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Design and Simulation of a PLC and IoT-based Railway Level Crossing Gate Control and Track Monitoring System using LOGO

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Abstract:
In the current research report, designing and simulation of a Programmable Logic Controller (PLC) and an Internet of Things (IoT)-based railway level crossing controlling and track monitoring system has been presented. As such, we need an automated system. In this paper, the main concern is to design a PLC and an IoT-based automatic interlocking system to protect trains from accidents or clashes and ensure the safety and security of the passengers. We have designed a model using LOGO software with the PLC as the main heart of the control system. The ladder logic program for PLC was developed using LOGO software on a personal computer and then downloaded into the PLC. For communication between the PLC and computer, an RS485 serial port was used. To detect the presence of a train on the track, ultrasonic and radio frequency (RF) transducers and infra-red (IR) sensors were used as both the transmitters and receivers. The system was simulated using LOGO software. In the system, we have incorporated Internet of Things (IoT) and Visual Basic programming software to connect it with the mobile Apps and create Graphic User Interface (GUI) respectively. In the future, we will implement it on large scale using hardware and will build a central database system through which monitoring can be done smoothly.

***Keywords**: LOGO, Visual Basic, Design, Simulation, PLC, Railway Level Crossing Gate, Railway Track, Controlling and Monitoring System.*

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I. Introduction

As per the definition of the Merriam-Webster Dictionary, the term 'automation' denotes "1: the technique of making an apparatus, a process, or a system operate automatically, 2: the state of being operated automatically, or 3: automatically controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human labor" [1]. That is, humans can be replaced through the automation process. Bangladesh is one of the most densely populated countries in the world, currently, in terms of population it is in 8th position, and in terms of population density, it is in 10th position in the world [2]. As such, to manage various systems of this country for this huge number of people quickly and safely, we need smart devices and systems everywhere to automate the whole systems of the country, because all the populous countries in the world are moving towards automation [3].

In Bangladesh, the railway communication system is a significant means of transportation system among the mass people. In recent day railway system is very common transportation system and at the same time, it is often prone to accidents that are caused by a variety of mechanical and human faults. Normally due to the restless working of train drivers and due to lack of proper monitoring and alerting devices accidents are very frequently occurring in the railway system. But the rail tracks pass over the surface communication tracks including the national highways. When a train passes through these intersecting junctions between rail and surface road tracks, barriers usually called rail gates are placed on the surface tracks to stop the vehicle movement. At present, manual controlled rail gates and manual flags are used at such intersections to signal the trains from the intersections before trains arrive. Due to several limitations of manual operations, sometimes train and vehicle crash incidents can't be avoided at these junctions; in European Union countries 29% of railway gate accidents occurred of total railway-related accidents during the period 2014-2019 [4]. Bangladesh has also observed several accidents on the railway tracks due to the derailment of trains (~90%) though the accidents at the junctions between railway and surface tracks are minimal [5-6]. Out of the several categories of rail track accidents, the rail track accident is number one [7].

The railway level crossings are maintained in two different ways, such as manned and unmanned methods [8]. Currently, interlocking is being used in a railway signaling system. Interlocking is defined as the arrangement of junctions or crossings in such a way as to avoid the collision and derailment of trains and to check a route request and provide a suitable one so that no collision occurs. However, this interlocking system can't ensure 100% safety to the people [9]. The prevailing orthodox signaling system mostly relies on verbal communication via telephonic and telegraphic exchange. The speech signal of the human voice acts here as the input to the human ears to decide which railway track is to be allocated for an incoming or outgoing train. Since humans are prone to make an error at any time, there is always a huge possibility that misinformation may happen [9]. As such, the incorrect selection of the track for a train may be made and thus resulting in an accident, such as a collision between two trains [10].

On the other hand, at the railway gate, the current practice is to use the cautionary light signals and humanoid level crossing gates to alert the drivers of the vehicles plying on the road and pedestrians about a train approaching towards the gate. After the departure of the train, the on-duty person at the station informs the gatekeeper about the arrival of the train through the telephone call and telegraph message. Then the person-in-charge at the level crossing gate closes the gate manually. However, sometimes the train delays for some reason but the gatekeeper might have closed it upon getting the tele-signal. As a result, the road traffic is halted for an extra period causing traffic jams on the roads, and sometimes, it becomes so longer [11].

Since the economic prosperity has always been dependent on increasing the capacity and rationality of railway-based transportation systems [12], therefore, it is imperative to build the infrastructure and operate this transportation system in such a way so that it may create a great impact on the economic activities of Bangladesh and thereby, making the railway transportation system sustainable and safe. In Bangladesh, there is a state-owned rail transport agency called Bangladesh Railway (BR) that operates and maintains the whole railway network of the country. Approximately, the railways cover 32% of the total land area of Bangladesh. BR operates a track of 2706 km and provides passenger and cargo services through 502 stations [13]. In terms of the number of employees per km of railway tracks, Bangladesh possesses an average place amongst the Asian nations. This is 14 in Bangladesh as related to 25 in India. However, there is an increasing trend for privatization of working manpower worldwide to diminish the total operational and maintenance costs of railway systems to improve the performance of the railway [14]. There are 2856 level crossings in Bangladesh, of which 1,468 or 55% are authorized and 1,200 or around 45% are unauthorized, and there are no appointed persons for duty at 961 authorized railway level crossing gates across Bangladesh and as a result, these places have become hotspots for train accidents, according to the Bangladesh Railway (BR) [15]. Moreover, there are approximately 1,361 illegal railway level crossings in Bangladesh as well and these are even more unguarded and dangerous for the trains and people. As per the official records, 263 people died in 297 train accidents in the last 10 years [16].

