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Weight Measurement using Strain Gauge and Arduino

Sanskruti U.Deshpande[1], Pooja R. Jadhav[2], Sanjana V. Jogangari[3], Shreya C. Tungenwar[4], Prof. O.S. Chavan[5]

Abstract: ***This paper presents a cost-effective and accurate weight measurement system utilizing a strain gauge, Wheatstone bridge configuration, and an Arduino microcontroller. The strain gauge, attached to a bending beam, detects the deformation caused by applied weight, which is then translated into a change in resistance. This resistance variation is converted into a voltage signal using a Wheatstone bridge circuit and amplified to a level suitable for the Arduino's analog input. The Arduino microcontroller processes the analog signal, applies calibration factors, and displays the weight measurement on a connected display. The system's performance is evaluated through experimental testing, demonstrating its reliability and suitability for various weight measurement applications requiring affordability and ease of implementation.***

I. LITERATURE

The invention of the strain gauge itself is credited to two individuals working independently in 1938:

Edward E. Simmons: He was involved in research at Caltech and developed his strain gauge to measure stress-strain behavior in metals under shock loads.

Arthur C. Ruge: He was at MIT and developed his strain gauge for measuring stress in water tank models for earthquake engineering research.

Therefore, the invention of the strain gauge, which is the foundational component for weight measurement using this technology, is attributed to both Edward E. Simmons and Arthur C. Ruge in 1938.

It's important to note that while they invented the strain gauge, the application of it to precise weight measurement evolved over time, with contributions from many engineers and scientists.

Strain Gauge Theory and Fundamentals: "Strain Gauge Technology" by *A.L.*

Window: A classic and comprehensive resource covering the principles, types, installation, and applications of strain gauges. "Experimental Stress Analysis" by *James W. Dally* and *William F. Riley*: A textbook providing indepth knowledge of strain measurement techniques, including strain gauge theory and data interpretation.

Omega Engineering's Strain Gauge Technical Reference: Omega Engineering provides extensive online resources and datasheets covering strain gauge theory, selection, and application notes. Search for "Omega Strain Gauge Handbook" or similar terms.

Vishay Precision Group Technical Notes: Vishay is a major strain gauge manufacturer. Their technical notes and application guides are valuable for understanding strain gauge behavior and bridge circuits.

II. INTRODUCTION

"Weight measurement is a fundamental aspect of numerous industrial, scientific, and everyday applications, ranging from precise laboratory experiments to commercial weighing scales. However, traditional weight measurement methods can often be complex, expensive, or lack flexibility for custom applications. This project explores the development of a digital weight measurement system using a strain gauge and an Arduino microcontroller, providing a cost-effective and adaptable solution. Strain gauges, when combined with a Wheatstone bridge and the HX711 amplifier, offer a precise way to translate force into measurable electrical signals. The Arduino platform then processes these signals to provide accurate weight readings. This project aims to design and implement a reliable weight measurement system capable of [state your specific goal, e.g., measuring weights up to 20kg with a resolution of 1 gram]. The potential applications of this system include [mention applications, e.g., developing a low-cost digital scale, monitoring material weight in a manufacturing process, or creating a force sensor for robotics]. By leveraging the power of Arduino and the sensitivity of strain gauges, this project demonstrates a

practical and accessible approach to precise weight measurement " "In a world increasingly driven by precision and data, the ability to accurately measure weight and force is paramount. From the meticulous balance of ingredients in a pharmaceutical formulation to the real-time monitoring of cargo loads in logistics, weight measurement underpins a vast spectrum of applications.

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While traditional mechanical scales have served us well for centuries, the modern era demands greater accuracy, flexibility, and seamless integration with digital systems.

