Industrial Automation
Color Mixing Plant
Group 10

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1 Introduction

The goal of this project is to familiarise ourselves with industrial automation by proposing a monitoring and control infrastructure for a color plant consisting of five mixing stations.

In section 3, the plant is identified and the I/O signals, alarms and interlocks are listed. In section 4 the architecture of the color plant is specified, along with the choice of several components ranging from the choice of PLCs to the SCADA server. In section 5, the synoptic view required to supervise the whole plant is proposed and implemented using WinCC OA, the supervision system provided. In section 6 a failure analysis is made and preemptive solutions are proposed. Finally we conclude in section 7 and provide a global view of the work done during this project.

2 Task Assignment Between the Group Members

For the duration of the project, all the group members attended a weekly meeting to discuss the work division and the progress made. The work load was divided as follow:

- Functional Analysis: Thomas M. and Leonardo worked on the I/Os while Filip and Thomas B. worked on alarms and interlocks
- Automation Architecture: Filip worked on the architecture of the plant helped by Leonardo in the choice of components
- Supervision: Leonardo focused on the WinCC OA implementation.
- Qualitive Dependability Analysis: Thomas B did the FMEA analysis
- Deliverables: Thomas M. put most of the report together and everyone contributed to the presentation

3 Functional Analysis

Several assumptions are made about the system: It is assumed that the five mixing stations are identical, thus we will consider only one and duplicate it. If something concerns the whole plant instead of one mixing station it will be explicitly marked as such. The mixing tank and output pipes are considered to be frequently cleaned, thus no sensors are needed to control the quality and potential corruption of the paint. All color valves can be opened at the same time. There is no gravity influence on the flow. The velocity of the mixing is irrelevant.
The list of output signals and the list of input signal are given respectively in tables 1

and 2. The naming convention is given under the designation column. The actuator type column design which kind of actuator the specific signal control. When the signal is designate as digital, it can take the value 0 or 1. Analog means the the quantity measured is continuous and has been discretised. The naming convention to distinguish the signals is: the first number designate the mixing station from 1 to 5. The letter at the second position designate the tank the signal is going to. The letters used are: C for cyan, M for magenta, Y for yellow, K for black, W for white and P for the mixing tank. The last part of the name designate the actuator or sensor. the designation are: V for valve, M for pump, P for pump, LD1 for the discreet level sensor high-high, LD2 for the discreet level sensor high, LD3 for discreet level sensor low, LD4 for the discreet level sensor low-low, LA for analog level sensor. F stands for flow-meter, SFe stand for the flow-meter at the exit of the color pipe. If the F is followed by an e, it indicate that the flow-meter is at the exit of a pipe. G stands for the gyroscope on the mixer.

Designation	Actuator type	function	Signal type	Signal range
1CV	Valve	control output of cyan paint	Analog	0-100
1MV	Valve	control output of Magenta paint	Analog	0-100
1YV	Valve	control output of yellow paint	Analog	0-100
1KV	Valve	control output of black paint	Analog	0-100
1WV	Valve	control output of white paint	Analog	0-100
1PV	Valve	control the output of the mixing tank	Analog	0-100
1PM	Mixer	control mixing	Digital	0-1
1PP	Pump	empty mixing tank	Digital	0-1
1E	Emergency switch	stop whole station	Digital	0-1
AE	Main switch	stop whole plant	Digital	0-1

Table 1: List of output signals (control) for station 1

Valves: The signals 1CV, 1MV, 1YV, 1KV and 1WV controls the valves of the color tanks. The signal goes from 0 which mean the valve is close to 100 which mean that the valve is fully open. The signal 1PV control the valve that by which the mixing tank is emptied.

Mixer: The signal 1PM switch on and off the mixer.

Pump: The signal 1PP activate the pump that transfer the paint from the mixing tank to the filler station.

Emergency signals: 1E stop the whole station, it can be send manually or automatically if a leakage is detected. AE stops the whole color mixing plant. It can be used for example if a natural hazard such as an earthquake happens.

Designation	Sensor type	function	Signal type	Signal range
1CLD1	Level sensor	level indicator: high-high	Digital	0-1
1CLD2	Level sensor	level indicator: high	Digital	0-1
1CLD3	Level sensor	level indicator: low	Digital	0-1
1CLD4	Level sensor	level indicator: low-low	Digital	0-1
1CLA	Level sensor	remaining amount of paint	Analog	0-0.2 $[m^3]$
1PLD1	Level sensor	mixing tank paint level: high	Digital	0-1
1PLD2	Level sensor	mixing tank paint level: low	Digital	0-1
1PLA	Level sensor	amount of paint in the mixing tank	Analog	0-100
1CF	Flow-meter	amount of paint leaving cyan tank	Analog	0-100
1MF	Flow-meter	amount of paint leaving magenta tank	Analog	0-100
1YF	Flow-meter	amount of paint leaving yellow tank	Analog	0-100
1KF	Flow-meter	amount of paint leaving black tank	Analog	0-100
1WF	Flow-meter	amount of paint leaving white tank	Analog	0-100
1SFe	Flow-meter	amount of paint leaving color pipe	Analog	0-100
1WFe	Flow-meter	amount of paint leaving the white pipe	Analog	0-100
1PF	Flow-meter	amount of pain leaving the mixing tank	Analog	0-100
1PFe	Flow-Meter	amount of paint entering the filler station	Analog	0-100
1PG	Gyroscope	check if mixer is rotating	Digital	0-1

Table 2: List of input signals (sensing) for station 1

Level sensors: There are two types of level sensors. Digital level sensors emit a signal when the paint's level is higher than the sensor. Each color tank has four of those sensors (signals 1CLD1, 1CLD2, 1CLD3 and 1CLD4 for the cyan tank of station 1) and the mixing has two of those (signals 1PLD1 and 1PlD2 for staation 1). The analog level sensors measure the current amount of paint inside the tank. There is one for each color tank as well as for the mixing tank.

