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Original Research Paper

Emergency Mode of Control of Rubber Belt Conveyors via PLC System Arduino Opta

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Abstract: The purpose of this article is to investigate emergency modes in conveyor belt technology, focusing on improving protections and interlocks for greater reliability when controlled by the Arduino Opta controller. The operation of a simulation model of a rubber conveyor belt using a programmable logic controller and relay-contactor groups is presented. An experimental study of the operation of a physical model of a rubber belt conveyor was carried out using installed sensors to obtain information about the condition of the facility in real time. This was done simultaneously with the optimization of the parameters of the automation model, after which the analysis and synthesis of the Ladder program for command and control was used. The visualization, based on a programmable logic controller "Arduino Opta" and sensors for obtaining process data are of different types to cover all the key elements of the rubber belt conveyor. The article highlights the characteristics, performance, requirements and operational procedure of the belt conveyor control systems, considering emergency situations such as slippage, breakage and overload. The lab bench is built to allow for the upgrade and renewal of the control system thanks to the open structure of the controller. The practical implications of this work are that based on this template, additional implementations may present an opportunity for the development of applications such as conveyor belts in the mining industry and logistics of transporting various goods and materials.

Keywords: Emergency Control, PLC, Rubber Belt Conveyor, SCADA, Sensor.

1. Introduction

Mining activities require constant transportation of materials to different points on the plane and in space. The range of transportation of materials varies widely, from meters to hundreds of kilometers. A key feature that determines the quality and varieties of industrial transport vehicles is the characteristic of the action - continuous and cyclical.

Belt conveyors are the most common machines for continuous transport. They are found as stand-alone machines, as components of lifting and conveying systems, as building blocks of belt feeders, continuous-action loaders, etc. They have the following advantages: applicable to almost all bulk and unit loads, high productivity and transport length (Maritsa East 6000м.), low energy and operating costs, simple and inexpensive construction, easy control and automation.

Automating the movement of materials with belt conveyors minimizes the need for manual labor, allowing businesses to allocate human resources to more critical tasks. This not only reduces labor costs, but also increases operational efficiency. Rubber belt conveyors consist of the combination of mechanical and drive components, as well as sensors for monitoring and controlling the system. An example of a Rubber belt conveyor device is presented in Figure 1.

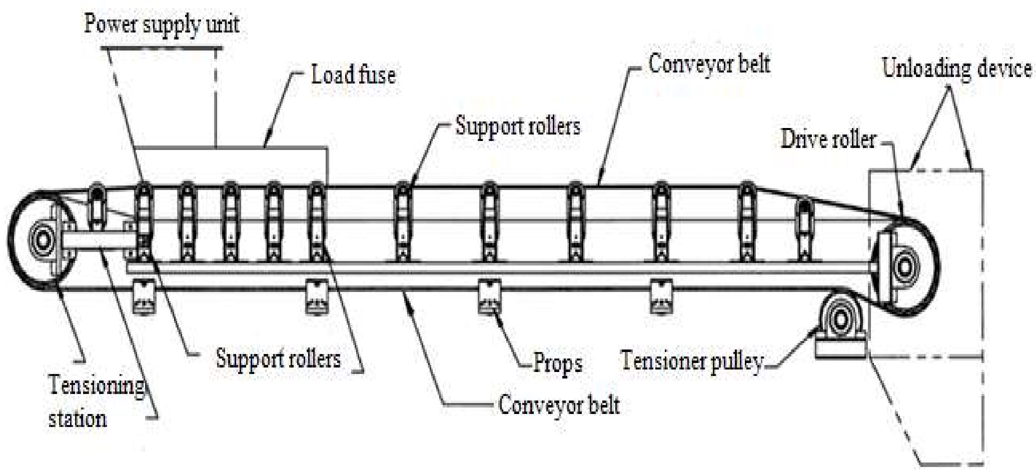


Figure 1. Rubber belt conveyor Devices

The following are the components:

- Power supply unit
- Load fuse
- Support rollers
- Conveyor belt
- Drive roller
- Unloading device
- Tensioner rolley
- Supports
- Support rollers at feeder
- Tensioning station

The drive of a rubber belt conveyor is a key process by which the belt is set in motion and the material is transported. This is done by an electric motor that transmits torque to the drive drum. Typically, asynchronous three-phase motors are used. The induction motor is widely used in industry to drive various mechanisms, including real rubber conveyor belts. These motors are preferred because of their reliability, efficiency, and relatively low cost. Depending on the needs of the conveyor belt, the power can range from a few kilowatts to hundreds of kilowatts. The motor speed is usually fixed and can be, for example, 1500 rpm or 3000 rpm, but the speed is adapted to the requirements of the conveyor belt by means of gearboxes. To achieve the appropriate speed of rotation of the conveyor belt, the motor is usually connected to a gearbox that reduces the speed and increases the torque. The motor must be protected against overload, overheating and other undesirable conditions. This can be achieved by thermal relays, circuit breakers and other protective devices. They can be mounted directly on the conveyor frame or be located separately and connected by a belt drive or chain transmission. Asynchronous motors provide stable and continuous operation, which is critical for maintaining the production process. They are known for their durability and minimal maintenance requirements. They offer high energy efficiency, which results in lower operating costs.

