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Research article

Design and Automation of a PLC-Based Dust Suppression System for Mineral Processing Plants

Moses Kwesi Annan[1], Isaac Papa Kwesi Arkorful[2,*], Ramatu Al-hassan[3]

[1]Department of Electrical Engineering, University of Mines and Technology, Tarkwa, Western Region, Ghana
[2]Department of Electronics Engineering, Norfolk State University, Norfolk, Virginia, United States
[3]Department of Professional Science, Middle Tennessee State University, Murfreesboro, Tennessee, United States
*Correspondence: pkwesiarkorful@gmail.com

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Abstract: Excessive dust generation in mineral processing and crushing plants poses serious occupational and environmental health challenges. Prolonged exposure to fine particulate matter—particularly Total Suspended Particulates (TSP) and Particulate Matter below 10 µm (PM_{10})—has been linked to respiratory diseases and reduced air quality in surrounding areas. Dust concentration data collected over a nine-year period revealed that approximately 20 % of TSP values exceeded the 150 µg/m³ safety limit, while 25 % of PM_{10} readings surpassed the 70 µg/m³ threshold, with peak levels reaching over 300 µg/m³ during dry months. These findings underscore the need for continuous and responsive dust control in processing environments. This study presents the design and simulation of an automated dust suppression system using a Programmable Logic Controller (PLC) integrated with dust and water-level sensors. Developed in RSLogix 500 and visualized in LabVIEW, the system automatically detects hazardous dust levels and activates low-pressure water spray nozzles in 15-second suppression cycles, with dust concentration re-checked after each cycle until levels fall below safe thresholds. MATLAB was employed to analyze nine years of historical dust concentration data and establish the threshold parameters used to configure the PLC control logic. Simulation results demonstrate reliable real-time monitoring, automated threshold-triggered suppression, and elimination of manual intervention in dust concentration control. The proposed automation framework provides a scalable solution for improving air-quality compliance, worker safety, and operational efficiency in mineral processing facilities.

Keywords: programmable logic controller, mining, RSLogix 500, LabVIEW, MATLAB, crushing plant.

1. Introduction

Dust is a common environmental component, consisting of fine, dry particles originating from various natural and human activities. It accumulates on surfaces, both indoors and outdoors, and is often carried through the air by wind currents. Sources of dust range from natural elements such as soil erosion and decomposing organic matter to human activities, including domestic and industrial emissions, vehicular movements, farming, and mining operations. In particular, industrial processes, such as mining, generate significant amounts of dust, which can pose health risks to workers through prolonged exposure [1], [2]. Due to its small particle size and lightweight nature, dust can travel long distances through the atmosphere, often covering extensive areas [3], [4], [5]. Some dust particles can remain suspended in the air for extended periods, sometimes traveling thousands of kilometers before settling [6], [7]. Mining activities, especially open-pit operations, significantly contribute to atmospheric dust pollution [8]. Processes such as drilling, blasting, and crushing release fine dust particles into the environment, affecting air quality and increasing health risks for workers and nearby communities [9], [10]. The problem is especially pronounced in enclosed processing facilities such as crushing and screening plants, where limited ventilation causes fine particulate matter to accumulate rapidly, creating concentrated exposure zones.

Work-related respiratory diseases caused by prolonged exposure to dust and other airborne pollutants remain a major concern in the mining industry [11]. Inhalation of dust, aerosols, fumes, and toxins has been linked to respiratory conditions such as asthma, pneumonia, bronchitis, and emphysema. According to [12], a study conducted on miners from two Ghanaian gold mines revealed that the incidence rates of asthma, pneumonia, bronchitis, and emphysema were 47%, 14%, 9%, and 5%, respectively, with coughing being the most frequently reported symptom. Mining has long been associated with occupational health hazards, particularly in developing countries, where exposure to mine waste continues to pose significant risks [13]. A carbonate processing plant was studied where ore is processed into aggregates through multiple stages of crushing. The process involves the use of primary jaw crushers and secondary cone crushers, which break down the ore into smaller sizes. Conveyor belts and discharge chutes facilitate the movement of the crushed material, while segregating screens classify the ore into desired sizes. However, the impact of crushing, segregation, and discharge processes generates large volumes of dust, leading to environmental and health concerns.

Currently, the engineering team at the carbonate plant employs a high-pressure sprinkler system to spray water into the primary jaw crushers as a dust control measure. Additionally, water is applied to the ore in the ROM bin before crushing to minimize dust emissions. Despite these efforts, dust generation remains a persistent issue, particularly at critical points such as discharge chutes, impact beds, cone crushers, and screens. Given the limitations of the current dust suppression methods, there is a need for an improved system to monitor and control dust levels at these critical hotspots. Implementing a more effective dust management strategy is essential to reducing environmental pollution and ensuring the health and safety of workers at the facility [14], [15], [16].

Mining activities such as blasting, hauling, and crushing contribute significantly to dust emissions, exposing both workers and surrounding communities to hazardous airborne particles [10], [17]. Confined areas such as crushing plants present the highest risks, as fine dust particles accumulate rapidly under limited ventilation conditions. However, in enclosed environments like processing plants, dust buildup is more concentrated, necessitating effective suppression mechanisms [18].

A study in [19] identifies chronic respiratory diseases as a major occupational hazard in the mining industry. Workers exposed to high dust concentrations in poorly ventilated areas are at risk of developing conditions such as pneumoconiosis, silicosis, and chronic bronchitis. This research highlights the urgent need for improved dust control technologies in high-risk zones like crushing plants. Traditional dust control methods, such as manual water spraying, have been widely used but often prove inefficient in high-dust environments. In [20], the authors argue that automation in industries can significantly improve dust suppression by allowing real-time monitoring and adaptive control. The integration of automated sensors and control systems ensures that dust suppression measures are activated as soon as dust levels exceed safe thresholds, improving both efficiency and worker safety.

