Tensile Machine User Interface

Zechariah Gajadhar, Anjali Dhobale, Nicholas Cuneo, B.S. Mechatronics Engineering
Vaughn College of Aeronautics and Technology, United States,
zechariah.gajadhar@vaughn.edu, anjali.dhobale@vaughn.edu, nicholas.cuneo@vaughn.edu

Mentors: Shouling He, PhD, Yougashwar Budhoo, PhD.
Vaughn College of Aeronautics and Technology, United States, shouling.he@vaughn.edu, yougashwar.budhoo@vaughn.edu

Abstract – In this paper, we developed a Graphical User Interface (GUI) for a Tinius-Olsen Tensile Machine using MATLAB. At present, students use the Tinius-Olsen Tensile Machine to perform tension tests that determine mechanical properties of different types of specimens. The stress and strain values, from these tests, are manually recorded and used in Microsoft Excel to generate the specimen's stress-strain plot. The main objective was to create a user-friendly interface to improve student interaction with outdated mechanical testing laboratory equipment. The interface is comprised of an Arduino Uno microcontroller, an ADS1115 16-bit ADC chip and a Logitech web camera. A data acquisition board was built in order to accurately transfer the digital representation of the analog data from the machine to the computer. In the software interface, signal processing techniques were used to reduce data inaccuracies before a real time mechanical stress-strain curve was plotted. Once the stress-strain curve is obtained from the experiment, the Fracture Stress, Fracture Strain, Elastic Modulus and Strain Energy of the specimen are displayed on the screen. Additionally, the GUI interface allows for a live video stream and an image capture feature, which allows students to view the experiment from a safe distance. By developing this user interface, students can interact with the tensile testing machine more effectively and will be able to quickly obtain the stress-strain curve and conduct real time qualitative data analysis.

Keywords – Signal Processing, GUI, Data Acquisition, MATLAB

I. INTRODUCTION

Mechanical engineering students at Vaughn College use various equipment to conduct necessary experiments in the Mechanical Testing Laboratory [1]. One of the equipment utilized is the Tinius-Olsen 10000 tensile machine, which assists students in determining material properties like the Tensile Strength and Young's Modulus of various specimens.

This tensile machine displays the force and elongation experienced by a specimen on an LED board. The displayed values are employed for stress-strain analysis. Currently, students record a video of experiment data from the LED display using a camera. Afterwards, these values are entered into Microsoft Excel to generate a stress-strain plot. Therefore, we proposed to use the machine efficiently by developing a Graphical User Interface (GUI) and data acquisition board, which can plot a real-time stress-strain curve as well as monitor key aspects of the specimen's behavior while under tensile loading. This real-time synthesis and analysis will serve as a cost-efficient educational tool for students to use in laboratory experiments.

Our aim was to design and develop a user interface that will transfer the test data from the tensile machine to a computer using a data acquisition board, display a live video stream of the experiment, conduct real time analysis, and display test results through a Graphical User Interface (GUI) running under MATLAB environment. The experimental data from the tensile machine will be sent to a microcontroller. Further, this data will be processed to display test results, such as a real time stress-strain curve as well as key material properties like Modulus of Elasticity. Key features of the interface will include real-time plotting, integration of an Exponential Moving Average (EMA) filter to measure elongation and load, as well as a webcam to monitor specimen behavior and material properties calculations.

II. RELATED BACKGROUND

The Tinius-Olsen 10000 Tensile Testing Machine is used to obtain the engineering stress-engineering strain curves for different materials e.g. steel and aluminum under tensile loading. From the obtained curves, important mechanical properties of these materials can be determined, such as Modulus of Elasticity (Young's Modulus), Yield Stress, Tensile Strength, and Ductility.
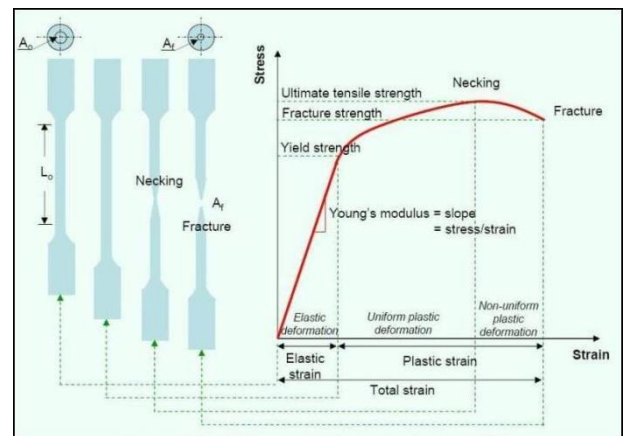