Flow-meters: The flow-meters measuring the actual amount of paint leaving each tank (signals 1MF, 1YF, 1KF and 1Wf for station 1). The signals are normalized so that 0 is when the is no flow and 100 is when the flow is at its maximal when the valve is fully open. Several redundant flow-meters are added to the system to detect leakage: One flow-meter is situated at the end of the color pipe (1SFe), one at the end of the white pipe (1WF) and one at the filler station (1PFe).

Gyroscope: This sensor is situated on the mixer to check if it is rotating properly (1PG).

List of alarms:

-The signal 1CLD1 triggers a color supply shortage alarm.

-If the valve of the mixing tank is opened (1PV) and no flow is measured with the flow-meter (1PF) then the alarm, Mixing tank not emptying is sent.

-if one of color valve is opened (1CV, 1MF, 1YV, 1KV and 1WF) and the corresponding flow-meter (1CLA, 1MLA, 1YLA, 1KLA and 1WLA) doesn't measure the associated flow then the alarm Color tank not emptying properly is sent.

-A signal closing a valve is emitted (1CV, 1MF, 1YV, 1KV and 1WF) and the the corresponding flow-meter signal (1CLA, 1MLA, 1YLA, 1KLA and 1WLA) contains data of a flow then the alarm valve not closed properly is sent.

-If a command signal doesn't respect an interlocks: Interlock not respected alarm.

-If the command signal (1PM) activate the mixer and the gyroscope (1PG) doesn't measure a rotation then the alarm, mixer not functioning is sent.

-If the sum of the flow signal of the color tank (1CF, 1MF, 1YF and 1KF) is not the same as the flow measured at the exit of the pipe (1SFe) while flow is in steady state then the alarm. leakage in the color pipe is sent.

-If the flow at the exit of the white tank (1WF) is not the same as the flow at the exit of the white pipe (1WFe) while the flow is in steady state then the alarm, leakage in the white pipe is sent.

-If the flow at the exit of the mixing tank (1PF) is not the same as the flow entering the filler station (1PFe) while the flow is in steady state then the alarm, leakage in the mixing tank pipe is sent.

List of interlocks:

-Mixing initiated without enough paint in the mixing tank: the mixer can't be activated (1PM) before the low digital level sensor (1PLD2) detect paint.

-Not enough time spend in mixing tank when opening mixing tank exit valve: Time delay between the detection of a flow pouring into the mixing tank (1SFe and 1WFe) and the control command to open the exit valve (1PV) and activate the pump (1PP).

-Mixing tank valve (1PV) stays closed while the color tank valves (1CV, 1MV, 1YV, 1KV and 1WV) are open.

-The pump can't be activated (1PP) before the mixing tank valve (1PV) is opened.

-The mixer can't be activate is not running while the mixing tank is empty: o7 can't be send before i6 is received.

-The color valves (1CV, 1MV, 1YV, 1KV and 1WV) can't be opened while the high digital level sensor (1PLD1) detect that the mixing Tank is full.

4 Automation Architecture

The Goal of the automation architecture is to control each actuators of each of the five mixing stations and provide sufficient information about operations to supervision level. Of course, only useful information should be display at the SCADA level otherwise the plant supervisors would be overwhelmed. The state of each mixing station is displayed on the SCADA HMI screen installed in the control room. Should a problem occur, an alarm is displayed on the screen to alert the operator. The orders from the operator contain the desired color mix and quantity to produce, the mixing station takes charge of the process behind it and reports progress. It is possible to single-handedly shutdown one or all of the stations. This can be triggered by the ManagerPLC 0, shown in figure 1, that serves as a watchdog for all plant operations, or by the operators directly. The idea behind the ManagerPLC being that it can react faster than the human operators, yet it doesn't have priority over human commands.