The authors in [21] explore the use of dust sensors in industrial environments, noting that real-time monitoring is key to effective dust suppression. By integrating sensors with automated control systems, mining operations can significantly reduce human exposure to dust and improve regulatory compliance. However, challenges such as sensor calibration, environmental interference, and maintenance requirements must be addressed for widespread adoption. In [22], the authors discuss the benefits of using Programmable Logic Controllers (PLCs) such as RSLogix 500 for industrial automation. PLCs allow for logic-based decision-making in industrial processes, enabling automatic activation of dust suppression systems based on real-time sensor data. This research highlights how PLC-based automation minimizes human intervention, reduces response time, and improves dust control effectiveness in enclosed mining environments.

MATLAB is widely used for processing and analyzing environmental data, including air quality and dust concentration levels. In [23], the authors demonstrate how MATLAB can be utilized to analyze dust levels in mining communities, enabling more accurate assessment and decision-making for dust suppression strategies. By applying data-driven approaches, mining companies can develop more efficient and proactive dust control solutions. While numerous studies have examined dust pollution in mining environments**,** there is limited research on the integration of automated dust suppression systems specifically using RSLogix 500 for logic-based control**.** Most existing dust control measures rely on manual interventions or basic water spraying techniques**,** which are often inefficient in confined areas like crushing plants [15], [16]. Previous automated dust control studies have primarily employed generic PLC platforms or proprietary SCADA-based systems, with limited documentation of RSLogix 500 ladder logic implementations for sensor-driven dust suppression in mineral processing environments [21], [22]. Additionally, the use of MATLAB for analyzing real-time dust monitoring data in mining communities remains underexplored**.** There is a need for research that bridges the gap between dust sensor technology, PLC-based automation, and real-time data analysis to develop an intelligent, adaptive dust suppression system tailored for high-risk areas within mining operations. The proposed framework is adaptable to various mineral processing environments where airborne dust poses occupational and environmental risks.

2. Methods

The PLC controls the order of operation of the equipment employed in the dust suppression system to ensure ready response to hazardous levels of dust concentration in the atmosphere. The system turns on immediately when the carbonate crushing plant initializes its crushing process. The water levels of the tanks are monitored using water level sensors when the system initialises. Low water level in the tank is solved by triggering a water pump to fill the tank to an acceptable level. The tank pump operation signal checks as false when the water level reaches this the set level. In case the tank water level is within acceptable range (higher than minimum threshold value), the system proceeds to check dust concentration values at identified hotspots using dust sensors. A low dust concentration level sets the system into a loop, checking for dust concentration levels at time intervals of 30 seconds till a high value is recorded.

A high dust concentration level triggers an alarm for 5 seconds, notifying the operators and workers on site of hazardous dust levels. The alarm resets after 5 seconds. After the alarm resets, the system pumps water from the tank through pipes, controlled by valves, to suppress the high levels of dust concentration. Water is sprayed from nozzles at a controlled low pressure. High pressures of spray will disperse airborne dust further into the atmosphere; a condition which is undesirable and needs to be avoided by spraying at low pressure. The system closes the valves after 15 seconds. Dust concentration levels are checked again at this point. If the concentration of dust is still high, the system loops at this stage until a low concentration is recorded which resets the whole system to start the sequence.

2.1. System Components and Software Resources

The following hardware components and software tools were used in the design and simulation of the dust suppression system. The hardware components used are listed below and software tools are listed in table 1:

- Electric ball valves: These are normally closed and are used to control the flow of water through pipes
- Nozzles: Used to create pressure in the water stream flowing through the pipes. It also breaks up water into droplets, purposely so that dust particles get attached to these droplets and sink to the ground under their own weight.
- Alarms: The alarms are used to alert operator and personnel on site of high dust concentration levels
- LED lamps: These are in the alarm system to visibly notify the operator.
- Motor driven centrifugal pump: The pump is used to increase the pressure of water to fill the tank and to push water through pipes to nozzles.
- Dust sensor: The dust sensors detect the presence and concentration levels of dust in the atmosphere
- Submersible water level sensor: The submersible water level sensor measures real-time values of the water levels in the water tanks which store water for suppression

Table 1. Resources used.

Resource	Function
RSLogix 500 English	Used to program the ladder logic.
RSLinx Classic	Used as communication driver to provide connection between the RSLogix 500 and the computer environment.
LabVIEW 2017 Version	Used to program the graphical user interface for monitoring and supervisory control.

2.2. Data Collection, Analysis, and Interpretation

The three types of dust particles include total suspended particulate matter (TSP), inhalable particulate matter (PM10), and fine dust particulate matter (PM2.5). When inhaled into the body, these particles pose very serious health issues to workers. TSP, PM10, and PM2.5 are all connected in a hierarchical manner such that PM10 is a component of TSP and PM2.5 is a component of PM10 [24]. Dust concentration data were obtained from the environmental monitoring department of the carbonate processing plant described in Section 1 for the period from August 2010 to April 2019. These measurements were obtained from the mine village, located approximately 220 m from the stockpile and 365 m from the crushing plant. Two measurements, the total suspended particles (TSP) and PM10 (particulate matter) values, were obtained over this period of time. Figure 1 and Figure 2 show the TSP and PM10 values, respectively.