The need to monitor and collect different types of data for different nodes of the system requires the selection of various types of sensors. Sensors for speed, movement and lane slip control can be:

- mechanical – frictional and centrifugal.
- electronic – tachogenerators, induction and photoelectric converters – are based on control of the differences in the rotation speeds of the two sensors.
- microphone – when friction occurs, noises of a certain frequency occur.
- thermal with a bimetallic plate, which releases the contact system when heated.
- thermal using thermal balloons – based on the expansion of the liquid upon heating and actuation of a switch.

2. Literaure Review

The optimal efficiency of conveyor belt systems has been widely discussed in the literature. As reported in [1], maintaining optimal operational efficiency is crucial for reliable conveyor performance. The implementation of energy-saving algorithms and variable frequency drives (VFDs) for speed control contributes significantly to reducing electricity consumption [2]. Furthermore, the influence of various factors affecting the load on conveyor rollers has been examined in [3].

The type of damage depends on the structural parameters of the conveyor, the type of transported material and the operating conditions [4] [5]. Belt conveyors (Figure 1) allow for fast and efficient transportation of bulk materials with different physical and mechanical properties, with a low degree of degradation during high-speed and long-term conveying [6] - [9].

According to Hrabovský [10], the development of specialized belt conveyors has evolved considerably, yet the most common failures are still closely related to the conveyor belt itself [11]. Kroll et al. [12] highlight that energy-efficient conveyor belts and optimized carrier rollers are among the key innovations in the next generation of underground conveyor systems.

In [13], Fedorko G. et al. consider the implementation of the finite element method (FEM) model in the concept of digital twins designed to measure key properties and characteristics of rubber-textile conveyor belts on pipe conveyors.

The authors Giertz L. et al. describe [14] the problems of transporting bulk materials with different speeds and angles of inclination of the conveyor belt. The results of tests on the energy efficiency of conveyor belt transport systems show that the energy consumption of their drive mechanisms can be limited by reducing the main resistances in the conveyor, described in [15] Bajda M. et al.

The deflection behavior of a conveyor belt is influenced by centrifugal forces [16] [17] acting on both the belt and the transported material along the deflection curve [18]. Increasing belt tension is often necessary to minimize resistance, especially at higher belt speeds [19]. Laboratory tests remain essential in evaluating the durability and lifespan of conveyor belts [20] - [23].

From a control and automation perspective, programming of conveyor systems can be implemented using the PLC Ladder programming language [24] - [26]. Furthermore, the use of SCADA technology allows real-time monitoring and control of complex systems such as gas turbines [27], which demonstrates its potential applicability in conveyor systems as well.

The reliability of rubber conveyor belts has also been investigated. For instance, [28] analyzes the reliability function of rubber belts in open-pit mining machinery, taking into account belt length and operating time. Similarly, [29] studies how different transported materials—such as overburden, lignite, and mixtures—affect the rate of damage accumulation in St-type conveyor belts.

Potential belt ruptures due to overloading remain a critical issue, as discussed in [30]. Various rupture detection methods aim to provide early warnings and automatic shutdowns to prevent costly failures. The HS-423 sensor developed by Hansford Sensors (UK) can be attached to conveyor components such as roller bearings to detect wear and prevent unplanned breakdowns through early intervention [31].

Building a physical model on which various emergency situations can be simulated, helping to improve PLC control systems through visualization and data storage. The open-source code used in Arduino Opta will facilitate system maintenance and increase productivity, efficiency, and lead to a lack of discrimination against individuals or groups.

3. Methodology

Arduino Opta is a modern PLC platform that allows you to expand automation projects while taking advantage of the open Modbus protocol. Designed in partnership with "Finder" [32], a leading manufacturer of industrial and building automation devices. Thanks to its computing power, Arduino Opta enables a wide range of real-time control, monitoring and predictive maintenance applications. Secure and durable design, it supports OTA (over the air) firmware updates and ensures data security from hardware to the cloud.

Opta® is versatile and can be used by Original Equipment Manufacturers (OEMs) to control small industrial machines, such as micro-PLCs for process control, from the most basic, thanks to its easy configuration and flexibility (can be programmed basically like an Arduino Uno or with a PLC IDE with all IEC 61131-3 languages), to more complex ones, requiring high computing power or even machine learning capabilities (can run AI on the edge). Opta® can be used as a gateway thanks to its connectivity capabilities (Modbus TCP/RTU - Ethernet + Wi-Fi/Bluetooth Low Energy), to send telemetry from equipment/sensors and to retrofit existing industrial machines that do not have connectivity capabilities. Other use cases are in building automation, for example for access control, lighting/HVAC control, and reservoir management [33].

The structure of the Arduino Opta is presented in Figure 2.