Fig. 1 Shape of Ductile Specimen at Various Stages of Testing

During a typical tensile experiment, a dog-bone shaped specimen is gripped at its two ends and is subjected to an axial load which will elongate, at a determined rate, until its fracture [2]. Figure 1 shows a specimen during different cycles of a tensile test. The corresponding stress-strain curve is shown as well.

III. Mathematical Equations

Stress is the applied force or system of forces that tends to deform a body. The value of mechanical stress (σ) is calculated by dividing the amount of force (F) applied by the machine by the cross-sectional area (A) of the specimen. The common units are in Psi (lbs/in^2) or Pa (N/m^2).

$$\sigma = F/A \qquad (1)$$

Strain is the response of a system to an applied stress. Engineering strain (ε) is defined as the amount of deformation in the direction of the applied force divided by the initial length of the material (Lo). It is a dimensionless quantity.

$$\varepsilon = \Delta L/L_0 \qquad (2)$$

The Modulus of Elasticity, also known as Young's Modulus (E), is the rate of change of strain as a function of stress. The common units are in Psi (lbs/in^2) or Pa (N/m^2).

$$E = \sigma/\varepsilon \qquad (3)$$

IV. Load Analog Signal

Inside the Tinius-Olsen Machine, the mechanical force is first converted to an electronic signal by a strain gauge, mounted in the sensing element of the load cell, which receives an excitation signal from a power supply in the machine [7]. The load cell then sends an output signal to the force amplifier of the machine. Finally, this analog signal is converted to a digital representation and is displayed as units of force on the front panel. The range of the load subjected to the specimen can be from 0 to 10,000lbf. The highest voltage output is +/- 1 VDC from the machine. In other words, 0.45V voltage output would indicate a 4,500lbf load being applied to the specimen. The accuracy of the load-sensing element to send out the correct analog voltage was verified by attaching a known load of 22lbs to the grippers, which consequently sent out a signal of 0.0022V.

V. Elongation Analog Signal

Within the Tinius Olsen Machine, the extension measurement is first converted to an electronic signal by use of an optical encoder mounted on the motor drive shaft [7]. This encoder will give so many counts proportional to the distance travelled by the crosshead. This measurement now feeds into a ROM and digital to analog converter to provide +/- 1 VDC signal output. The maximum measuring extension signal ranges from 0 to 50 inches and is shown on a LED display. The extension measurement was tested by displacing the load cell by 1 inch and verified using Vernier calipers.

VI. Data Acquisition

A. Arduino Uno Microcontroller

The Arduino Uno R3 Microcontroller [4] was selected primarily because of the availability of MATLAB support for Arduino Platforms through serial port communication. It consists of a MATLAB API (class definition file) on the host computer and a server sketch program that runs on Arduino.

Therefore, the Arduino analog and digital I/O can be easily accessed from MATLAB's command line.

The 10-bit ADC Convertor on the Arduino has the ability to detect 1023 discrete analog levels with a reference voltage from 0 to 5V. However, due to the smaller resolution of the 10-bit ADC, the Arduino was unable to detect a load change of 50 lbs, yielding unacceptable higher percentile errors greater than 5% range. Therefore, to improve the resolution, we used the 16-bit ADS1115 ADC board.
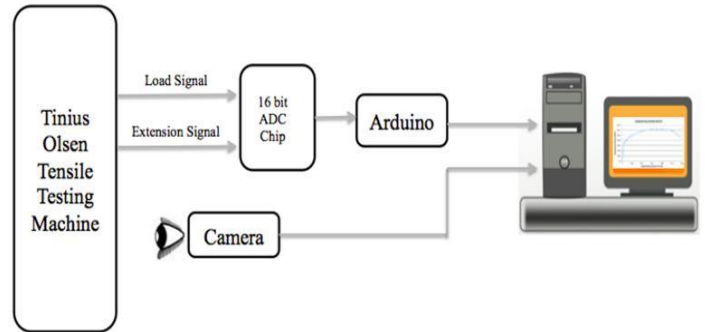