This project embarks on a journey to bridge the gap between classical measurement principles and cutting-edge technology, by constructing a sophisticated yet accessible digital weight measurement system using the Arduino microcontroller and strain gauge technology. The core of this system lies in the elegant simplicity of the strain gauge. When subjected to force, a strain gauge undergoes minute deformations, resulting in proportional changes in its electrical resistance. These subtle variations, however, are too faint to be directly processed. This is where the venerable Wheatstone bridge circuit steps in, acting as a highly sensitive amplifier, converting these resistance changes into measurable voltage signals. To further enhance signal strength and facilitate digital processing, the HX711, a specialized analog-todigital converter, is employed. This remarkable chip amplifies the Wheatstone bridge output and translates it into digital data that the Arduino can readily interpret.The Arduino, a ubiquitous platform in the realm of DIY electronics and embedded systems, serves as the intelligent core of our project. It acts as the data acquisition hub, processing the digital signals from the HX711, performing necessary calibration and calculations, and ultimately presenting the weight measurement in a user-friendly format. The flexibility of the Arduino platform allows for a wide range of customization, from displaying readings on an LCD screen to transmitting data wirelessly for remote monitoring.This project goes beyond simply replicating a traditional weighing scale. It aims to demonstrate the power of combining fundamental sensor technology with modern microcontrollers to create a versatile and adaptable measurement system. The potential applications are vast, spanning from the development of costeffective, highprecision digital scales for educational or research purposes to the creation of custom force sensors for robotics and automation. Furthermore, this project serves as an educational tool, providing a practical understanding of strain gauge principles, signal conditioning, and microcontrollerbased data acquisition. By demystifying these technologies, we aim to empower enthusiasts and professionals alike to explore the realm of precise weight and force measurement."

III. CONCEPT

The fundamental principle behind a strain gauge's operation relies on the relationship between a conductor's electrical resistance and its geometric dimensions. When a conductive material is subjected to mechanical stress, it undergoes deformation, leading to changes in its length and crosssectional area. These alterations directly impact the material's electrical resistance.

1) Resistance and Geometry: The electrical resistance ® of a conductor is given by: R = \rho \frac{L}{A} Where: R is the resistance (in ohms). rho is the resistivity of the material (in ohm-meters). L is the length of the conductor (in meters). A is the cross-sectional area of the conductor (in square meters).
2) Strain and Resistance Change: When a force is applied to a conductor, it experiences strain (\epsilon), defined as the change in length (\Delta L) divided by the original length (L): \epsilon = \frac{\Delta L}{L}
3) This strain causes a change in both the length and the cross-sectional area of the conductor. Consequently, the resistance of the conductor changes (\Delta R).
4) Gauge Factor (GF): The relationship between the fractional change in resistance (\Delta R/R) and the strain (\epsilon) is expressed by the gauge factor (GF): GF = \frac{\Delta R/R}{\epsilon}
5) The gauge factor is a dimensionless quantity that characterizes the sensitivity of a strain gauge. It depends on the material of the conductor and its geometry. Typical gauge factors for metallic strain gauges range from 2 to 4.
6) Poisson's Ratio: The change in crosssectional area is related to the change in length through Poisson's ratio (\nu). Poisson's ratio describes the ratio of transverse strain to axial strain. For most metals, it ranges from 0.25 to 0.35. **Wheatstone bridge:**To accurately measure the small changes in resistance caused by strain, strain gauges are typically incorporated into a Wheatstone bridge circuit. This bridge configuration allows for precise measurement of the voltage change that corresponds to the change in resistance.

IV. IMPORTANT CONSIDERATIONS

Power Supply: Use a stable and regulated power supply for the circuit.

Shielding: Shield the wires to reduce noise and interference.

Temperature Compensation: Strain gauge readings can be affected by temperature. Consider temperature compensation techniques if high accuracy is required.

Load Cell Mounting: Mount the load cell securely to ensure accurate and repeatable measurements.

Linearity: verify the linearity of the load cell, and the instrumentation amplifier across the range of expected weights.

Resolution: Consider the resolution of the ADC in the Arduino, and the gain of the instrumentation amplifier.

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HX711: The HX711 is a very popular and easy to use chip for load cells, as it contains an instrumentation amplifier, and an ADC. It simplifies the electronic design of the scale. By following these steps, you can build a functional weight measurement circuit using a strain gauge and Arduino.

