

SIGNAL CONDITIONING OF STRAIN GAUGE SENSORS

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ABSTRACT: Strain gauge sensors are used extensively in industrial machines and testing equipments. The output signal of these sensors is basically an analog voltage in the millivoltage range. Interfacing these sensors to a computer system is used to be a challenging problem. There are many popular solution strategies and designers must always compromise between cost, accuracy, and reliability. In this research a real design problem is presented. It is a rehabilitation of a *Materials Testing Machine* which is partially destroyed during the last war on Gaza. Many possible solution strategies are described and the most suitable one to the case study is adopted. The proposed design has been successfully implemented and the machine is returned back to work properly.

KEYWORDS: Signal conditioning, Materials testing, Microcontrollers, Strain gauge

1. INTRODUCTION

The Tinius Olson H10K materials testing machine is shown in Figure 1. It has a frame capacity of 10 kN allowing it to test a wide range of materials such as rigid plastics, films, paper, packaging materials, filter material, thin sheet metal, adhesives, foils, food, toys, and medical devices [1].



Figure 1: The Tinius Olson H10K materials testing machine

The machine may be modeled as shown in Figure 2. The material under test is fixed between points a and b . Point b is stationary while point a is allowed to move up or down using a DC motor screw jack with a user-defined speed. The resultant force (F) on the material and the displacement of point a which is called *the material deformation* (D) are calculated by the controller and presented to the user on a graphical display. Material scenes people relies on this test to judge on the quality of material after sketching the applied force versus the material deformation [2,3].

The displacement is detected by a 1000 pulse quadrature optical encoder [4]. On the other hand, the force is measured via a 10 KN s-type strain gauge incorporated in the mobile crosshead [5].

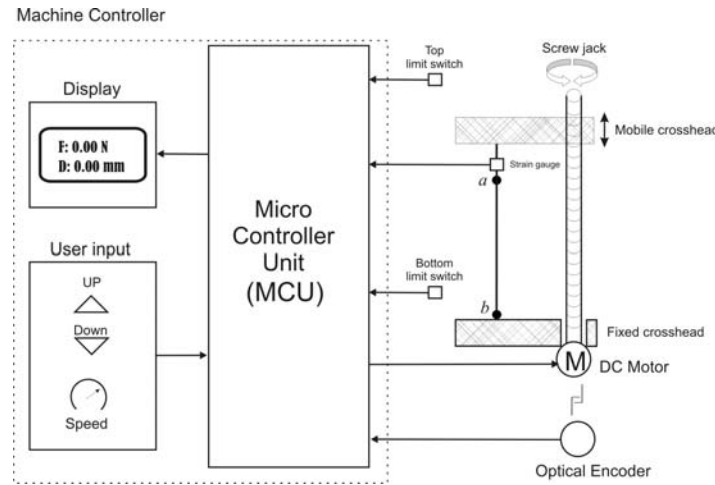


Figure 2: Model of the material testing machine

The machine under consideration is unique in Gaza. It belongs to the *Materials and Soil Laboratory* at the Islamic University and it is characterized by its precession and long deformation range measurement. It is originally controlled via a professional microcomputer system. Unfortunately, this system is totally damaged during the last war on Gaza and ordering a new controller may cost as much as 8000 US\$. Due to the siege on Gaza, we had to rely on viable solutions to let the machine return back to work quickly. It is the aim of this work to describe our approach to resolve the problem. We succeeded to build a reliable low-cost controller (about 300 US\$) based on available electronics in the local market. The main contribution lies behind the success on interfacing the strain gauge to a PIC microcontroller.

The rest of this paper is organized as follows: in Section 2, strain gauge sensors are investigated. Section 3 addresses their signal conditioning issues. Section 4 presents the controller design and finally in Section 5 Conclusions and suggestions for future work are summarized.

