serial port of the computer and monitored by LabVIEW.

One of the features of this offer is the ability to troubleshoot and monitor the status of all components, such as uninterruptible power supplies, battery, SCADA interface, and passenger notification systems. The components and relationships between components in this kit were as follows:

❖ The controller board included the main processor and its complete electronic components
❖ Train detection sensors were inputs of the system
❖ Signals and brake contact were a system output
❖ Interface board monitored the train’s position by computer
❖ Number of digital inputs: 12 (for train detection sensors)
❖ Number of digital outputs: 30 (for signals) + 1 wireless (for train movement control)

In the control logic of this micro, the position of the train was first read, then the information was sent to the original by means of sub-slabs, and with the help of digital processing inputs, and after processing and issuing the command to the signal lights and the wireless contact or brake movement, the status was sent by the corresponding port to the computer and then monitored by the software.

As stated above, LabVIEW is one of the most powerful industrial automation software programs that can be installed on the computer and control and monitor the process components. It was used here as a microcontroller train monitoring system. The program first takes the process information including the status and blocks number from the serial port of the device and sends it to the indicators that are actually designed for the train path of the model. To get data from the serial port, it is necessary to configure it first. Now, it is essential specify the mode of receiving or sending information. Because in this section we wanted to get the data from the micro-element so we put the reader in the buffer element. Because we sent the information in the micro-programming as a bundle, we needed to separate the data to get the required data. In order to separate the information by giving OFFSET the number of isolated data; the information can be received and then displayed on the graph. As shown in the block diagram, to determine the status of each block after data separation; if the code of each block is one, its index is clear and the position of the train is monitored.

![Figure 5. Implemented laboratory model](image)

5. Conclusion
In this paper we designed and implemented a control, monitoring and supervision system for train movement based on fixed block signaling system with AVR microprocessor. First, from a given track and signal plan of a metro line section, the logic of interlocking was extracted and the logic implemented
on the AVR microprocessor. Due to the high importance of safety in the signaling system, and complexity of interlocking logic in lines with many inputs and outputs, we first tested the system using a laboratory prototype and then exploited it. It is a good idea to use fast and convenient equipment and tools to assure the safety of the designed system. PLC and AVR microprocessors are among these tools. This kit that has been designed and implemented in this study may be used in the following cases:

❖ To monitor and control light and heavy repairs of the metro and rail system
❖ To monitor and control the signs and needles at suburban train depots
❖ Train traffic operators and train drivers
❖ Test logic written for rail transport lines before consolidation and final implementation
❖ Exhibition and laboratory applications
❖ Tests on movement safety factors.

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