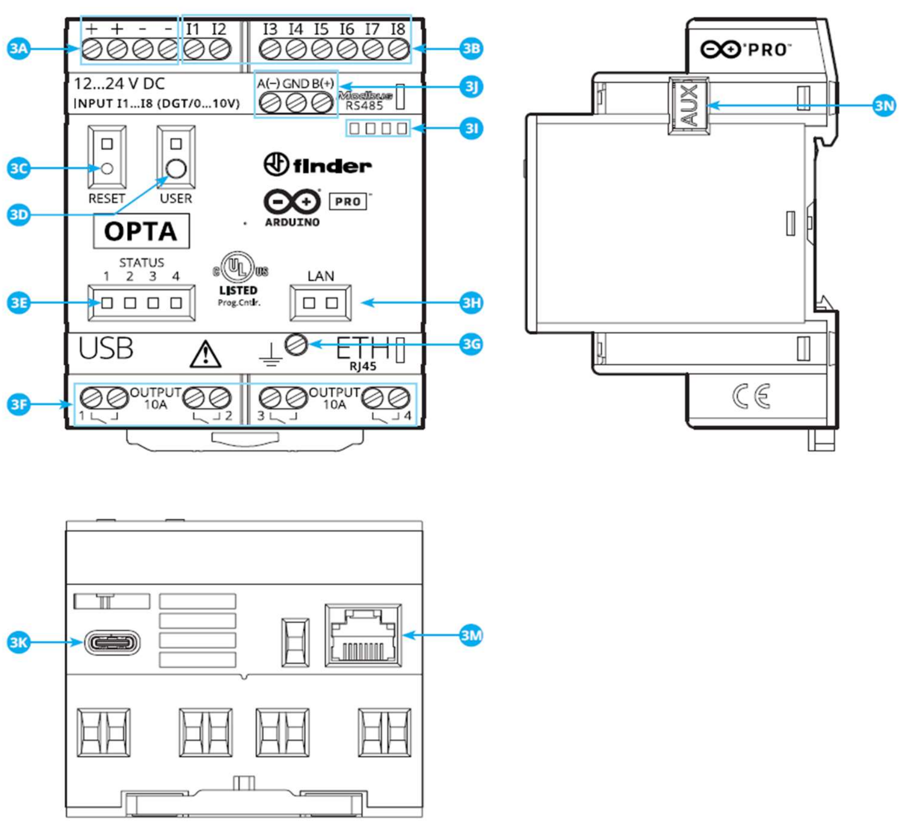


Figure 2 Structure of Arduino Opta

The following are the components:

- 3A Power supply terminal 12-24VDC
- 3B Programmable digital/analog input terminal I1-I8 0-10V
- 3C Reset button
- 3D User programming access button
- 3E Outputs 1-4 status indicator light
- 3F Relay NO outputs 1-4 terminal
- 3G Ground
- 3H Network connectivity indicator
- 3I Nameplate connector
- 3J Expansion module (Modbus) RS-485 connector
- 3K User interface and programming connector
- 3M Network connectivity connector
- 3N External module connection connector

The Arduino PLC IDE allows the use of the five programming languages defined by the IEC 61131-3 standard:

- Ladder Diagram
- Functional Block Diagram
- Structured Text
- Sequential Function Chart
- Instruction List

A highly configurable user interface offers a convenient unified programming environment, with the ability to use a wide range of pre-installed libraries and function blocks.

Rubber belt conveyors are an example of an object of automatic control in industrial systems, they can be considered as automatic control systems. Modeling conveyor dynamics and development of control algorithms is the subject of active research [34].

Figure 3 presents a schematic diagram of an automatic control system.

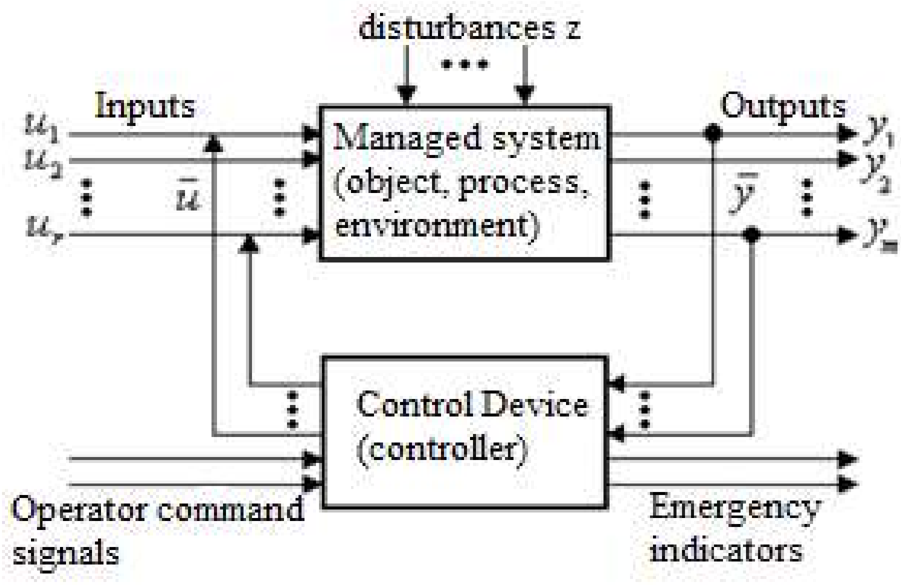


Figure 3 Automatic control system

Where the disturbances z represents the input signals from the sensors. The inputs are the operator start/stop command signals, and the emergency stop signals. Emergency indicators are activated when a signal is received from the emergency sensors. The output is the drive of the rubber belt conveyor. The transfer functions of a belt conveyor describe the relationship between the input and output of the system – usually in the form of a mathematical equation that is used to model the dynamics of the system. Automatic control systems operate on the basis of control laws, which are an algorithm or functional dependence, according to which the PLC forms the control action (Figure 4). To solve the practical task of controlling a rubber belt conveyor, information about overload, displacement and rupture of the belt web is monitored.