Therefore, in this research work, we aimed to provide an automatic railway level crossing gate control and railway track monitoring so that humans can be replaced at these level crossings. This will reduce the operation time of the gate being closed by closing it at the right time and will ensure the safety of the people's lives. Besides, the system will also detect any faults on the railway track, and send the signal to the concerned station via its messaging system to alert the station master before allocating that faulty track to a particular train. The proposed system ensures high reliability as it is not labor-intensive and as such does not prone to any error.

The research paper has been structured as follows-

Section II reviews the literature on railway gate control and track monitoring systems, section III describes the modeling of hardware designs based on PLC and IoT, section IV elucidates ladder programming design using flow charts, section V demonstrates the simulation of ladder diagrams with explanations, and in the end, section V recaps the report with the final words and concepts for imminent jobs.

II. Literature Review

From a long period ago, several researchers proposed the Programmable Logic Controller (PLC) based system for the automation of the railway and traffic control systems [9, 17-19]. Before that, the automation of the control systems was implemented using a microprocessor or microcomputer [20-21].

Programmable Logic Controller (PLC) is a digital computing device having several inputs and output terminals, wide temperature ranges, insusceptibility to electrical noise, and resistance to shaking and influence. In PLC, a memory device stores the ladder program of the system. The PLC-based system is called a real-time system because the output must be produced if there are applied inputs within a defined time frame. Since the memory is a non-volatile type, therefore, it can be easily reprogrammed and updated [22-24].

R. Gopinathan and Sivashankar proposed a railway level crossing gate control system using the PLC. Their main objective was to make the railway gate operating system automatic to avoid frequent accidents occurring in manned or unmanned railway level crossing to reduce operating time and to provide safety though no data is showing how much time was reduced. The whole system is managed by the sensors to detect the arrival of trains and the operation by the PLC [25]. Another similar work was found in another research article based on PLC proposed by K. P. Varade and N. P. Tarle. However, the authors did not provide any outcome of their work [26]. In another article, the authors proposed a simple, reliable, and cost-effective railway gate opening and closing system. Their developed prototype system worked well in laboratory set-up [27].

Besides, the railway gate control system was proposed to automate using various types of microcontrollers, RF systems, sensor networks, global navigation satellite-based systems, optical fiber-based systems, etc. For example, Krishna, et al., proposed a modern cost-effective, and accurate solution for the railway information system using the RF module and ARM7 microcontroller along with a few electronic parts and devices to control the railway level crossing gate and to display important information of the railway system [28]. As another example, C. Tukkoji et al. proposed a trustworthy, operational, and practical automatic railway gate shutting system using infra-red (IR) sensors. The system was realized based on IoT. Whenever the IR sensor and Arduino Nano microcontroller trigger the closing of railway level crossing gates coupled to the motor driver circuits upon arrival of the train towards the level crossing. This system can detect any obstacle (for example, a vehicle) nearby the gate via the IR sensors by inhibiting the closing of the railway level crossing gates and alarming the locomotive consequently slowing it down or stopping based on the need [29]. Microcontroller-based DC motor control is very effective and that is why many researchers choose this technology [30-32].

M. B. Mahfuz et al. proposed an intelligent and automatic railway transport system to avoid threats like crashes and derailments by detecting trains using the Global Navigation Satellite System (GNSS) to find the coordinates and hurdle revealed at railway level crossing gates. The gate control at level crossings was done using Light Emitting Diodes (LEDs), microcontrollers, and servomotors. Communication between trains and railway level crossings was kept using Global System for Mobile (GSM) techniques. They also developed a web-based central control system to observe the positions and actions of trains using such navigation technology [33]. N. K. Das et al. recommended the application of a Global Positioning System (GPS) based train-monitoring system that could trace a train at any instant to avoid train accidents and to help the passengers to know the train status. Here, a GPS–GPRS module conveys the position statistics to a web server [34].

M. D. Anil et al. proposed an advanced method of avoiding railway accidents based on the sensor network, which comprises numerous features, such as automatic speed control in curves, collision finding, fire detection, separating of couch spontaneously when a fire is sensed, automatic railway gate control and track continuity finding. This system uses IR sensors, fire sensors, ZigBee, and other embedded systems to stop the train using its electric braking system [35]. Jesuraj and Hemalatha in their paper discussed the development of an economical and design-friendly prototype model of an automatic railway level crossing gate controlling system using a piezoelectric pulsation sensor. When the train passes through the sensors, the signal is communicated to the gate activation circuit via the RF transmitter-receiver module. Then the motor actuates the gate and thus it is closed within 30 s of time. The motor actuates the gate again automatically after 180 s when the train departs the sensor [36].

