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An Inexpensive Tensile Test Machine

Research Article

Pevril Demir Arı[1,*], Fatih Akkoyun[1], Mustafa Burak Günay[3]

[1]Izmir Democracy University, Faculty of Engineering, Department of Mechanical Engineering, Izmir, Türkiye
[3]Ministry of Industry and Technology, Ankara, Türkiye

Author E-mails:
pevril_demir@hotmail.com
fatih.akkoyun@idu.edu.tr
mburakgunay@hotmail.com
P.D. Arı ORCID ID: 0000-0002-1032-6528
F. Akkoyun ORCID ID: 0000-0002-1432-8926
M.B. Günay ORCID ID: 0000-0002-3720-7414

*Correspondence to: Pevril Demir ARI, Izmir Democracy University, Faculty of Engineering, Department of Mechanical Engineering, Izmir, Türkiye

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Abstract

Tensile testing is a fundamental method for understanding the mechanical properties of materials. In this study, a low-cost tensile testing setup was developed. The design aims to provide a practical and economical solution for educational institutions and small-scale research projects. The developed system is built from locally available components and is based on simple mechanical principles. Using force sensors and linear motion mechanisms, the tensile strength and elongation properties of the specimens were successfully measured. The experimental results showed that the system works with high precision and successfully measured important properties of the tested materials such as tensile strength. Compared to commercial devices, this setup provides a substantial cost advantage while maintaining acceptable levels of accuracy. As a result, this setup, which stands out as a low-cost and practical alternative, is considered to be especially suitable for use in educational laboratories and small-scale projects.

Keywords: Tensile Testing, Tensile Strength, Material Testing System, Mechanical Properties.

1. INTRODUCTION

Tensile testing is one of the most widely used methods for evaluating the mechanical properties of materials. It provides essential information such as tensile strength, elongation, and modulus of elasticity, which are critical for material selection and engineering design. Despite its importance, commercial tensile testing machines are often expensive, making them inaccessible to many educational institutions and small-scale research facilities[1].

The need for affordable and practical solutions has become increasingly evident, particularly for academic laboratories where cost constraints often limit the availability of advanced testing equipment. Low-cost testing setups Load cells designed with locally sourced components, present an opportunity to bridge this gap while maintaining acceptable levels of accuracy and reliability[2,3]. This study focuses on the development of an inexpensive tensile test machine tailored to meet the needs of educational and small-scale research applications. The proposed system combines simplicity in design with cost-efficiency, using readily available materials and straightforward mechanical principles. By integrating force sensors and a linear motion mechanism, the setup is capable of measuring the tensile properties of materials with a high degree of precision[4-6].

In the following sections, the design, fabrication, and performance evaluation of the developed tensile test machine are presented. The results demonstrate the viability of this system as a cost-effective alternative to commercial devices, particularly in environments with limited financial resources[7-9]. Load cells are widely used to measure forces in various applications, including weighing scales, where the strain of the load cell determines an object's weight. A load cell typically consists of a counterforce and force transducers, such as strain gauges, which convert force into an electrical signal. These transducers are commonly arranged in a Wheatstone bridge configuration for precision. In industrial applications such as checkweighers, load cells play a critical role, as these applications demand high-speed and accurate measurements [10–13]. This study focuses on developing a 3D force transducer and a real-time force measurement system tailored for agricultural machinery. The system is designed to monitor force variations at the three-point linkage of tractors, enabling real-time data transmission via USB communication. Key design considerations include real-time and graphical data visualization, robustness, linear output, dynamic calibration, and high accuracy. Figure 1 illustrates the developed transducers and the accompanying electronics. This system provides an efficient solution for monitoring force dynamics in agricultural operations [14-16,19].