2. STRAIN GAUGE SENSORS

A strain gauge is a conducting wire whose resistance changes by a small amount when it is lengthened or shortened. The change in length is small, a few millionths of a

millimeter. The strain gauge is bonded to a structure so that the percent change in length of the strain gauge and structure are identical. A *foil-type* gauge is shown in Figure 3a. The active length of the gauge lies along the transverse axis. The strain gauge must be mounted so that its transverse axis lies in the same direction as the structure motion that is to be measured. Lengthening the bar by tension lengthens the strain gauge conductor and increases its resistance. Compression reduces the gauge's resistance because the normal length of the strain gauge is reduced.

Strain gauges are made from metal alloy such as Constantan, Nichrome V, Dynaloy, Stabiloy, or Platinum alloy. For high-temperature work they are made of wire. For moderate temperature, strain gauges are made by forming the metal alloy into very thin sheets by a photoetching process. The resultant product is the so called “*foil-type*” strain gauge [6].

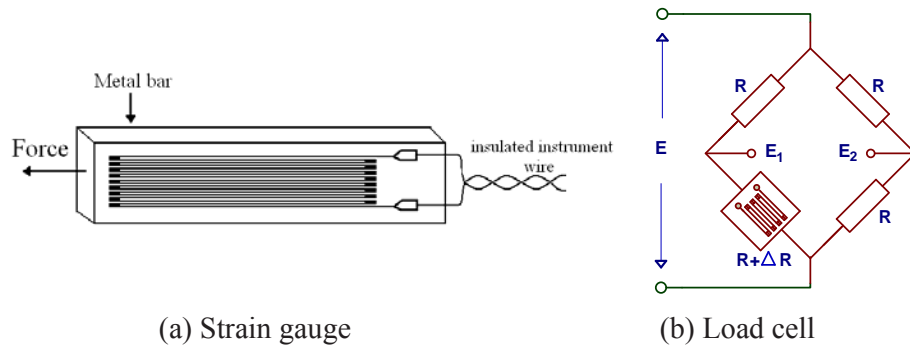


Figure 3: Strain gauge and the resistive bridge structure

In order to measure force using a strain gauge sensor, the change of resistance in the gauge (ΔR) must be measured. To measure resistance, a technique to convert a resistance to a current is needed. The most common technique is to place the strain gauge in one arm of a resistance bridge, as shown in Figure 3b. Assume that the gauge is unstrained, so that its resistance = R . Under these conditions $E_1 = E_2 = E/2$ and $E_1 - E_2 = 0$. The bridge is said to be balanced. If the strain gauge is compressed or stretched, R will change by ΔR and the differential voltage $E_1 - E_2$ would be given by

$$E_1 - E_2 = E \frac{\Delta R}{4R + 2\Delta R} \cong E \frac{\Delta R}{4R}$$

When a strain gauge is arranged in a resistive bridge, the resultant device is usually called a *load cell*. Load cell manufacturers apply some ideas to improve load cell stability against temperature changes and enhance its gain $(E_1 - E_2)/E$. Today's standard load cells have a wide and sufficient range of operating temperature and a gain in the range of 2 mV/V at full scale [7]. That is if a 10 Kg capacity 2mV/V load cell is excited with 5V supply, then the maximum output voltage (at 10 Kg load) will be 10 mV. Obviously, these standard load cells require a precise signal conditioning circuit which able to provide a stable excitation voltage and meanwhile amplifying the cell output about 1000 times.