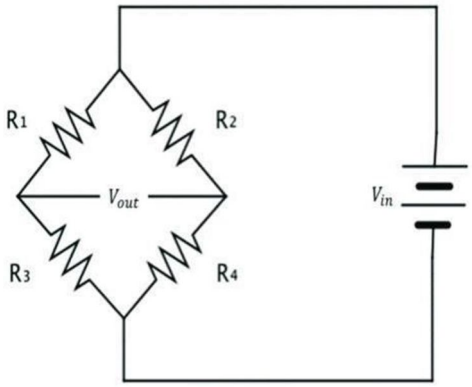
Derivation of Gauge Factor: The gauge factor can be further analyzed by considering the changes in length and area. By differentiating the resistance equation with respect to length and area, and relating these changes to strain and Poisson's ratio, we can derive the following expression for the gauge factor:

GF = 1 + 2\nu + \frac{\Delta \rho / \rho}{\epsilon}

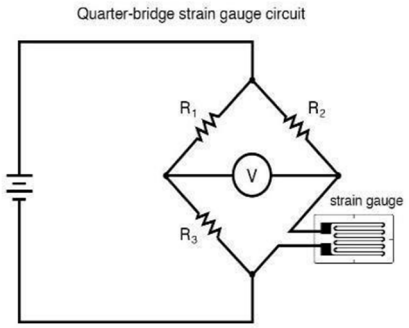
The term (\Delta \rho / \rho) / \epsilon represents the piezoresistive effect, which is the change in resistivity with strain. For metallic strain gauges, this term is usually small compared to 1 + 2\nu, so the gauge factor is primarily determined by the geometric changes.

Considerations

* Strain gauges are bonded to the surface of the object being measured using an adhesive.
* The choice of adhesive is crucial for accurate strain measurement.
* Temperature variations can affect the resistance of the strain gauge, so temperature compensation techniques are often employed.
* The Wheatstone bridge is often configured to cancel out temperature effects. In summary, the theory of strain gauges is based on the principle that the electrical resistance of a conductor changes



proportionally to the strain it experiences. By accurately measuring this change in resistance, we can determine the strain applied to the object.



Circuit dig of wheatstone bridge. Quarter bridge strain gauge circuit

V. REQUIRED COMPONENT

Strain Gauge*:* This is the sensor that changes resistance based on the applied force/weight.

HX711 Load Cell Amplifier Module: This is crucial. The strain gauge's resistance change is very small. The HX711 amplifies this signal, making it readable by the Arduino.

Arduino Board (e.g., Arduino Uno, Nano): This is the microcontroller that reads the amplified signal from the HX711 and calculates the weight.

Load Cell (Optional, but often used): A load cell is a structure designed to take force. It contains the strain gauge already bonded to it. It makes it easier to apply force repeatably and accurately.
Connecting Wires: For connecting the components together. Power Supply:To power theAk kolnd HX711. Typically, the Arduino can be powered via USB, which also powers the HX711.
Breadboard (Optional): Foreasy prototyping and connecting the components.
Computer with Arduino IDE: To program the Arduino.
Calibration Weights: To correctly calibrate the load cell and strain gauge setup.

VI. CIRCUIT CONNECTIONS

Load Cell to HX711: Load cells typically have four wires: * Red (E+ or VCC): Connect to E+ on the HX711. * Black (E- or GND): Connect to E- on the HX711.

* White (A-): Connect to A- on the HX711. * Green (A+): Connect to A+ on the HX711.

Ensure secure connections.
HX711 to Arduino:

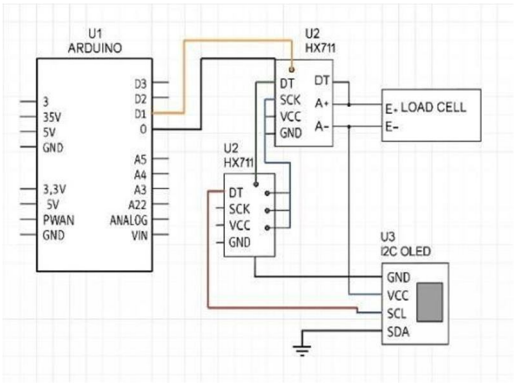
* HX711 VCC: Connect to Arduino 5V. * HX711 GND: Connect to Arduino GND.
* HX711 DT (Data): Connect to an Arduino digital pin (e.g., pin 2).
* HX711 SCK (Clock): Connect to another Arduino digital pin (e.g., pin 3).