Therefore, the objectives of this research are to-

i. Identify the problems of the railway tracks
ii. Design a railway level crossing gate control system based on PLC and IoT
iii. Simulate the designed control system

This proposed idea provides the automatic monitoring and controlling device in the locomotive itself to provide remedial action under track crack, track collision, track changing, traffic light indication, and gate control. This idea deals with two things; one is it has to issue automatic control signals to the parameters concerned and the second is to install the control room in the locomotive itself to have fast action. The recommended automatic railway protection control system provides the overall control for the train with the help of a single PLC. This system provides the control for automatically closing and opening the gate, and ON/OFF traffic lights indication for status of the gate open and close, anti-collision of two trains at the same track, and identifying track crack by using ultrasonic sensor.

III. Hardware Design using PLC and IoT

The block diagram of the automatic railway level crossing gate control and track monitoring system to be implemented is shown in Fig. 1. The sensor node located on the rail track at a specific distance from the level crossing gate senses the arrival of the train. This sensed signal goes to the PLC's input. After processing the input signal, the PLC sends an appropriate output signal to control the operation of the level-crossing gate. When the train moves on the railway track, the position switch tracks its position and then directs the input to the PLC to point out the arrival of the train. This cuts the gate opening or closing times significantly in comparison to the manual operation of the same. Besides, this replaces the human deployment round the clock at the level crossing. As a result, the accident chances are reduced significantly. An ESP8266 module [37] has been used to connect the device to the cloud network so that any problems identified by the system can be supplied to the mobile phone via the cloud and mobile Apps.

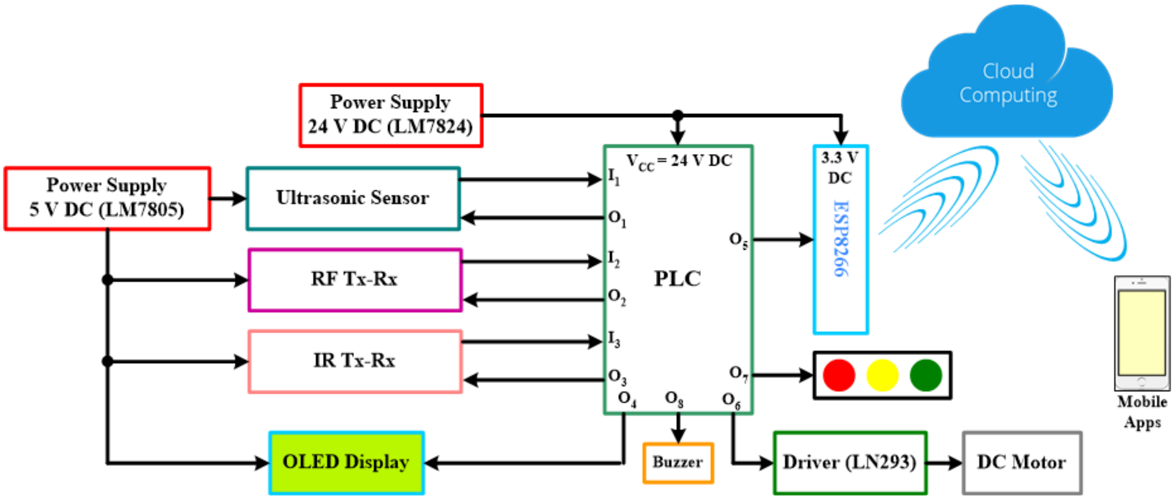

Figure 1: A practical block diagram of the PLC and IoT-based railway level crossing gate control and track monitoring system

As we know that the PLC, which is the heart of the current system under consideration, is a high-performance control device that is extensively being employed in the Distributed Control Systems (DCS). There are three sensors to communicate with the PLC, such as ultrasonic sensor, RF transmitter-receiver, and infra-red (IR) sensor with the input/output terminals of the PLC. For these purposes, devices need to be controlled via the controlling part to control and monitor the system.

The proposed automatic railway gate control and track monitoring system provides the overall control for the locomotive considering the various parameters with the help of a single PLC and the entire process is monitored using the Internet of Things (IoT)-based cloud computing system and mobile Apps. This system provides the control for automatically closing and opening the gate, and ON/OFF traffic lights indication for status of the gate open and close, anti-collision of two trains at the same track, and identifying track faults or any obstacles present on the track by using the ultrasonic sensors. The parameters are automatically controlled from a single control room with PLC installed in the locomotive. This work used RS-485 communication protocol to communicate between the PLC and PC for the monitoring software because RS-485 can be utilized fruitfully over long-distance communication and in electrically very harsh noisy atmospheres. Several receivers may be attached to a particular network in parallel [38].

The integrated circuit, L293 is an inexpensive, dual-channel H-Bridge motor driver capable of driving a DC motor in both directions. It can provide an output current of 1 A per channel and can be operated from a wide range of supply voltage from 4.5 V to 36 V [30].