4. Finding and Discussion

4.1. Experimental work on controlling a rubber belt conveyor using PLC

At the Moscow State University "St. Ivan Rilski", a laboratory stand was built with the help of Eng. T. Ignatov, it represents a model of a rubber conveyor belt and control with an Arduino Opta programmable logic controller and relay-contactor groups (Figure 4).

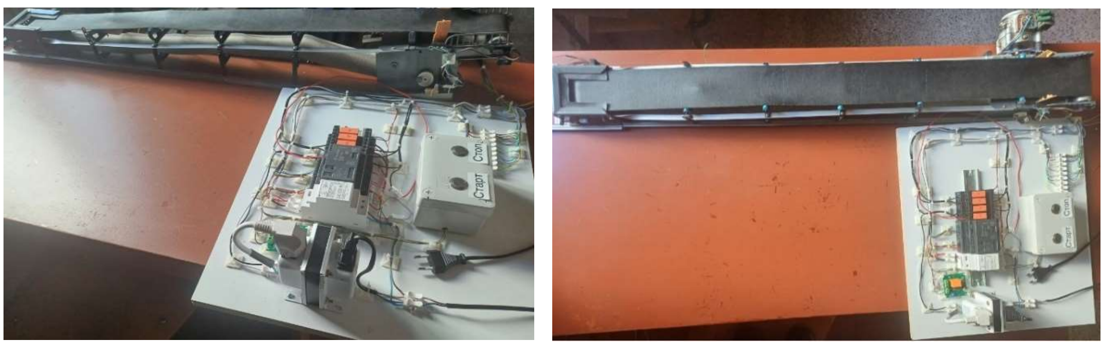


Figure 4. Laboratory Stand of a Rubber Belt Conveyor

The experimental study of the operation of a rubber belt conveyor and the operation of the installed sensors for monitoring the different types of possible failures in real time is presented. The visualization, based on a programmable logic controller "Arduino Opta" and sensors for obtaining process data are of different types to cover all the key elements of a rubber belt conveyor.

The installed sensors are shown in Figure 5.

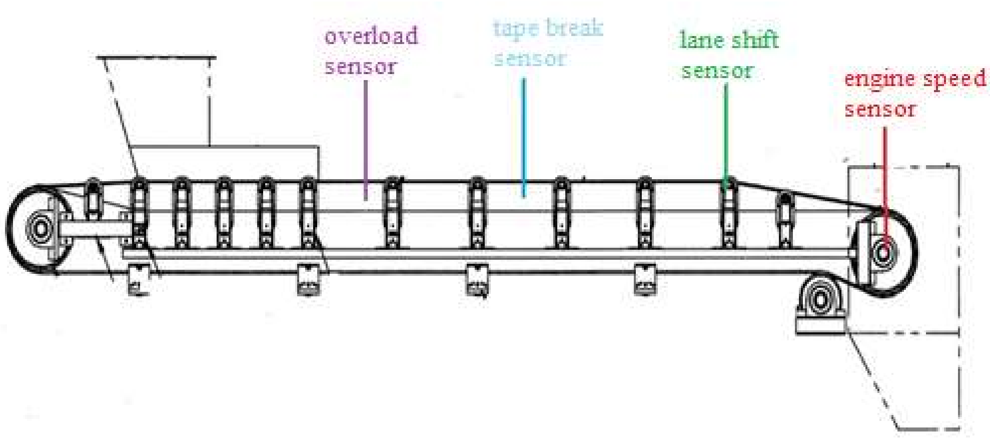


Figure 5 Sensor location

The following are the components:

- Overload sensor
- Tape break sensor
- Lane shift sensor
- Engine speed sensor

For the purposes of automated control of the laboratory bench, sensors with analog output have been selected (Figure 6). They have an output voltage of 12V, which corresponds to logical 1 (True). When the sensor is activated, the voltage at the Input of the programmable controller drops and the input state changes from logical 1 to logical 0, which is considered an error (Fault). Changing the state of the inputs is considered a disturbing effect and, accordingly, an error. In these cases, the error is the difference between the setpoint and the actual output of the system.

$$\varepsilon(t) = v(t) - y(t) \quad (1)$$

where:
$\varepsilon(t)$ is steady state error
$v(t)$ is setpoint
$y(t)$ is system output

