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by Harri Jones

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Assignment: 1. Instrumentation for Automation Systems

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A structured and well presented report Good evidence of research with correct use of Harvard from a good range of sources. Good practical work with analysis and testing including a testing table.

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1. System Investigation

The focus on this assignment is the Process Station and Water Recirculation sub-systems on the CIM System

The P&ID diagram (*See Figure 8 for Process Rig*) contains four control loops.

TC511 – Temperature Control tank B1

LC541 – Level Control tank B1

FC531 – Flow control into each tank

FC535 – Flow control for tank B1

The interconnection between the Processing rig and water recirculation is the water pipe which runs from the top tank to the bottom tank. The top tank will refill the bottom tank on demand. (*See Figure 9 for Water Recirculation*)

1.1 Temperature Control

The CV produced by the temperature controller goes directly in to the SSR using PWM which controls the heater. The Temperature transmitter TT511 produces the PV. The circuit continues through 2 solenoid valves and into the cooling fan and into the pump amplifier LY541 these add cold water to the system which will affect the temperature. The temperature sensor used is a PT100 which goes to a signal conditioner converting the frequency into voltage and current. The voltage is fed to an analogue input on the PLC where the signal is converted into degrees on the PLC program.

PT100 Temperature Sensor.

The sensor is suitable for the application as it has a range of -75°C to $+260^{\circ}\text{C}$ which is more than enough for the fluid used (water). The sensor has a resolution of $\pm 0.1^{\circ}\text{C}$. The PT100 has a 100Ω resistance at 0°C and a resistance of 138.4Ω at 100°C . The 2-wire sensor has an accuracy of $\pm 0.30^{\circ}\text{C}$ at 0°C and a $\pm 0.80^{\circ}\text{C}$ at 100°C . A method to get a better accuracy would be to use a 3 or 4 wire configuration. The temperature and resistance relationship should be linear, linearizing the resistance will give a more accurate temperature reading. (*Datasheet from (Thermosense, 2017)*)

1.2 Level Control

Tank B1 on the diagram is controlled via the Level controller LC541, the level is sensed by the Level transmitter LT541. The water flow is controlled by the Pump LY541 and can be emptied by using the Drain solenoid valve V500. LS541 is also part of the loop which is a low-level limit switch.

The PMC 133 has an accuracy of $\pm 0.2\%$ and an operating temperature limit of -10°C to $+70^{\circ}\text{C}$. It has a max pressure of 10bar and a pressure measuring range of 0 – 40mBar. The supply voltage is 12.5 – 30V DC. (Datasheet from (Endress+Hauser Instruments, 2012))



Figure 1 – LT541

1.3 Flow control – 531 & 535

The water pressure comes from the recirculating water system and the flow is sensed by the Flow transmitter FT531. The proportional valve VF531 controls the flow by using a restrictor to change the size of the flow passage. The flow controller FC531 regulates the flow rate. Tank B2, B4 and B6 each have solenoid valves which the water travels through to enter the tank. The flow of liquid causes the turbine within the flow meter to rotate and produce frequency pulses. The rotation rate of the turbine is proportional to the flow rate and the RPS (revs per second) are proportional to the amount of liquid passing through. The pulses are counted and scaled into RPS (revs ^{per} second) which can then be turned in to litres for minute.

The CV produced from Flow Controller FC535 is fed to the pump amplifier LY541 and the PV is coming from Flow Transmitter FT535. The interlocks on the solenoid valves V515 or V516 are to make sure the pumped water can flow to the tank B1.

Flow Meter

The flow meter has a flow range of 0.25 to 4L/min and. The flow meter has an accuracy of $\pm 1.0\%$ and a maximum pressure of 20bar.

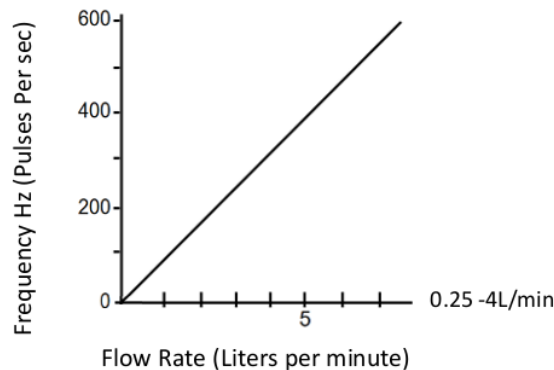


Figure 2 – Flow Graph

The graph shows that as the Flow rate increases the frequency increases giving a linear result. At a flow rate of 4 Litres (maximum) 300 pulses are produced. (Datasheet from (RS Pro, 2015))

1.4 Encoder

Above the chambers of the processing rig sits a gripper which moves horizontally back and forth down the line. The gripper moves via a conveyor belt above. The belt has a rotary encoder attached to it; the encoder converts the motion of the belt to an electrical signal to the plc to determine the position of the gripper. The encoder displays the position of the gripper on the HMI situated on the process station. The encoder on the processing rig has range of 500 pulses per revolution and a rotation speed of up to 10000rpm which is suitable for this application. (Datasheet from (Baumer Incremental Encoder, 2018))

1.5 Distance Sensor

Above the water chambers is a distance sensor which is aimed at the gripper. The sensor gives a measurement of how far along the belt the gripper has travelled. The sensor is doing a similar task as the encoder however at a less accurate reading. The O1D102 sensor has a measuring range of 0.2-3.5m and a sampling rate of 1-50Hz. (Datasheet from (IFM, 2021))

2. Research

2.1 Industry 4.0

Industry 4.0 is changing how companies improve, manufacture and distribute their products. Companies are upgrading to newer technologies such as IoT, AI and cloud computing to improve their production. The factories are installing robotics, embedded software and more advanced sensors. Data is collected for companies to give better control, and data visibility. Industry 4.0 allows for the ability to predict when issues will occur before they happen which will assist in boosting the profits of the companies by being more efficient. (Epicor, 2021)