The monitoring software has been developed with Visual Basic, very good for interface-level programming [37]. After that, this was linked with the PLC. As such, the monitoring software demonstrates better performances on controlling the automatic gate control and track monitoring system.

An infra-red sensor (IR sensor) is a photonic device having a spectral sensitivity within the infrared wavelength ranges from 780 nm to 50 µm. These are extensively employed in motion detectors to turn on lamps or to activate the alarm to perceive undesirable visitors. This sensor is used to detect the presence of incoming trains towards the railway level crossing.

An ultrasonic sensor can transmit and detect the ultrasonic wave above 20 kHz. It uses a transducer, like a microphone to send and receive ultrasonic pulses that carry information about an object located at a particular distance. This occurs when high-frequency ultra-sound waves reflect from that object and thus produce a distinct echo pattern [39]. The elapsed time between sending and getting back of the pulse is used to compute the distance.

Multiplexing is used to send one or more analog or digital signals over a common transmission line at different times or speeds. Such type of device is called a Multiplexer. It is a combinational logic circuit used to switch one of several input channels through to a single output channel based on some combination of the control signals. Multiplexers can connect or control multiple input lines called “channels” one at a time to a single output channel. Digital multiplexers circuits are made from high-speed digital logic gates so that the switching operation becomes very faster because these gates are constructed from very high-speed MOS transistors [40].

Time Division Multiplexing (TDM) is a communication technique by which we can transmit two or more signals through a common channel. In TDM, signals at the incoming channels are distributed into equal fixed-length periods. After multiplexing in the period, these signals are then communicated over a common shared channel and re-generated into their original formats through de-multiplexing. A Time Division Multiplexing (TDM) circuit designed in Proteus is shown in Fig. 2.

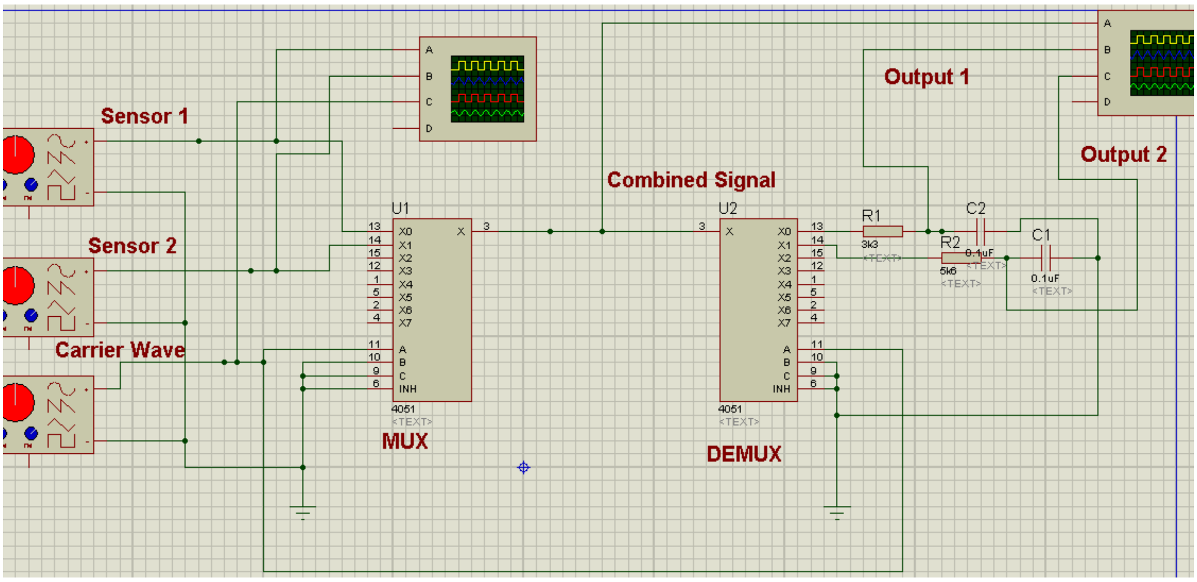

Figure 2: A simple Time Division Multiplexing (TDM) circuit designed in Proteus software

IV. Software Design

LOGO software is very easy to draw and quick to configure. It allows the user to create ladder programs by picking the particular functions and their connections by drag-and-drop. Auto-arrangement of communication and presentation in network mode is possible for a maximum of 16 nodes. In this mode, one can drag a signal from one ladder program to another by the drag-and-drop method. It is possible to switch the ladder program step-by-step and to simulate and test it on the PC even in the offline mode. Therefore, time can be saved when any errors occur in the ladder program and one needs to troubleshoot that program. It is possible to perform an online test during operation. It has a broad security model for the ladder programs and entrees to the controller portion. Using this software, six characters can be displayed for every 16 lines of every message text, and in the exterior text display; six characters for every 20 lines can be displayed. It also has two integrated web servers, through which text messages can be delivered. The flow chart of the LOGO software programming is shown in Fig. 3.

For this task, we needed also to create a Visual Basic (VB) program. There are two techniques to create software for a motor controller using the personal computer (PC), such as the native USB interface and the virtual serial port. The native USB interface technique has the facility to alter the parameters of configuring the system and then to select the motor controller using its sequential digit. This technique also allows recovering from momentary interruptions so rapidly. On the other hand, the virtual serial port interface technique is easy to use for novice and inexperienced ladder logic programmers.