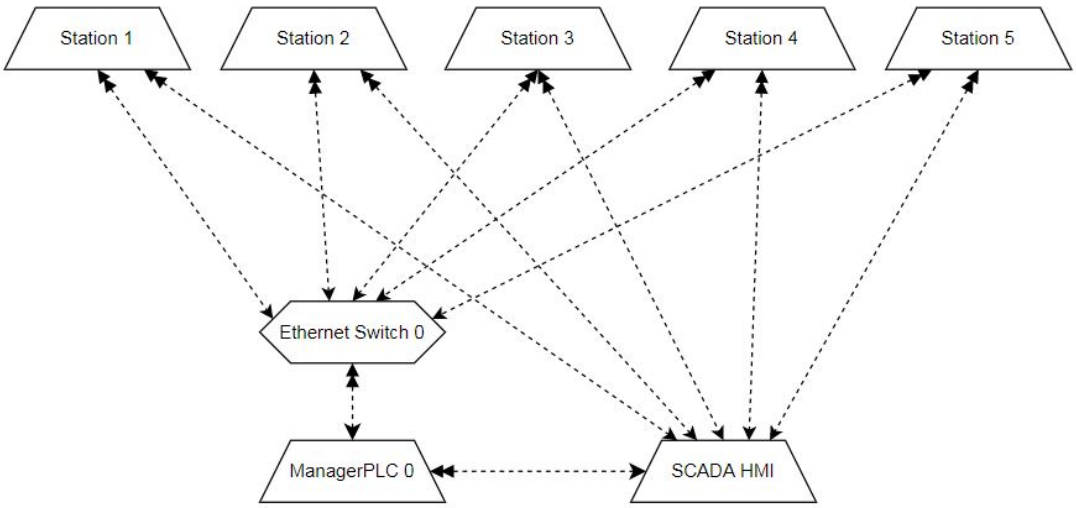

Figure 1: Overview of the color mixing plant

The data flow connecting The SCADA to the sensors and actuators of one mixing station is shown in figure 2. Z correspond to the number of the station going from 1 to 5. The architecture will be explained with more details using figure 3 to 6. The supervision will be developed in detail in section 5.

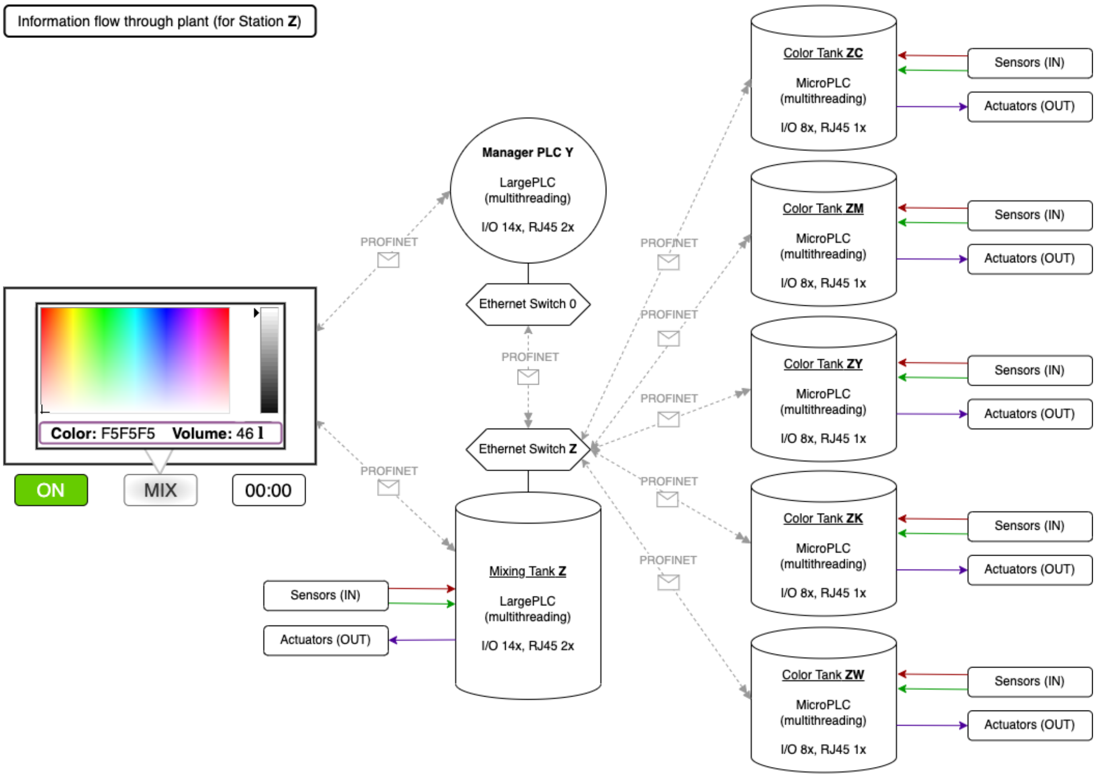

Figure 2: Data flow of one mixing station

The field bus used to connect The manager PLC to the SCADA is the PROFINET bus. It is based on Ethernet which is future proof and permits to operate at high transmission speed without the need for special devices to connect to the operator's workstation. The architecture of the Manager PLC is shown in figure 3. The typical speeds being around 100Mbps, if we account for expansion possibilities and limit our current plant to 50% of that bandwidth. We can still assume data transfers of 10Mbps per mixing station, which is more than enough for our application. The commands are transmitted via an Ethernet switch to the main PLC of each mixing station, which are situated on the mixing tank.

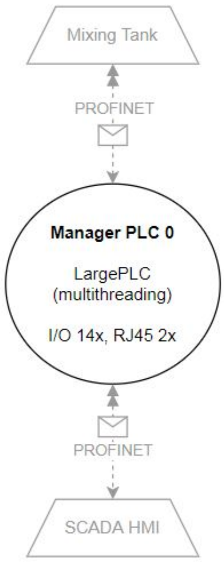

Figure 3: Manager PLC 0

The architecture at the mixing station level is shown in figure 4. The field bus is arranged in a star layout with an Ethernet switch at its heart. It connects the SCADA, the Manager PLC, the main PLC of the station situated on the mixing tank and the MicroPLC of each of the color tank. Z correspond to the number of the station.

