

# Evaluating the Performance of an Arduino-Based Strain Sensor System in a Cantilever Beam using Plastic Ruler Under Load Conditions

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## Abstract

Strain measurements are essential for evaluating the structural integrity of engineering systems, enabling early detection of potential failures and supporting maintenance strategies. However, traditional strain measurement methods are often expensive and complex, limiting their accessibility for small-scale and educational applications. This study addresses these limitations by developing an Arduino-based strain sensor system for cantilever beam testing, using a plastic ruler as a low-cost test sample. The system integrates a strain gauge bending sensor module Y3, an Arduino microcontroller, an LCD for real-time data display, and a buzzer and LED to provide alerts when critical strain thresholds are exceeded. Calibration was performed using known weights to establish the relationship between output voltage and strain, and the system was tested under incremental loads of 50g, 100g, and 150g, with three readings recorded per load to ensure accuracy and repeatability. Experimental results were compared with theoretical predictions calculated using cantilever beam mechanics, and graphical plots were generated to analyse the strain distribution. The results demonstrated a strong correlation between measured and theoretical strain values, with an average error of 2.1%, confirming the system's reliability and accuracy. The Arduino-based system proved to be cost-effective and user-friendly, providing a practical and accessible tool for educational purposes. In conclusion, this system offers an effective approach to exploring strain distribution and bending mechanics, making it suitable for structural health monitoring in small-scale applications and enhancing learning in engineering education. Future work could focus on integrating wireless communication and expanding the system's capacity to test different materials.

## 1. Introduction

Structural integrity is important in engineering systems to ensure safety and reliable operation under various load conditions [1]. The ability to accurately measure strain is essential to understanding how structures behave under deformation, enabling early detection of potential failures and supporting the development of maintenance strategies. Traditional strain measurement techniques, although accurate, often involve expensive and complex equipment, making them inaccessible for educational and small-scale projects [2][3].

In recent years, advancements in microcontroller technology, particularly on the Arduino platform, have introduced cost-effective and user-friendly alternatives for strain measurement. Arduino-based systems offer a simplified approach to real-time data acquisition and analysis, providing an affordable solution for structural health monitoring [4]. These systems can capture strain data in various experimental setups by integrating strain gauges with microcontrollers [5][6].

Cantilever beams, commonly used in engineering education, offer a convenient way to illustrate basic mechanics concepts such as bending and strain distribution [7]. Their simplicity of form and predictability of deformation make them suitable for practical demonstrations. This study utilizes an Arduino-based strain sensor system to evaluate the performance of a cantilever beam using a plastic ruler as a test sample.

The primary objectives of this study are to design and implement the strain sensor system, assess its performance under varying load conditions, and analyse the results to establish its reliability. By addressing the limitations of traditional methods, this research aims to provide a low-cost, accessible solution that enhances learning in educational settings while also contributing to the field of structural health monitoring [8].