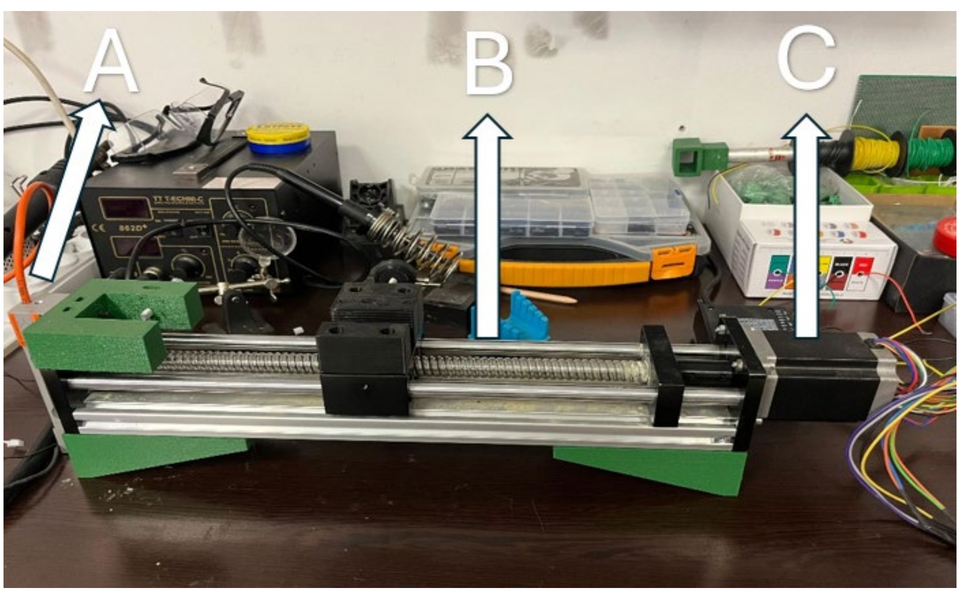

Figure 1: The Developed Tensile Test System. A: LoadCell, B: Linear Rail Guide, C: Motor.

2. MATERIAL AND METHOD

A. Mechanics

Due to their affordability and precision, load cells are extensively used in industrial instrumentation [17,18]. Strain gauge load cells, a common type for force or load measurement, offer accuracy levels ranging from 0.03% to 1%. In this study, strain gauge-based load cells are employed as force transducers. The mechanical structure of these transducers, designed specifically for detecting three-dimensional force variations, is depicted in Figure 2. These custom-designed 3D force transducers enable precise measurement of forces in multiple directions.

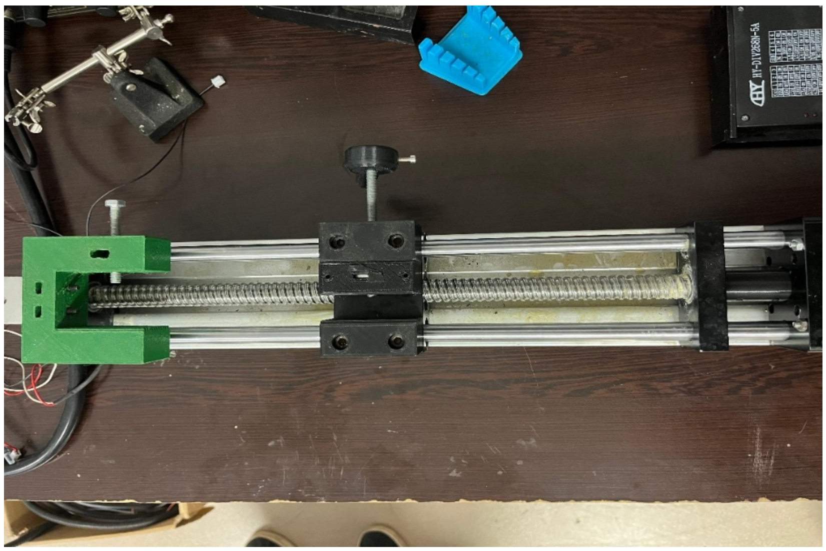

Figure 2: Tensile Mechanism.