Smart sensors allow for the transformation of companies by making them more efficient and productive. Sensors are one of the core components in Industry 4.0 by allowing transitions such as height, length and positions in facilities to be collected analysed and processed. Sensors allow for the user to remotely detect and record the feedback, such as electrical signals to a change in temperature. They boost production of the business, feedback valuable information, reduce overall costs and allow companies to compete. (Mohd Javaid, 2020)

2.2 IO-Link

IO-Link is standardized worldwide, it is a communication protocol that exchanges data from sensors and actuators these are commonly connected by fieldbus which allows for them to be in remote locations. The sensors or actuators are connected to a master which communicated to the controller. The master processes analogue values and digital signals. A benefit of these is that they can be integrated in to pre-existing systems and can be communicated by Modbus, Profinet and Profibus. (Jowett, 2019)

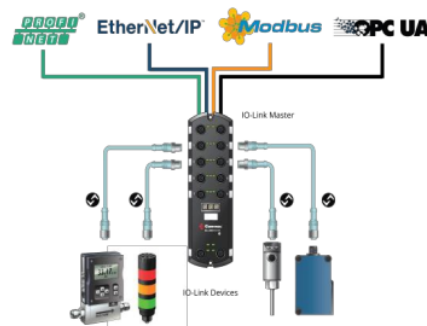


Figure 3 – IO-Link

Process Data – This shows the state of the sensor from the input/output data or communicate with the actuator state. 1 bit – 32 bytes of information is sent every communication cycle. An example of this would be a sensor reading the distance and sending the information to the master.

Service Data – This allows for detailed information to be obtained about the device such as serial numbers, model, parameters etc. Knowing this data can assist in identifying or configuring a device.

Event Data - Notifications such as warnings or errors are sent to the master from the IO-Link device. These notifications can be anything from information about alarms to overheating.

(Phoenix Contact, 2021)

2.4 Upgrading Sensors

The PT100 is outdated, upgrading the temperature sensor to an IO-Link compatible one would be beneficial. The upgrade is a TCC931 IFM Temperature Transmitter, this sensor has more precise measurements and logs the diagnostic values.

	Current: PT100	Upgrade: TCC931
Temperature range	-75°C to +260°C	-25°C to +160°C
Accuracy	± 0.30°C	± 0.20°C

(Datasheet from (IFM, 2021))

Sacrificing the temperature range is worth it as the temperature won't exceed more than 100 which is the boiling point of water. The more precise accuracy will give a better reading.

A recommendation would be a RUP500 Encoder which is IO-Link compatible. Advantages to changing to this is that it has a visible LED display on it, and it can be configured as an encoder, counter or speed monitor.

	Current: GI355	Upgrade: RUP500
Max Rotation speed	10000rpm	12000rpm
Pulses per revolution	500	1000

(Datasheet from (IFM, 2021))

what about flow and level?

2.5 Improving the maintenance and reliability of the system

Adding machine mount I/O reduces arc flash, having the I/O mounted on the outside of the electrical cabinet allows maintenance to be performed without having to open the cabinet and entering an unsafe environment. The controls can be diagnosed, troubleshot and replaced all outside of the cabinet. Machine mounted I/O saves time on maintenance as the failed points are accessible and visible. The diagnostics from the device allow narrowing down the scope of the problem. Information is provided on the details of the failure and therefore valuable time can be saved as the technician will know and prepare for the issue in advance. (Balluff, 2021)

IO-Link allows for an advanced diagnostic on the sensors, engineers can read additional information on the health and history of the sensor. When replacing a device and connecting to the system, IO-Link uploads its stored parameters which makes it easier for installation and programming. When replacing a device IO-Link will verify if the replacement is the correct product. Digital communication between the sensors and PLC allows for saving costs on cabling and integration time. (Turck, 2020)

3. Environmental, Sustainable Development, Commercial Risk and Codes of Practice

The water used on the processing rig and water recirculation is re-used and cycles throughout the machine. This lowers water consumption which benefits the environment. No waste is produced from the CIM system which assists in reducing waste in landfills. A factor to consider would be to use components which use less energy, this ^{Spelling}intern will lower the power consumption of the machine resulting in less electricity used. Overproduction waste occurs when parts are produced which are not required, to prevent this 'Just in Time' manufacturing can be implemented.

The introduction of Industry 4.0 would promote sustainable development within the CIM system. Implementing newer and more reliable devices such as sensors or actuators can prevent downtime on the machine and reduce costs on replacing faulty devices. The implementation of IO-Link reduces the use of hardware which reduces the cost and waste. Instead of producing a second machine, the consideration of upgrading the software to improve production rates can be discussed.

To achieve the best accuracy a sensor should be calibrated, this is because two of the same sensors could yield a slightly different reading. Temperature may affect the change in response as well as the 'age' of the device.

4. Calibration of Pressure Sensor

A Multimeter was used to read the rising and falling output voltage, the pressure was increased in intervals of 0.5bar. With this the hysteresis error was able to be calculated (See figure 4).

Measureand pressure (Bar)	Output Voltage (V)		Linear Value	Non-linearity error		Hysteresis Error
	Rising	Falling		Rising	Falling	
0	0	0	0	0	0	0
0.5	1.1	1.04	1	-0.1	-0.04	-0.06
1	2.04	2.01	2	-0.04	-0.01	-0.03
1.5	2.99	3.02	3	0.01	-0.02	0.03
2	3.98	4.01	4	0.02	-0.01	0.03
2.5	4.97	5.01	5	0.03	-0.01	0.04
3	5.99	5.99	6	0.01	0.01	0
3.5	6.97	7.03	7	0.03	-0.03	0.06
4	7.98	8	8	0.02	0	0.02
4.5	8.98	9.01	9	0.02	-0.01	0.03
5	10	10	10	0	0	0

Figure 4 – Pressure Sensor Table

static sensitivity?

The rising and falling values were linear. As the values had a minor difference the lines on the graph are almost overlapping each other. The largest hysteresis error was 0.06 giving a percentage of 0.6%. (See Appendix 12.1.3 for graph)

5. Calibration of Temperature Sensor

A Multimeter was used to read the rising and falling output current, the temperature was increased in intervals of 10°C. With this the hysteresis error was able to be calculated (See figure 5).

