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A well structured and presented report Information presented is mostly accurate and well researched from a wide rang eof sources. Calibration exercises are very good but further analysis was possible and not all conclusions are correct. Good design adaptations with testing table but no evidence. Good coonclusions and recommendations.

good structure

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1. System Investigation

1.1. Flow Loop 535

Loop 535 controls the flow of water into the cleaning tank B1. The controller FC535 receives feedback from FT535 which allows the controller to alter its correction factor to ensure the output to the amplifier LY541 is correct. LY541 then amplifies the control signal to the DC Pump P1. LY541 also receives signals from the level and temperature controllers. The flow is dependent on the level loop 541 of B1 tank as if high level switch LS543 is engaged then water in flow will be inhibited.

Instrument	Specification
RS Pro Radial Flow Meter (RS PRO, 2022)	• 0.25L/min -> 6L/min • 300Hz at 4L/min • 500Hz full scale • 4600 pulses/litre • $\pm 1\%$ linearity

Table 1

1.2. Level Loop 541

Loop 541 controls the level of water in the tank B1. The controller LC541 receives feedback from LT541 which is immersed in the tank and outputs to both valve V500 and the amplifier LY541. V500 is controlled when the level in the tank is becoming too high – the valve will then be operated to drop the level of the tank by draining the water into tank B0. The output to the amplifier is one of three signals that include: flow control and temperature control. The level signal to the amplifier ensures that a proportional flow rate into the tank is allowed for so as to not overfill the tank, and to allow a heavier flow if the tank is empty.

Instrument	Specification
Endress & Hauser PMC133 (Endress & Hauser, 2021)	• Up to 40 bar • -40 to 100°C • Output – 4-20mA • $\pm 0.2\%$ set span error • $\pm 0.1\%$ non-linearity error

Table 2

1.3. Temperature Loop 511

Loop 511 controls the temperature of the water in tank B1. The controller TC511 receives feedback from TT511 on the current temperature of the water and the controller then works out the error and alters the correction factor to match the setpoint. The TT511 is a PT100 RTD that is connected to a signal conditioner before feeding back to FC511. The controller then sends an output signal to a solid-state relay – as long as LS542 is healthy – which is to say that there is a sufficient volume of water in the tank. The SSR is used for greater control accuracy of the temperature as it can receive a PWM signal from the controller – rather than the on-off control of a mechanical relay.

Instrument	Specification
Industrial RTD PT100 (Process Parameters, 2022)	• -50 to 250°C • $\pm 0.3^{\circ}\text{C}$ • 3-wire • Platinum Resistance Thermometer

Table 3

1.4. Flow Loop 531

Loop 531 is a second flow control. The flow of water is controlled into each of the 'Rinsing Chambers' in the system – B2, B4, and B6 – from the 'Water In' valve. FC531 controls this via the proportional valve VF531 and receiving feedback of the current flow from FT531.

Instrument	Specification
RS Pro Radial Flow Meter (RS PRO, 2022)	• 0.25L/min -> 6L/min • 300Hz at 4L/min • 500Hz full scale • 4600 pulses/litre • $\pm 1\%$ linearity

Table 4

2. Research

The CIM-system investigated in Section 1 is controlled via various sensors. These sensors include: RTDs, pressure transmitters, turbine flow sensors, laser sensors, and an incremental encoder. All these sensors have been in place for numerous years and would benefit from being replaced with Industry 4.0 ready sensors in line with other improvements that have been made to the system. The benefits of the sensors will be researched in detail below – along with their drawbacks.

Industry 4.0 refers to the 4th industrial revolution, with the others being mechanization, electricity, and IT (Gilchrist, 2016). The Fourth Industrial Revolution can be described as the move towards automation with Big Data exchange. The technologies included in this are: Industrial Internet of Things (IIOT), Smart Factories and Manufacturing, cloud computing & artificial intelligence (AI). The overall Smart Factory will be made up of automated lines with wireless and wired connectivity between sensors, controllers, and actuators, which will monitor the entire process while making autonomous choices (Gastreich, 2020). Zühlke states that “The vision is that we take an internet down to the lowest level – every sensor and actuator is a participant in the Internet of Things. Each device has its own IP Address, so it can be addressed in this network” (2013).

A communications protocol called IO-Link, could be used as the new protocol for the replacement sensors in the CIM system. IO-Link is used primarily for communications between 3-wire sensors and actuators (Jowett, 2019). The sensors and actuators are the slave devices in the system, and they are all connected to an IO-Link master. The master is connected to the controller via a fieldbus connection, such as: Profinet, Profibus, or Modbus (Profibus, 2020). The masters' ports can be configured to be in a digital input (DI), digital output (DO), or a read/write communications mode (IO-Link, 2022). A typical IO-Link system could include a DI proximity sensor, a DO lighting tower, and read/write communications to a motor. IO-Link has various transmission types, with cyclic transmissions such as Process Data and Value Status, and acyclic transmission such as Device Data and Events (Pigan & Metter, 2008).

Smart sensors can be used as part of a predictive maintenance program, as the sensors can feedback their condition to the controller – and from there the controller can relay this information to the operator via an HMI screen message, or a text message sent to the maintenance team informing them of future failure (Groover, 2016). In the event of an impending catastrophic failure, the machine can put itself into hold mode until this fault is rectified (Bolton, 2015). These intelligent sensors can also measure various process values at once – saving on numerous sensors to monitor the process values (Mortenson, 2020).

Table 5 details the characteristics of sensors which could replace the existing instruments used on the CIM system.