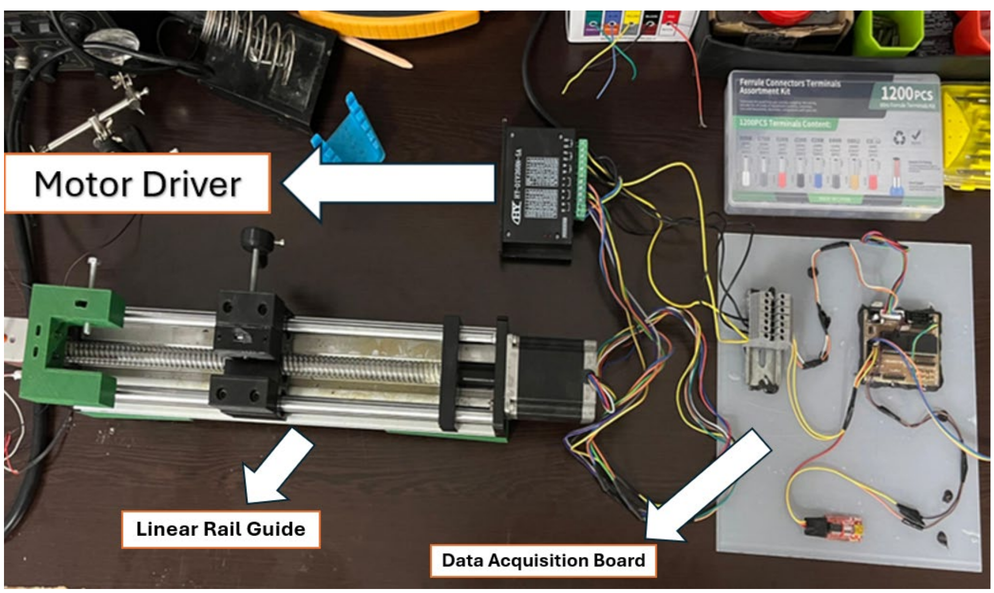

Figure 3. General Structure of the System.

The mechanical design criteria for the 3D force transducer used in the load cells are outlined in Figure 5.

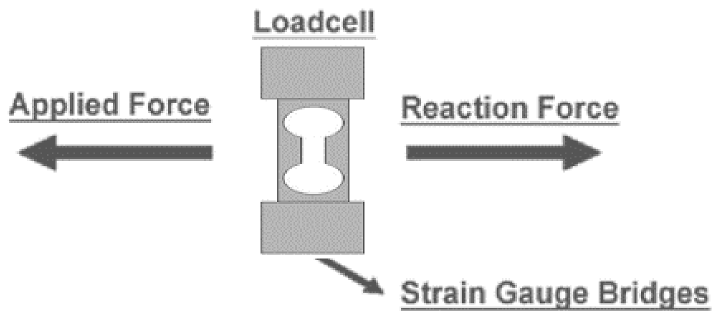

Figure 4: Force Equilibrium of the Load cells.

B. Electronics

A 3D force measurement system was designed to monitor forces acting on a three-point linkage using load cells. The system comprises three load cells, a microcontroller unit (MCU), an analog-to-digital converter (ADC), an USB interface, and a computer. Strain gauges were integrated into the load cells to detect force variations, and a Wheatstone bridge configuration was employed for signal conditioning. The analog voltage signals generated by the bridges were digitized using a 24-bit ADC. The processed digital data was transmitted to the computer via RF communication, where it was graphically displayed in real-time. The system's block diagram is illustrated in Figure 6.