Measureand Temperature (°C)	Output Current (mA)		Linear Value	Non-linearity error		Hysteresis Error
	Rising	Falling		Rising	Falling	
0	4.06	4.06	4	0	0	0
10	5.66	5.66	5.6	-0.06	-0.06	0
20	7.27	7.29	7.2	-0.07	-0.09	0.02
30	8.88	8.89	8.8	-0.08	-0.09	0.01
40	10.5	10.5	10.4	-0.1	-0.1	0
50	12.11	12.11	12	-0.11	-0.11	0
60	13.72	13.72	13.6	-0.12	-0.12	0
70	15.33	15.33	15.2	-0.13	-0.13	0
80	16.94	16.94	16.8	-0.14	-0.14	0
90	18.55	18.55	18.4	-0.15	-0.15	0
100	20.1	20.1	20	-0.1	-0.1	0

Figure 5 – Temperature Sensor Table

The rising and falling values were linear, as the temperature increases the current increases. As the values had a minor difference the largest hysteresis error was 0.02 giving a percentage of 0.2%. (See Appendix 12.1.4 for temperature graph)

6. Calibration of Level Sensor

A Multimeter was used to read the rising and falling output current, the level was increased in intervals of 10cm. With this the hysteresis error was able to be calculated (*See figure 6*).

Measureand Level (cm)	Output Amps (mA)		Linear Value	Non-linearity error		Hysteresis Error
	Rising	Falling		Rising	Falling	
7	6.18	6.18	6.18	0.00	0.00	0
8	6.55	6.59	6.57	0.02	-0.02	0.04
9	7	6.99	6.97	-0.04	-0.03	-0.01
10	7.4	7.36	7.36	-0.04	0.00	-0.04
11	7.78	7.75	7.75	-0.03	0.00	-0.03
12	8.17	8.16	8.14	-0.03	-0.02	-0.01
13	8.53	8.54	8.54	0.01	0.00	0.01
14	8.94	8.92	8.93	-0.01	0.01	-0.02
15	9.32	9.34	9.32	0.00	-0.02	0.02
16	9.73	9.73	9.71	-0.02	-0.02	0
17	10.11	10.12	10.11	0.00	-0.01	0.01
18	10.49	10.49	10.50	0.01	0.01	0
19	10.88	10.89	10.89	0.01	0.00	0.01
20	11.36	11.28	11.28	-0.08	0.00	-0.08
21	11.7	11.67	11.68	-0.02	0.01	-0.03
22	12.05	12.04	12.07	0.02	0.03	-0.01
23	12.46	12.46	12.46	0.00	0.00	0

Figure 6 – Level Sensor Table

how did you work out this data?

The graph is linear beginning at 6.18cm and rising to 12.46cm. The largest hysteresis error is 0.08cm giving a percentage of 0.8% (*See Appendix 12.1.5 for graph*)

7. Calibration of Position Sensor

The position of the gripper was measured by 3 methods, visual, encoder and laser. The tape measure began at 201mm and was zeroed (*See figure 7*).

Distance (mm)		Encoder (mm)		Laser (mm)		Error
Actual	From 0	Actual	From 0	Actual	From 0	
201	0	80.4	0	269.76	0	0
301	100	178.6	98.2	380.46	110.7	12.5
401	200	278.6	198.2	474.08	204.32	6.12
500	299	377.6	297.2	579.57	309.81	12.61
600	399	476.3	395.9	681.43	411.67	15.77
700	499	576.5	496.1	791.29	521.53	25.43
801	600	677.3	596.9	889.26	619.5	22.6
901	700	777.3	696.9	991.02	721.26	24.36
1001	800	877.3	796.9	1088.24	818.48	21.58
1100	899	976.9	896.5	1189.53	919.77	23.27
1200	999	1077.7	997.3	1287.35	1017.59	20.29
1300	1099	1176.2	1095.8	1384.7	1114.94	19.14
1400	1199	1276.9	1196.5	1482.06	1212.3	15.8

Figure 7 – Position Sensor Table

The graph is linear beginning at 0mm and rising to 1276mm. The largest error is 25.43 between the encoder and laser (See Appendix 12.1.6 for graph).

8. Design Adaptation for Maintenance and Reliability

Software modifications were carried out on the PLC program and HMI screens.

8.1 TT511 – Auto Sequence

Start and stop pushbuttons for DC Pump P1 and AC Pump P2 were added along with led status lights to indicate that the pumps are running. (See appendix 12.1.7 for Auto Sequence HMI screen)

8.2 TT511 – Temperature Instrument

The PID values; Kp, Ki and Kd, On, Off and a Status lamp to indicate that it's running were added to the HMI screen (See appendix 12.1.8 for Temperature HMI screen). A graph was also added to the HMI screen to display the Setpoint (Blue), Process Variable (Red) and the Control Variable (Green). (See appendix 12.1.9 for Temperature HMI graph)

8.3 LT541 – Level Instrument

The PID values; Kp, Ki and Kd, On, Off and a Status lamp to indicate that it's running were added to the HMI screen *(See appendix 12.2.1 for Level instrument HMI)*. A graph was also added to the HMI screen. *(See appendix 12.2.2 for Level HMI Graph)*

8.4 FT535 – Flowrate Instrument

The PID values; Kp, Ki and Kd, On, Off and a Status lamp to indicate that it's running were added to the HMI screen *(See appendix 12.2.3 for Flowrate Instrument HMI)*. A graph was also added to the HMI screen. *(See appendix 12.2.4 Flowrate HMI graph)*

8.5 FT531 – Flowrate Instrument

A graph was also added to the HMI screen *(See Appendix 12.2.5 Flowrate Instrument HMI)*. The graph displays the Setpoint (Blue). *(See appendix 12.2.6 Flowrate HMI Graph)*

8.6 Robot Manual Control

Two displays for the encoder were added one shows the measured value and the other shows a visual representation of where the gripper is above the water chambers. *(See Appendix 12.2.7 for Robot Manual Control HMI)*

The encoder had to be programmed in to the PLC on TIA, the tags were created *(See Appendix 12.2.8 for PLC Tags)*. A Network was created and a Conversion block was added *(See Appendix 12.2.9 for Encoder Network)*.