3. SIGNAL CONDITIONING

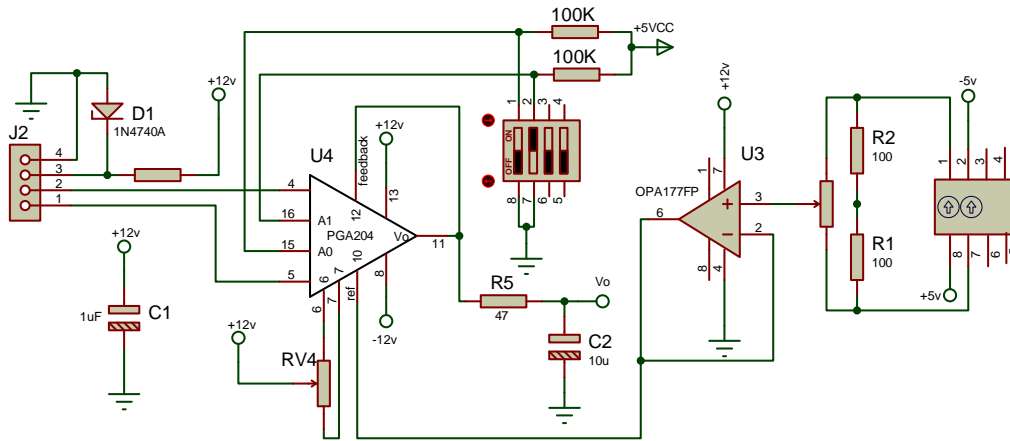
The output signal from a strain gauge sensor needs amplification, filtering and isolation. An extensive survey and laboratory experimentation is made on the commonly used integrated circuit amplifiers [8-15]. The main results are summarized in Table 1. We converged on an instrumentation amplifier integrated circuit (PGA204) from *Burr-Brown Corporation* to be the core of a signal conditioning circuit for our strain gauge sensor. It is a low cost, general purpose programmable-gain instrumentation amplifier offering excellent accuracy. Gain is digitally selected (1, 10, 100, 1000 V/V) by two TTL address lines.

Table (1): Survey summary of commercial integrated circuit amplifiers.

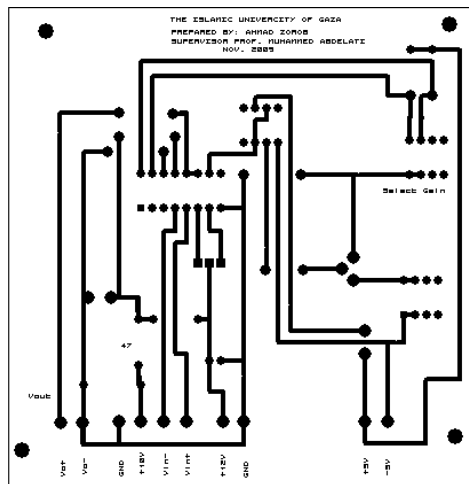
Model	Voltage Gain	Remarks
INA114	1-10000	<ul style="list-style-type: none"> • Gain is set using a variable resistor ($R_{min}=5 \Omega$). • Over voltage protection up to ± 40 V. • Cut off frequency of 100 kHz.
INA118	1-1000	<ul style="list-style-type: none"> • Precision, Low Power. • Gain is set using a variable resistor ($R_{min}=50 \Omega$). • Over voltage protection up to ± 40 V. • Cut off frequency of 7 kHz.
INA122	5-10000	<ul style="list-style-type: none"> • Low quiescent current 60 μA. • Gain is set using a variable resistor ($R_{min}=20 \Omega$). • Wide power supply range. • Single Supply: 2.2V to 36V. • Dual Supply: $-0.9/+1.3$V to ± 18V.
CLC430	1-2	<ul style="list-style-type: none"> • High Bandwidth 20-100 MHz Op Amp. • Low gain signal conditioner suitable for video signals.
PGA204	1, 10, 100, 1000	<ul style="list-style-type: none"> • Gain is digitally selected. • Low cost and available in local market. • Excellent accuracy. • Ideal for our application. • Battery operated system.
PGA205	1, 2, 4, 8	<ul style="list-style-type: none"> • Gain is digitally selected. • Low cost and available in local market. • Excellent accuracy. • Ideal for wide range of applications. • Battery operated system.
AD521	0.1-1000	<ul style="list-style-type: none"> • The instrumentation can be calibrated. • Gain is set using a variable resistor ($R_{min}=100 \Omega$). • Not recommended for new designs.
AD620	1 – 10000	<ul style="list-style-type: none"> • Low cost • Gain is set using a variable resistor ($R_{min}=100 \Omega$).