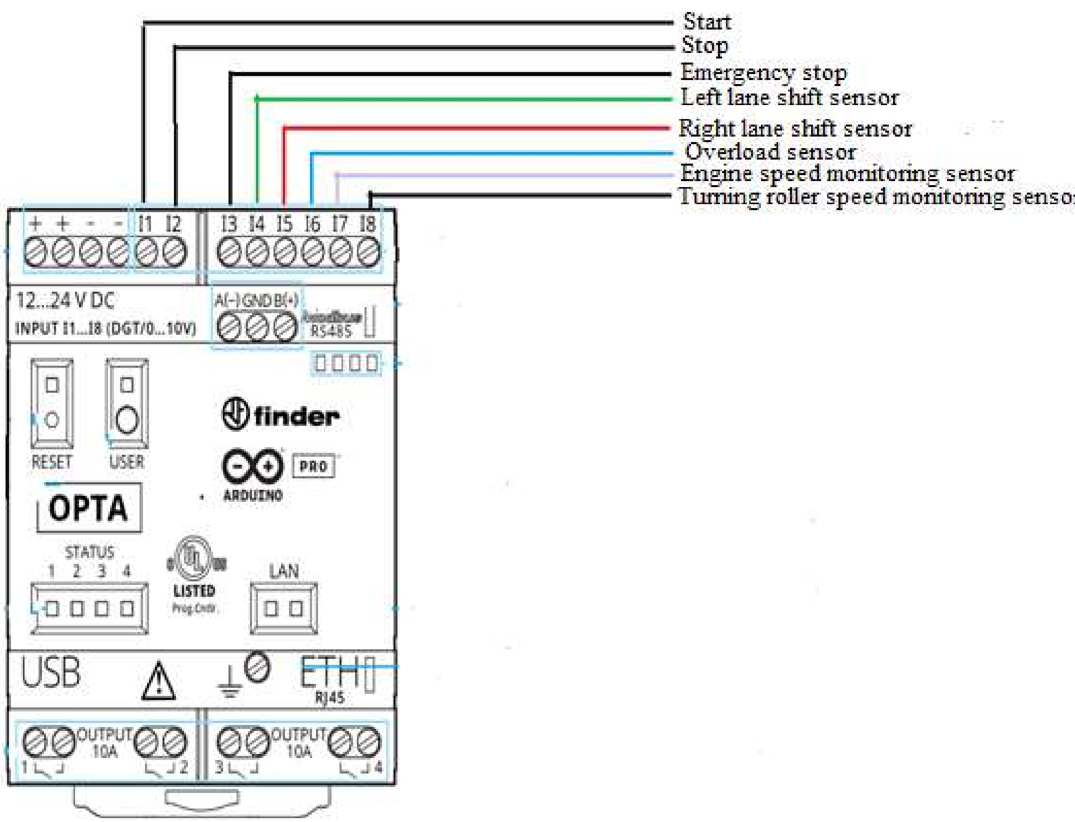


Figure 6 Schematic for defining the inputs of the Arduino Opta PLC

Figure 7 shows a connection diagram of the relay groups for controlling the rubber conveyor belt. Relay groups are connected to the relay outputs of the programmable logic controller in order to galvanically separate the operational from the power circuit for supplying the rubber conveyor belt motor.

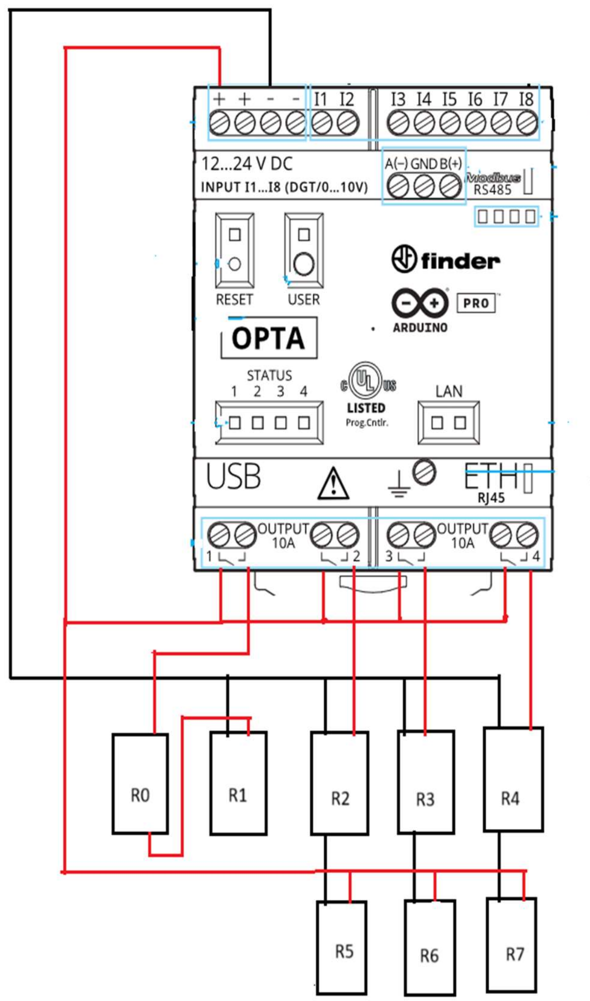


Figure 7. PLC Arduino Opta Outputs Diagram

4.2. Operating Principle of The Built System

A block diagram (Figure 8) is presented with a description of the system's operating principle. The different levels of structuring are outlined in colored outlines, when possible, for implementation in SCADA. Each SCADA system may consist of several parts, including sensors, RTU/PLC, computer servers, computer workstations, communication infrastructure, computer network equipment and various peripheral devices [35]. The integration of belt conveyors with SCADA and PLC systems allows the incorporation of optimization and predictive maintenance algorithms [36].