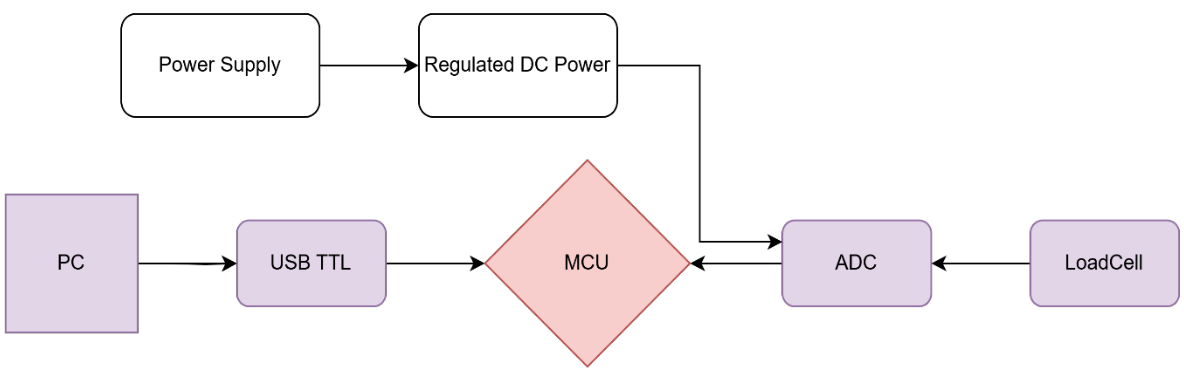

Figure 5. Block Diagram of the Measurement System.

In this system, regulated DC power supplies were used to provide power to the Wheatstone bridges on each load cell. Each load cell was independently powered using a dedicated power unit. The analog signals generated by the bridges were captured using 24-bit ADCs, which converted the signals into digital data. This digital data was then transmitted to the microcontroller through serial communication. The microcontroller sent the processed information via an USB interface, while the receiver unit forwarded the data to the computer through a USB connection.

To minimize noise in the load cells, a regulated DC power supply was used to power the Wheatstone bridges. Additionally, cable shielding was grounded to further reduce interference, as illustrated in Figure 7.

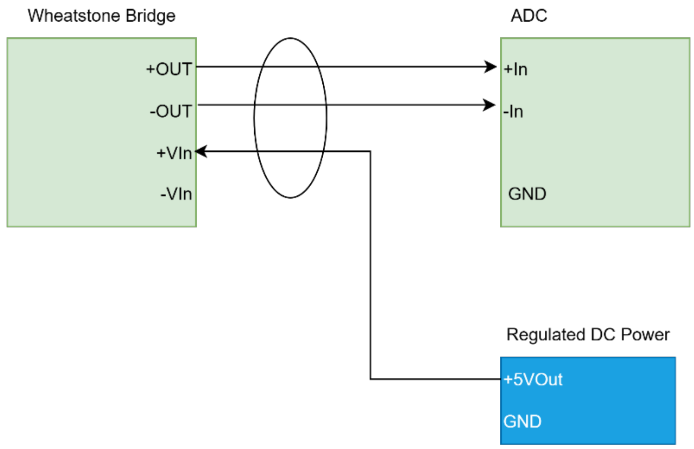

Figure 6. Shield Grounding for Noise Reduction.

The system incorporates full bridge strain gauges, as shown in Figure 8, on the load cells for thermal compensation. A 5V excitation voltage is used to power the bridges, and the strain gauges have a resistance of 120Ω.

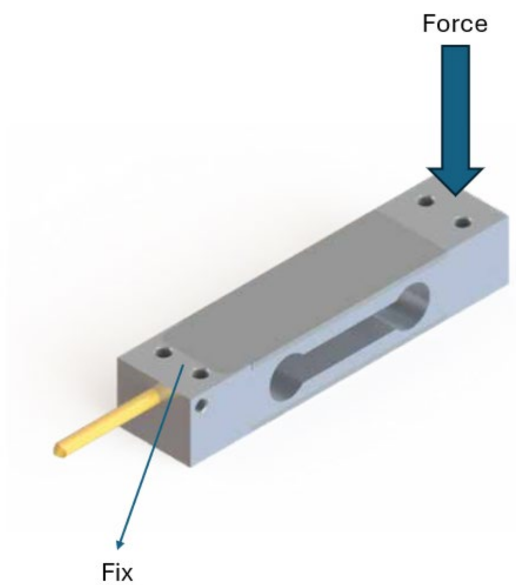

Figure 7. LoadCell Layout.