Type of Sensor	Previous Sensor	New Sensor	Characteristics	Figure(s)
Flow	FT531 & FT535	SM6000 (IFM, 2022)	- Measuring Range 0.1...25L/min with 0.02L/min Accuracy -20...80°C with 0.02°C Accuracy 0.15s Response Time 2DO, 1AO - PNP/NPN 4...20mA Output	9
Level	LT541	01D300 (IFM, 2022)	0.2...10m Measuring Range ±1.5...6.5cm Accuracy 1Hz Sampling Rate 2DO, 1AO - PNP 4...20mA Output	8
Temperature	TT511	TM4431 & TR2349 (IFM, 2022)	-40...150°C - PT100 Class A ±0.15°C Accuracy 0.33s Response Time	6, 7
Encoder	XT	RM3011 (IFM, 2022)	8192 steps 4096 revolutions 25 bit - Profinet-IO - Absolute – Multiturn - Programmable: Resolution per rev	10

Table 5

All the sensors researched in table 5 are IO-Link compatible, creating a connected system with the sensors communicating with one another, through the IO-Link master. The sensors

can all be setup and monitored via one software application – LR Device – which greatly improves ease of use. LR Device can be used to extract the operating parameters of each instrument on a set time basis to compare with previous recordings, and from there investigate any changes that are required (IFM, 2022). The sensors themselves also provide additional benefits when compared with the current sensors used, such as the SM6000 flow sensor, which can also measure the temperature of the water. This feature gives us a second temperature monitoring device and could be used to compare the temperature of the water before entering the tank B1 and then measure how long it takes – via the TM4431 – to reach the set temperature setpoint (IFM, 2022).

In regard to maintenance and reliability, the sensors in table 5 will improve both these as they are more accurate and have quicker response times – which coupled with the PID loops will improve the performance and reliability of the sensors. Through IO-Link, the sensors have diagnostic features which can report any errors or unusual conditions so the maintenance technician can act on these issues before they cause a breakdown (Pepperl+Fuchs, 2022).

this is an excellent section

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

In the CIM-system water is recirculated between tanks B0 and B1, and also between the rinsing chambers and the collect tank. The water from the collect tank can be reused and diverted to the water inline to refill the tanks. This reduces the need for fresh water to be added to the system repeatedly and also limits the amount of human interaction needed in the control of the system as the water recirculates itself.

Sustainable development is described by the United Nations as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (1987). Due to the increase in population and affluence, newer eco-efficient products are being consumed more – making environmental impact go up, even though new products are sustainably produced (Life Cycle Engineering: Technology-Based Solution to Sustainability?, 2018). To increase the sustainability of the CIM system the number of sensors used must be reduced. Spares must be kept for each part to ensure the continued running of the process. These parts in service and spares are driving up the demand for these parts – therefore increasing the manufacturing of the items and the associated energy costs to make these parts. If one of the modern Industry 4.0 sensors were used, a reduction of different types of sensors could be seen, as seen in Section 2 there are now sensors which can monitor multiple process variables. The SM6000 flow sensor can also measure temperature and total quantity of liquid passed through the sensor, so theoretically this one item could replace FT535, TT511, and LT541 (IFM, 2022). This modification may not be as accurate as three separate sensors, but it improves the sustainability of the system. Similar changes will be required in industry as the continued consumption of goods like these are not sustainable forever due to finite amount of resources on earth (Engineering Council, 2013).

If a similar system was to be produced for a customer, the relevant codes of practice and commercial risks would have to be considered. Along with the above sustainable development issues considered, Health and Safety is the biggest issue. Modern control systems must conform to several regulations and standards, including: BS EN 60204:2018 Safety of Machinery and BS 7671 18th Edition Wiring Regulations. A system like the CIM would have to ensure that moving parts were not accessible – preferably by an interlocked guarding system (CENELEC, 2018).

4. Calibration of Pressure Sensor

The results in table 6 prove the pressure sensor was calibrated correctly with a small non-linearity error seen on all test values – apart from at 0 bar – which had much larger errors. At 1 bar and 5 bar, there was no error.

Measured Pressure (Bar)	Output Voltage (Volts)		Linear Value (Volts)	Non-linearity error (Volts)		Hysteresis Error (Volts)
	Rising	Falling		Rising	Falling	
0	0.18	0.24	0	0.18	0.24	0.06
0.5	1.05	1.04	1	0.05	0.04	-0.01
1	2	2	2	0	0	0
1.5	2.98	3	3	-0.02	0	0.02
2	3.97	4	4	-0.03	0	0.03
2.5	4.98	5	5	-0.02	0	0.02
3	5.97	6	6	-0.03	0	0.03
3.5	6.97	7	7	-0.03	0	0.03
4	7.98	7.97	8	-0.02	-0.03	-0.01
4.5	8.98	8.99	9	-0.02	-0.01	0.01
5	10	10	10	0	0	0

Table 6

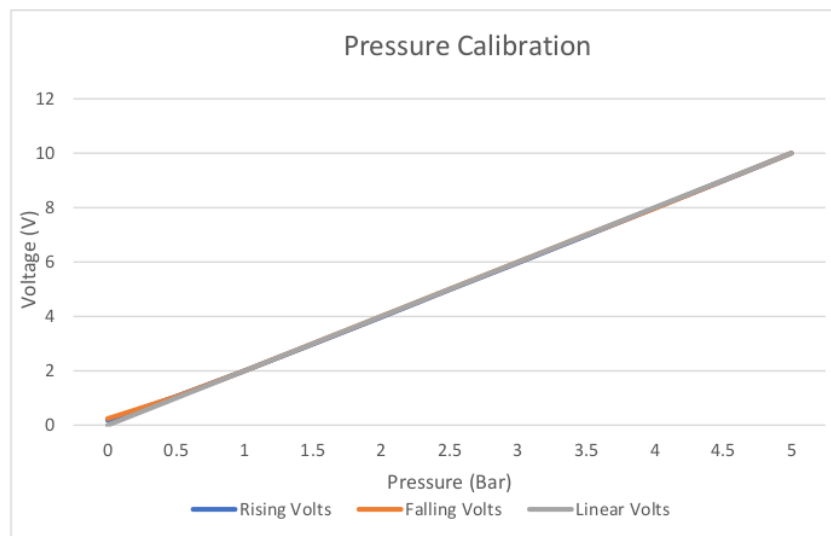


Figure 1 – Pressure Graph

you could have calculated the static sensitivity, the max non-linearity error and the max hysteresis error as a percentage of FSD.

