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by Iwan Griffiths

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1. Work Plan for Lifelong Learning and Risk Assessment

To begin with, the Piping and Instrumentation diagram will need to be investigated in order to understand the role of each control loop that is used within the Process Station and Water Recirculation sub-systems. Technical data will then be provided that includes Punctuation Error range and other relevant parameters that makes them suitable for their application. The systems pressure sensor, temperature sensor, level sensor, and position sensor will then be calibrated and suitable results tables with relevant graphs will be produced to show its static performance. Conclusions will then be drawn regarding their quality in terms of standard instrumentation parameters. Research will then be carried out into the four sensors as they will need to be replaced to make them more compliant with the demands of modern manufacturing systems that are in line with Industry 4.0 and support I/O Link. The social and environmental effects of these sub-systems will then be discussed as well as the maintenance and reliability of the system. The risk assessment carried out prior to completing the assignment can be found in Table 1 - Risk Assessment.

This is a good work plan

2. System Investigation

The flow control loop 535 controls the flow of water into tank B1. The Flow Controller FC535 provides a CV to the pump amplifier LY541 with the flow transmitter FT535 providing the PV for the loop. An interlock is required with either the solenoid valve V516 or V515 in order to ensure that water is able to be pumped backup into the pump. The sensor used in this loop is equivalent to the RS PRO Radial Flow Turbine Flow Meter for Liquid and is labelled as FT535. The sensor is capable reading a 0.25-6.5L/min flow with maximum pressure of 20bar, both ranges being suitable for this application. (RS PRO, 2023)

The Temperature Control Loop 511 controls the temperature of the water in tank B1. The temperature controller TC511 provides a CV to an SSR (Solid State Relay) through a PWM which controls the heater. The PV for the loop comes from the temperature transmitter TT511. Then the low water level switch LS542 provides an interlock to stop the water from being heated when under a certain temperature. The cooling fan, the solenoid valves V516 and V515, and the pump amplifier LY541 all help to reduce the temperature of the water within the system by adding cold water/cooling the water. The sensor used in this control loop is equivalent to the Jumo Temperature Sensor and is labelled as TT511. The sensor offers a range of -50°C to 400°C which is plenty as the highest temperature that the water can reach will be 100°C. (Jumo, 2011) *our sensor and signal conditioner are set up in the range 0 to 100 degrees*

The Level Control Loop 541 controls the level of the water in tank B1. It is controlled by the level controller LC541 with the level itself being sensed by the level transmitter LT541. The tank is emptied via a solenoid valve and water pumped back in is controlled by the pump amplifier LY541. The low water limit switch provides an interlock for other functions within the system. The sensor used in this control loop is the Endress +Hauser Cerabar PMC 133 and is labelled LT541. The sensor is a differential pressure transmitter that works by calculating the differential pressure between the liquid and gas within a closed tank system as well as considering the temperature within the system as this will affect the gas. (Lukat, 2020) The maximum temperature range for the sensor is -40°C to 85°C, with a maximum pressure of 60bar, both ranges being suitable for the application. (Endress + Hauser, 1993)

The Water Input Flow Control Loop 531 controls the flow of the water into the system. The flow transmitter FT531 senses the flow of the water with pressure of the water coming from the recirculating water system. The proportional valve VF531 and the flow controller FC531 controls the overall flow of the system. The solenoid valves V510 and V511 allow water to enter each of the tanks. The sensor used in this loop is equivalent to the RS PRO Radial Flow Turbine Flow Meter for Liquid and is labelled as FT531. The sensor is capable reading a 0.25-6.5L/min flow with maximum pressure of 20bar, both ranges being suitable for this application. (RS PRO, 2023)

3. Calibration of Pressure Sensor

For this task the pressure sensor Druck, LPM5360 and a table of results was created followed by a graph to display the findings was calibrated. The pressure was increased in increments 0.5bar ranging from 0.0-5.0bar. A multi-meter was then used to measure the output voltage of the pressure sensor at every increment with all values being returned to 0 before each measurement. Errors were then calculated for the both the rising pressure voltage and the falling voltage by subtracting the voltage value from the linear value. Static sensitivity was then calculated by dividing the output range of the of the sensor by the input range. *this would have been done first*