The electronic system processes force data from the load cells and transmits it to a computer. This measurement setup supports remote data collection using RF signals, with a robust USB interface ensuring reliable communication between field and remote units. A custom-designed interface developed using C++ software is utilized for real-time data analysis and visualization. The user interface allows interactive monitoring of factors such as offset, force variations, and graphical outputs for each transducer. A microcontroller (MCU) handles data acquisition, while an analog-to-digital converter (ADC) converts analog force signals into digital values. The USB interface is connected to the computer via a USB interface for seamless data transfer.

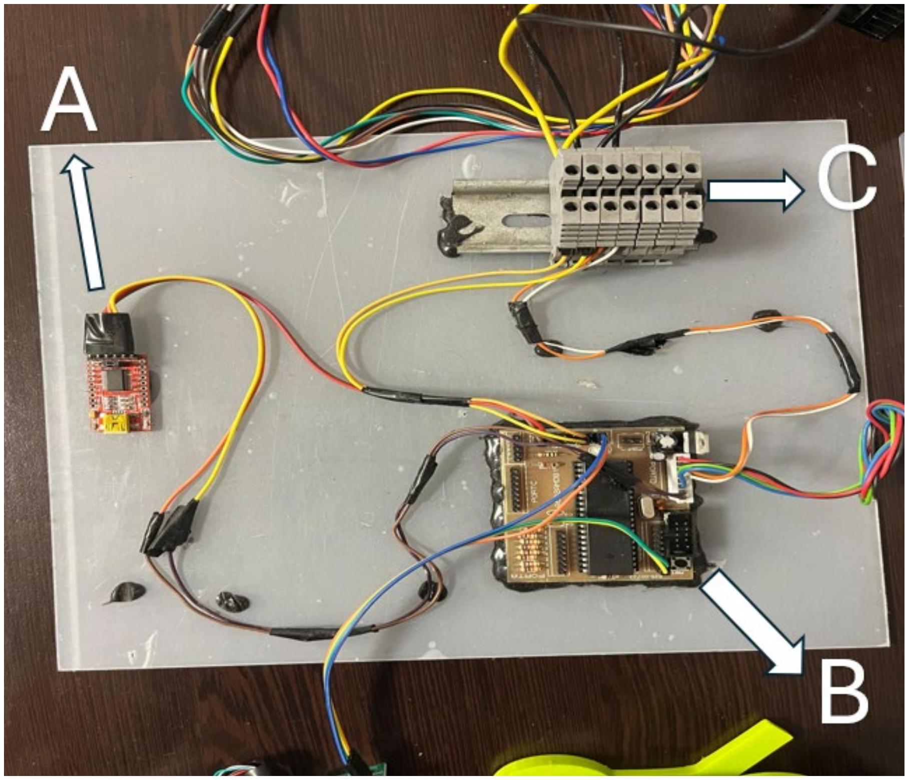

Figure 8: Electronical Parts of the System. A: USB Interface, B: MCU, C: MCU Motor Driver Connection Terminal.

3. RESULTS

Prior to the development of the electronic system and mechanical design, theoretical calculations were conducted to determine the upper and lower limits of the measurement system, ensuring the desired measurement range and step response. Based on these calculations, key characteristics of the mechanical transducer and electronic system were identified to guide the development process. During the design phase, theoretical evaluations were performed specifically for a full-bridge strain gauge load cell. The outcomes of these calculations are presented in Table 1, which illustrates the expected voltage output corresponding to both minimum and maximum load conditions.