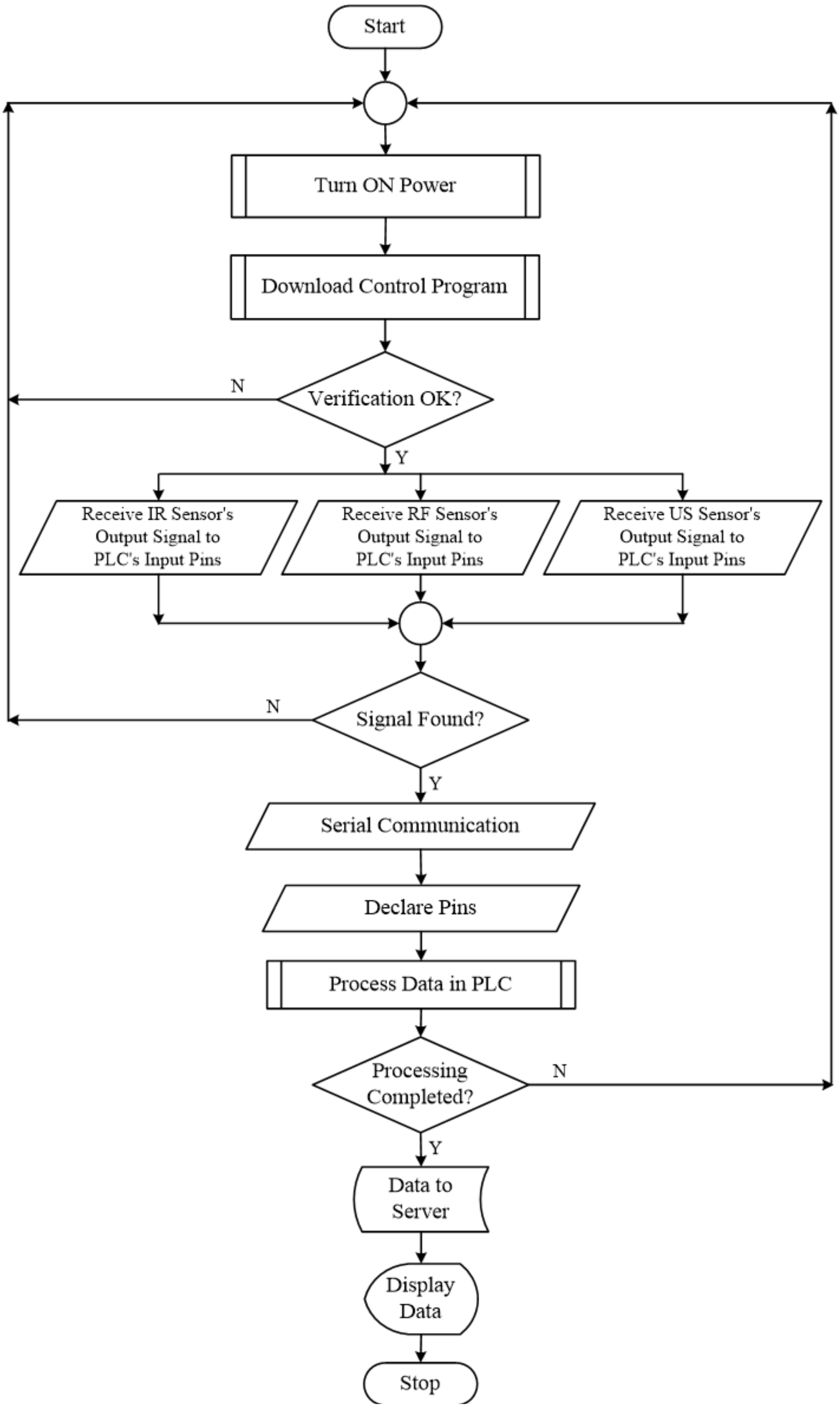

Figure 3: Flow chart of the PLC and IoT-based railway level crossing gate and track monitoring and control system

V. System Operation

When any train is coming from anyone's side then the sensor situated on that track gets HIGH and a signal is generated from the first sensor. The output of the sensor is then fed to the input of the PLC that generates a sound signal for a while by interpreting the signal according to the instruction sets written using a ladder logic program in a personal computer and then sends an appropriate signal to its output ports to close the barriers for the road traffic. Before that, the traffic signal gets red color, and the signal for the train line gets green color by which the train can cross through the level crossing gate. When the train passes out from the level crossing gate then the end side's second sensor gets HIGH and gives a signal to the PLC by which the PLC sends the signal to open up the barriers and then the signals come in their normal positions (i.e., OFF position). The working of this system is fully controlled by the ladder programming so that every decision taken by the PLC executes an action and all other timing and actions must be accurate.