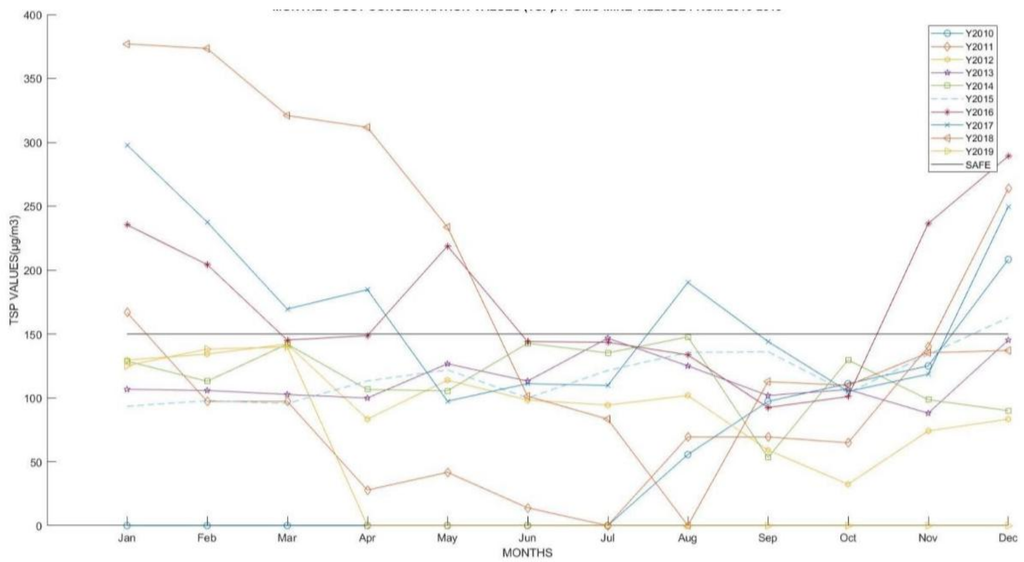


Figure 1. Plot of monthly TSP dust values from 2010-2019.

From Figure 1, 20 out of 102 measured values from August 2010 to March 2019 were above the allowable respirable concentration threshold of 150 µg/m3. Again, 7 out of these 20 values were above 250 µg/m3, with the highest values above 300 µg/m3 being recorded from January 2018 to April 2018. Hence, about 1 in every 5 dust measurements was hazardous. The black line in Figure 1 shows the safe limit value of 150 µg/m3 as set by the Environmental Protection Agency (EPA) permissible limits. Higher levels of dust concentration were observed during the months from November to through to April, which are typical of the dry season. Measurements Plots below the black line in figure 1 represent the safe working conditions recorded during this period of time. It can be inferred that greater values of TSP would be recorded at the carbonate crushing plant than at the village which is about 365 m away from the crushing site.

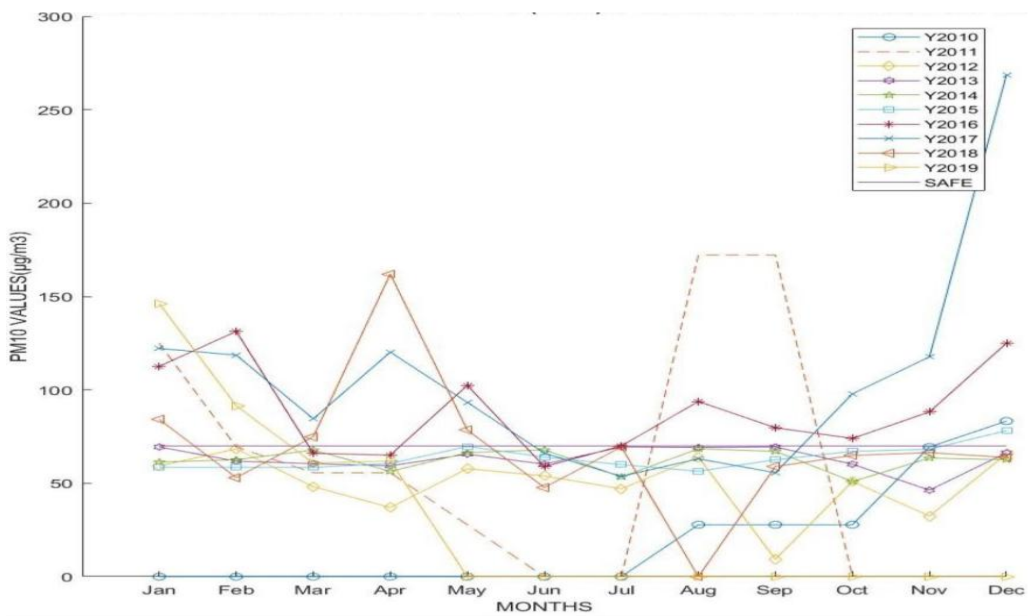


Figure 2. Plot of monthly PM10 dust values from 2010-2019.

PM10 dust filters filter finer samples of dust as compared to TSP filters which filter a wide range of dust from finer to larger particles. PM10 dust filters filter dust with diameter less than equal to 10 µm. Hence, PM 2.5 dust are captured under PM 10 dust too. From Figure 2, it shows 27 out of 105 values recorded from August 2010 to April 2019 were above the safe atmospheric dust concentration limit of 70 µg/m3. 14 out of the 27 excessive dust values measured were above a critical value of 100 µg/m3, while 4 out of the 27 excessive passed the 150 µg/m3 threshold. High concentrations of fine dust recorded at the mine village, approximately 365 metres from the carbonate crushing plant indicate that even higher values of dust concentration will be obtained at designated hotspots of dust production within the crushing plant. Higher values of dust concentration were obtained from November to April. Due to the absence or scarcity of rain during these months, dust concentrations were observed to be way above the safe limit of 70 µg/m3 and hitting an all-time high of 268.7 µg/m3 in December of 2017.