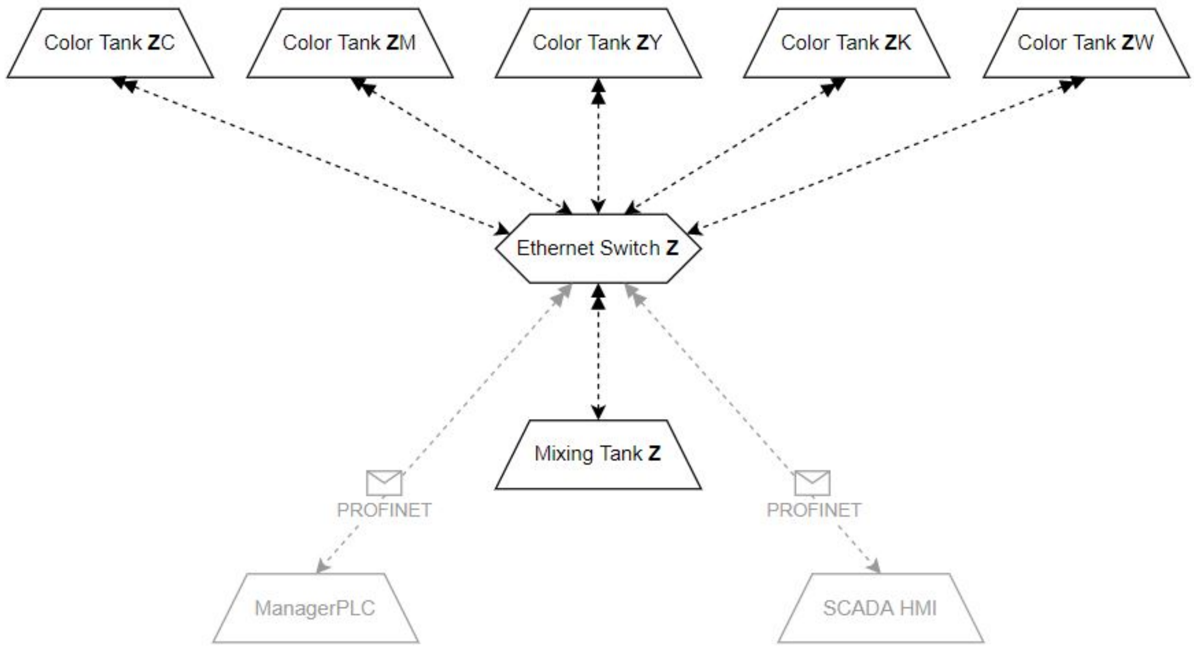

Figure 4: Overview of a color mixing station

The PLC at the mixing tank makes sure all the interlocks of the mixing station are respected. It receives the input signals of the various sensors shown in figure 5. The two level sensors of the mixing tank are event-driven. The low-level sensor is here to make sure take there is enough paint in the mixing tank for the mixer to work. The high-level one interrupts the pouring of paint in the mixing tank in order to avoid overflow. It should not trigger in a normal process as the command from the SCADA is limited to the maximal capacity of the mixing tank. All the other sensor linked to the mixing tank are cyclic. They provide a feedback on the process of the mixer, output valve and the pump and control the absence of leakage. The outputs are the commands to the mixer, output valve and the pump. The main PLC send an alarm to the SCADA if a interlock is not respected or a problem occurs. The command received from the Manager PLC is processed and divided into a command for each of the color tank. The command consist of an amount of paint the color tank needs to pour to respect the command of the operator.