5. Calibration of Temperature Sensor

The results in table 7 prove the temperature sensor was calibrated correctly with a small non-linearity error seen on all test values, with the most common error being 0.01. Almost half of the hysteresis errors were 0, proving the values to be accurate when rising and falling.

Temperature	Output Current (mA)		Linear Value	Non-linearity Error		Hysteresis
	mA Falling	mA Rising		Error Rising	Error Falling	
0	4.03	4.02	4	0.02	0.03	0.01
10	5.62	5.62	5.6	0.02	0.02	0
20	7.22	7.21	7.2	0.01	0.02	0.01
30	8.82	8.81	8.8	0.01	0.02	0.01
40	10.42	10.41	10.4	0.01	0.02	0.01
50	12.01	12.01	12	0.01	0.01	0
60	13.61	13.61	13.6	0.01	0.01	0
70	15.21	15.2	15.2	0	0.01	0.01
80	16.81	16.8	16.8	0	0.01	0.01
90	18.4	18.4	18.4	0	0	0
100	19.99	19.99	20	-0.01	-0.01	0

Table 7

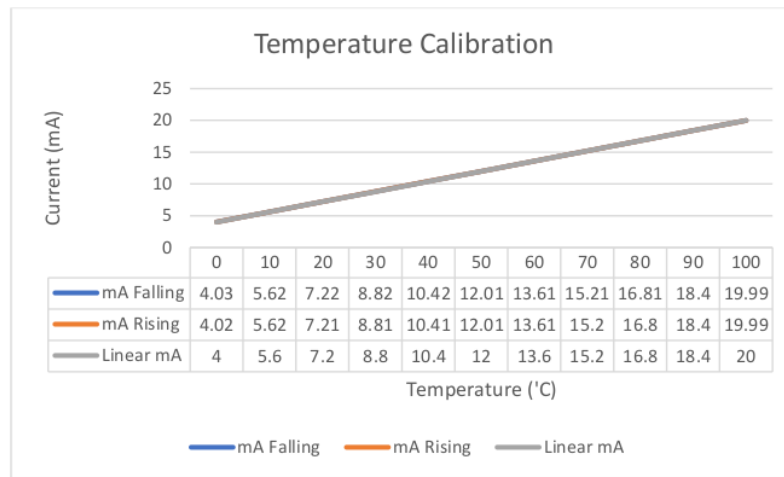


Figure 2 – Temperature Graph

6. Calibration of Level Sensor

The results in table 8 show the level sensor to have an increased error when compared with the previous two tasks, but still fairly accurate. The biggest issue is the hysteresis error, as there are quite significant differences between the rising and falling mA values.

Level (cm)	mA Rising	mA Falling	Linear Value	Error Rising	Error Falling	Hysteresis Error
7	6.08	6.1	6.08	0	-0.02	0.02
8	6.64	6.48	6.48	-0.16	0	0.16
9	6.97	6.86	6.88	-0.09	0.02	0.11
10	7.36	7.25	7.28	-0.08	0.03	0.11
11	7.8	7.63	7.68	-0.12	0.05	0.17
12	8.2	8.06	8.08	-0.12	0.02	0.14
13	8.56	8.45	8.48	-0.08	0.03	0.11
14	9	8.8	8.88	-0.12	0.08	0.2
15	9.34	9.21	9.28	-0.06	0.07	0.13
16	9.75	9.59	9.68	-0.07	0.09	0.16
17	10.19	10	10.08	-0.11	0.08	0.19
18	10.52	10.39	10.48	-0.04	0.09	0.13
19	10.9	10.81	10.88	-0.02	0.07	0.09
20	11.33	11.21	11.28	-0.05	0.07	0.12
21	11.71	11.68	11.68	-0.03	0	0.03
22	12.11	11.97	12.08	-0.03	0.11	0.14
23	12.48	12.48	12.48	0	0	0

Table 8

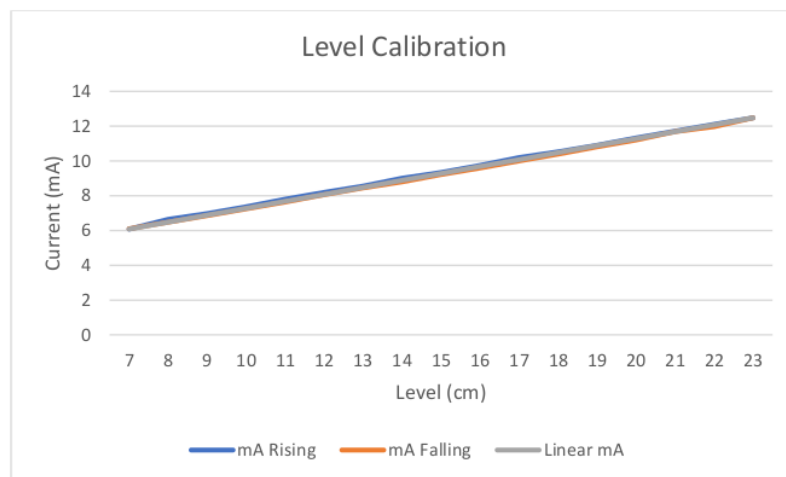


Figure 3 – Level Graph

the encoder is accurate, the eye is not

7. Calibration of Position Sensor

The results of the position sensor are shown in table 9, the errors for this calibration are significantly bigger than previous tasks, with errors up to -4 for the encoder, and -51.6 for the laser. The smallest error for the encoder is -1.4, while the laser is -17.8. Two tests were taken for both the encoder and the laser, with the results of both tests similar, proving both sensors to be consistently inaccurate. The biggest hysteresis error for the encoder was -1.1, with the lasers' being -4.9. For the laser, at the 480mm point there was the biggest error, but then followed by the smallest error at 580mm.