1) Yellow outline includes the sensors located in Figure 6 and connected to the PLC in Figure 7. For example, the sensor for tearing the web is an infrared light barrier consisting of a transmitter with an IR diode and a receiver photodiode. When the web is torn, the material falling through the gap breaks the barrier and the PLC issues an alarm signal for a malfunction.
2) The blue contour shows the operation of the programmable logic controller (PLC), which, based on information received from its inputs (sensors) in Figure 7, sends a command to its outputs in Figure 8.
3) The green loop includes process equipment, signaling and HMI. In the event of an emergency stop or a signal received from one of the sensors, a light signaling for an emergency is turned on and the oscillogram is changed to the one presented on the computer screen thanks to the Arduino IDE.
4) The red outline shows the possibility of connecting a personal computer, through which the

logic of emergency control can be set via PLC using the Ladder diagrams shown in Figure 10, monitoring the parameters in real time. At this level, a database of operating characteristics, connection to a "cloud" data storage space and a remote-control center can be built and stored.

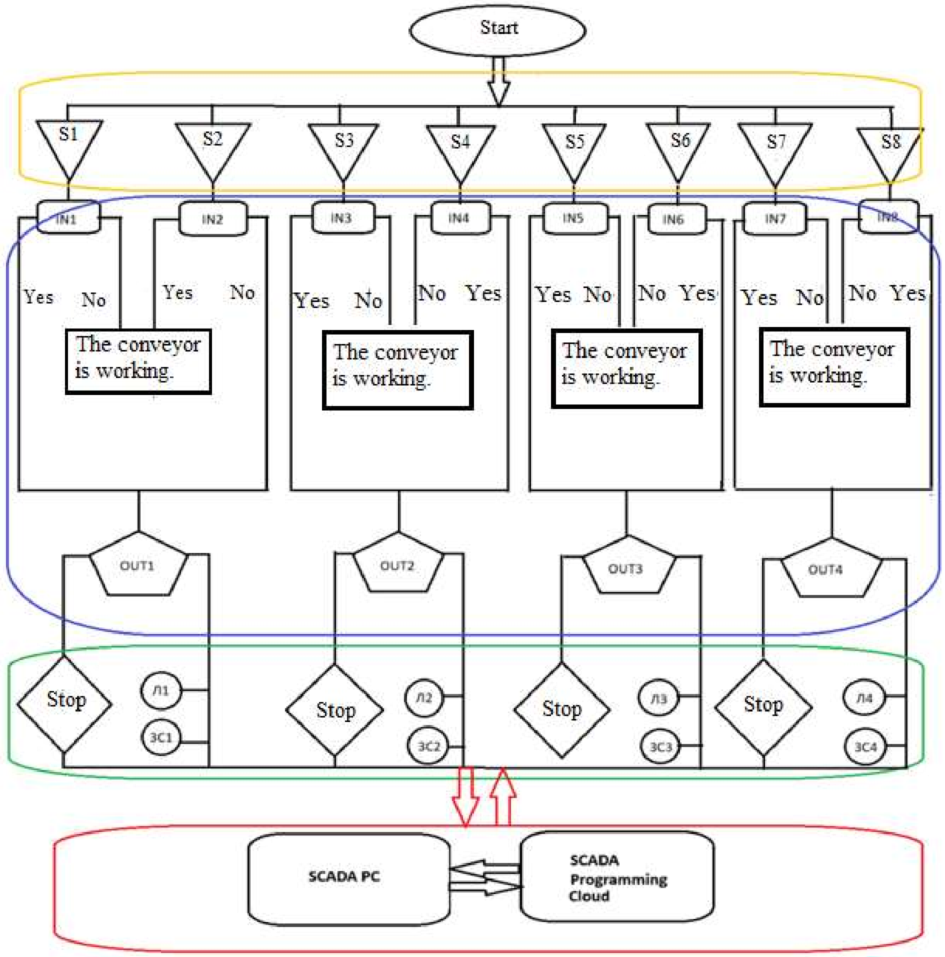


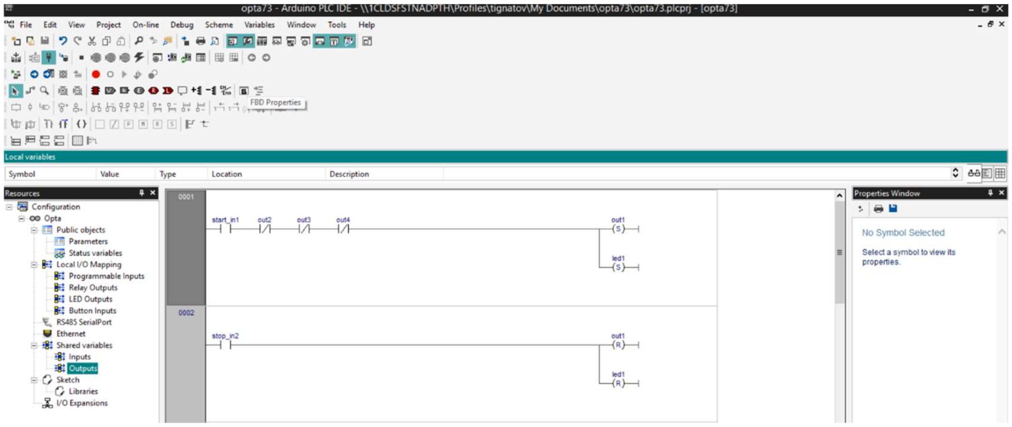
Figure 8. Block Diagram of The System Operation

Table 1 describes the inputs from Figure 6 relative to the outputs from Figure 7 and the control effect that the controller exerts on the laboratory bench.