In the system, there is a buzzer connected to the system for generating warning sound signals before closing the barriers so that the accidents can be minimized and the security level can be increased by alerting all concerned. For the system to operate properly, we require 24 V DC input voltage for the PLC. This DC voltage is obtained by designing a DC power supply using a voltage regulator IC, LM7824, and two capacitors having capacitance values of 0.33 µf and 0.1 µf at its input and output terminals respectively. For the forward and reverse side of rotation of the DC motor drive, we need to reverse the polarity of the voltage. As such, a combination of two relays was connected to feed a forward and reverse voltage for the desired direction of operation of the railway level crossing gate through the DC motor drive.

The ultrasonic sensor module sends an ultrasonic pulse out at an ultrasound frequency of 40 kHz. The ultrasound travels through the air and bounces back to the sensor if it is impeded by any obstacle or object. By computing the passage time and then multiplying it with the speed of sound, the distance between the object and the receiver is computed. Ultrasound sensors can also detect clear objects as well. To identify the presence of an object, ultrasonic sensors can sense it irrespective of its color, surface texture, or material composition. However, for a very soft object, it may be difficult to detect due to the sound absorption by the object.

To exhibit the information on the smartphone screen at any distant site, an assimilated Internet of Things-based server group titled Blynk was utilized.

The whole system operation is shown schematically in Fig. 4. The ultrasonic and RF sensors detect the rail track conditions and the arrival of the locomotive on the track. The sensed signals are then sent to the input ports of the PLC and accordingly the PLC processes the signals to produce the appropriate output signals at its output ports for the motor driver circuits to close the gate and traffic signals to turn red via a short yellow on the road. When the train passes completely the level crossing gate, the IR sensor is activated and then it sends the signals to the input ports of the PLC. Accordingly, the PLC processes the signals to produce the appropriate output signals at its output ports for the motor driver circuits to open the gate and traffic signals to turn green on the road.

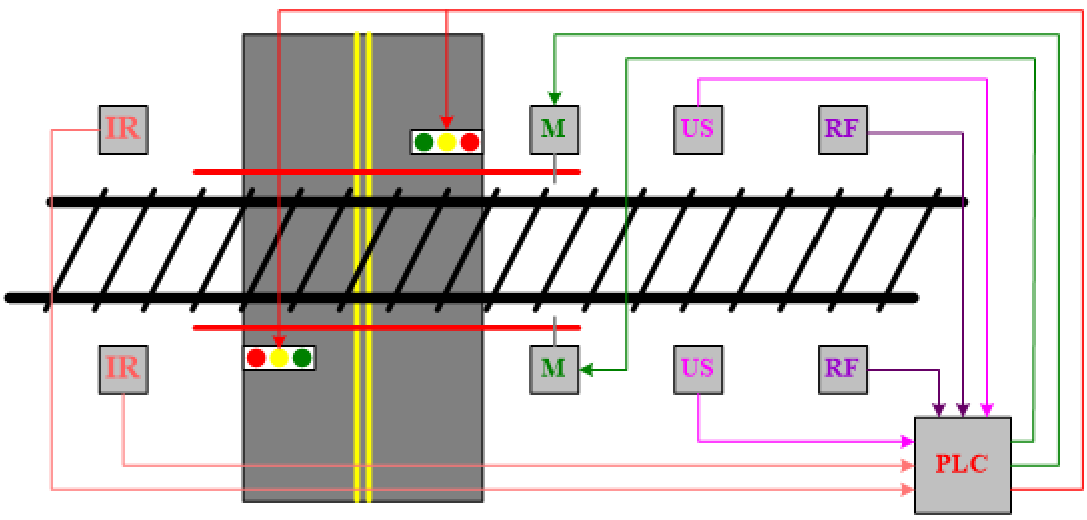

Figure 4: Schematic demonstration of the automatic operation of the system

VI. Simulation of Ladder Logic Program of PLC

The relay ladder logic diagram is a kind of programming language that is employed to program a PLC. In such a program, various graphical type inputs and outputs are used. The ladder logic looks like the relay logic diagram. To observe the ladder logic programming, a few snapshots are shown in Figs. 5-6.

LOGO programming language software is used to write, edit, compile, run, debug, and download the program to the PLC. Another communication software is used to transmit or receive the binary signal from the personal computer to the PLC and vice-versa by creating a duplex data transfer protocol with a standard error checking code. The most advantageous issue of using a PLC is that if a single PLC is engaged for multiple railway level crossing gate controlling and monitoring circuits of a particular rail track then the system is automatically synchronized, and as such no supplementary synchronizing equipment are required and thus previous warning signals can be produced to decrease the chances of mishaps.

The power rails are indicated by vertical lines on both sides of a relay ladder logic-based program. The vertical rail on the left side is called the hot and that on the right-hand side is known as the neutral rail. Between these two rails, there are horizontal lines that are known as rungs and on each rung, there are inputs (placed at the left side) and outputs (placed at the right side). When an input is closed then the power flows from the hot rail through the input to the outputs and in the end towards the neutral rail. Input is applied to the switches, sensors, etc. and the output is provided to the relay coils, motors, actuators, etc. external to the PLC. When the rails are activated by applying power to them, the hot rails and rungs become red color as shown in Fig. 5.