2.3. PLC-Based Dust Suppression System Design

The design employs an electric pump which pumps water at a pressure of 1 atm to fill the tank when the water level goes below 20% of tank volume using a water inlet valve. Another pump is fixed to supply water to the nozzles through 250 mm pipes installed along the walls of the crushing plant. The flow of water through these pipes is controlled by electric ball valves whose operation is remotely controlled by the PLC. In place of nozzles at certain identified hotspots of dust concentration, a dust suction unit has been proposed as part of the design to suppress dust by suction. The absence of water in this unit makes it a preferred alternative to address the dust concentration at hotspots where the spraying of water in any form may present a likely fault to electrical wiring or equipment. Note that the dust suction unit is proposed here as a design element for electrically sensitive hotspots; its simulation and performance evaluation are reserved for future work. Figure 3 shows the block diagram of the PLC input and output modules.

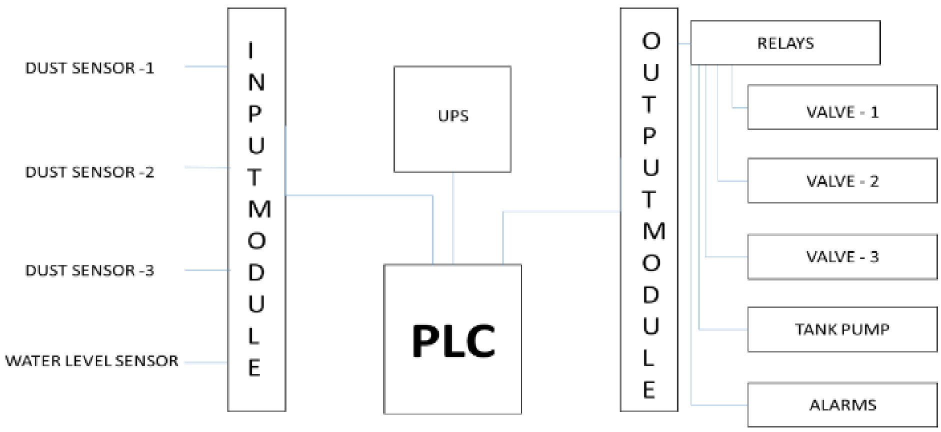
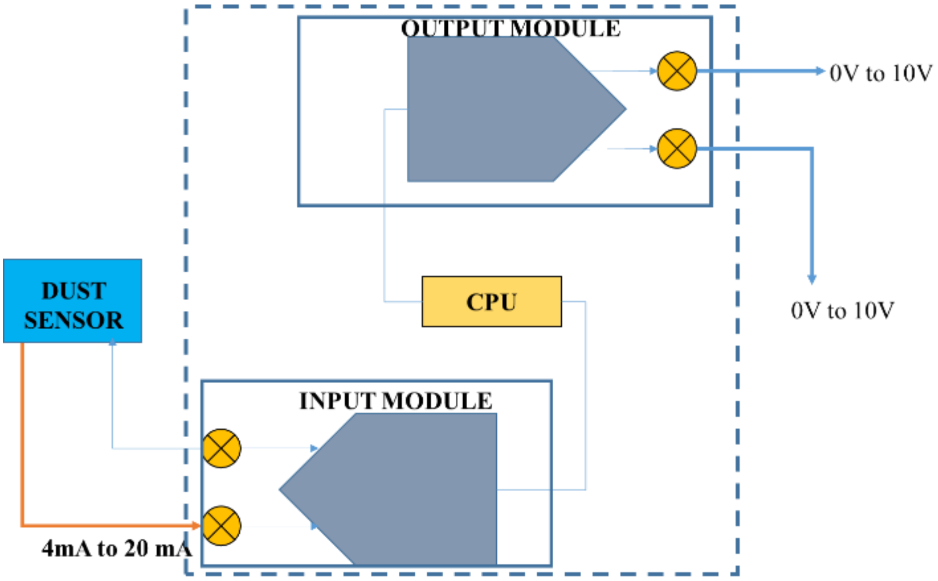


Figure 3. Block diagram of PLC inputs and outputs.

Alarms are integrated into the system to alert workers on site of hazardous levels of dust concentration. The PLC system is linked to the LabVIEW interface to allow visualisation of the system's operation.

Figure 4. Dust sensing system block diagram.