Fig.2: System Overview: The Electronic Module and Camera Output is sent into Graphical Software Interface

B. ADS1115 16-bit ADC Breakout Board

In order to address the low-resolution problem of a 10-bit ADC convertor, we incorporated the Arduino Breakout ADS1115 Board [5]. This board offers a 16-Bit ADC resolution, allowing us to increase the data accuracy from 4.8mV to 0.07mV sensitivity of the load output analog signal. This board is connected to Arduino via I2C protocol. The Inter-integrated Circuit (I2C) Protocol is a protocol intended to allow multiple digital integrated circuits to communicate with the main chip. Each I2C bus consists of two signals: SCL and SDA, as shown. SCL is the clock signal, and SDA is the data signal. I2C requires 2 pins to communicate between the board and a microcontroller. We were successfully able to configure the ADS1115 16-bit chip and establish I2C Communication between the board and Arduino. MATLAB 2014a Arduino IO Package contains functions to establish I2C Communication.

The ADC Configuration register is a 16-bit register whose bit values must be set prior to reading conversion results from the conversion register. The digital value of 18144 disables the comparator, sets the configuration register for analog input pin A0 and allows for a conversion mode of 860 samples per second rate. These values can be adjusted based on how many and which inputs are required.

After the ADC configuration register is set, the 'readRegister' function from Arduino IO Library is used to enter the address for the conversion register, 0x00 and read the positive signed binary results of the conversion. Based on the incoming values from the tensile machine, the digital value of the voltage output will be displayed in the MATLAB's Command Window and used to verify our measurements.

VII. SIGNAL PROCESSING

A. Analog to Digital Conversion

Based on the ADS1115 datasheet, a single ended input covers only half the ADS1115 input scale for positive voltages; therefore, one bit of resolution is lost [5]. The ideal digital units available to measure positive voltages are 32767. The ADS1115 reference voltage ranges from 0 to 5V. However, using the internal ADS1115 Programmable Gain Amplifier (PGA), set at 4x gain, will give us a +/- 1.024V range. This would push the 1V input signal over the entire 16-bit range of the ADC, compared to the limited range 1V would offer without adjusting the gain settings.
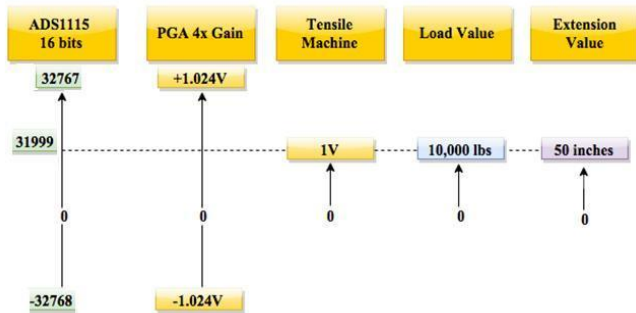
Fig. 3 16-bit Analog to Digital Conversion Diagram Displaying the Voltage Levels and its Relation to Physical Load & Extension

B. Exponential Moving Average (EMA) Filtration

The exponential moving average curve is a discrete 1st- order feedback low-pass filter. At any time, the output of the filter is a weighted sum of the new input value and the old filter output. Filter co-efficient controls how much filtering is applied. The following mathematical equation was programmed into MATLAB, in order to filter the extension noise as seen in Figure 4. Based on the analysis in Table 1, a filter co-efficient of 0.15 (85%) was chosen.