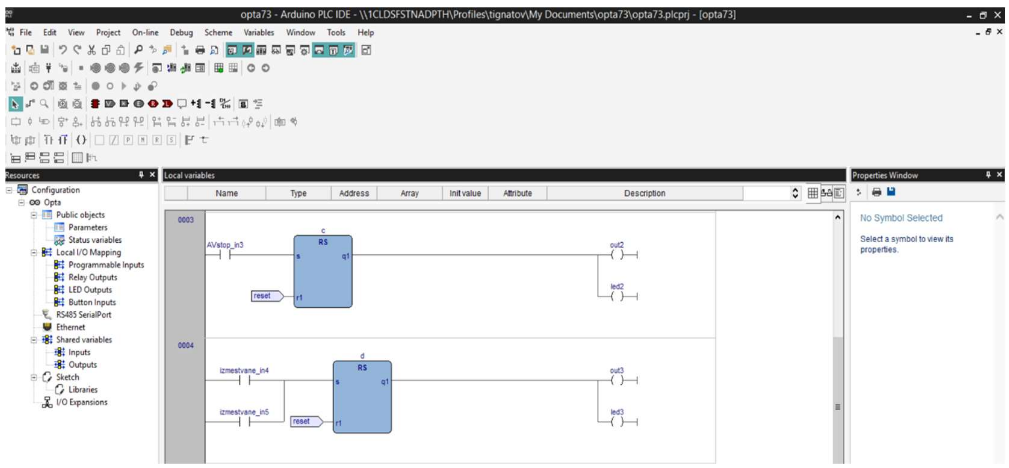
Table 1. Description of PLC Arduino Opta inputs

№	Type	Determine
I1	Start rubber belt conveyor	Starts the rubber belt conveyor/Alarm
I2	Stop rubber belt conveyor	Stop the rubber belt conveyor/alarm
I3	Emergency stop	Stop the rubber belt conveyor/alarm
I4	Conveyor belt displacement sensor left	Stop the rubber belt conveyor/alarm
I5	Conveyor belt shift sensor right	Stop the rubber belt conveyor/alarm
I6	Overload sensor	Stop the rubber belt conveyor/alarm
I7	Engine speed sensor	Stop the rubber belt conveyor/alarm
I8	Turning drum speed sensor	Stop the rubber belt conveyor/alarm

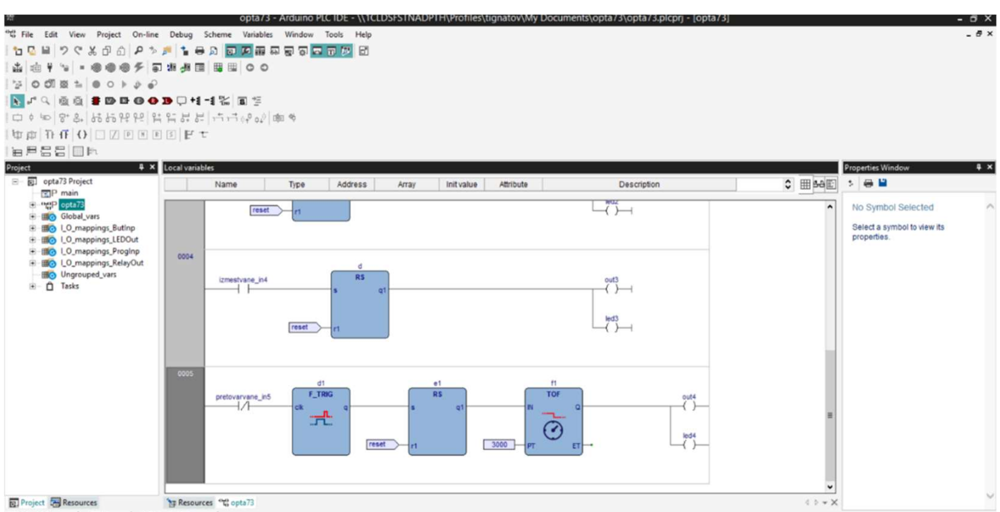
Based on Ladder Logic, the control program for a rubber belt conveyor presented in Figure 9.