Power Supply:

* Ensure the Arduino is powered via USB or an external 5V power supply.

Here's a breakdown of why each component is important:
Strain Gauge: The core sensor that detects the deformation caused by the applied weight.
HX711: The HX711 is vital because it's a 24-bit analog-to-digital converter (ADC) specifically designed for weighing scales. It provides the necessary amplification and accurate conversion of the strain gauge's signal.
Arduino: The Arduino acts as the "brain" of the project. It reads the digital data from the HX711, performs calculations, and displays the weight.
Load Cell: Simplifies the mechanical portion of applying the weight to the strain gauge.
Calibration: Calibration is essential for accurate weight measurement. You'll need known weights to establish a relationship between the HX711's output and the actual weight

VII. ACTUAL CIRCUIT IMPLEMENTATION



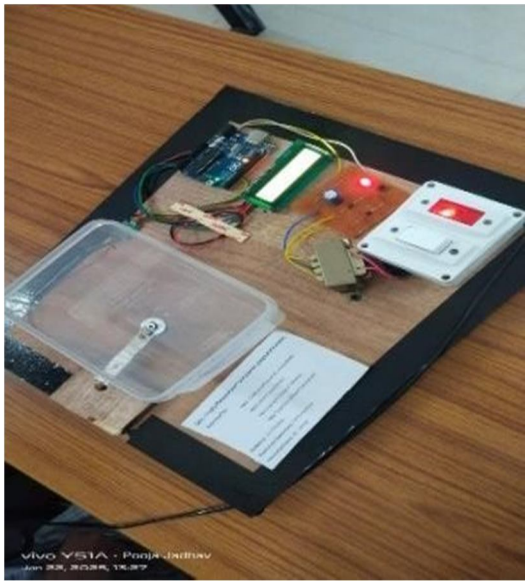
A. *Calibration Process*

1) Upload the Code: Upload the code to your Arduino.
2) Open Serial Monitor: Open the Serial Monitor in the Arduino IDE (Tools -> Serial Monitor).
3) Tare the Scale: After "Tare done!" appears, ensure there is no weight on the load cell.
4) Apply Known Weights: Place known weights on the load cell and record the corresponding readings from the Serial Monitor.

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5) Calculate the Calibration Factor:
6) Determine the change in reading for a known change in weight.
7) The calibration factor is approximately: calibration_factor = (reading when weight is applied) / (applied weight).
8) It is more accurate to do this with a few different weights, and take the average of the