For $\in [0,1]$

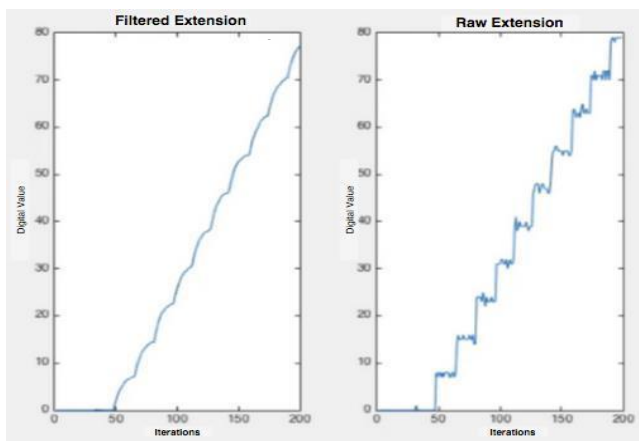$$Xfilt-new = (1-\alpha)*gXfilt-old + \alpha*gXraw \qquad (4)$$

Fig. 4: Raw Extension Data Displayed on Right, While Smooth Filtered Data Displayed on the Left with Filtration Factor of 0.15

TABLE I
EFFECTS OF FILTER COEFFICIENT

Filter Co-efficient	Average Percentile Error	Type of Curve	Time lag
0.1	7.5%	Smooth	High
0.15	1.6%	Smooth with little irregularities	Low
0.2	1.1%	Irregular	Low

VIII. TENSILE INTERFACE SOFTWARE MODULE

MATLAB is a matrix-based technical computing program widely used throughout the scientific, engineering and mathematical communities [3]. A graphical user interface (GUI) is a graphical display in multiple windows containing controls that enable the user to perform interactive tasks. GUI's provide a pictorial interface between a user and program code, facilitating ease and frequency of use. This user is not required to develop code, script, or type commands to accomplish the given task

Using MATLAB *Guide*, our team was able to develop a GUI that will be able to access data (e.g. Load and Extension from the Tinius-Olsen Machine), plot and display a real-time stress-strain curve of the specimen once the user enters the initial cross-sectional area and original length of the specimen. Additionally, a display of specimen properties such as Elastic Modulus, Fracture Stress, Fracture Strain and Strain Energy has been included.

Image Acquisition Toolbox™ was used to acquire images and video from the Logitech web camera [6] directly into MATLAB®. Adding a camera view adds an element of safety for students who can observe the experiment from a safe distance, on a remote workstation. As the stress-strain plot is divided into different regions, students will be able to examine the specimen and its behavior, at that exact region (e.g. Elastic, Plastic, Necking or Fracture) using the real time stress-strain plot.

Fig.5: Start Window to Launch Application

Fig.6: Camera Preview Window showing
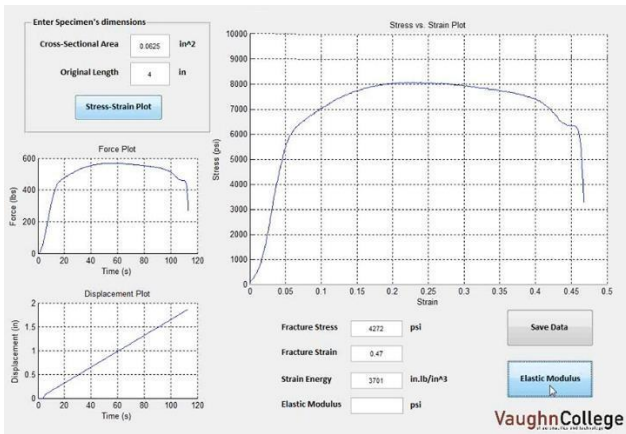Nylon Specimen under Tensile Test