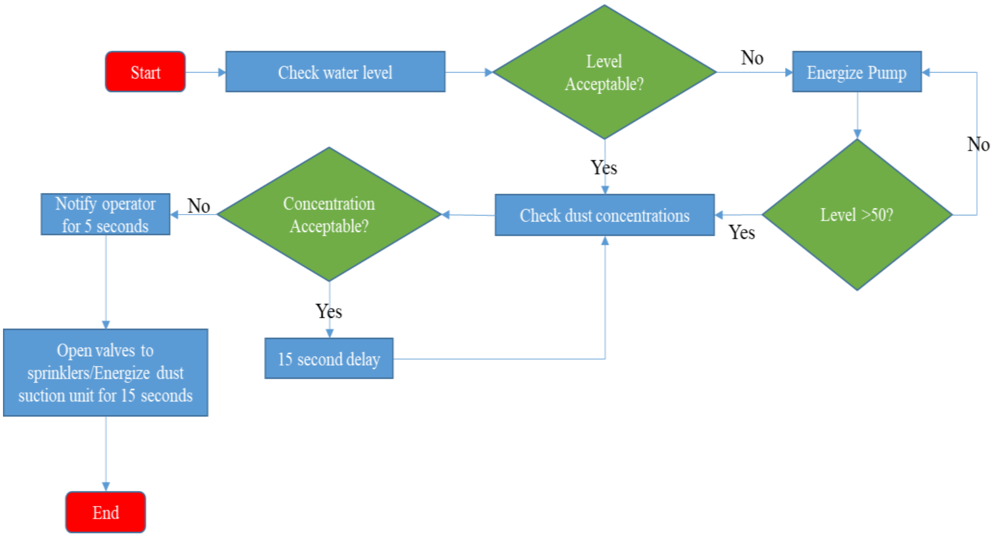


2.4. System Operation Logic and Flowchart

The whole process is initiated when the crushing plant system starts. The operation of the flowchart is analysed into detail below:

1) **Step 1**: The system initiates with the measurement of water tank levels using the water level sensor. These sensors give the system an input signal which specifies the level of water in the tank. If the water level is above a set minimum threshold value, the system proceeds to obtain dust concentration values from the dust sensors. A water level below the minimum threshold activates a water pump to fill the tank to a set level (50%) before the system proceeds to check for dust concentration values.
2) **Step 2**: The system accepts measured dust concentration levels and compares it against a reference value beyond which the concentration is interpreted as hazardous. If the levels of dust concentration are within acceptable limits (lower than the maximum allowable threshold for dust concentration), the system enters a loop at this stage and repeats this activity every 30 seconds.
3) **Step 3**: The system triggers an alarm for 5 seconds to warn workers of dangerous levels of concentration. After 5 seconds, the alarm resets.
4) **Step 4**: After the alarm resets, the valves are opened to release water through sprinklers to control the concentration of dust at the hotspot. Water is sprinkled at low pressure. High pressures of water will result in scattering dust further into the atmosphere.
5) **Step 5**: The valves reset into normally closed position after 15 seconds. The system delays for 15 seconds and resets the system to begin from start.

Figure 5. Flow chart of dust suppression system.



3. Results and Discussion

Figure 6 depicts the LabVIEW environment when the dust and water tank levels were normal. Figure 7 shows a 15 second timer on rung 0000 which times down when there is normal water level. In Figure 8, low water level and high dust levels are recorded simultaneously. The low water level signal triggers a timer which energizes for 15 seconds after which the next action is taken.

Figure 6. Normal levels of dust and tank water.

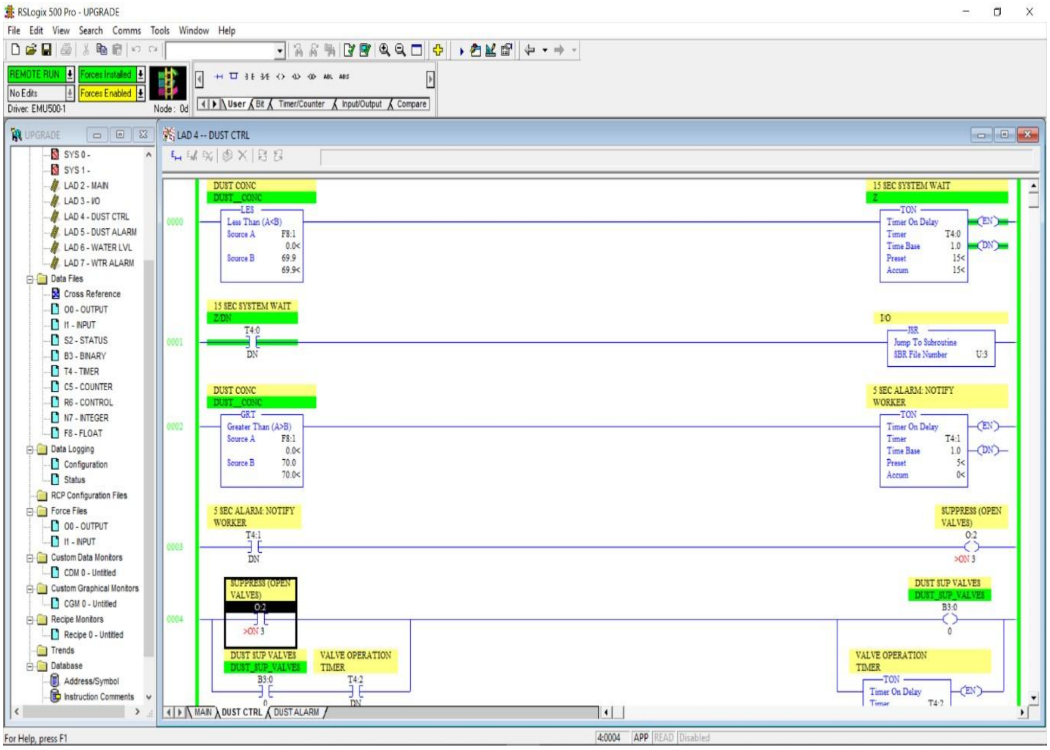


Figure 7. A 15 second timer triggered on Rung 0000.

Figure 8. High dust level and low water levels recorded.