8.6 HMI Testing Table

Test	Expected Result	Actual Result	Pass/Fail	Evidence
TT511 – Activating the heater by pressing the 'On' pushbutton.	The setpoint was set to 50 °C, the CV increases making the PV increase up to the setpoint value	The PV increases up to 42.91°C on the HMI however it is gradually climbing up to 50°C. The CV increases.	Pass	(See appendix 12.1.9 for Auto Sequence HMI screen)
LT541 – The setpoint is set to 20cm.	The PV should increase to 20cm and remain at that value	The PV increases to 23.10cm and remains at that value	Pass	(See appendix 12.2.2 for Level HMI Graph)
FT535 – Pressing start will activate the pump and pressing stop will turn it off	The graph should show it refilling the tanks and stopping	The graph shows the flow rising and coming to a stop before rising again.	Pass	(See appendix 12.2.4 Flowrate HMI graph)
FT531 – The HMI screen allows for the engineer to see the flowrate visually	When manually opening the VF531 valve the flowrate should display on the HMI	The valve opened manually and the flowrate displayed on the HMI	Pass	(See appendix 12.2.6 Flowrate HMI Graph)

9. Conclusions and Recommendations

1.5 line spacing

Each control loop of the Process Station and Water Recirculation sub-systems were investigated, and the instrumentation was described. Technical data was provided for each of the sensors in the control loops. Research was carried out on upgrading the sensors, newer sensors were suggested for replacing the current ones. Industry 4.0 was also researched on how its improving companies from data analysing to production. The environmental aspects of the CIM were discussed from the water to the waste along with the discussion of the codes of practice for calibrating the sensors.

Placed in groups of three, calibration procedures were carried out on four of the sensors, the results were tabulated and placed on a graph to view the response. Modifications were added to the HMI screens of the sensors from 'Start' and 'Stop' pushbuttons to graphs to give a visual display of how they're operating. The encoder was added to the program, a display was placed on the HMI to indicate where the gripper is situated over the water chambers. Tests were performed to check if the HMI and sensors were operating correctly. All tests successfully passed.

Recommendations for the CIM system were made in Task 2 regarding upgrading to IO-Link compatible sensors.

10. Team Working

Groups of 3 were created to carry out an appropriate calibration procedure for the pressure, temperature, level and position sensors. One member was on the multimeter obtaining the readings, one member was adjusting, and the other was documenting the readings on to excel to produce a table. Tasked with documenting the readings, excel was used to note down the readings achieved from each calibration procedure and graphs were produced. Software modifications were done on HMI screens such as graphs for visual representations and run and stop buttons. An encoder was added which meant creating new tags and implementing a new ladder network. Once done a value display was placed on the HMI screen along with a diagram which shows where the gripper is along the belt.