(a) Start/Stop Buttons



(b) Emergency Stops and Lane Shift Signals

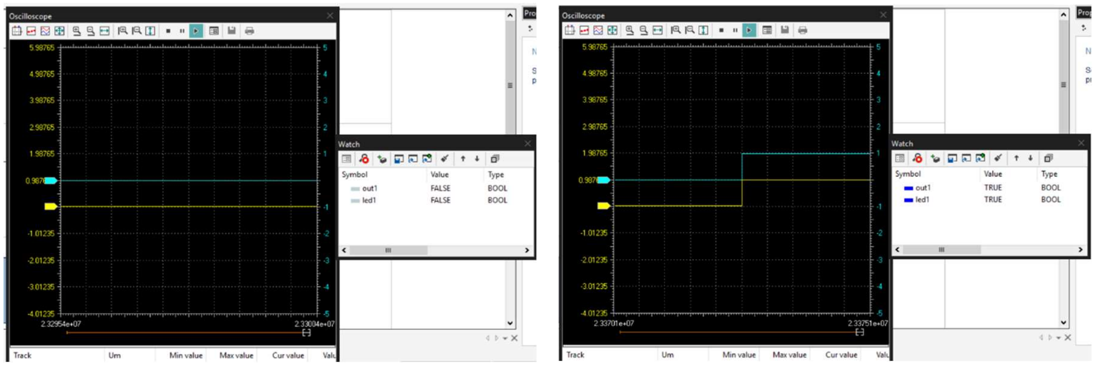


(c) Overload Signal

Figure 9. Ladder Diagram

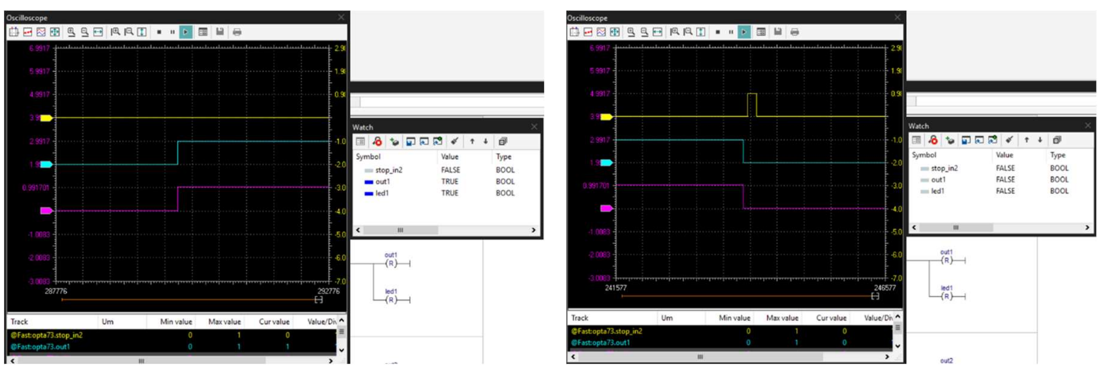
The experimental study focuses on testing procedures for emergency conditions of the operation of a physical rubber conveyor belt - slippage, rupture and overload, implementing control with an Arduino Opta programmable logic controller. Experiments have been carried out with the logical structure, signals and different types of sensor connections. PLC allows the logic of the organization of input and output signals to be implemented with the Arduino Processing programming language.

Using Arduino PLC IDE, the following oscillograms are presented:



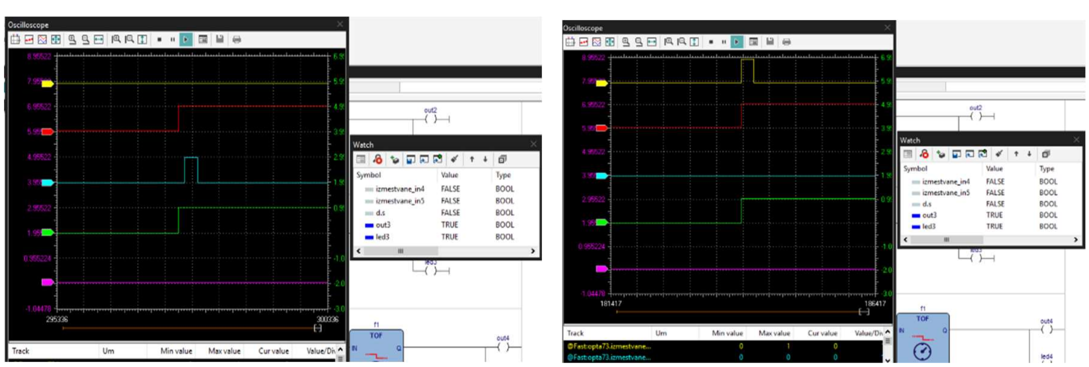
(a) Oscillogram Start Button Not Active (b) Oscillogram Start Button Active

Figure 10. Oscillograms for START Button Activation



(a) Oscillogram Stop Button Not Active (b) Oscillogram Stop Button Active

Figure 11. Oscillograms for STOP Button Activation



(a) Oscillogram Lockout Shift Band Left (b) Oscillogram Lockout Shift Band Right

Figure 12. Oscillograms for Lane Shift Lockout

5. Conclusion

The design and development system for automatic control of a rubber belt conveyor, which has simulation capabilities, has been implemented. The experiments that can be carried out are in the field of sensors, electric drives and system software. A study of emergency operating modes has been carried out on the physical model. An analysis of the problems related to emergency situations has been carried out. Experiments have been carried out that help minimize economic losses when restoring the conveyor's operating capacity. They show that it is possible to prevent or eliminate emergency situations in which a serious disruption of the technological process or equipment damage may occur. Based on the presented work, additional implementations can present opportunities for developing applications in the mining industry and logistics for transporting various goods and materials in real time. The hardware elements, the programming environment and the visualization based on the programmable logic controller "Arduino Opta" allow for upgrading and updating the control system.

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Author's Declaration

The authors hereby declare significant contributions to the research process, manuscript preparation, and publication stages.

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