The 15 second timer has been added to the water level control ladder to check false sensing of the low water level condition. Water can be wavy and hence trigger a false value of water level as the waves have high and low points. If the water level recorded is an actual value, the timer deenergizes after 15 seconds for the tank pump to be triggered on. A false value resets itself as the high points in the wave will return values of water level which are higher than the critically low level. Although there is a high dust value recorded, the system overrides that signal and pumps water into the tank until the water level is 50% or more of the full tank volume. An examine if-close bit has been programmed into the water pump control to force the pump into an off position when the water level reaches a 50% or more of the tank volume. For all values less than 50% of the tank volume, the examine-if-close bit remains false. It checks as true for all water levels greater than 50%, turning into an open position and turning off the pump. Figure 10 shows the alarms triggered by the low water level. A notification to the operator can be reset by a reset button on the HMI. The reset control can be seen on rung 0002 in Figure 10. Figure 11 shows control action taken by the PLC to suppress the high dust level recorded in Figure 8. A 5 second timer energizes an alarm to notify workers at the plant of hazardous levels of dust. The timer deenergizes after 5 seconds. The down bit of the timer energizes the valves to open to spray water through nozzles to suppress dust. Figure 12 shows high dust level alarm controls.

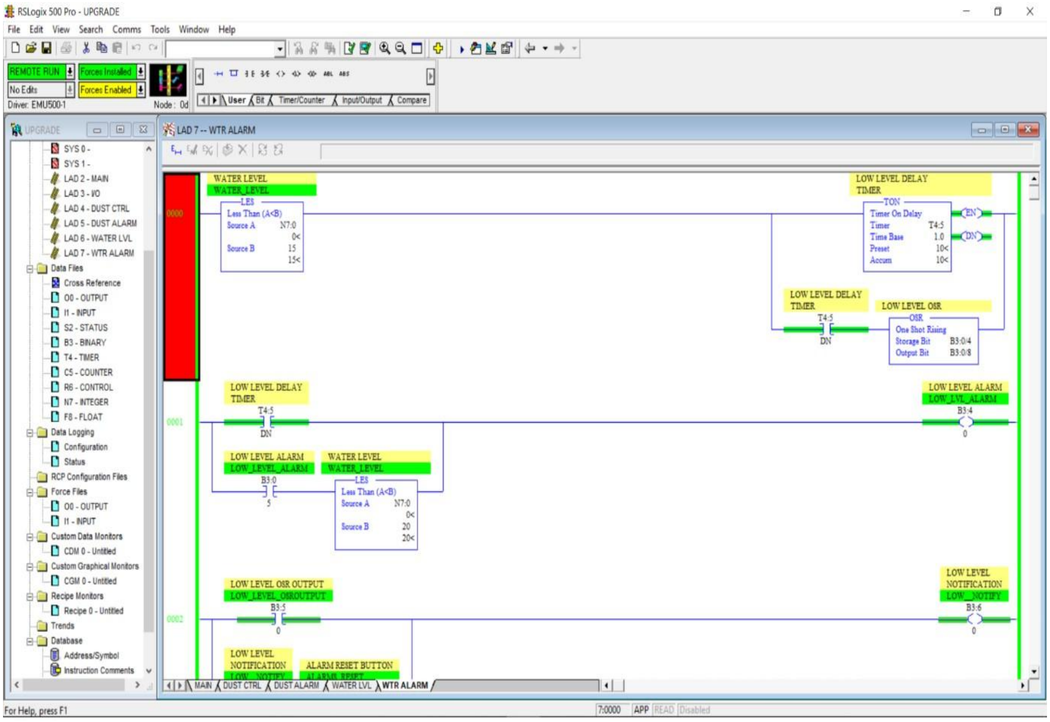


Figure 9. Tank Fill Pump Active.

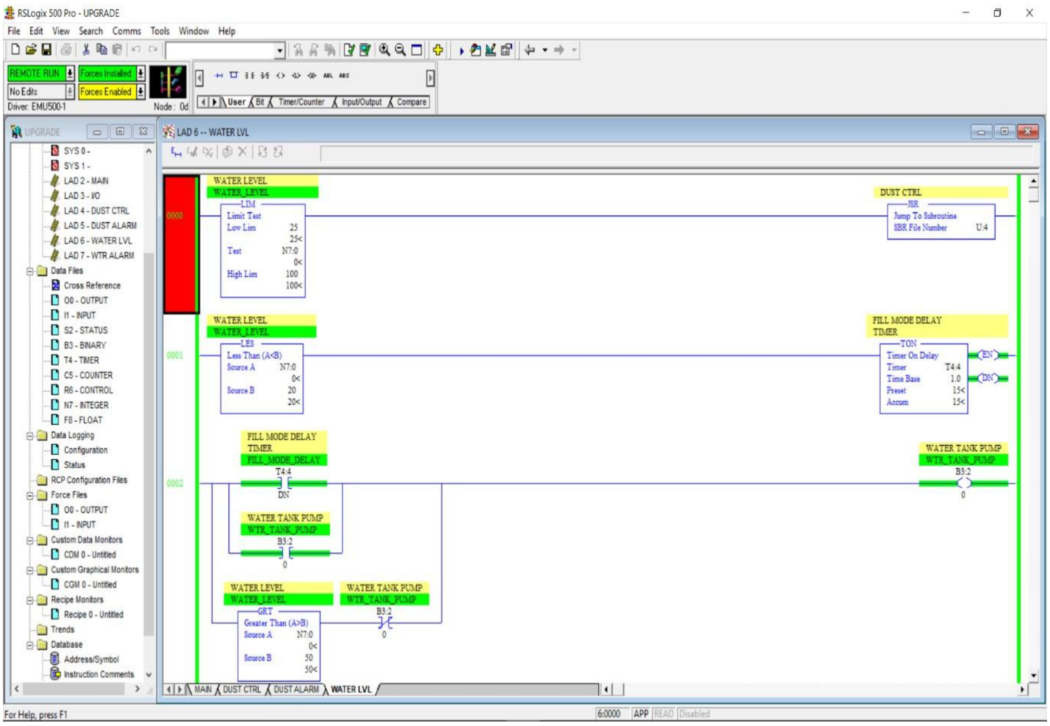


Figure 10. Tank Fill Pump Active.