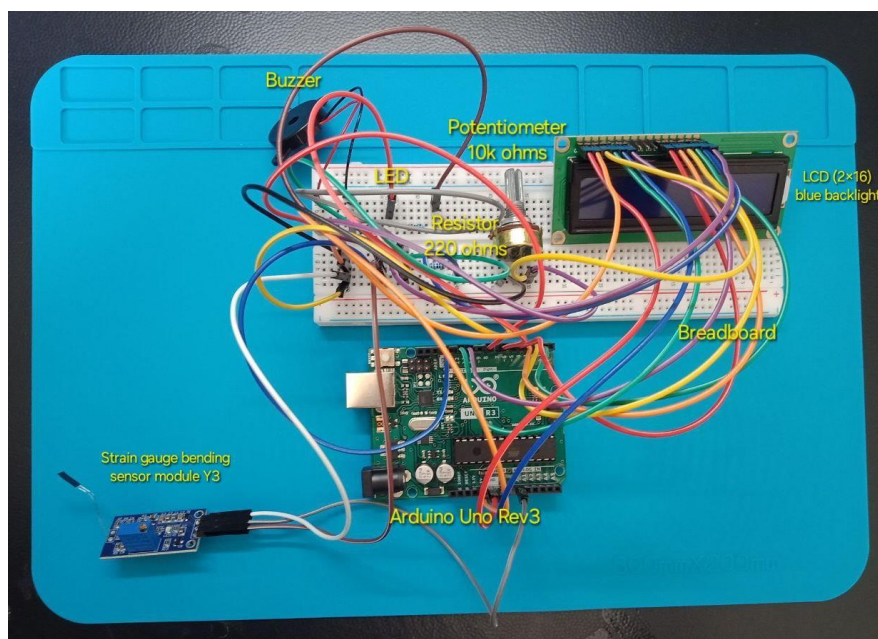
## 2. Materials and Methods

### 2.1 System design and development

To develop an Arduino-based strain sensing system that can measure and analyse strain in a cantilever beam configuration, the system design and development process requires a seamless integration of hardware and software [9][10][11]. A breadboard was used to connect the hardware parts for prototyping and testing. Adhesive was used to firmly connect the strain gauge, the main sensor, to the cantilever beam (a plastic ruler) in order to guarantee precise strain detection during deformation. The Y3 amplifier module, which was attached to the strain gauge, enhanced the tiny voltage signals that the strain gauge produced when it was under load.

To enable the Arduino Uno to process the signal, the output of the Y3 module has been connected to the analog input pin. Digital pins are used to interface the DS-LCD-162AB with Arduino to display the strain data in real time. As an additional warning mechanism, the system is equipped with a buzzer and LED. By connecting them to the Arduino's digital output pins, they allow activation when a certain strain threshold has been crossed. The Arduino USB port provides power to the system which also facilitates programming and debugging.

The software that has been used for this system is the Arduino IDE, utilizing C/C++ as the programming language. Custom code was written to read analog signals from the Y3 module and convert them to strain values using calibrated relationships. The software is designed to perform data acquisition in real time, process the data and display the results on the LCD. A conditional statement has been programmed to activate an LED and a buzzer when the strain value crosses a critical threshold, ensuring immediate warning.