Tape Actual (mm)	Encoder 1	Encoder 2	Laser 1	Laser 2	Encoder Error	Encoder Error 2	Laser Error	Laser Error 2
0	0	0	0	0	0	0	0	0
80	78	78.6	39.7	38.9	-2	-1.4	-40.3	-41.1
180	177.5	178	143.5	142.8	-2.5	-2	-36.5	-37.2
280	277.4	278.1	247.8	242.9	-2.6	-1.9	-32.2	-37.1
380	377	377	349.5	349	-3	-3	-30.5	-31
480	476.8	477.9	428.7	428.4	-3.2	-2.1	-51.3	-51.6
580	576.6	576.4	562.9	561.6	-3.4	-3.6	-17.1	-18.4
680	676.4	677.2	660.5	658.9	-3.6	-2.8	-19.5	-21.1
780	777	777.3	761.5	760.7	-3	-2.7	-18.5	-19.3
880	877.3	876.8	859.4	857.9	-2.7	-3.2	-20.6	-22.1
980	977.2	976.3	959.2	959.6	-2.8	-3.7	-20.8	-20.4
1080	1077.1	1076.5	1057.3	1057.1	-2.9	-3.5	-22.7	-22.9
1180	1176.4	1176	1156.1	1154.4	-3.6	-4	-23.9	-25.6
1280	1277.1	1276.8	1252.7	1252.5	-2.9	-3.2	-27.3	-27.5

Table 9

the only good thing about the laser is that it is repeatable

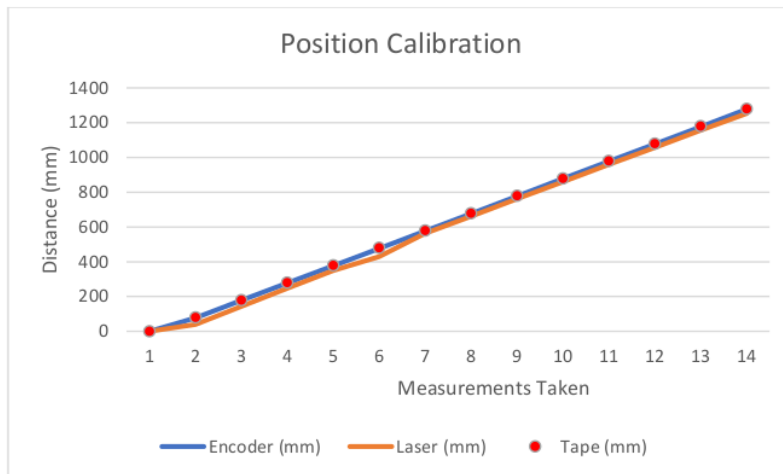


Figure 4 – Position 1 Graph

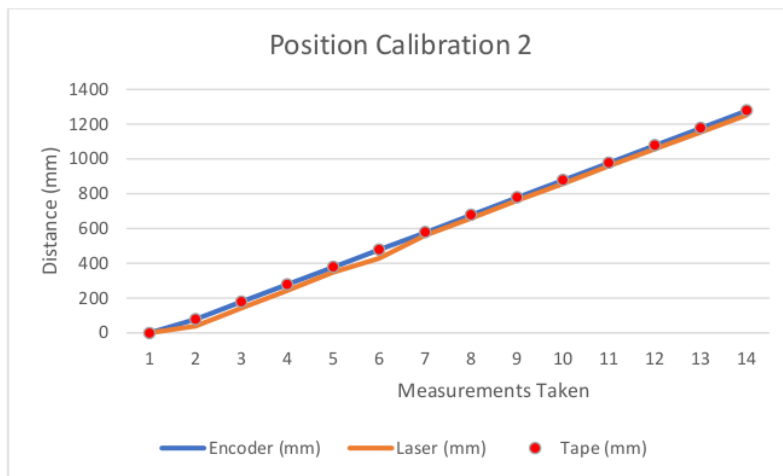


Figure 5 – Position 2 Graph

8. Design Adaptation for Maintenance and Reliability

An issue was found with HMI 133 – located at the process station – as this HMI lacked the ability to make modifications to the various control loops in the system. The only HMI which had the means to make modifications was HMI 103 which is not local to the process station. This area was highlighted for improvement as if HMI 133 had the same functions as HMI 103, then modifications could be made and analysed in real-time, rather than working between the process station and the remote HMI.

HMI 133 was to be programmed to control the following loops:

- Flow Loop 535
- Level Loop 541
- Temperature Loop 511

The maintenance technician could then start and stop the PID control of the loops, tune the PID values, modify the setpoints, and monitor values via a graph.

Another improvement to the system was an HMI screen added to control the Laser Arm Movement. This change would allow the Arm to be moved in the X, Y, and Z axes via soft push buttons. The position of the Arm along the x-axis was also displayed as value taken from the encoder, but a graphic was also added to move along the screen while the Arm was moving. This graphic was also placed next to indicators which showed which tank the Arm was currently over. Changes were made to the PLC program to achieve this with a data block added as 'Encoder Position'.

Picture Type	Figure(s)
Temperature HMI	12, 18, 19
Level HMI	13, 17
Flow HMI	11, 20
PLC Code	15, 16
Robot Arm	14, 21, 22, 23

Table 10

good evidence of testing but no testing table

9. Conclusions and Recommendations

the first paragraph is a summary but is not needed

In this report, various tasks were undertaken to enhance the understanding of Instrumentation and Integrated Automation Systems – using the CIM system. The report can be split into two separate sections. One comprised the investigation of the current system, research of improved Industry 4.0 sensors to replace existing sensors, and environmental and sustainable development of the system. While the second section is comprised of calibrations of the sensors used and design modifications made to the HMI.

Each control loop was investigated, with research undertaken to determine the performance of each instrument by accessing their technical datasheet. Due to the age of some instruments, it was difficult to find all of the exact datasheets. In these cases, an informed and educated decision was made to choose the closest alternatives datasheet, which was done by using the known parameters of the system such as the flow of 4L/min when searching for a similar flow meter to use – for example a 20-30L/min sensor would not be used as an alternative. This lack of information regarding some instruments becomes the first point in the case for replacement instruments to be used.