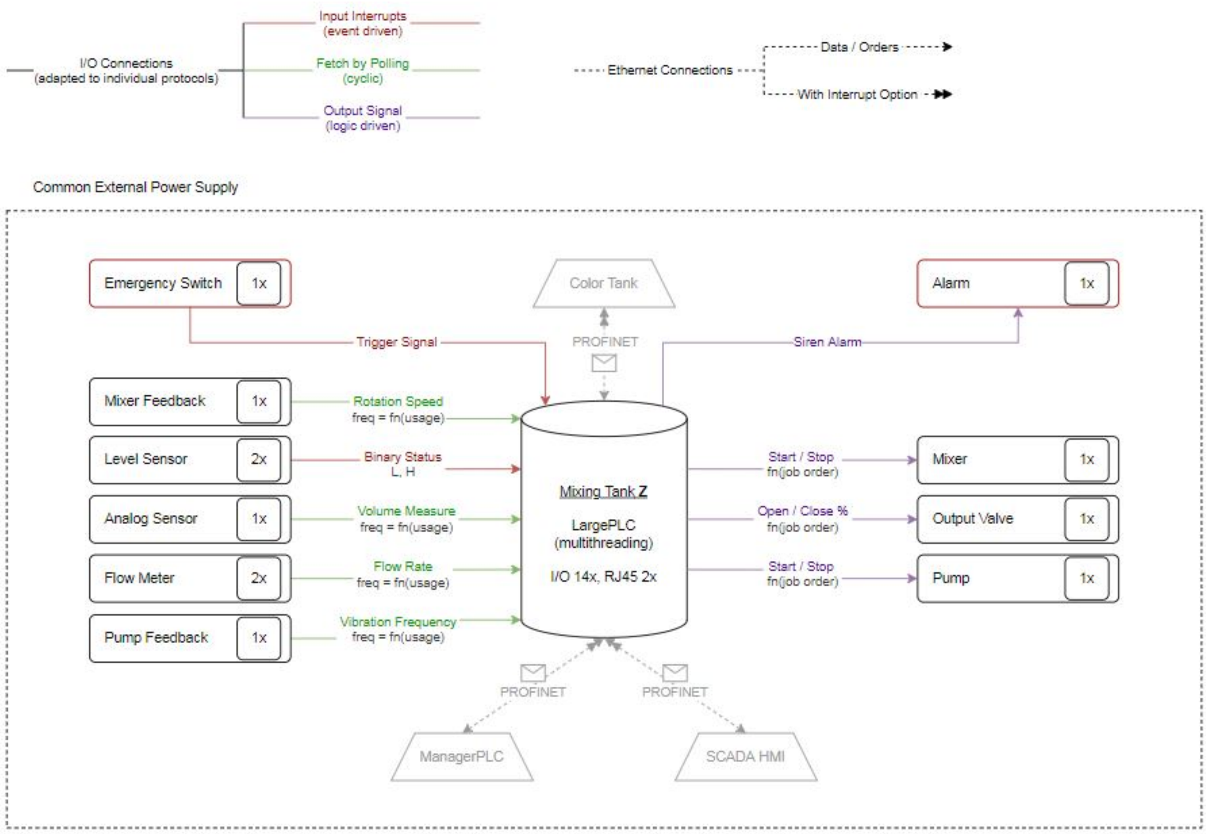

Figure 5: Overview of mixing Tank Z

The color tanks possess a micro PLC that receive the command from the mixing tank PLC. It transmit the command to the valve and keep it open until the right amount of paint is poured. The progress of the process is observed using the analog level sensor and the flow meter which are cyclic sensors. The four event-driven level sensors are used to control the amount of paint inside the color tank. The color tank overview is shown in figure 6, the letter X corresponds to the color of the tank: C for cyan, M for magenta, Y for yellow, K for black or W for white.

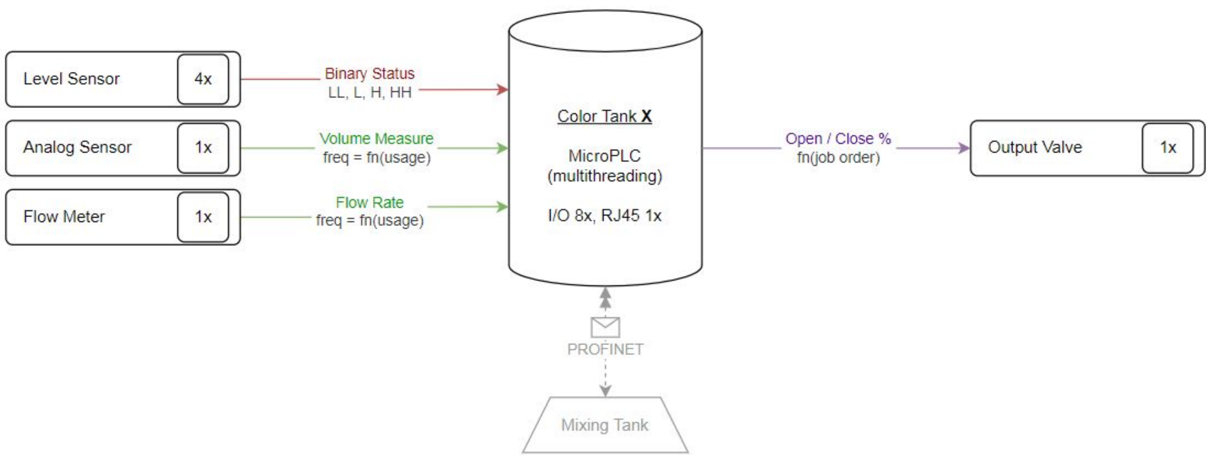

Figure 6: Overview of a Color Tank

4.1 Components

The Manager PLC and the main PLC of each of the five mixing station are a S7-1200 PLC [1] from Siemens shown in figure 7. The twenty-five micro PLC of the color tanks are the LOGO 8 (6ED1052-1CC08-0BA0) micro PLC [2] from Siemens shown in figure 8.

Supplier:	Siemens
Product type designation:	CPU 1217C
Supply Voltage:	24 V DC
lower limit(DC):	20.4 V
upper limit (DC)	28.8 V
Current consumption	600 mA
Work memory:	150 kbyte
Load memory:	4 Mbyte
Number of digital inputs:	14
Number of digital outputs:	10
Number of analog inputs:	2
Number of analog outputs:	2
Interface type:	PROFINET
Dimensions:	150x100x75 mm
Weight:	530 g

Figure 7: Siemens S7-1200

Supplier:	Siemens
Mounting:	on 35 mm DIN
Supply Voltage:	24 V DC
lower limit(DC):	20.4 V
upper limit (DC)	28.8 V
Number of digital inputs:	8
Number of digital outputs:	4
Dimensions:	71.5x90x60 mm

Figure 8: 6ED1052-1CC08-0BA0 Siemens

The Ethernet switch of each mixing station require eight ports (see figure 4). The product select for this task is the 2891002 Phoenix Contact [3] Industrial Ethernet Switch shown on figure . It has the necessary amounts of ports and a data transmission speed of 100 Mbps.