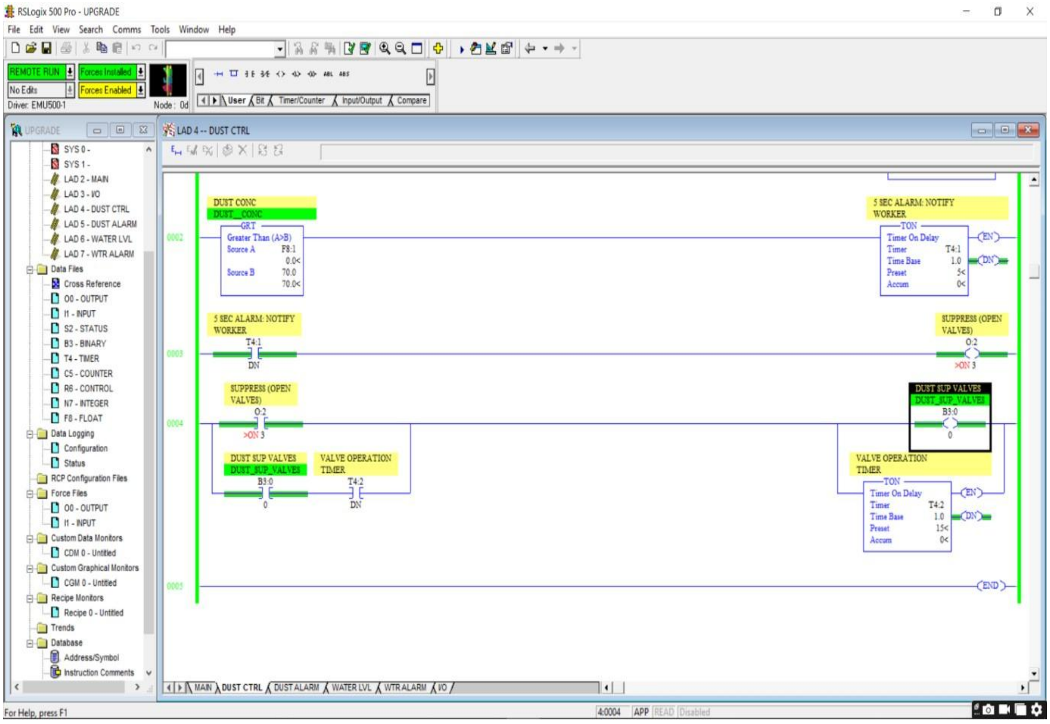


Figure 11. Dust suppression valves active.

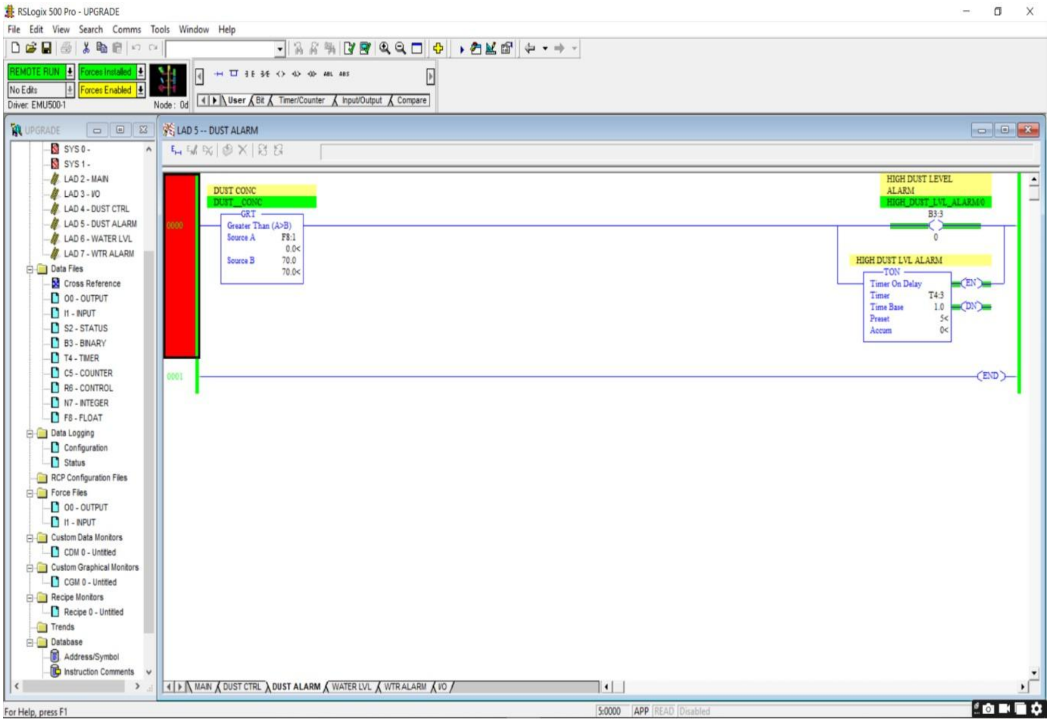


Figure 12. High dust level alarm active.

Figure 13 shows a high-water level recorded and notified by the HMI. This notification can be reset using a reset button as seen on rung 0004 in Figure 13.