11. Citation List

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12. Appendix

12.1.1 Process Rig Diagram

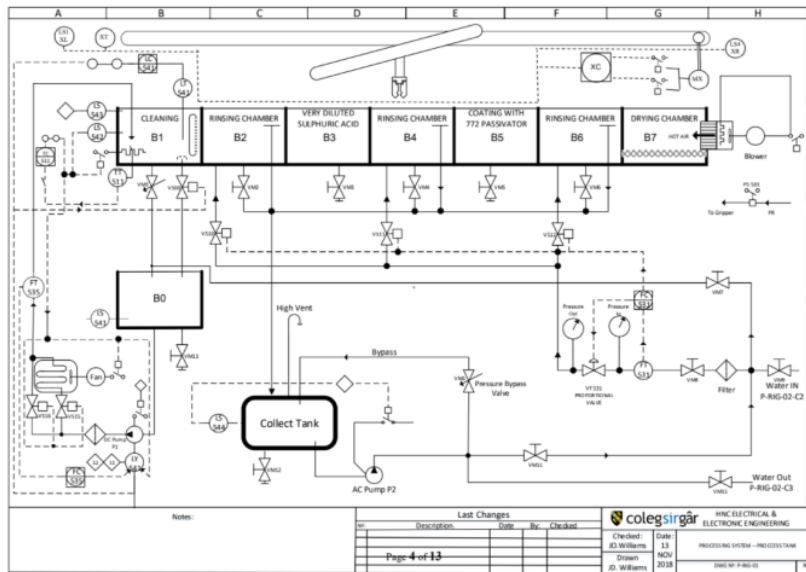


Figure 8 – Processing Rig Diagram

12.1.2 Water Recirculation Diagram

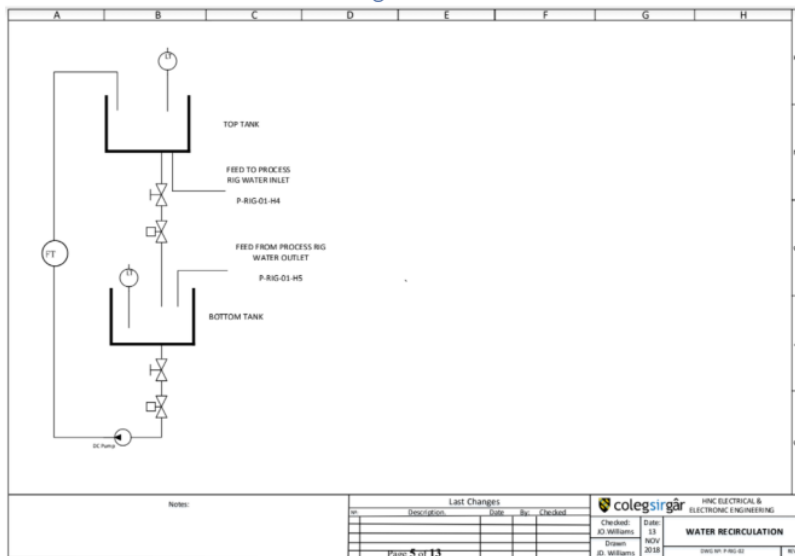
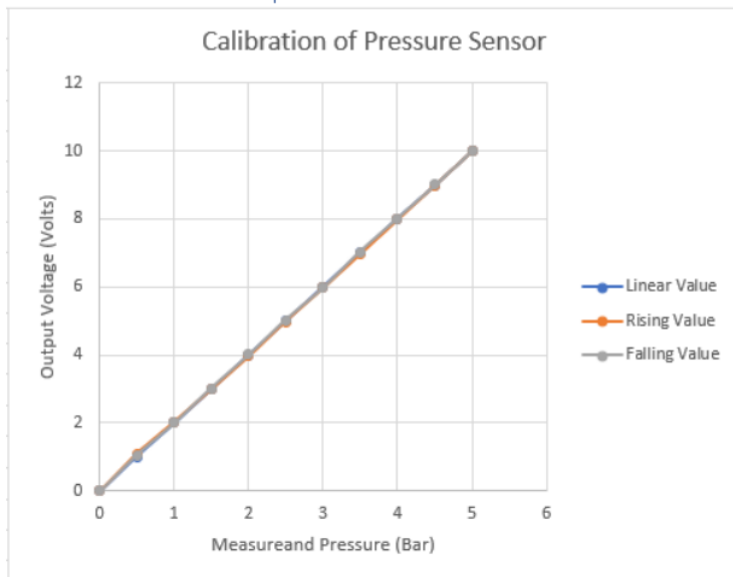
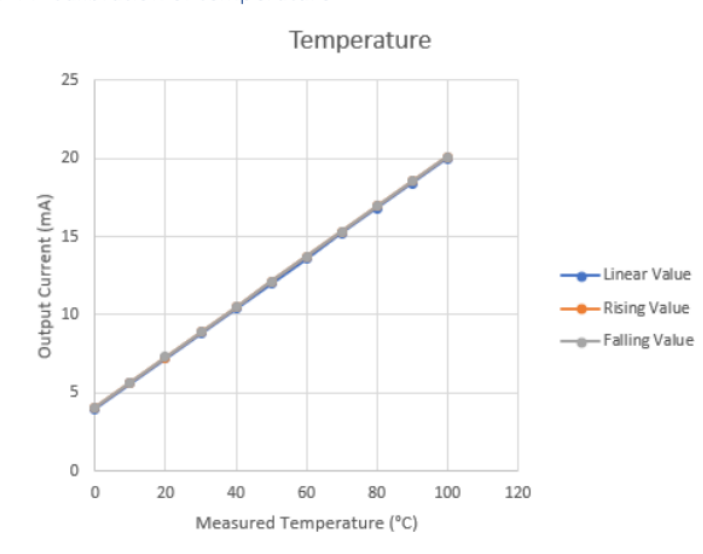