As can be seen in the graph in Figure 1 - Pressure sensor calibration and by looking at the results tabulated in Table 2 - pressure Sensor Calibration the worst-case linearity error was 0.9% and the worst-case hysteresis error was 0.3%. Comparing these errors to the quoted linearity error of $\pm 0.25\%$ and hysteresis error of 0.02% from the datasheet provided by Druck, it can be seen that the sensor is not operating within tolerances outlined by the manufacturer and so will likely require replacing. A suitable replacement is discussed in Replacement of sensors. (Druck, 2023)

4. Calibration of Temperature Sensor

For this task the sensor equivalent to the Jumo Temperature Sensor was calibrated, and a table of results was created followed by a graph to display the findings. A fluke loop calibrator was used to simulate the water increasing temperature in increments of 10°C from 0°C to 100°C and then repeated by simulating the water decreasing in temperature from 100°C to 0°C. A multimeter was used to take current output readings from the temperature sensor in the range of 4-20mA with the temp being 0°C at 4mA and 100°C at 20mA.

As can be seen in the graph in Figure 2 - Temperature Sensor Calibration and by looking at the results tabulated in Table 3 - Temperature Sensor Calibration the worst-case linearity error was 10.625% or 10.625°C and the worst-case hysteresis error was 0.625% or 0.625°C. No reference to accuracy can be found on the datasheet provided by RS PRO in regard to the sensor so it cannot be determined whether or not the sensor is operating within tolerances outlined by the manufacturer. However, the worst-case linearity error is quite high, and so a recommended replacement can be found in Replacement of sensors.

5. Calibration of Level Sensor

In order to carry out the calibration of the level sensor, multi-meter was connected in series with the level sensor to get accurate readings of the current in the output signal, and a measuring tube was used to get readings of the actual level. The results were tabulated and the multiplier, divisor, and offset were then calculated using the following equations

$$\text{Multiplier} = 12.47 - 6.11 = 6.36$$

$$\text{Divisor} = 23 - 7 = 16$$

$$\text{Offset} = 12.47 - \frac{6.36}{16} * 23 = 3.3275$$

The scaled value was then calculated with 7cm being raw value:

$$\text{Scaled value} = \frac{6.36}{16} * 7 + 3.3275 = 6.11$$

As can be seen in the graph in Figure 3 - Level Sensor Calibration and by looking at the results tabulated in Table 4 - level sensor calibration the worst-case linearity error was 0.1075mA or 10.75% and the worst-case hysteresis error was 0.16mA or 16%. Comparing these errors to the quoted linearity error of $\pm 5\%$ and hysteresis error of $<0.01\%$ from the datasheet provided by Endress+Hauser, it can be seen that the sensor is not operating within tolerances outlined by the manufacturer and so will likely require replacing. A suitable replacement is discussed in Replacement of sensors. (Endress + Hauser, 1993)

6. Calibration of Position Sensors

For this task the sensor O1D102 photoelectric distance sensor was calibrated, and a table of results was created. A measurement was taken every 100mm from the position 0mm to 1300mm and then the same repeated coming back starting at 1300mm to 0mm with the sensor having a 200mm offset. The readings were taken from an HMI that displayed values from both the sensor and the encoder on the actual motor, the values were cross referenced, and errors calculated using

$$\text{Encoder minus offset} - \text{laser minus offset} = \text{Error(mm)}$$

As can be seen in the table of results seen in Table 5 - position sensor calibration the worst case error when going from 0mm to 1300mm was $\pm 14.55\text{mm}$ and the worst case error when going from 1300mm to 0mm was $\pm 16.21\text{mm}$. Comparing these errors to the quoted error of $\pm 32\text{mm}$ from the datasheet provided by ifm, it can be seen that the sensor is still operating within tolerances outlined by the manufacture and so the sensor does not require to be replaced. (ifm electronic, 2017)

7. Research

Industry 4.0

Industry 4.0 isn't a particular thing, more a representation of the modern state of producing product with the digitalization of manufacturing. Industry 4.0 will likely build upon the foundation set by the 3rd industrial revolution, the use of computers and automation within manufacturing, and see the addition of autonomous systems fuelled by data and machine learning. As industry 3.0 had already integrated computers into the manufacturing process, industry 4.0 will allow for all these machines to be able to be connected together and so create and share information. Industry 4.0 allows for manufacturing processes to be optimized quickly and efficiently by collecting large amounts of data that can provide information on maintenance, machine performance, and potential issues the machine/process may have, and so is able to analyse said data and identify patterns that humans would be unable to do within a realistic timeframe. Industry 4.0 will also likely see the introduction of more robots into the manufacturing space which will safely and quickly support manufacturers and also greatly reduce labour costs. (Marr, 2018) Correctly cited