PS Series Load cell model was used that manufactured by Pulse Electronic [20] for calibrating the designed 3D force transducers. Table 1 is based on the capacity and output signal of the load cell with a load capacity of 20 Kg. For basic calculations the maximum Capacity (Emax) 20 kg, output signal 2 mV/V, excitation voltage 10 V are used. The output voltage was calculated as follows:

$$V_{Out} = Output\ Voltage\ x\ Excitation\ Voltage\ x\ \frac{Force}{Maximum\ Capacity}$$

Table 1: Applied Force versus Tension & Compression.

Force (kg)	Output Voltage 10V (mV)	Output Voltage 12V (mV)	Amplified Voltage (mV)
0.00	0.00	0.00	0.00
2.86	2.86	3.43	438.86
5.71	5.71	6.86	877.71
8.57	8.57	10.29	1316.57
11.43	11.43	13.71	1755.43
14.29	14.29	17.14	2194.29
17.14	17.14	20.57	2633.14
20.00	20.00	24.00	3072.00

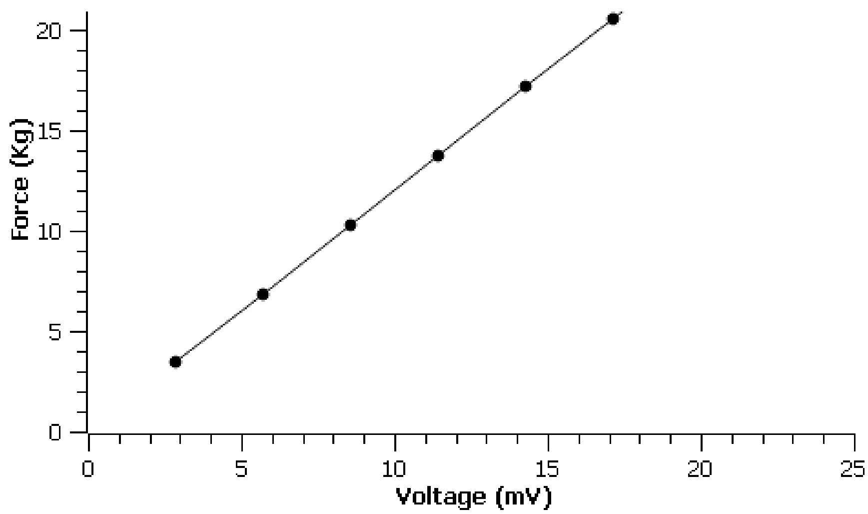

Figure 9. Force as a Function of Voltage. (12V).

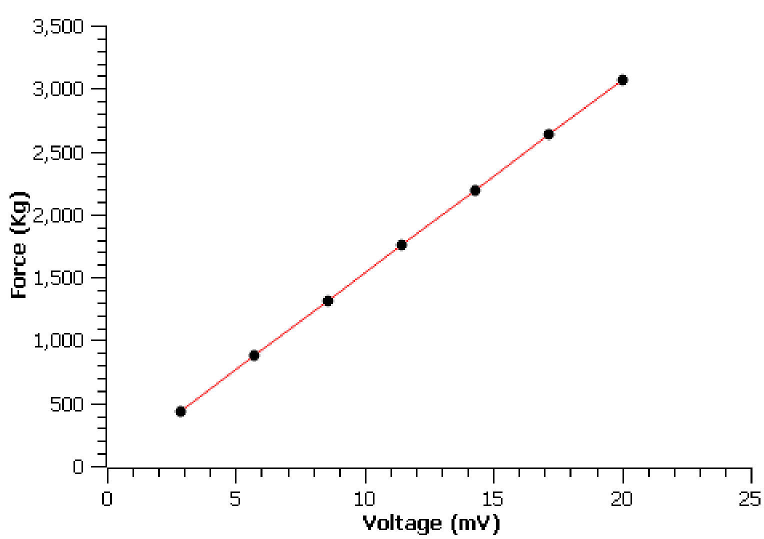

Figure 10. Force as a Function of Voltage (Amplified Voltage).