The excitation of the sensor must be a very precise and stable voltage source around 10 volts. Standard voltage regulators (such as LM7810) are unsuitable as they may have some voltage drop. Therefore, we designed a 10V zener diode regulator circuit for that purpose. At the output stage a simple RC filter is implemented to suppress any possible high frequency noise. The complete signal conditioning circuit along with its layout and implementation are shown in Figure 4. The implemented board was just for

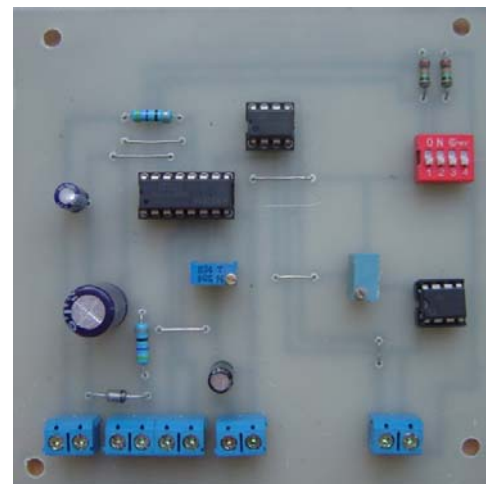
experimentation purposes. Later in this work, it will be integrated within a larger printed circuit for our machine containing regulated power supplies, a microcontroller (MCU), a Liquid Crystal Display (LCD), and other components.



(a) Schematic circuit diagram.



(b) Printed circuit layout.



(c) Implemented board.

Figure 4: The implemented signal conditioning circuit.

4. CONTROLLER DESIGN

The control system may be partitioned to two subsystems as illustrated in Figure 5. The lower subsystem is responsible for adjusting the direction and speed of the DC motor. On the other hand, the upper subsystem is responsible for acquisition of the force and displacement values via the strain gauge and optical encoder respectively. Moreover, it is responsible for blocking the DC motor in case of excess tension in order to protect the strain gauge against mechanical damage.

The direction and speed controller circuit is shown in Figure 6. It is a standard H-bridge relay circuit with a variable DC supply based on SC141D Triac [16].

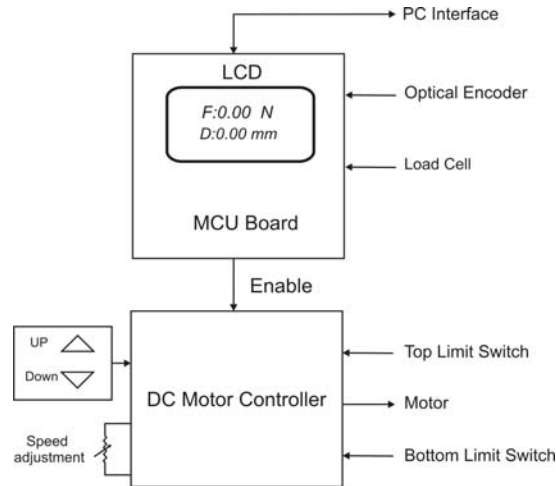


Figure 5: Decomposing the controller into two subsystems.

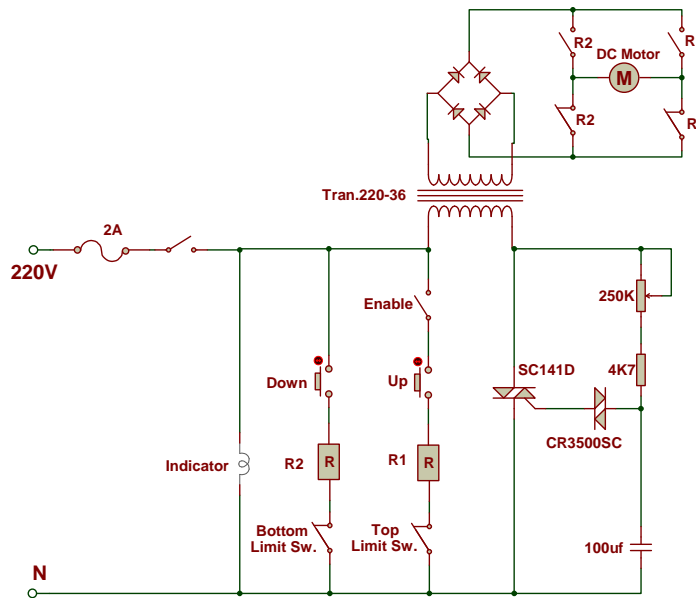


Figure 6: Direction and speed controller circuit.