I/O link

I/O link is an increasingly used system that provides many advantages over standard I/O and extends to the globally recognised PLC standard IEC 61131. It is a point-to-point communication system that allows for sensors and actuators to exchange process data, service data, and events within the system in which it's being used. Process data is an input/output that will provide information on the current/required state of the sensor or actuator. Service data, or Service Protocol Data Units (SPDUs), allows for detailed information about the sensor or actuator to be retrieved. The SPDUs can provide anything from the version/type of sensor and serial numbers to the more in-depth configuration, detailed diagnostic or status. Any necessary information can be made available the manufacturers of said sensors and actuators. Events typically provide information on any alarms encountered or any informational messages, as these will occur too rarely to be included within the process data and so can be reported without the need for SPDUs to be queried. These messages will come through I/O link's built-in event facility. (CONTROL, 2023)

Replacement of sensors

Thus, it is important for manufacturers to update their current equipment in order to stay in line with emerging standards. This can be done with the college's Integrated Automation System in the G8 laboratory, also known as the CIM system. The RS PRO Radial Flow Turbine Flow Meter for Liquid used in both control loops 531 and 535 could be replaced with ifm's SBG232. It has a range of 0.3...15 l/min and a pressure rating of 40 bar which allows headroom for future changes to the machine as well as supporting I/O link and complying with the PLC

These are good suggestions

standard IEC 61131 which would bring the control loop in line with industry 4.0. (ifm electronic, 2022)

The sensor equivalent to the Jumo Temperature Sensor used in the Control Loop 511 could be replaced with ifm's TA2531 temperature transmitter. It has range of -50...200°C which provides plenty headroom given the application for which it is required. The sensor also supports I/O link which would bring the control loop in line with industry 4.0. (ifm electronic, 2022)

The sensor Endress +Hauser Cerabar PMC 133 used in the control loop LT541 could be replaced with ifm's LMC502 sensor for point level detection which uses the same method of calculating the differential pressure between the liquid and gas within a closed tank system as well as considering the temperature within the system as this will affect the gas. The temperature range for the sensor is 20...100°C and a max pressure of 40bar, both being more than suitable for the current application and potential future upgrades.

The sensor

unfinished sentence

8. Environmental, Maintenance and Reliability

The two sub systems are likely to draw a decent amount of power. Seeing as the UK's power is only about 36.3% renewable, then it may be said that the subsystems could play a small part in global warming. Much of the materials used to build the subsystems are of non-sustainable which contributes to the potential resource available globally. The maintenance of the subsystems would be less strenuous once the sensors had been replaced as the sensors will be able to communicate any faults within the system. Many of the current sensors are fairly dated, i.e. the Endress+hauser sensor is over 20 years old and is more liable to breaking down and so in a manufacturing setting would potentially cause a significant amount of downtime.

9. Conclusions and Recommendations

Write in the third person

This assignment has allowed me to learn new knowledge in regards to system instrumentation and helped me to further develop my skills as an engineer. It has provided a further insight into different types of sensors previously unexplored and learn more about how to read and understand P&ID drawings, and what sensors are most suitable for different applications, especially in regard to industry 4.0 and I/O link. I have learnt how to calibrate different types of sensors and how to analyse the results of said calibrations and so will aid in any future potential career within engineering

In order to improve upon this assignment, I would have carried out each calibration more than once to ensure that reliable results were obtained and untainted by human error. The calibrations could also have been carried out individually instead of in groups so as to reduce any human error.

This reads too much like a personal reflection

10. Team Working

Working as a team to carry out the calibrations enabled for precise readings to be taken by having one person adjusting the control variable to its required increments, one person taking readings of the non-control variable, and one person recording the results. This also meant that the calibrations could be carried out quickly and efficiently. Working as team also helped to develop the ability to work as a team in professional setting by ensuring that everyone had an equally important role.

