IDT PROJECT PROPOSAL

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Abstract

The overarching team-goal of this project is to produce a calibrated and controllable surface profilometer. Housed in a re-purposed 3-D printer casing, the surfaces will be limited in size to the centimetre-cubed scale. The existing stepper motors will be used for manoeuvring the measurement device, namely a cantilever array, and to employ it in a raster scanning motion. Two measurement methods will be employed: Firstly, similar to methods utilized in AFM, a laser is reflected off the cantilever into a detection array. Secondly, strain gauges mounted on the cantilever will contort, producing resistances which will act as the basis for measurement once calibrated. Ideally, both variations should be in agreement. The latter of these two methods will be the focus of this proposal.

1 Instrument Description

1.1 Purpose & Value

Within the overall surface profilometer project, outlined here is the strain gauge measurement apparatus, which will work in tandem with the cantilever itself. Where the cantilever deflects upward and downward in relation to the specific surface being analysed, the gauges will be proportionally stressed or unstressed. The resulting resistances from this action will then be used, once calibrated, to measure the corresponding height changes of the tip. More on the specifics of this process will addressed in Section 1.2.

This apparatus in itself is of no immediately apparent use. However, exercised in conjunction with the incremental stepping motion allowed by the stepper motors opens up more opportunity. While performing a raster scan of a given test surface, once fully functioning and calibrated, this strain gauge dependent apparatus will allow for successive, rolling height measurements to be stored. These height measurements can then be stored and reconstructed to produce digital surface profiles for any given test piece within the instructed limits.

1.2 Design Elements

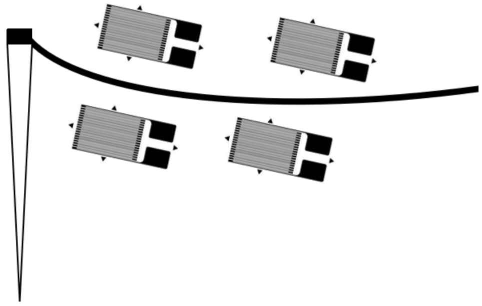
This apparatus will consist of four codependant elements and the two respective power supplies necessary for their operation.

Four Strain Gauges will be utilized, two on the top-face of the cantilever and two on the bottom-face, placed in mirrored positions to their counterparts. When stressed or unstressed upon the cantilever deformation, their resistive output changes will be the core on which this operation relies.

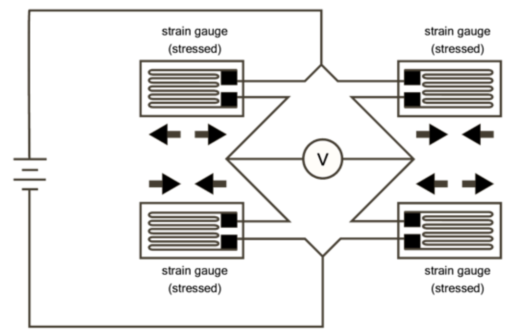
A Wheastone Bridge will then be created, using the strain gauges in each of the four resistor positions to form a full bridge configuration. The quantity of strain gauges was specifically chosen so that this configuration would be possible. The advantage of the full bridge is that the output is balanced and so is directly proportional to the applied force without the need for any approximation.[1]

An Instrumentation Amplifier will then be used to amplify the relatively small output of the bridge. The two output nodes will be fed into the non-inverting and inverting inputs of the chip respectively. An instrumentation amplifier simply denotes a high gain dc-coupled differential amplifier with single-ended output, high input impedance, and high CMRR. While a general operational amplifier may be used for this purpose in the right configuration, achieving a sufficiently high CMRR becomes more difficult without introducing unnecessary error. As such, a dedicated instrumentation amplifier with a two-op-amp design was preferred for its purpose built attributes. For example, output of the bridge, with $\pm 10V$ of excitation will produce somewhere in the region of $\pm 10^{-3}V$. Therefore, in targeting a producible gain of 100 should produce a single-ended output of $\approx \pm 1V$. [2]. The specifics of these considerations will be later addressed in Section 2.