The force and displacement acquisition unit is designed using a PIC16F877A microcontroller [17]. It features 256 bytes of EEPROM data memory, self programming, 8 channels of 10-bit Analog-to-Digital (A/D) converter, and a Universal Asynchronous Receiver Transmitter (USART). All of these features make it ideal for more advanced level A/D applications in automotive, industrial, appliances and consumer applications. The schematic diagram of our design is shown in Figure 7 and the manufactured one is shown in Figure 8.

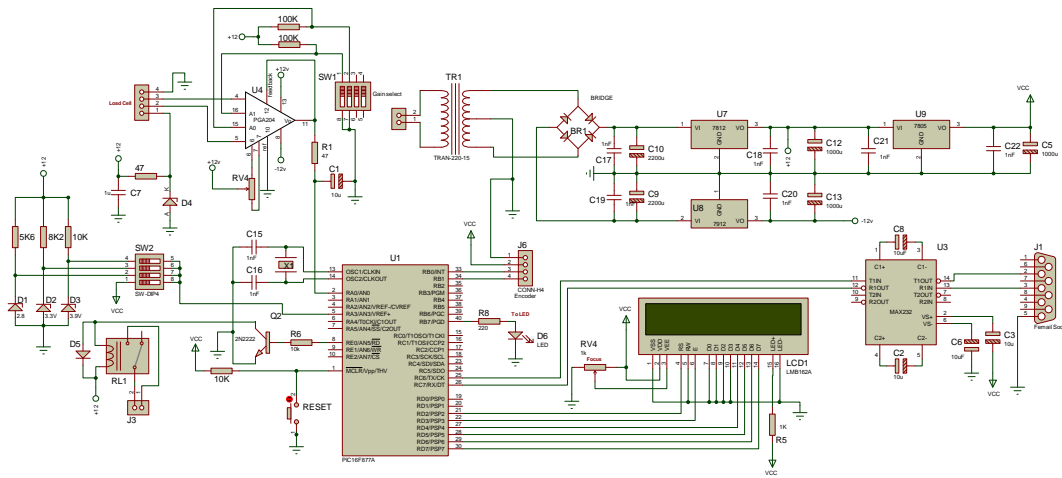


Figure 7: Schematic of the force and displacement acquisition unit.

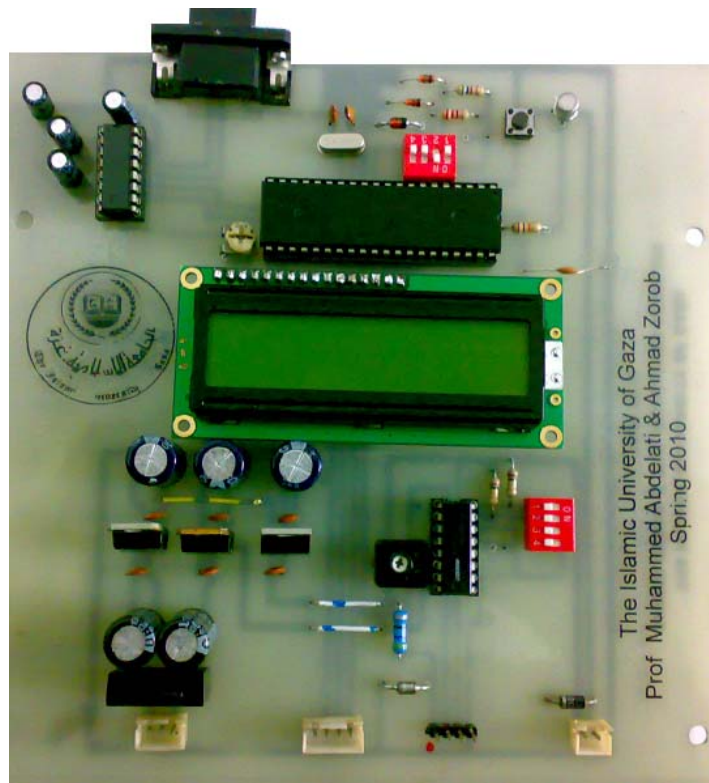


Figure 8: The Manufactured MCU Board.