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12. Appendix

Potential Hazards	People at risk & how	Actions already in place	Further Actions required
Electric shock/Electrocution	Technician/operator	All systems grounded, surge protection in circuit	Lock off equipment prior to carrying out work
Mechanical Failure	Technician/operator	Emergency stops, safety guard	Increase size of guards to prevent entrapment

Table 1 - Risk Assessment

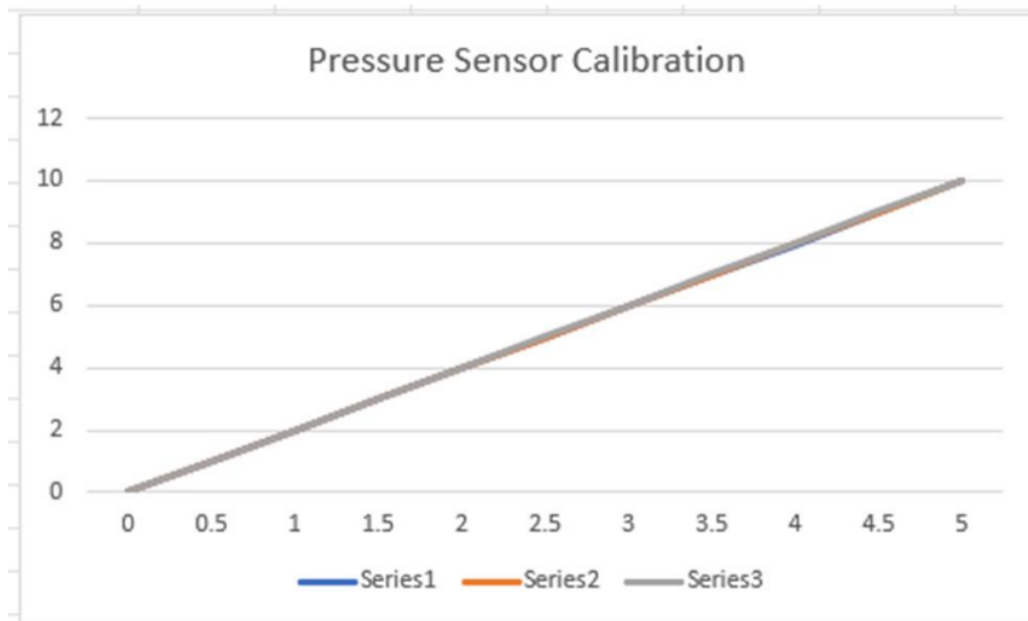


Figure 1 - Pressure sensor calibration

Measured Pressure (Bar)	Output Voltage (Volt)		Linear Value (Volts)	Non-linearity Error (Volts)		Hysteresis Error (Volts)
	Rising	Falling		Rising	Falling	
0	0	0.06	0	0	0.06	-0.06
0.5	1.02	1	1	0.02	0	0.02
1	1.99	1.96	2	-0.01	-0.04	0.03
1.5	2.98	2.98	3	-0.02	-0.02	0
2	3.97	3.97	4	-0.03	-0.03	0
2.5	4.95	4.96	5	-0.05	-0.04	-0.01
3	5.95	5.96	6	-0.05	-0.04	-0.01
3.5	6.94	6.94	7	-0.06	-0.06	0
4	7.94	7.95	8	-0.06	-0.05	-0.01
4.5	8.96	8.94	9	-0.04	-0.06	0.02
5	9.97	9.97	10	-0.03	-0.03	0