Figure 9: 2891002 Phoenix Contact

The S7-1200 is ideal for an automation system of medium dimension, with no strict requirements on the performance. It provides the functionalities required by the plant at a relatively low price and with a compact design. The integrated PROFINET interface, allows a easy communication with the LOGO micro PLC and with the upper SCADA level. The selected model 1217C has two integrated ethernet ports allowing an easier connection to the local switch for the single tanks and with the upper level.
The LOGO 8, with its low cost (around 100 CHF), its small dimension and the integrated ethernet port, is the optimal choice to transmit the control signal to the single tank actuator and receive the signals from the sensors. The number of integrated input and output is enough to cover all the signal of a single tank, without adding I/O extension cards.
The two type of PLC are disposed in a common configuration client-server [4], this allows to avoid individual cables or wires for every single signal.
Because both PLC have integrated ethernet ports, PROFINET was the obvious choice. PROFINET grants a communication through TPC/IP protocol, with a high flexibility an reliability, an easy installation and a higher speed compared to PROFIBUS. Scalability being an important design factor to us, we made sure our data bandwidth could support another Mixing Station being added to the system. Standard PROFINET speed is over 100Mbps. For scalability and margin on this number, assume 10Mbps budget per Station and ManagerPLC in our design architecture. The ManagerPLC can then expect 1Mbps to and from each Mixing Station and each Mixing Station can expect 1Mbps per second from each Color Tank and up to 3Mbps is allocated for its own operations, which makes it running at 80% of its bandwidth. These assumptions provide an upper bound of 40Mbps for our five mixing stations combined and each of them has an additional 20% margin for further expansion.

5 Supervision

5.1 Synoptic view

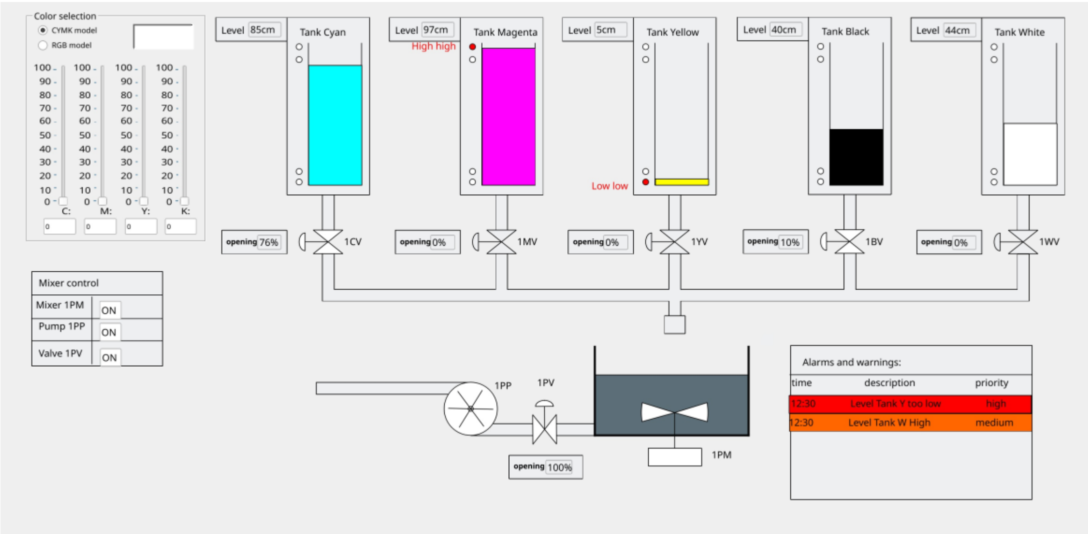

Figure 10: Detailed mixing station view

Following the principle introduced in the dedicated lecture, we removed the animation and simplified the design. Tank and pipes design are made simpler (no 3D) but still understandable. We tried to make the data as clear as possible including trends, range and units of measurements. The color coding is simpler and avoid the use of green for running components(like the mixer or the pump), instead we use white to indicate the activity.

Figure 10 is the synoptic view of a single mixing station implemented in WinCC OA. On the left side of the panel the control part is grouped together to give more rhythm to the view. On the lower right side a summary of the alarm is showed.

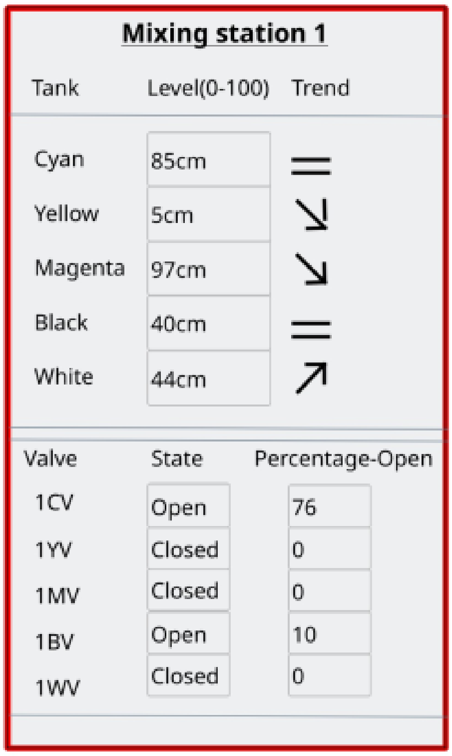

Figure 11: Summary of a single mixing station

To avoid adding to much complexity to the simulation, alarm and control are not functioning, the remaining parts, on the other hand, are correctly working if tested in WinCC OA. Figure 11 is a summary of the most important parameters of a single mixing station. It also signals the presence of alarms with a flashing red contour color,that can be investigated moving to the more detailed view already discussed. The idea is giving an overview of the state of the plant before addressing the specific problems and undertaking the necessary actions.
Figure 12 is a representation of the summary view of the five mixing station, it shows what could be the final implementation (this was not done in WinCC OA).