The design features a selectable precise reference voltage for the A/D converters of the microcontroller. Moreover, the MCU is loaded with a boot loader in order to allow in-circuit programming of the MCU via the USART port [18].

5. CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK.

The main objective of this research was to end up with a precise signal conditioning device for strain gauge sensors which are widely used in our industry. For years we used to rely on expensive monopolized black-box devices for that purposes. The results of this research are expected to help our local engineers to build their own solutions depending on tremendously cheap and available components. We believe that young R&D people in Gaza will combine the results of our research with their good experience in microcontrollers as well as Programmable Logic Controllers and contribute significantly to the development of our industry. We demonstrated through a real case problem the significance of our contribution which can not be denied under the present siege on Gaza.

In a future work, we plan to build a commercial multi-channel weighing indicator and investigate digital strain gauge sensors.

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REFERENCES

- [1] Tensile testing machines. [Online]. Available: <http://www.tiniusolsen.com/> last visited Jan. 2010.
- [2] Palestine Standards Institution, "Plastic testing methods- Determination of tensile properties of films", PS 99 Part4, July 1999.
- [3] ASTM Standards, "Roofing, Waterproofing, and Bituminous Materials", International Standards Worldwide, Vol. 4.04, 2003.
- [4] L. Mitchel, "Serial/Incremental Encoder", Mitchell Electronics Inc. September 2006.
- [5] Jerome E. Johnston, "Load Cell measurement using the CS3001/02/11/12 Amplifiers with the CS5510/11/12/13 ADCs", [Online]. Available: <http://www0.cirrus.com/cn/pubs/appNote/An330REV2.pdf>.
- [6] Richard Djugum, "Strain Gauges: Fabrication Processes and Techniques", VDM Verlag Dr. Muller, 2009.
- [7] William C. Dunn, "Introduction to Instrumentation, Sensors, And Process Control", Artech House Publishers, 2005.
- [8] Karl F. Anderson, "Current Loop Signal Conditioning", Practical Applications, Measurement Systems Engineer, NASA Dryden, Measurement Flight Research Center, Edwards, California 1995.
- [9] Precision, Low Power instrumentation Amplifier INA118. [Online]. Available: <http://focus.ti.com/lit/ds/symlink/ina118.pdf>.
- [10] Single Supply, MicroPower Instrumentation Amplifier INA122. [Online]. Available: <http://focus.ti.com/lit/ds/symlink/ina122.pdf>.
- [11] General Purpose 100MHz Operational Amplifier with Disable CLC430. [Online]. Available: <http://www.national.com/ds/CL/CLC430.pdf>.
- [12] Programmable Gain Instrumentation Amplifier PGA204. [Online]. Available: <http://www.chipcatalog.com/TI/PGA204.htm>.

- [13] Programmable Gain Instrumentation Amplifier PGA205. [Online]. Available: http://www.datasheetcatalog.com/datasheets_pdf/P/G/A/2/PGA205.shtml.
- [14] Integrated Circuit Precision Instrumentation Amplifier. [Online]. Available: <http://www.alldatasheet.com/datasheet-pdf/pdf/48003/AD/AD521.html>.
- [15] Low Cost Low Power Instrumentation Amplifier. [Online]. Available: http://www.analog.com/static/imported-files/Data_Sheets/AD620.pdf.
- [16] M. Abdelati, "Modern Automation Systems", Laxmi Publications, 2009.
- [17] Fernando E. Valdes-Perez and Roman Pallas-Areny, "Microcontrollers Fundamentals and Applications with PIC", CRC Press, Taylor and Francis Group Publisher, 2009.
- [18] Brandon Kuszenski, Philip R. LeDuc and William C. Messner, "A Platform for Building PIC Applications for Control and Instrumentation", American Control Conference 2005, IEEE Xplore, [Online]. Available: <http://www.IEEE.org/>.