Table 2 - pressure Sensor Calibration

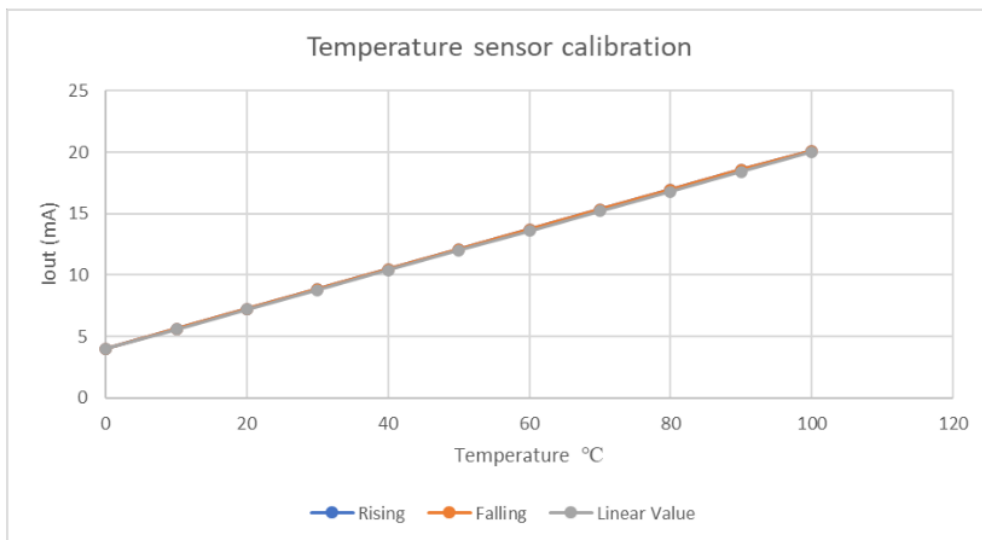


Figure 2 - Temperature Sensor Calibration

Temperature (Degrees celcius)	Output Amperage (mA)		Linear Value (mA)	Non-linearity error (Volts)		Hysteresis Error (Volts)
	Rising	Falling		Rising	Falling	
0	4	4.01	4	0	0	0
10	5.62	5.62	5.6	0.02	0.02	0
20	7.24	7.24	7.2	0.04	0.04	0
30	8.85	8.86	8.8	0.05	0.06	-0.01
40	10.47	10.48	10.4	0.07	0.08	-0.01
50	12.09	12.1	12	0.09	0.1	-0.01
60	13.71	13.72	13.6	0.11	0.12	-0.01
70	15.33	15.33	15.2	0.13	0.13	0
80	16.95	16.95	16.8	0.15	0.15	0
90	18.57	18.57	18.4	0.17	0.17	0
100	20.1	20.1	20	0.1	0.1	0