Table 1, Figure 9, and Figure 10 illustrate the linear relationship between load (force) and voltage in the context of a towing test rig. The load cell used in the towing test rig measures the force applied on it and converts this force into a low-voltage electrical signal. The table shows the output signals from the load cell under a 12V supply voltage and their amplification by an amplifier. For example, if the load cell has an output capability of 2 mV/V, it produces an output proportional to the applied load, and this signal is amplified to a readable level (e.g., 3072 mV) with an amplifier. Figure 9 visualizes how the output voltage varies with force under a 12V supply, while Figure 10 shows the amplified voltage. Both figures confirm the linear increase between voltage and load, demonstrating the accuracy of the calibration of the system and the linear performance of the load cell. With this data, the tensile test rig enables precise and reliable measurements when testing the tensile strength or elastic behavior of a material. This connection between voltage and force represents the basic operating principle of the setup used in materials testing.
According to the results obtained, when compared with the traditional methods in the literature, the following results were revealed in Table 2:

Table 2: Comparison of the Designed System with Traditional Systems.

Comparison Criteria	Traditional Tensile Testing Machines	Developed Low-Cost Tensile Testing Machine
Cost	High; expensive and designed for industrial and commercial use.	Low; built using locally available and cost-effective components.
Accuracy & Performance	High precision, wide measurement range, and compliant with industry standards.	Provides acceptable accuracy with a linear force-voltage relationship.
Application Area	Suitable for large laboratories, industrial research, and extensive material testing.	Ideal for educational institutions and small-scale research projects.
Technical Hardware	Equipped with high-resolution sensors, powerful servo motors, and specialized software.	Uses a microcontroller (MCU), ADC, and load cells in a simple design.
Data Collection & Processing	Automated reporting and advanced data analysis using specialized software.	Data transmission via RF and USB; real-time analysis using a C++-based interface.
Measurement Capacity	Capable of high-capacity and large-scale testing.	Limited capacity, suitable for small-scale tests.
User-Friendliness	Often requires expertise to operate, with complex user interfaces.	Simple and easy to use, making it suitable for educational purposes.
Calibration & Maintenance	Requires regular maintenance and calibration, which can be costly.	Requires minimal maintenance and offers

		simpler, cost-effective calibration.
Motion & Mechanism	Uses precision lead screws and powerful motors for high accuracy.	Operates with linear rail guides and low-cost motors.

Due to limited facilities, we were unable to conduct direct comparisons of test samples. However, we compared the results of our study with those reported in the literature by analyzing force and measurement outputs.

4. CONCLUSION

In this study, a low-cost and effective tensile testing machine was developed, providing accessible and reliable solutions for material testing. The tensile testing machine produces consistent stress-strain curves, accurately capturing material properties such as yield strength, tensile strength, and elongation. While it lacks certain advanced features found in commercial machines, its performance is comparable to higher-cost alternatives, making it an ideal solution for educational institutions and research settings with limited budgets. Additionally, the results demonstrated the system's ability to deliver dependable data, as evidenced by the linear force-voltage relationship observed in the calibration and testing phases. This relationship, visualized in the Voltage-Force graph, highlights the precise output of the system, with force measurements extending linearly up to 20 kg and amplified voltage outputs aligning with expected performance.

The force measurement system further enhances the setup, offering accurate three-dimensional force measurements and the ability to collect data remotely over distances up to 5 km. Its graphical interface, developed specifically for this project, enables real-time monitoring and analysis of field data. These features, combined with the affordability and reliability of the tensile testing machine, showcase that effective material testing and force measurement systems can be developed without the prohibitive costs typically associated with commercial alternatives. This study demonstrates that accessible and cost-effective tools can enhance educational and research opportunities in material science, bridging the gap between resource constraints and the need for precise, repeatable data.

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