The research undertaken involved the fourth industrial revolution and the relevant improvements in instrumentation technology, which could be utilised on the CIM system. The sensors chosen were of IFM manufacture and all IO-Link compatible. The same manufacturer was used to for consistency, as all the instruments have a similar interface which allows for easier understanding for technicians to use. IO-Link was shown to be a good starting point into the world of Industry 4.0, with the IO-Master communicating with numerous intelligent sensors in remote locations and all this data then transferred to the controller via one fieldbus connection.

The sustainability and environmental impact of the CIM system – and industry in whole – was investigated. The push towards a sustainable future in industry is a widely discussed topic. With the over-consumption of goods continuing to rise, a culture change is needed, and industry must start reducing their consumption or reusing where possible. The recirculation of water in the CIM system is a good feature that reuses water, rather than adding new.

Four sensors were calibrated, and results included in this report. The sensors were for: level, pressure, temperature, and position. In teams of 3, results were taken after performing a similar calibration procedure for each task. Measurements were taken of the rising and falling mA, voltage, and length, and compared with the linear value to find the error and hysteresis error. The calibrations were very accurate with only a small error observed, as can be seen in the tables and graphs. The least accurate result was the position calibration, as both the

the encoder is very accurate but the laser is not

encoder and laser were not as accurate as the other sensors, while the laser was significantly worse when compared with the encoder. The other issue with position calibration was the human error not accounted for when measuring the position – as the stopping point was chosen by eye.

Improvements were made to the design to increase reliability and maintenance. The local HMI station 133 was programmed to allow control of the system, as previously you were unable to from this station and would have to use the remote HMI 103. This allows the maintenance technician to check immediately how the system reacts to changes and if the devices are functioning correctly. The PID values can also be altered to fine-tune the loop to ensure optimum performance.

An improvement to the system could be the introduction of a servo motor for the position of the laser arm, or a variable frequency drive with PWM control. As seen in the calibration of the position sensor, it was difficult to stop the arm at exactly 100mm increments with the fixed speed and on-off control of the motor. While also suffering from human error when deciding on the correct stop point. With the improvement recommended above, these negative effects would be eliminated as the fine-tuned automated control would accurately move the arm in exact increments of 100mm. The encoder reading could then be compared with the laser to find the error.

10. Team Working

A group of 3 was put together to complete the calibration tasks. For the 4 tasks, the team remained in their roles to maintain a level of repeatability and consistency. The roles were as follows:

- Manual Operator
- Measurement Taker
- Data Compiler

The manual operator controlled each process loop. Filling and emptying the level, moving the robot arm, altering the temperature, and changing the pressure.

The measurement taker instructed the manual operator to stop when a point had been reached, such as every cm for the level and then relayed the information to the data compiler.

The data compiler entered the information into an Excel spreadsheet and converted the data into a graph.

This setup provided successful results as everyone was familiar with their role, allowing the team to succeed in finishing the calibration tasks promptly.

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Zuhlke, P., 2013. *Industrie 4.0 - The Fourth Industrial Revolution* [Interview] (5 December 2013).

12. Appendix



Figure 6 (IFM, 2022)



Figure 7 (IFM, 2022)



Figure 8 (IFM, 2022)



Figure 9 (IFM, 2022)



Figure 10 (IFM, 2022)