Table 3 - Temperature Sensor Calibration

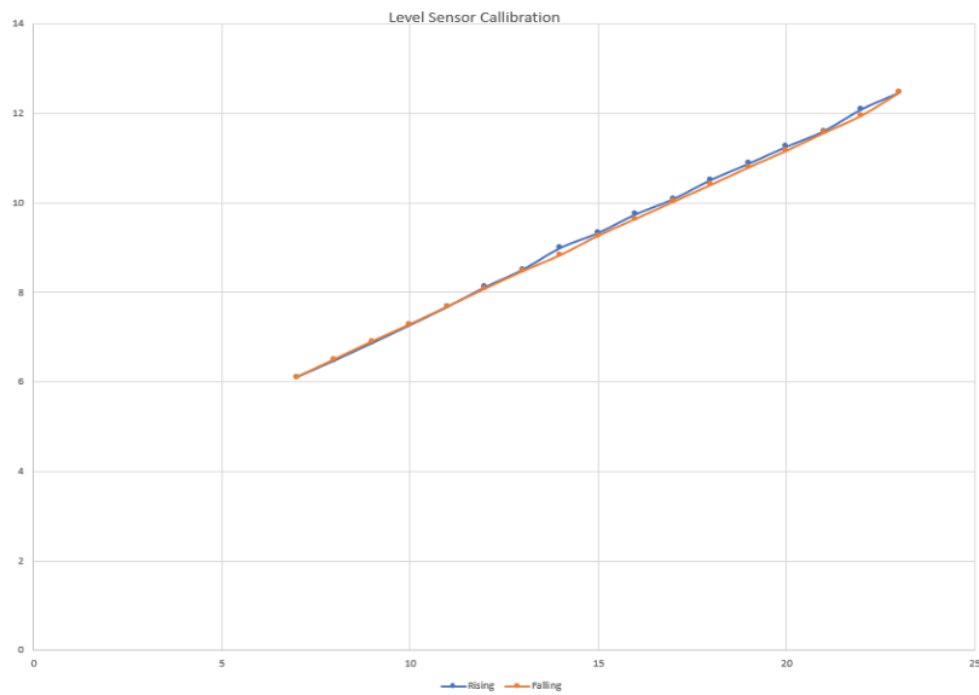


Figure 3 - Level Sensor Calibration

Measured Level (cm)	Output Current (mA)		Linear Value (mA)	Non-Linearity Error (mA)		Hysteresis Error (mA)
	Rising	Falling		Rising	Falling	
0	4.03	4.01	3.3275	0.7025	0.6825	0.02
7	6.11	6.11	6.11	0	0	0
8	6.48	6.51	6.5075	-0.0275	0.0025	-0.03
9	6.87	6.91	6.905	-0.035	0.005	-0.04
10	7.27	7.29	7.3025	-0.0325	-0.0125	-0.02
11	7.68	7.69	7.7	-0.02	-0.01	-0.01
12	8.12	8.09	8.0975	0.0225	-0.0075	0.03
13	8.51	8.48	8.495	0.015	-0.015	0.03
14	9	8.84	8.8925	0.1075	-0.0525	0.16
15	9.33	9.27	9.29	0.04	-0.02	0.06
16	9.75	9.65	9.6875	0.0625	-0.0375	0.1
17	10.09	10.03	10.085	0.005	-0.055	0.06
18	10.52	10.41	10.4825	0.0375	-0.0725	0.11
19	10.88	10.8	10.88	0	-0.08	0.08
20	11.26	11.17	11.2775	-0.0175	-0.1075	0.09
21	11.61	11.57	11.675	-0.065	-0.105	0.04
22	12.1	11.96	12.0725	0.0275	-0.1125	0.14
23	12.47	12.47	12.47	0	0	0

Table 4 - level sensor calibration

Encoder (mm)	Laser right	Encoder minus offset	Laser minus offset	Error		Encoder (mm)	Laser left	Encoder minus offset	Laser minus offset	Error
0.1	200.65	0	0	0		1299.8	1513.04	0	0	0
100.4	291.93	100.3	91.28	9.02		1200.8	1411.16	-99	-101.88	2.88
200.5	393.82	200.4	193.17	7.23		1100.3	1313.4	-199.5	-199.64	0.14
300.9	503.44	300.8	302.79	-1.99		1000.9	1211.93	-298.9	-301.11	2.21
399.6	601.75	399.5	401.1	-1.6		899.5	1110.65	-400.3	-402.39	2.09
499.8	707.78	499.7	507.13	-7.43		799.1	1009.23	-500.7	-503.81	3.11
600	813.94	599.9	613.29	-13.39		699.8	911.3	-600	-601.74	1.74
700.6	915.7	700.5	715.05	-14.55		600	810.34	-699.8	-702.7	2.9
800.2	1015.22	800.1	814.57	-14.47		500.6	704.41	-799.2	-808.63	9.43
900.4	1114.81	900.3	914.16	-13.86		400.3	597.33	-899.5	-915.71	16.21
999.2	1212.04	999.1	1011.39	-12.29		299.6	499.85	-1000.2	-1013.19	12.99
1099.4	1313.63	1099.3	1112.98	-13.68		200.9	402.5	-1098.9	-1110.54	11.64
1200.6	1411.54	1200.5	1210.89	-10.39		99.1	296.33	-1200.7	-1216.71	16.01
1299.6	1513.04	1299.5	1312.39	-12.89		-0.3	202.48	-1300.1	-1310.56	10.46

Table 5 - position sensor calibration

FINAL GRADE

GENERAL COMMENTS

Instructor

62/100

PAGE 1

PAGE 2

PAGE 3

QM

Punctuation Error

Punctuation error

Text Comment. This is a good work plan

PAGE 4

Text Comment. The whole report should be 1.5 line spaced with fully justified text

Text Comment. our sensor and signal conditioner are set up in the range 0 to 100 degrees

PAGE 5

Text Comment. this would have been done first

PAGE 6

PAGE 7

PAGE 8

PAGE 9



Correctly cited

Citation method conforms to Harvard standard, well done.

PAGE 10

Text Comment. These are good suggstions

Text Comment. unfinished sentence

PAGE 11

PAGE 12



Write in the third person

Don't refer to your self as I, me, my or others as you etc. Avoid personal references. If absolutely necessary, refer to self as "the author".

Text Comment. This reads too much like a personal reflection

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PAGE 19

GRADING FORM: NEW CSG-RUBRIC

IWAN GRIFFITHS

62

1. ENGAGEMENT WITH LITERATURE



A very good research section with from a wide range of sources cited and listed correctly using the Harvard method. 14/20

14

2. KNOWLEDGE AND UNDERSTANDING



A good system investigation and explanation of your calibration procedure and environment section. 12/20

12

3. COGNITIVE AND INTELLECTUAL



Good analysis of results. Unfortunately, your conclusion is more of a personal reflection. 11/20

11

4. PRACTICAL APPLICATION



Good use of calibration equipment and recording/graphing of results 13/20

13

5. TRANSFERABLE SKILLS



A good work plan, brief risk assessment and explanation of team working. Report is well structured, written (except for a few errors) and presented with mostly clear diagrams. Word count not exceeded. 12/20

12