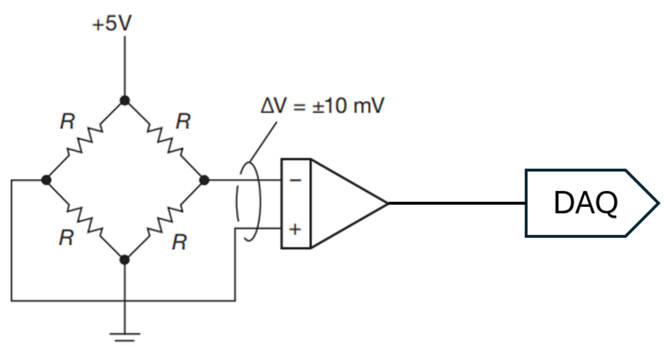
An ADC is the final element of the four part set-up. The output of the instrumentation amplifier will be fed into an ADC in the form of a DAQ. Utilizing this DAQ, a LabView code will then be written to appropriately calibrate and store the attained measurements. This code will be amalgamated into a master VI in conjunction with the LabView programs designed for the purposes of motor movement and laser detection.



(a) Cantilever / Strain Gauge Array



(b) Full Bridge Strain Gauge Configuration



(c) Bridge to Amplifier Output

Figure 1: Demonstration Schematics of Apparatus

2 Technical Specifications

2.1 Strain Gauge & Wheatstone Bridge

At the time of writing the exact model of strain gauge has not been established. However, it is in all likelihood that the parts used will be 120Ω, with a body length of 1cm. While 350Ω alternative may experience less in the way of self heating, with the chosen excitation value of the bridge this should not be a major factor. In addition, the 120Ω variety should also be slightly more sensitive for this specific op-

eration.
The Wheatstone Bridge will provisionally be powered with 5V excitation, as opposed to the also considered and common 10V alternative. With a conscious respect to power supply availability, by keeping the excitation voltage at 5V the opportunity to simplify power supply arrangements is an important thought to bare in mind. Depending on the strain experienced by the strain gauges, the output of the bridge may vary significantly. In general this output is calculated using the formula[3]:

$$\Delta V_{\text{out}} = \frac{V_{\text{exc}} \cdot \Delta R}{R_{\text{total}}}$$

From literature, the preliminary expectation would be a full scale output somewhere in the region of $\pm 10mV$.[2]

2.2 Instrumentation Amplifier & NI DAQ

The original consideration for the amplification portion of this apparatus was to build a differential amplifier using a general purpose operational amplifier with considerably high CMRR, such as the OP07. However, upon further investigation, a built for purpose instrumentation amplifier, such as the INA122P (chosen here), is far more suitable for this task. In brief, its higher CMRR, lower offset voltage,and its easily configurable 5-1000 gain are a small portion of the critical factors here.
One more advantage to the INA122P is its voltage supply capabilities. The range of $2.2 \geq V_s \leq 36$ allows for our voltage supply to once again be easily limited to the 5V threshold. If we consider the earlier preliminary $\pm 10mV$ full scale wheatstone bridge output, an estimation can be made with regard to a suitable gain selection here in order to be within the 0-5V range required by the NI DAQ being employed.
If a mid-range voltage value of say 2.5V was needed for input into the DAQ, the gain required would be:

$$\frac{2.5V}{10mV} = 250$$

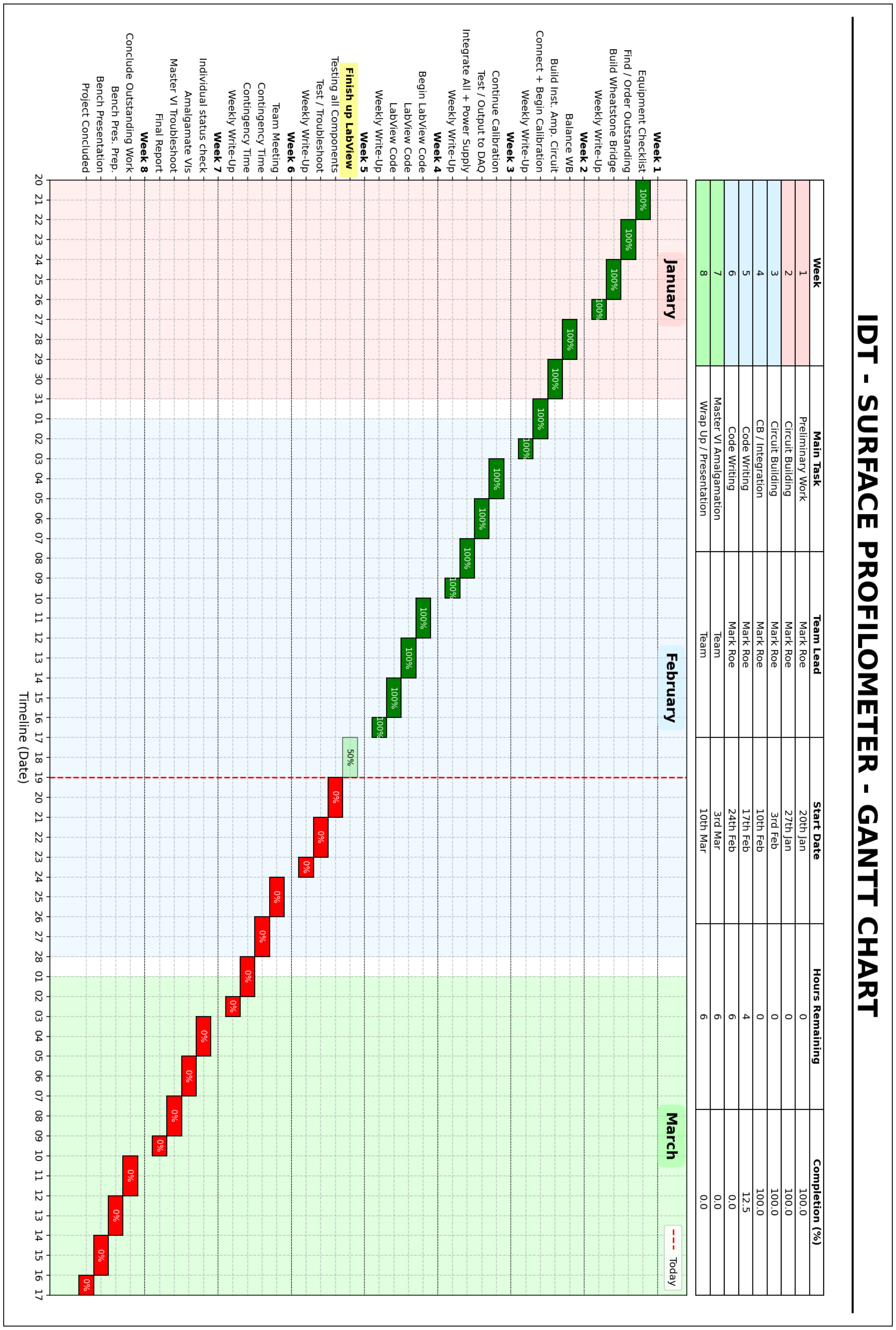
We can then use the INA122P's accompanying gain equation[4] in order to establish the required value of the gain-resistor R_G:

$$\text{Gain} = 5 + \frac{200k\Omega}{R_G} = 250$$

$$R_G \approx 816\Omega$$

The noise considerations involved when using a relatively high gain such as this will of course be addressed on an ongoing basis. The importance of calibration will also be paramount when dealing with small output values on the micro to millivolt scale.
An obvious point to address, having made these component specifications, is that this apparatus is specifically designed, at this stage, to deal with small strain values and thus small deflection values. While it could be adapted for versatility, the constraints of the housing structure dictate that sensitivity to the scale, as catered for here, is the primary objective of this project.

3 Provisional Timeline



***NOTE:** This chart has been included in a separate file. Data entered for demonstration only.

4 References

4.1 Literature References

[**1**]: All About Circuits. “Strain Gauges — Electrical Instrumentation Signals — Electronics Textbook.” *All About Circuits*, 10 July 2019. Available at:

https://www.allaboutcircuits.com/textbook/direct-current/chpt-9/strain-gauges/

[**2**]: Horowitz, P. and Hill, W. (1981). *The Art of Electronics*. Cambridge University Press, pp. 421–423.

[**3**]: Krause, R. A., & James, D. D. (2012). ”Strain Gauges and Their Applications.” IEEE Instrumentation & Measurement Magazine, 15(4), 20-24

[**4**]: INA122P Spec Sheet, Texas Instruments: https://www.ti.com/lit/ds/symlink/ina122.pdf?ts=1736498839483&ref_url=https

4.2 Image References

[**Fig.1 (a)**]: https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcSr5bWwRNO2dC1D2cNKYq5syxFJwf7kObS0rJhNNjZqPRlVSOdQLLU-Nrpg_zNp_RBXCHU&usqp=CAU

[**Fig.1 (b)**]: Horowitz, P. and Hill, W. (1981). *The Art of Electronics*. Cambridge University Press, p. 421.

[**Fig.1 (c)**]: All About Circuits. “Strain Gauges — Electrical Instrumentation Signals — Electronics Textbook.” *All About Circuits*, 10 July 2019. Available at:

https://www.allaboutcircuits.com/textbook/direct-current/chpt-9/strain-gauges/