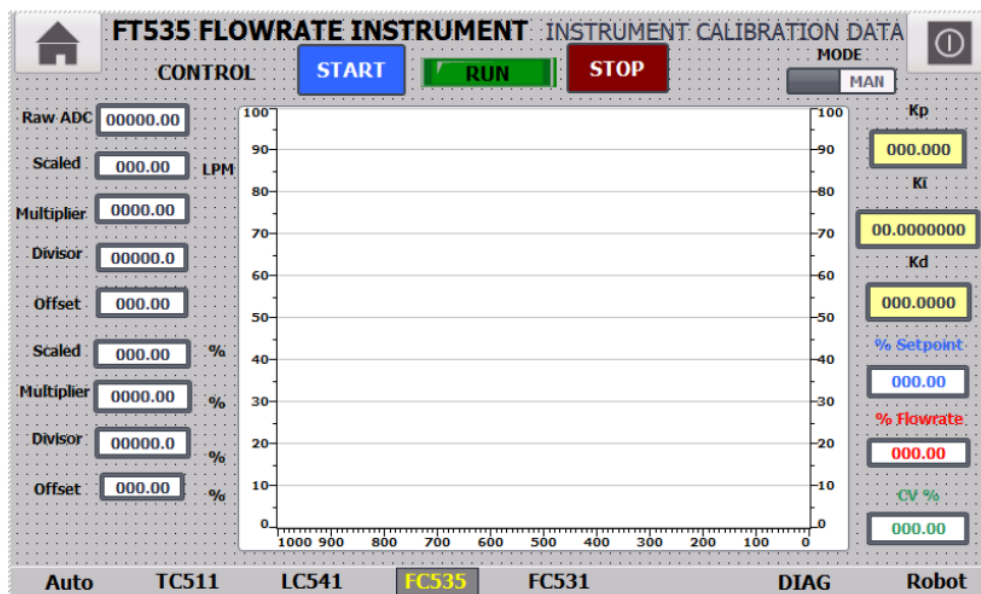


Figure 11 – Flow Screen

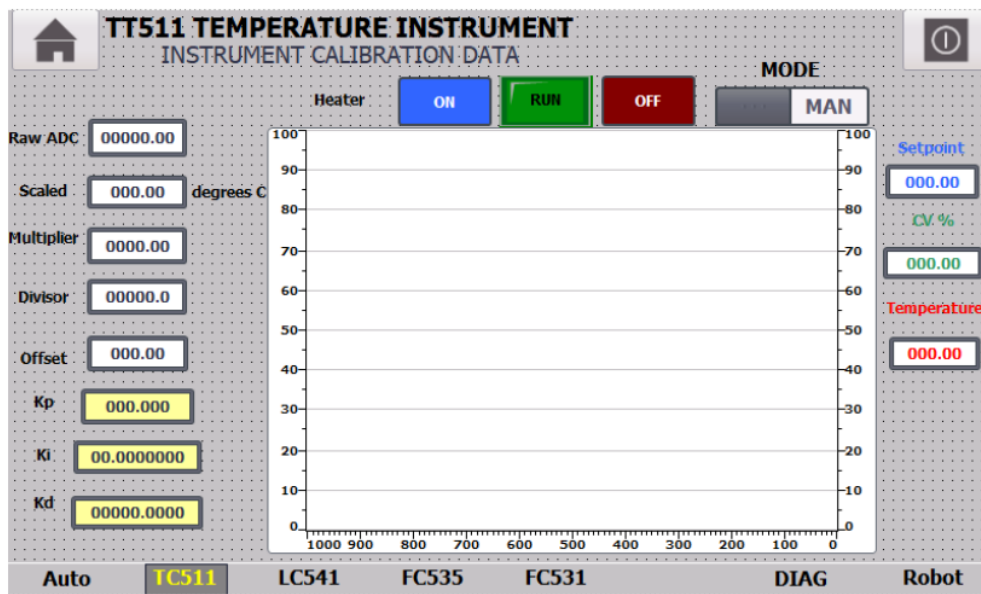


Figure 12 – Temperature Screen

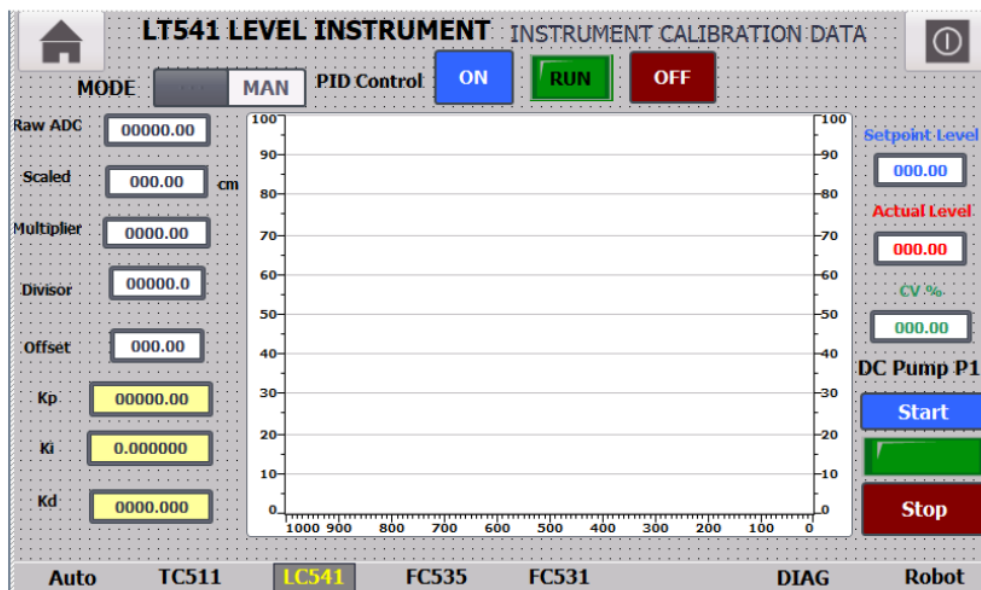


Figure 13 – Level Screen

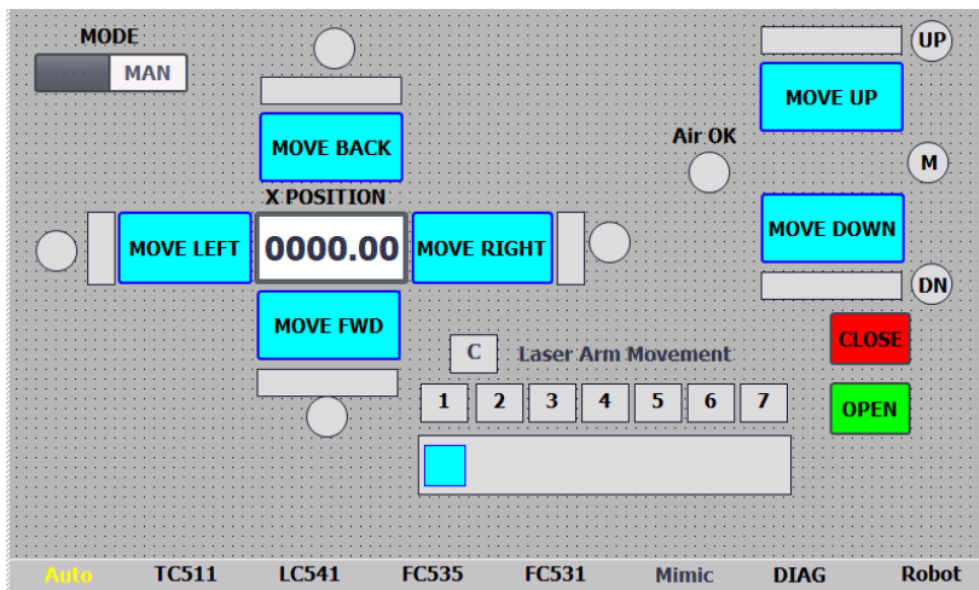


Figure 14 – Arm Screen

Encoder Position									
	Name	Data type	Start value	Retain	Accessible f...	Writa...	Visible in ...	Setpoint	C
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	junk	Real	0.0	☐	☒	☒	☒	☐	
7	HMI arm position	Int	0	☐	☒	☒	☒	☐	
8	Add new...			☐	☐	☐	☐	☐	