Figure 9 – Water Recirculation Diagram

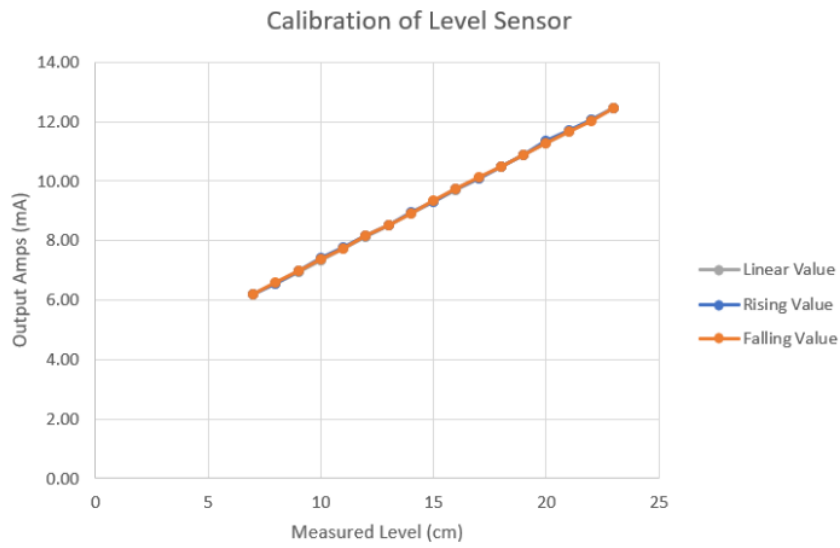
12.1.3 Calibration of pressure sensor



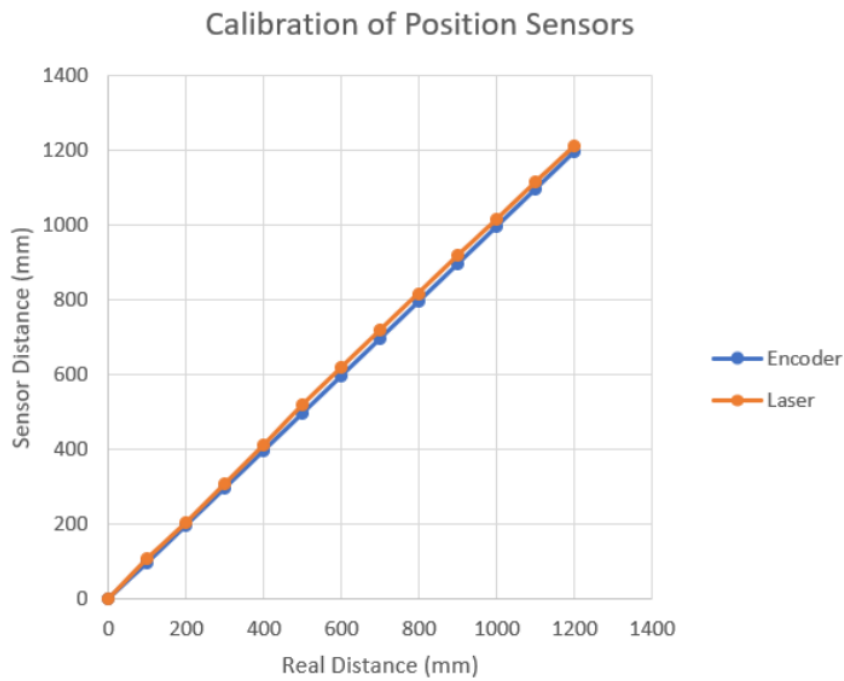
12.1.4 Calibration of temperature



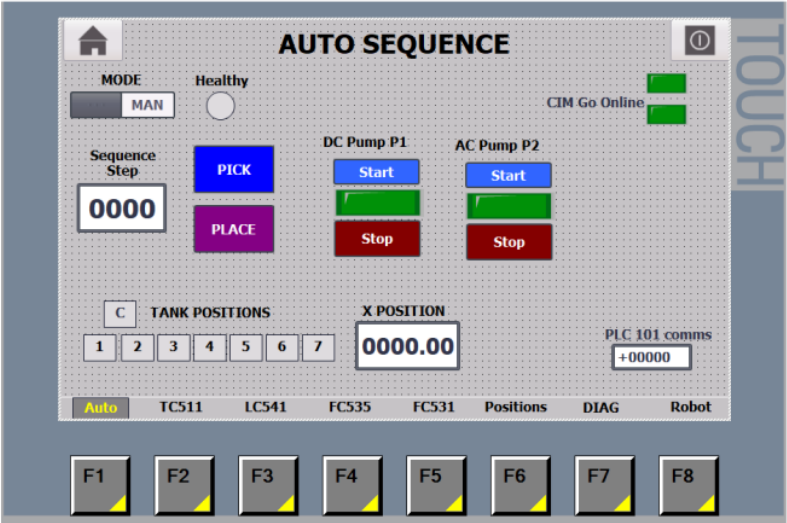
12.1.5 Calibration of level sensor



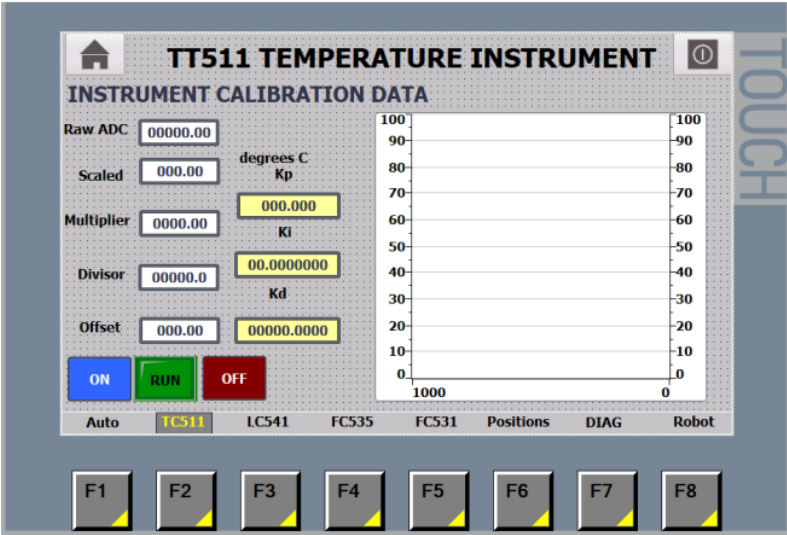
12.1.6 Calibration of position sensor



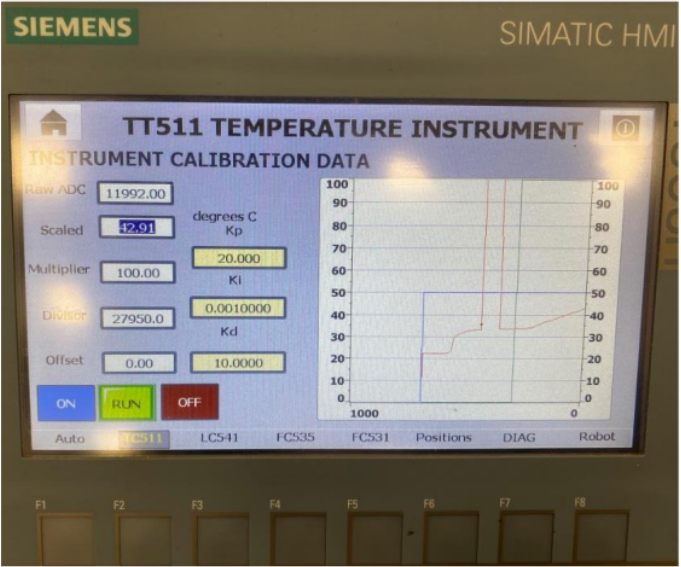
12.1.7 Auto Sequence



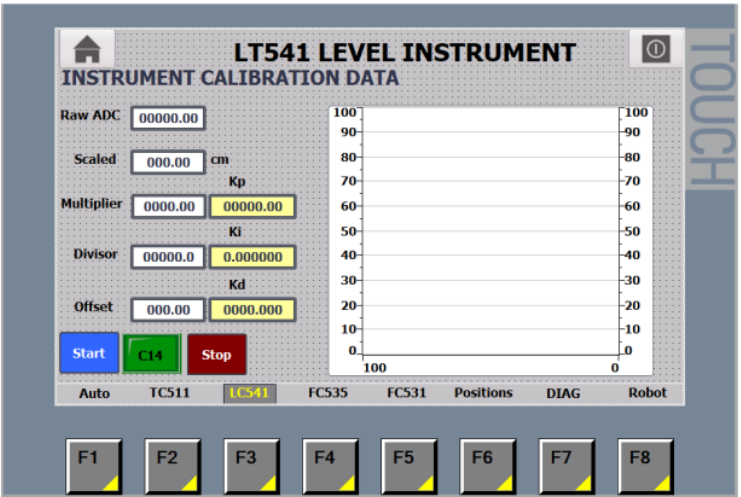
12.1.8 Temperature HMI



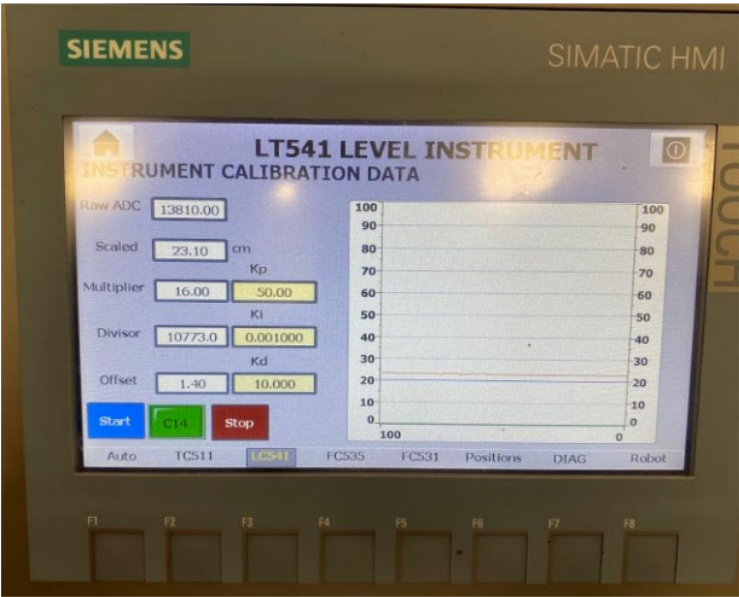
12.1.9 Temperature HMI Graph



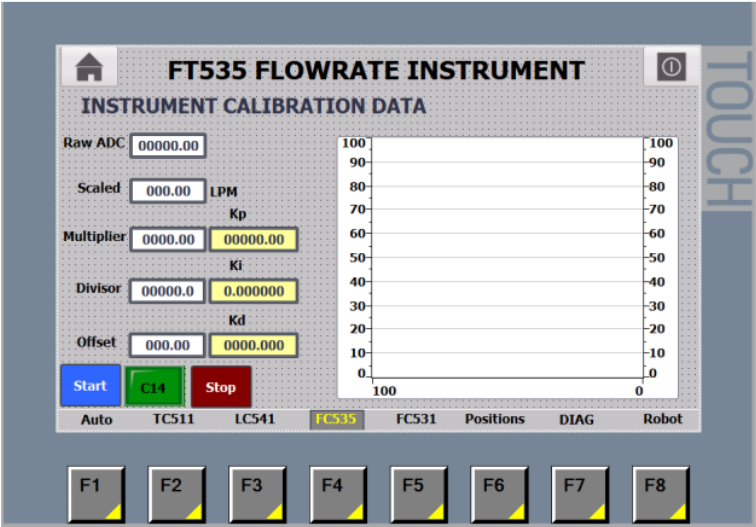
12.2.1 Level Instrument HMI



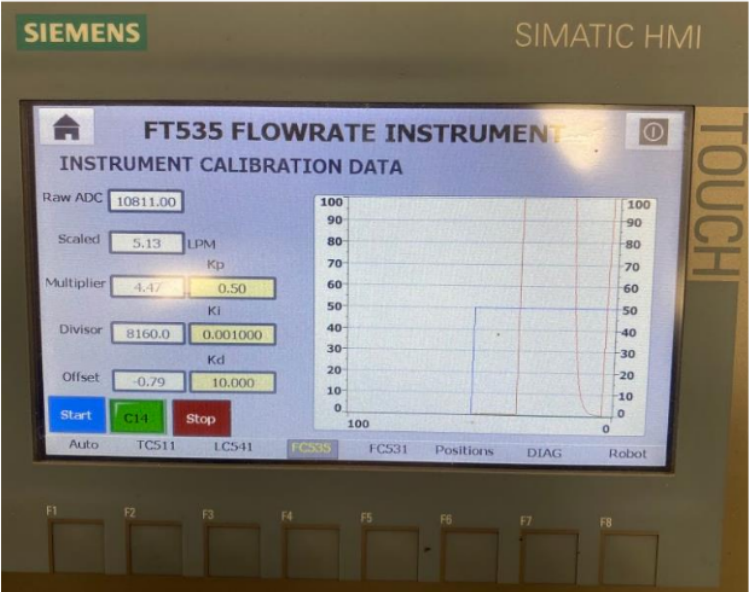
12.2.2 Level Instrument HMI Graph



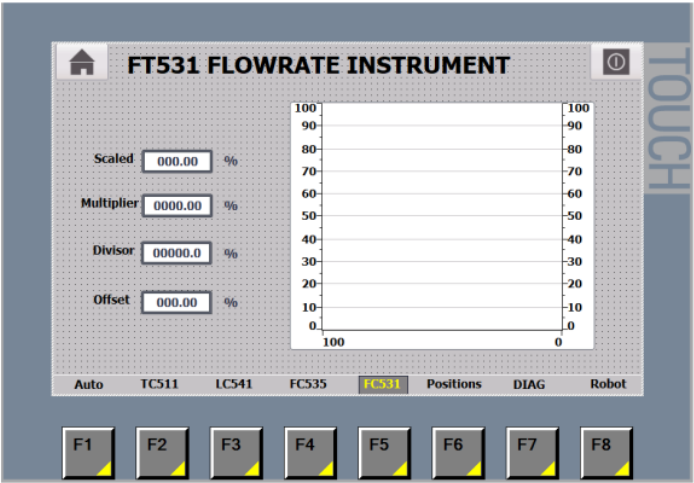
12.2.3 Flow Instrument HMI - FT535



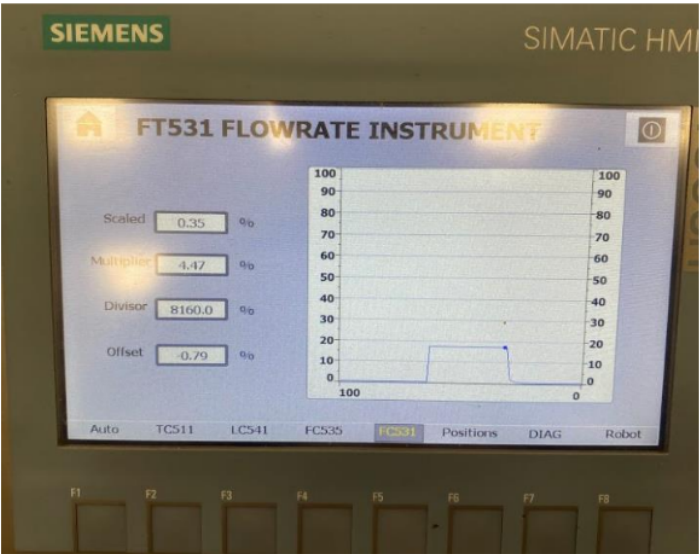
12.2.4 Flow Instrument Graph - FT535



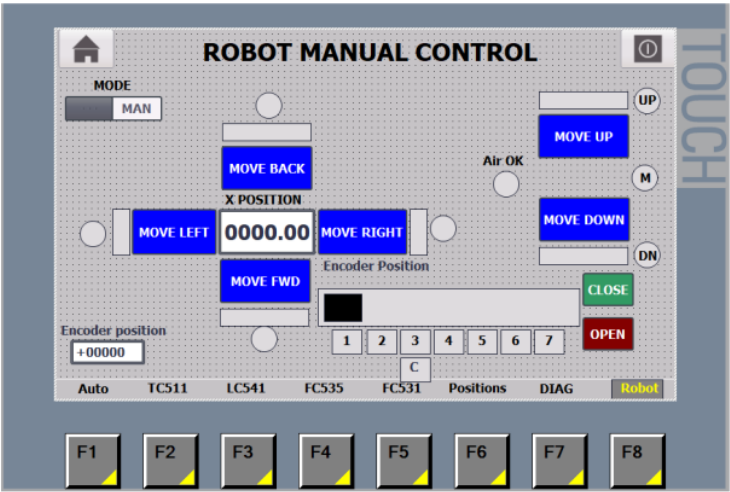
12.2.5 Flow Instrument HMI – FT531



12.2.6 Flow Instrument HMI Graph – FT531



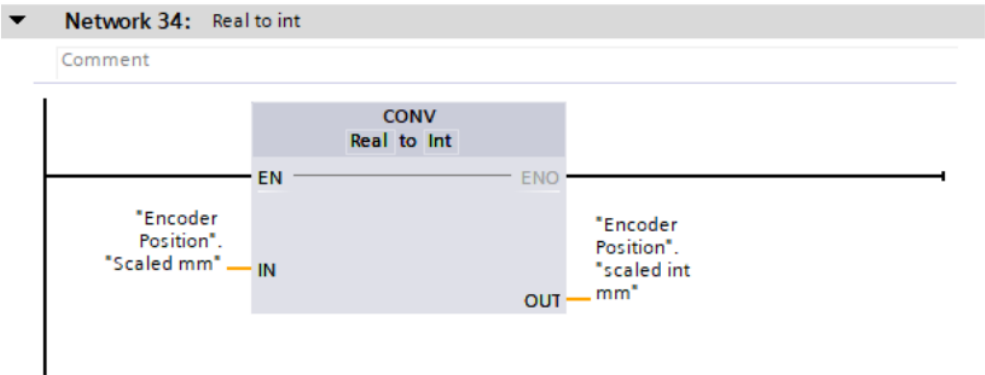
12.2.7 Robot Manual Control



12.2.8 Encoder Tags

Encoder Position								
	Name	Data type	Start value	Retain	Accessible f...	Writa...	Visible in ...	Setpoint