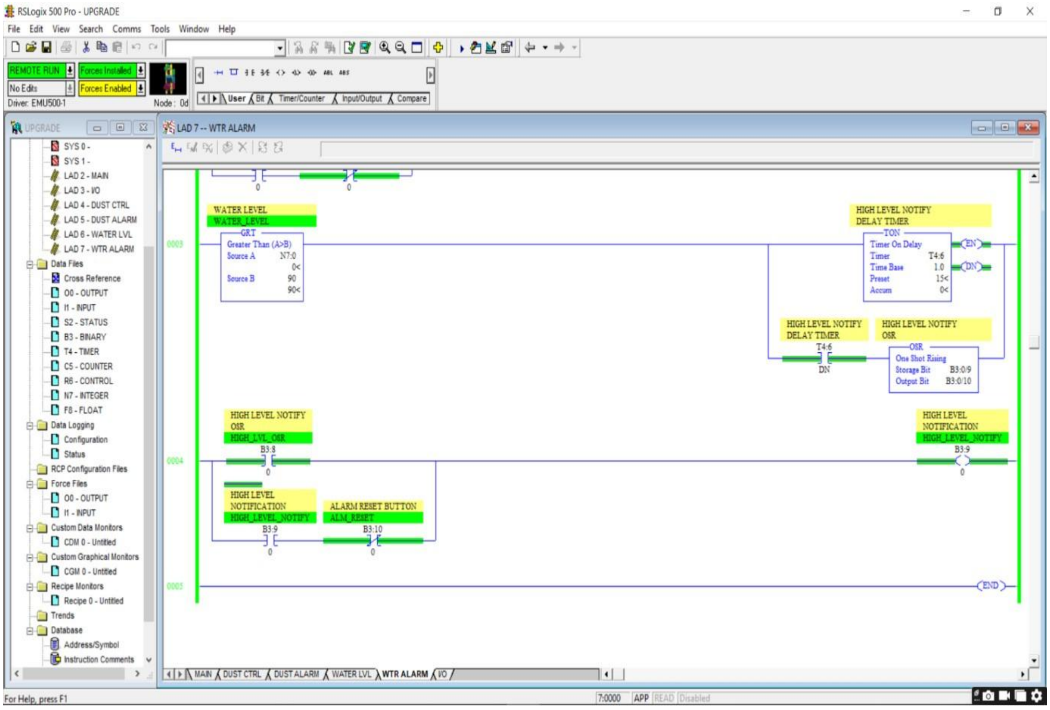


Figure 13. High water level notification.

The proposed design of the automated dust suppression system was successfully simulated with RSLogix 500 PLC programming software using LabVIEW as the human machine interface to keep track of dust concentration and water tank levels. Results obtained show that the water tank pump is triggered into action when a water level lesser than 20% of the tank volume is recorded. The pump was looped at this stage and automatically reset into off position when the water level was above 50% of the full tank volume.

The dust suppression controls came online after the water levels were above 50% as programmed in the water level control ladder, triggering water pumps and nozzles into action with the detection of dust concentration above 70 $\mu g/m^3$. After 15 seconds of suppression action, the system reset to begin from the head of the operation, checking for water level and subsequently, dust concentration levels. The automation of the controls of the various alarms and notifications were realized. The resetting of notifications by the operator was successful through the HMI controls using LabVIEW.

The simulation results confirm that the automated PLC-based system addresses the key limitations of manual dust suppression identified in the study site. By triggering a 5-second audible alarm and initiating water spray within a single control cycle, the system eliminates the reaction delay inherent to human-operated sprinklers, which require operator detection and manual valve activation. The 15-second suppression cycle, followed by automatic re-evaluation, enables adaptive control without continuous water discharge, hence reducing water consumption compared to fixed-schedule spraying systems [15], [16]. The water tank management logic, which prioritizes tank refilling before dust suppression when water level falls below 20% of tank volume, ensures system readiness and prevents dry-run pump damage. These combined features demonstrate that the proposed framework can improve both occupational health outcomes and operational efficiency at processing plants exhibiting dust exceedances of the type documented in Section 2.2.

4. Conclusions

This work successfully demonstrates the development and simulation of an automated, PLC-based dust suppression system designed to monitor and control hazardous particulate concentrations in mineral processing environments. The integration of RSLogix 500 for ladder logic programming, LabVIEW for real-time visualisation, and MATLAB for dust trend analysis enabled a fully automated control cycle—initiating water spray sequences, alarms, and tank refills without manual intervention.

Analysis of historical particulate data revealed that approximately 20 % of TSP measurements exceeded the 150 µg/m³ threshold, while 25 % of PM_{10} readings were above 70 µg/m³, confirming the necessity for automated and continuous suppression. Simulation results showed that the system effectively detected elevated dust levels, triggered a 5-second audible alarm upon threshold exceedance, and subsequently activated low-pressure water spray through adaptive 15-second suppression cycles until safe concentration levels were restored. The inclusion of water-level sensors ensured reliable tank management, preventing dry-run conditions and maintaining system readiness.

Overall, the proposed design achieved its objectives of improving air-quality compliance, occupational safety, and environmental protection through automation. By minimizing human dependence and introducing logic-based feedback control, the system provides a cost-effective, scalable framework adaptable to various crushing and mineral processing operations. Future enhancements may include IoT-enabled remote monitoring, PID-controlled spray optimization, and machine-learning-based predictive control for real-time adaptation to fluctuating dust conditions and seasonal variations.

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Conflicts of Interest: The authors declare no conflicts of interest.

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