Figure 15 – Encoder Position Data-block

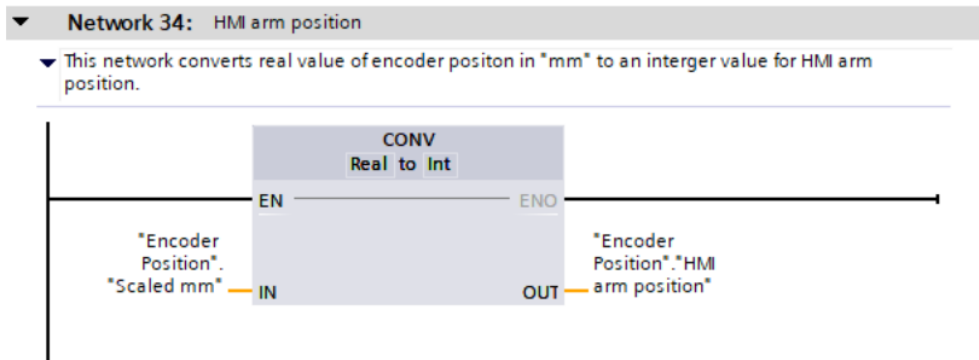


Figure 16 – Added Network to PLC

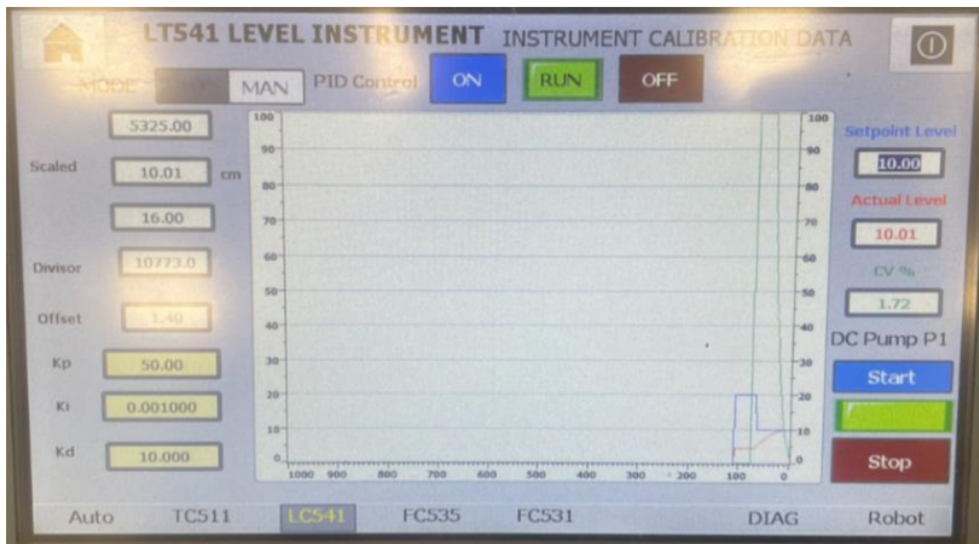


Figure 17 – Level maintained at 10cm

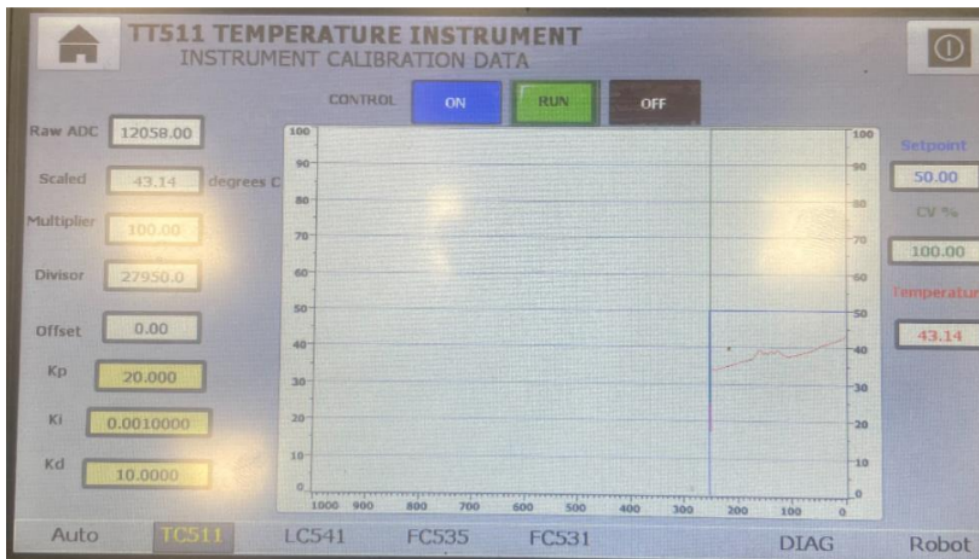


Figure 18 – Temperature rising to 50°C with CV at 100%

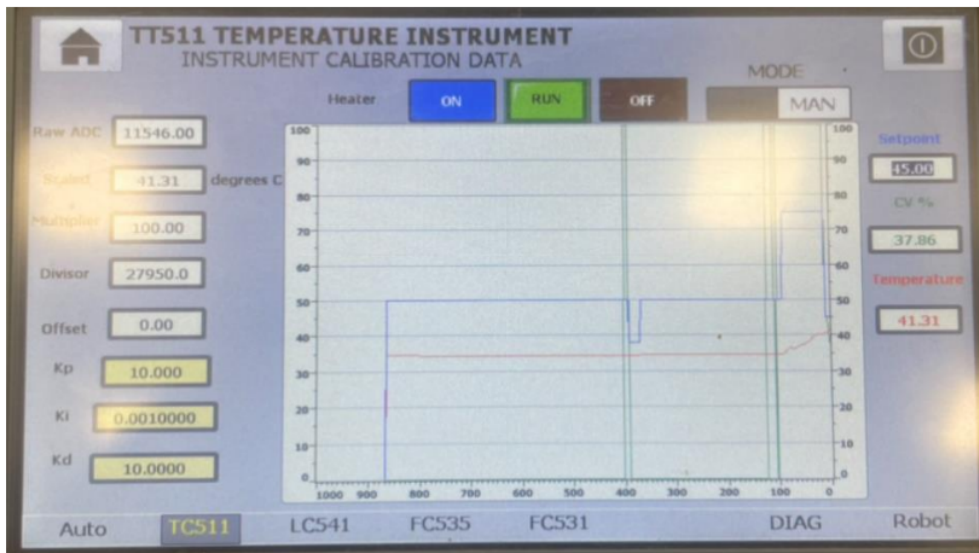


Figure 19 – Temperature rising to 45°C with the CV dropping

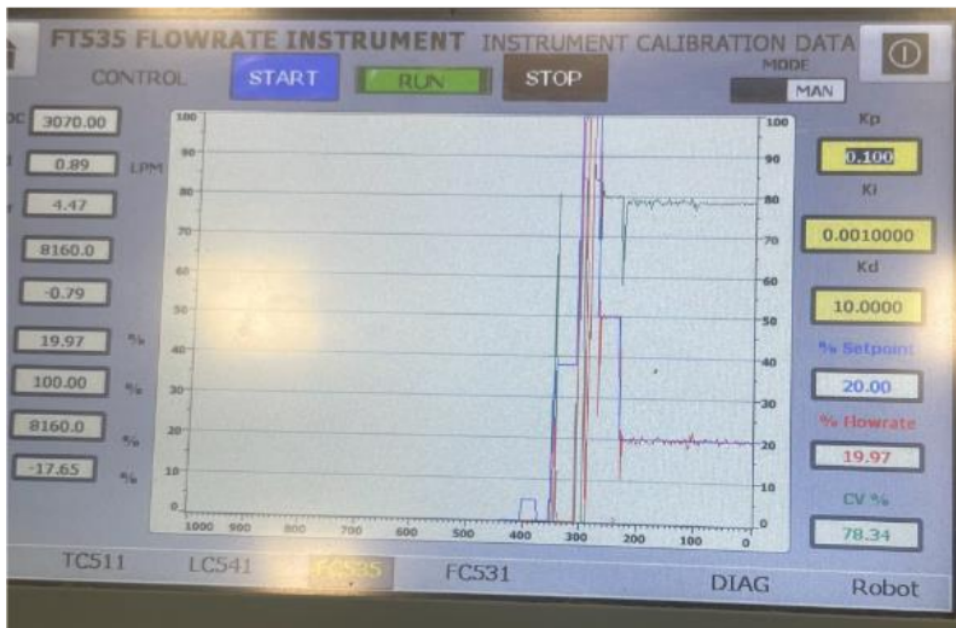


Figure 20 - Flowrate maintained at 20%

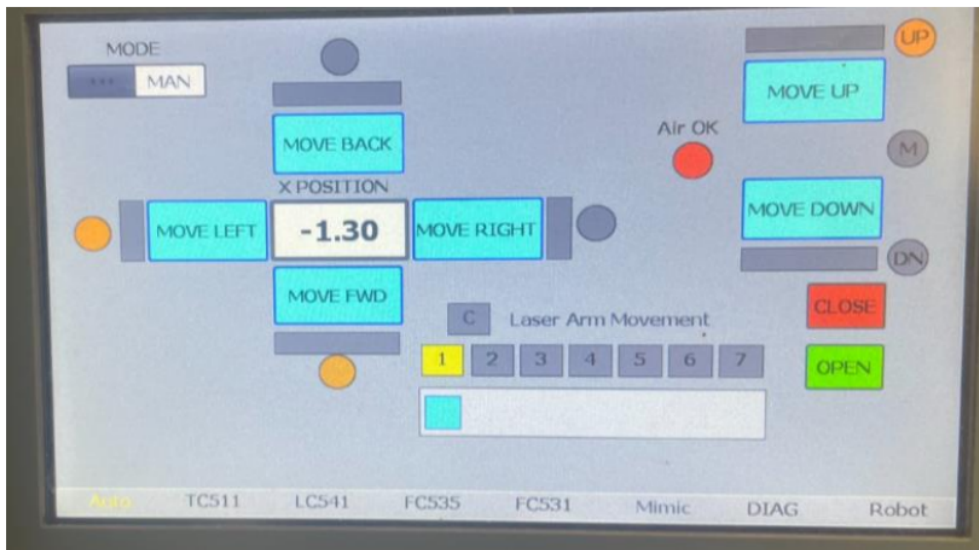


Figure 21 – Arm at Station 1



Figure 22 – Arm at Station 6



Figure 23 – Arm at Station 7

FINAL GRADE

GENERAL COMMENTS

Instructor

73/100

PAGE 1

Text Comment. A well structured and presented report Information presented is mostly accurate and well researched from a wide rang eof sources. Calibration exercises are very good but further analysis was possible and not all conclusions are correct. Good design adaptations with testing table but no evidence. Good coonclusions and recommendations.

PAGE 2

Text Comment. good structure

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

Text Comment. this is an excellent section

PAGE 9

PAGE 10

Text Comment. you could have calculated the static sensitivity, the max non-linearity error and the max hysteresis error as a percentage of FSD.

Text Comment. the encoder is accurate, the eye is not

Text Comment. the onlu good thing about the laser is that it is repeatable

Text Comment. good evidence of testing but no testing table

Text Comment. the first paragraph is a summary but is not needed

Text Comment. the encoder is very accurate but the laser is not

Text Comment. good range of sources

GRADING FORM: NEW CSG-RUBRIC

AERON SMITHAM**73****1. ENGAGEMENT WITH LITERATURE**

Engagement with an extensive range of relevant and credible literature. Consistently accurate application of referencing 16/20

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

14

5. TRANSFERABLE SKILLS



Work is coherent, very fluent and is presented professionally. Can work effectively independently and/or as part of a team, with an excellent contribution to group activities. Demonstrates excellent skills for employment requiring the exercise of some personal responsibility with an appetite for further development. 16/20

16