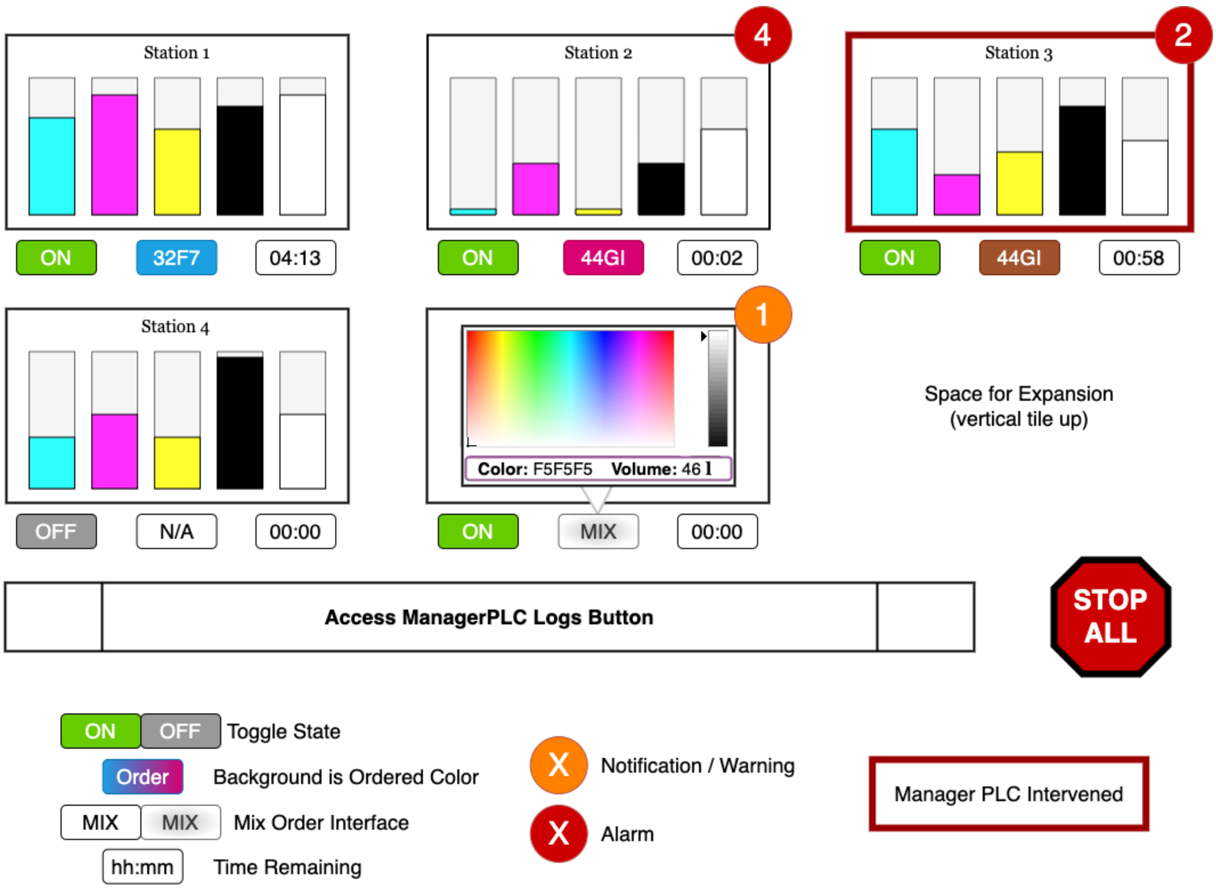

Figure 12: Synoptic plant view

6 Qualitive Dependability Analysis

6.1 FMEA analysis

The FMEA analysis was preferred over the FTA for two reasons:

- The non critical failures had to be identified
- Given this work is about automating a plant, few human interaction are required, and external events are limited. This makes it more likely to have an extensive catalog of the failure modes.

The detailed FMEA analysis is available in the annex 8.1.

6.2 Interpretation

Based on the FMEA analysis, critical failures have been identified. Every failure that leads to colors overflowing and pouring, resulting in heavy maintenance operations and complete stop of the station is classified as critical. Additional precautions and redundancies have been recommended in these cases. It is then to the discretion of the owner to decide whether this recommendations will be implemented or not.

Also, failure on the non-critical sensors can become critical if other related sensors are failing as well. They should therefore be considered as a fuse on the system, and treated as soon as they are detected to avoid more serious failures.

7 Conclusion

This report presents our solution for the implementation of the system architecture design of a color mixing plant from the field to the management level. For the team, it was a first step into the field of industrial automation involving considerations from different fields of engineering. Ranging from electronics to communications and human interfaces to risk considerations, we put together a proposition to automate this color plant.