Fig. 7: Stress-Strain Window with Experiment Results
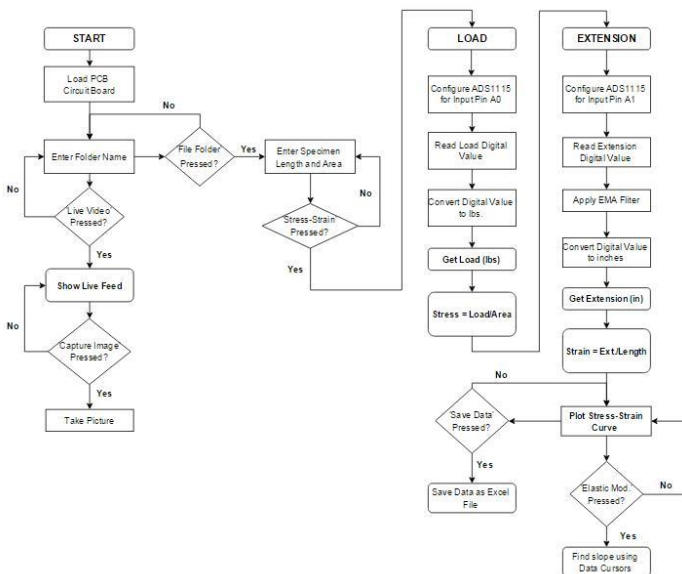
VIII. GUI PROGRAM FLOWCHART

Fig. 8: GUI Flowchart in Logic Sequence

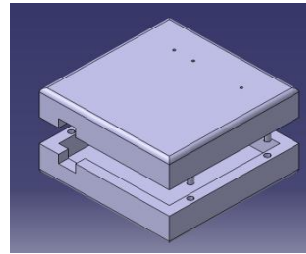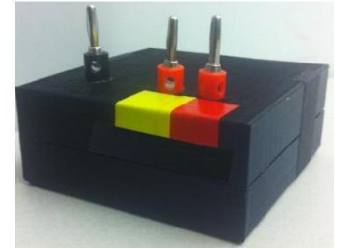## IX. PRODUCT PROTOTYPE

Fig.9: CATIA Case Design

Fig.10: 3D Printed Data Acquisition Board

The protective outer case for the electronic circuitry was designed in CATIA and 3D printed to prevent any damages to the board as shown in Fig. 9 and 10. Pin Connectors were attached to input wires that enable the user to connect the board to the machine.
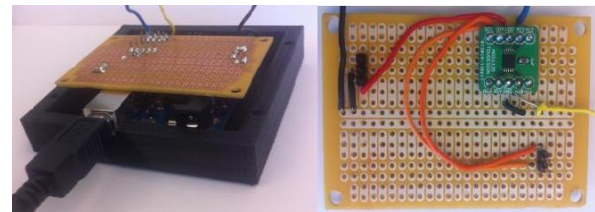

Fig. 11: Electronic Circuitry Enclosed in the 3D Printed Case

X. CONCLUSION

In this paper, we presented a Tensile Machine User Interface which included the design and development of a data acquisition board and graphical software. First, through the data acquisition board, which enclosed ADC circuitry, we acquired the digital representation of the signal. Then this data was processed for reduction in data errors and irregularities by implementing noise filtration and calibration techniques. Next, the processed signal was sent into a user-friendly interface to plot the real-time mechanical stress-strain curve. Finally, the user can interactively select data points on the curve to display the Young's Modulus of the specimen. Additional results such as Fracture Stress, Fracture Strain and Strain Energy of the tested specimen are also calculated and displayed. A custom-built product case was designed and 3D printed to house all the electronic components safely. The developmental costs of this project were modest. Hence, our product can be considered a success. By using inexpensive electronic tools - Arduino Uno microcontroller, ADS1115 16-bit chip, Logitech web camera, along with MATLAB's comprehensive computational ability, we can conduct real-time qualitative data analysis that yields useful information for engineering students.

XI. ACKNOWLEDGMENT

XII. REFERENCES

[1] Budhoo, Yougashwar (2014) "Lab Experiment 1 – Tensile Testing of Metals and Polymers" Handout, Vaughn College of Aeronautics and Technology.

[2] Beer, Johnston (2009) "Chapter 1 – Concept of Stress and Strain", Mechanics of Materials, 5th Ed.

[3] MATLAB Online Resource (2015) – http://www.mathworks.com

[4] Arduino Uno R3 Technical Documentation (2015) – www.arduino.cc/en/Main/ArduinoBoardUno

[5] ADS1115 Breakout Board Technical Documentation (2015) – http://www.tdvdesign.com/ADS1115/

[6] Logitech Camera C310 Technical Documentation (2015) – http://support.logitech.com/product/7076

[7] Instruction Booklet #89-8a – Series 10,000 Bench Universal Testing Machine.