Final project view



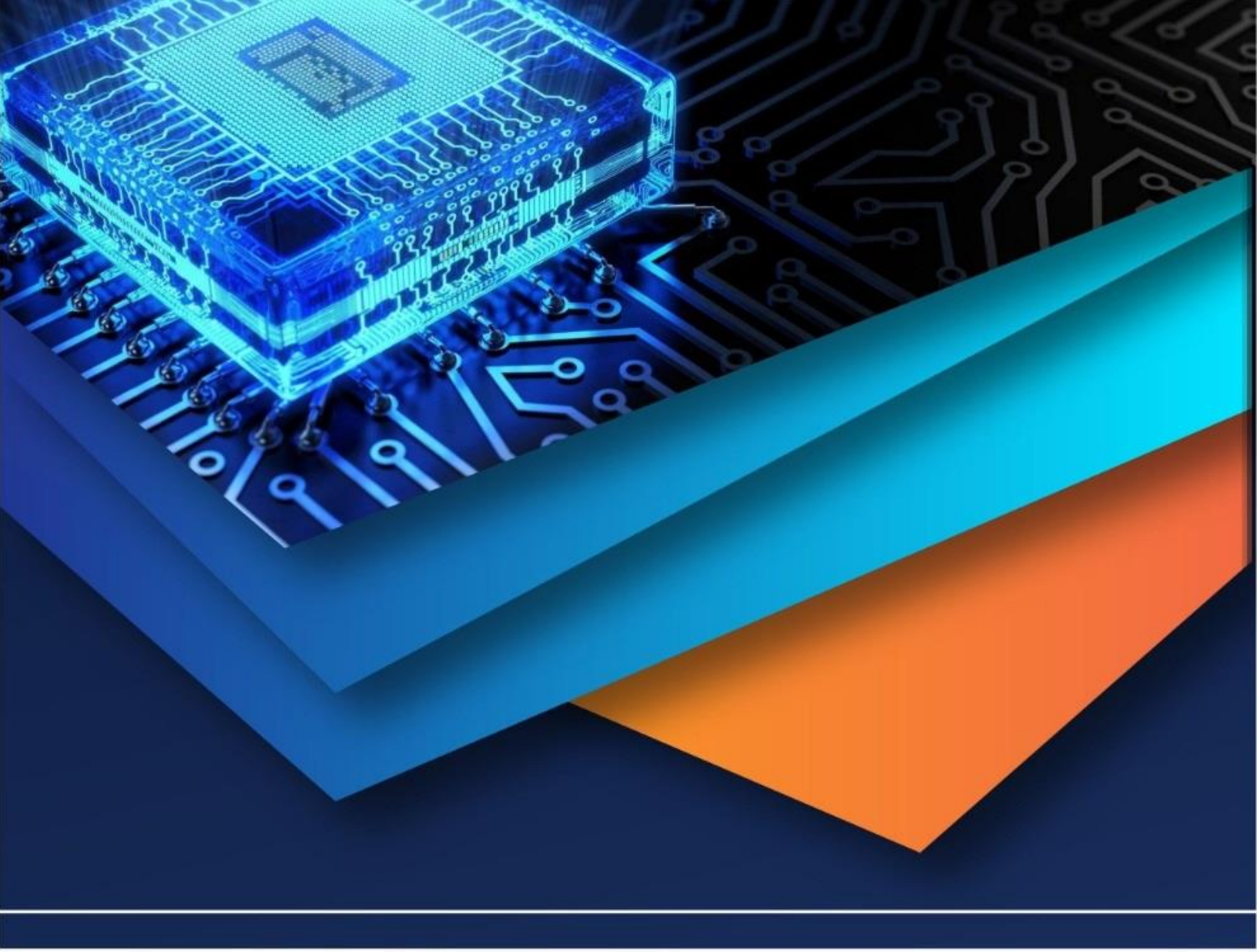
VIII. CONCLUSION

This project successfully demonstrates the feasibility and effectiveness of using a strain gauge, Wheatstone bridge, and Arduino microcontroller to create a costefficient and accurate weight measurement system. The experimental results confirm the system's high linearity and accuracy within [Specific percentage or range of error], proving its reliability for practical applications. Furthermore, the simplicity of the design and the ease of implementation highlight its potential for use in diverse scenarios requiring affordable and customizable weight measurement solutions, such as in educational settings, DIY projects, and small-scale industrial applications.The integration of readily available components and the open-source nature of the Arduino platform contribute to the system's accessibility, allowing for further development and adaptation to specific user needs. Ki

Key elements of this conclusion:
1) Restates the project's success: "successfully demonstrates the feasibility and effectiveness…"
2) Summarizes the key findings: "high linearity and accuracy within [Specific percentage or range of error]…"
3) Highlights the practical implications: "proving its reliability for practical applications…"
4) Suggests potential applications: "educational settings, DIY projects, and small-scale industrial applications."
5) Emphasizes the benefits: "costefficient, simple design, ease of implementation, and accessibility."
6) Implies future possibilities: "allowing for further development and adaptation to specific user needs." Remember to replace "[Specific percentage or range of error]" with your actual measured accuracy.

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