We first identified the purpose we were trying to achieve and what the operators and plant managers would accept to work with. This triggered some unwritten requirements around basic and simple design for dependability and to ease maintenance jobs and scalability options for further expansion. Given a set of sensors and actuators, we expanded the plant design to meet our requirements and identified signals to control the plant and the associated alarms to notify the operators in case of failure. We then put together an automation architecture based on our assumptions and bandwidth requirements and making sure it could be scaled with minor changes. We didn't have many components to choose for this design but those we did are basic, off the shelf and reliable. A high level

FMEA was performed to evaluate risks of our choices and areas for improvement. One outcome from these considerations was the addition of an emergency stop signal.

Altogether, this project provided us with a great insight into the thinking process of industrial automation and the use of WinCC OA. The Siemens workshop then introduced us to PLC programming and sensor interfacing. Furthermore, we carried out our team contract quite successfully so we are happy with this work and its outcome.

8 Annex

8.1 FMEA analysis of one station (xlsx attached to submission)

Area	Component name	Function	Failure mode	Failure cause	Failure effect - local	Failure effect - global	Failure detection	Other provision	Remark
	HH sensor	triggers an alarm preventing the filling of the tank	fails to activate	Hardware error	Tank may overflow	Color everywhere, damaging equipment and need for a extended maintenance	Visual (occurs only during filling), analog sensor	Establish visual inspection during the filling of the tank	Critical failure
	H sensor	triggers a warning informing the tank is almost full	fails to activate	Hardware error	No warning on tank reaching maximum capacity	Tank filling may be stopped abruptly	Analog sensor, HH sensor		
	L sensor	triggers a warning informing the tank is almost empty	fails to activate	Hardware error	No warning on color level being too low	Color may become unavailable suddenly	Analog sensor, LL sensor, SCADA calculations		
	LL sensor	triggers an alarm and an interlock preventing mixes containing this color to be prepared	fails to activate	Hardware error	Tank not providing color	Color mix not accurate	Flowmeter feedback, SCADA calculation		
Color tank	Analog level sensor	Informs the operator of the color level	wrong output	Hardware error	Inaccurate calculations of tank capacity, wrong maintenance schedule	Loss of productivity	SCADA calculations, digital sensors		
	Tank	holds the color	leakage	Contact with object	Tank leaking	Color everywhere, damaging equipment and need for a extended maintenance	Analog and digital sensors, visual inspections	Establish routine inspections	Critical failure
	Valve	releases the color from the tank	fails to open	Hardware error	Tank not providing color	Color mix not accurate	Flowmeter feedback		
			fails to close	Hardware error	Color pouring endlessly into the pipe	Color everywhere, damaging equipment and need for a extended maintenance	Flowmeter feedback	Add a security valve at the end of the color pipe	Critical failure
	Pipe	conducts the color to the mixing tank	leakage	Contact with object	Pipe leaking	Color everywhere, damaging equipment and need for a extended maintenance	Flowmeter feedback, visual inspections	Establish routine inspections	Critical failure
	Flowmeter (valve)	provides feedback from the valve	wrong output	Hardware error	SCADA not providing the real system state	Loss of productivity	SCADA calculations		
	Flowmeter (pipe)	checks the amounts of colored poured into the mixing tank	wrong output	Hardware error	SCADA not providing the real system state	Loss of productivity	SCADA calculations		
	Mixer	mixes the colors	fails to start	Motor broken	Colors not mixed	Color mix not accurate	Motor feedback	Establish routine inspections	
	Analog level sensor	Informs the operator of the color level	wrong output	Hardware error	Inaccurate calculation of mixing time and emptying time	Color mix not accurate, loss of productivity	SCADA calculations, digital sensors		
	L sensor	triggers a warning informing the tank is almost empty	fails to activate	Hardware error	No warning on mixing tank being almost empty	Loss of productivity	Analog sensor, SCADA calculations		
	H sensor	triggers an alarm and an interlock closing color valves	fails to activate	Hardware error	Mixing tank may overflow	Color everywhere, damaging equipment and need for a extended maintenance	Analog sensor, SCADA calculations	Establish visual inspection during the filling of the tank	Critical failure
Mixing tank	Flowmeter	checks the amounts of colored poured into the end pipe	wrong output	Hardware error	SCADA not providing the real system state	Loss of productivity	SCADA calculations		
	Pump	pumps the color mix to the endpipe	fails to start	Motor broken	Mixing tank may not empty correctly	Color mix unavailable	Flowmeter feedback		
	Valve	allows the mix to be pumped	fails to open	Hardware error	Mixing tank cannot empty	Color mix unavailable	Flowmeter feedback		
			fails to close	Hardware error	Color pouring without control into the endpipe	Color everywhere, damaging equipment and need for a extended maintenance	Flowmeter feedback	Add a security valve at the end of the color pipe	Critical failure
	Pipe	conducts the color mix to the exit	leakage	Contact with object	Pipe leaking	Color everywhere, damaging equipment and need for a extended maintenance	Flowmeter feedback	Establish routine inspections	Critical failure
	Tank	holds the color mix	leakage	Contact with object	Tank leaking	Color everywhere, damaging equipment and need for a extended maintenance	Analog and digital sensors, visual inspections	Establish routine inspections	Critical failure

8.2 WinCC OA (files attached to submission)

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