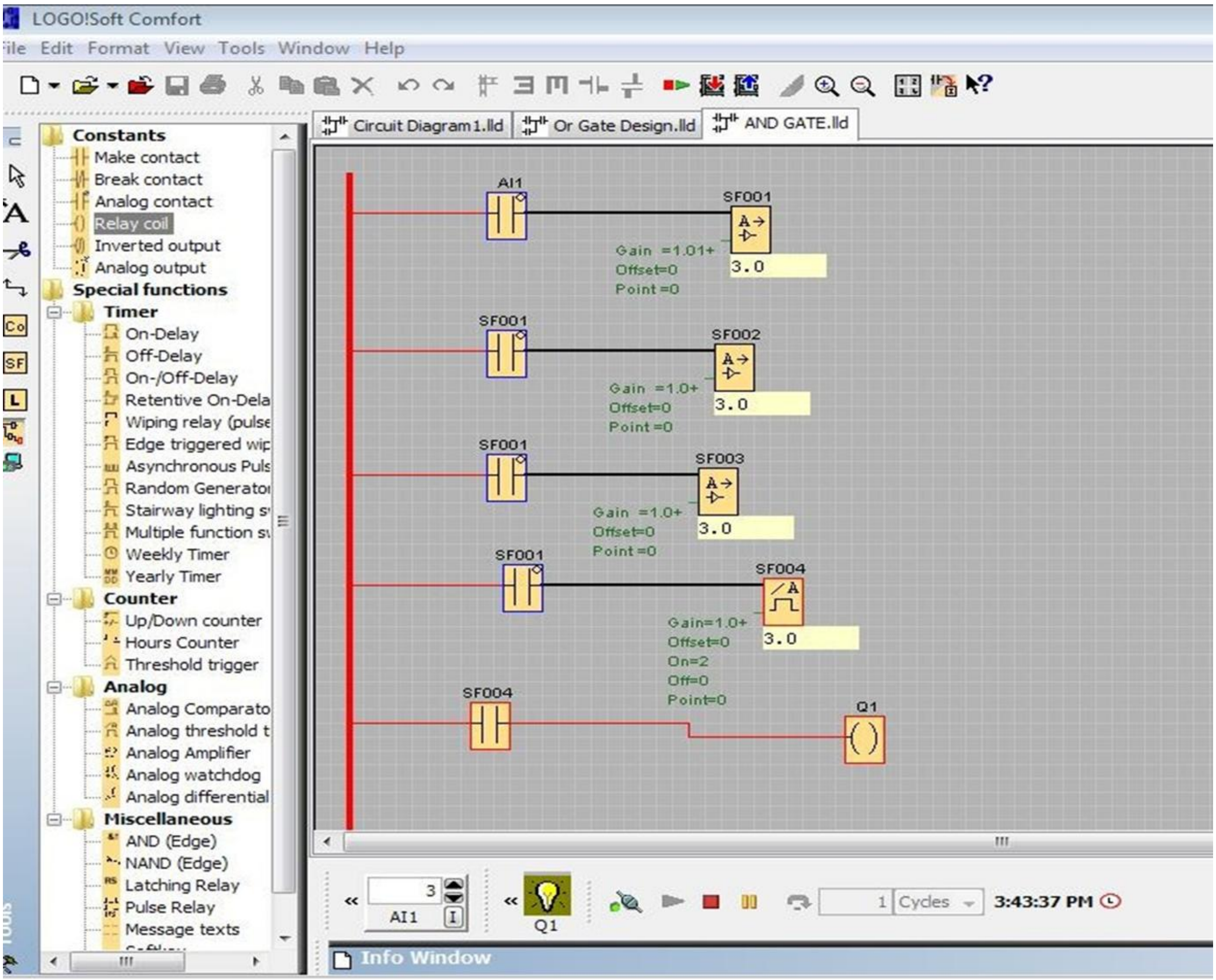

Figure 5: A part of LOGO software program with activation

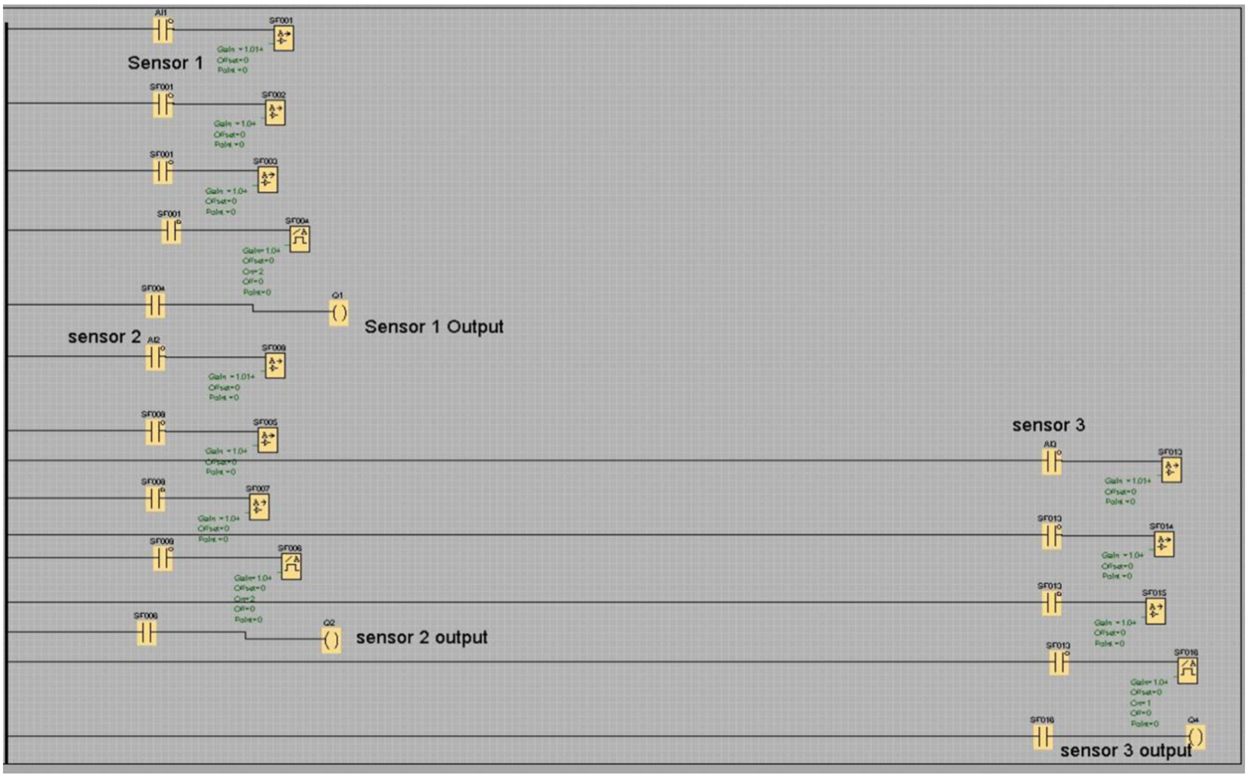

Figure 6: A part of relay ladder logic diagram before activation

Whenever the system detects a fault it is sent to the Organic Light Emitting Diode (OLED) screen and to the PC to be revealed in a suitable outline as depicted in Fig. 7. It shows a track fault (fishplate missing problem) detected in between two railway stations- Banani and Biman Bandar (BB) of Dhaka city.

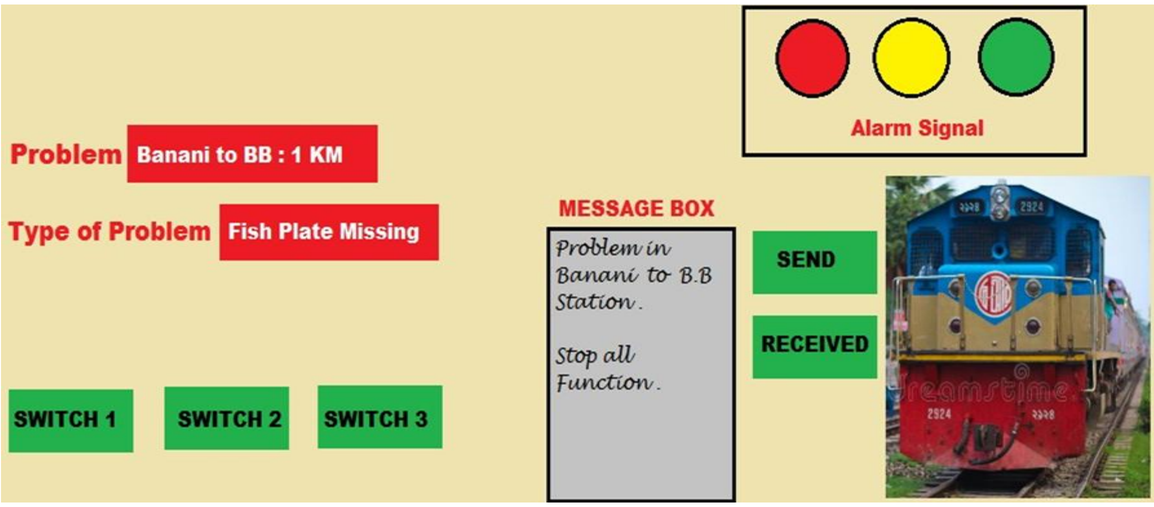

Figure 7: Exhibiting the text message via a programming interface designed using Visual Basic Software

VII. Conclusions

PLC and IoT-based railway track monitoring and control system has been designed using LOGO and Visual Basic software. These efforts are still under exploration stage, especially in Bangladesh and have not been practically implemented so far. Therefore, we made an effort to study it thoroughly and present a working model for the same. We concluded that as matched to the existing relay-based method used in Bangladesh, PLC based system would make it much more efficient because the whole controlling action would become automated. From the recent number of railway accidents data, a more efficient, accurate, and fail-safe automation of our existing system must be much needed. This would automate our system, reduce the manpower requirements, the manual operation would be replaced, and hence it would be cost-effective as well.

However, there are some limitations of the work. For example, it is designed with a cable and if its connection fails then the sensors will not work.

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