1	▼ Static			☐	☐	☐	☐	☐
2	Raw count	Real	0.0	☐	☒	☒	☒	☐
3	Offset	Real	0.0	☐	☒	☒	☒	☐
4	Count	Real	0.0	☐	☒	☒	☒	☐
5	Scaled mm	Real	0.0	☐	☒	☒	☒	☐
6	scaled int mm	Int	0	☐	☒	☒	☒	☐

12.2.9 Encoder Ladder Network



FINAL GRADE

GENERAL COMMENTS

Instructor

70/100

PAGE 1

Text Comment. A structured and well presented report Good evidence of research with correct use of Harvard from a good range of sources. Good practical work with analysis and testing including a testing table.

PAGE 2

PAGE 3

PAGE 4

PAGE 5

Text Comment. incorrect, this is a 3 wire sensor

PAGE 6

Text Comment. per

PAGE 7

PAGE 8

PAGE 9

Text Comment. what about flow and level?

PAGE 10

Spelling error

PAGE 11

Text Comment. static sensitivity?

PAGE 12

Text Comment. how did you work out this data?

PAGE 13

PAGE 14

PAGE 15

PAGE 16

Text Comment. 1.5 line spacing

PAGE 17

Text Comment. good range of sources

PAGE 18

PAGE 19

PAGE 20

PAGE 21

PAGE 22

PAGE 23

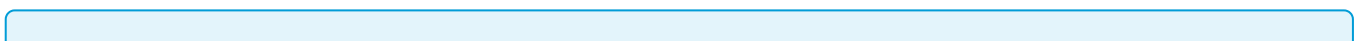
PAGE 24

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GRADING FORM: NEW CSG-RUBRIC



1. ENGAGEMENT WITH LITERATURE

-  Engagement with an extensive range of relevant and credible literature. Consistently accurate application of referencing. 14/20

14

2. KNOWLEDGE AND UNDERSTANDING

-  Excellent knowledge and understanding of the basic underlying concepts and principles of the subject. 14/20

14

3. COGNITIVE AND INTELLECTUAL

-  Sound evaluation of the underlying concepts and principles. Can interpret qualitative and quantitative data accurately. Ability to devise arguments using evidence to make mostly appropriate and valid judgements. 13/20

13

4. PRACTICAL APPLICATION

-  An advanced application of a range of taught, basic methods, materials, tools and/or techniques. The context of the application is well considered, and insightful. Excellent evidence of different

14

approaches to problem-solving in particular contexts and proposes appropriate solutions.
14/20

5. TRANSFERABLE SKILLS



Work is accurate, coherent, fluent, well-structured and organised. Can work effectively independently and/or as part of a team, with very good contribution to group activities. Demonstrates very good skills for employment requiring the exercise of some personal responsibility, with just occasional minor weakness. 15/20

15