**Fig. 1** The system's design

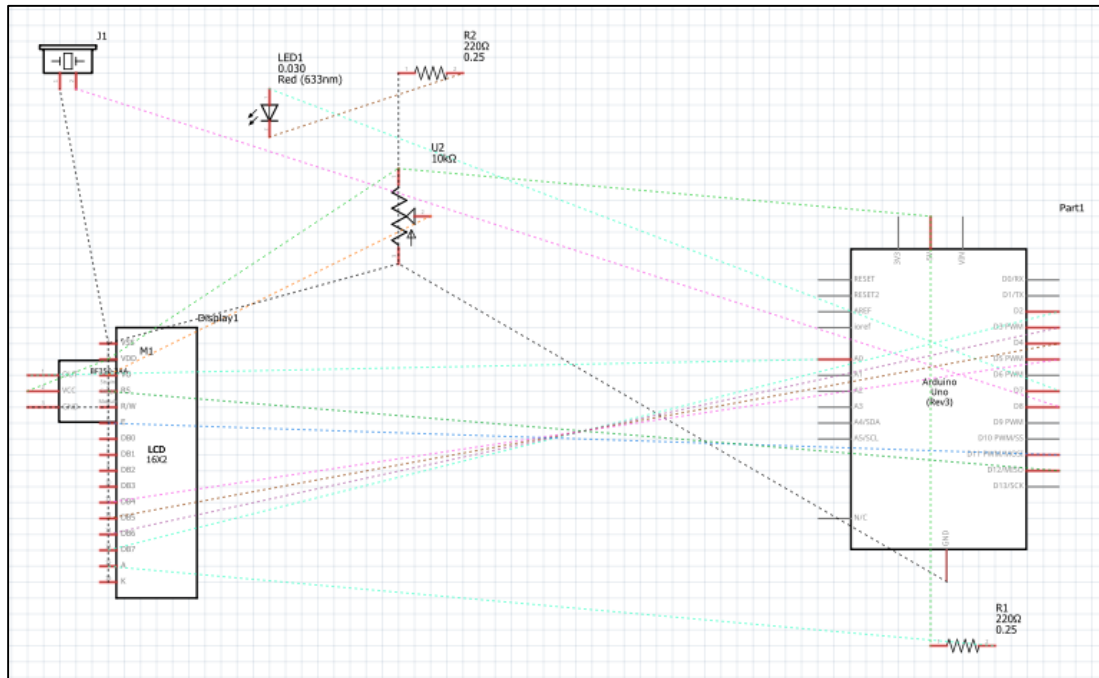


Fig. 2 The schematic diagram of the system's circuit

## 2.2 Block diagram

This system works by first applying a load to the cantilever beam. The strain gauge measures the resulting deformation and sends a voltage signal to the Y3 module, which amplifies it. The amplified signal is then processed by the Arduino, which calculates the strain value. These values are displayed on the LCD in real-time, while LEDs and buzzers provide feedback based on preset thresholds. The overall design ensures accurate strain measurement and provides timely alerts when critical conditions are met.

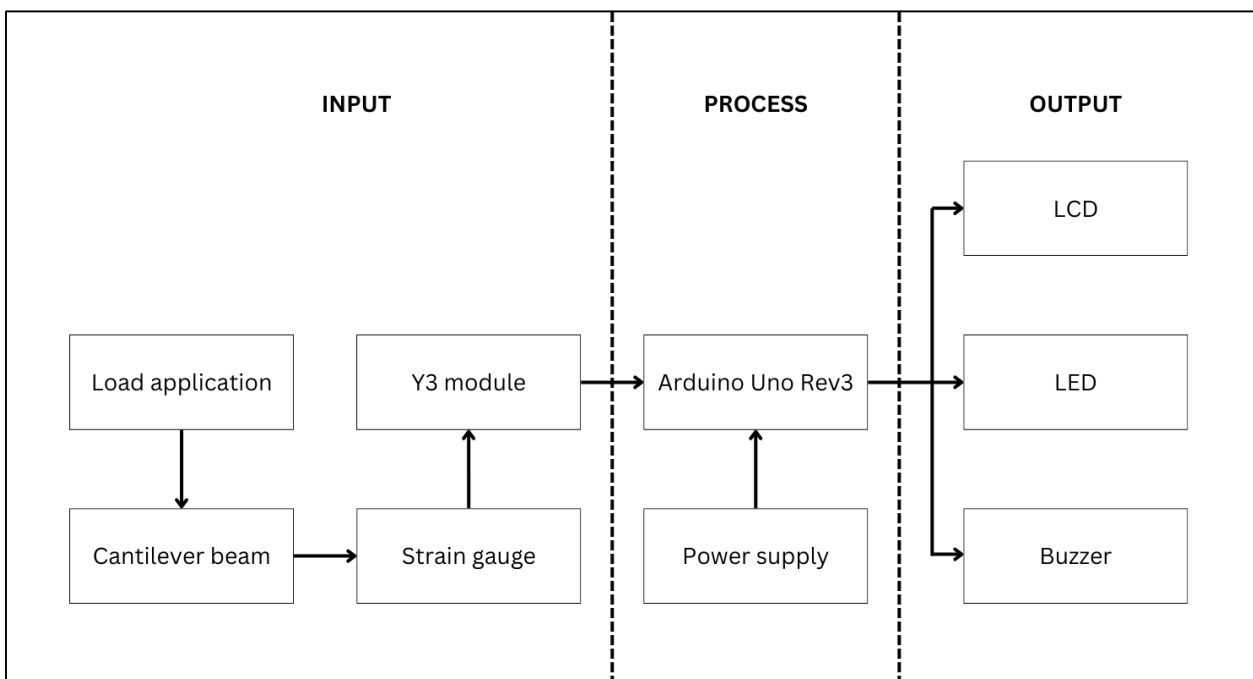


Fig. 3 The system's block diagram

## 2.3 Materials

Materials used in this study include an Arduino Uno R3 microcontroller, a strain gauge module (BF350-3AA), and a Y3 weighing amplifier module for signal processing. The DS-LCD-162AB is used for real-time display of strain readings, while a buzzer and LED are integrated to provide immediate feedback when the strain exceeds a predefined critical threshold. The experimental setup used a plastic ruler as a cantilever beam sample, with 50g, 100g, and 150g weight tools as loads. For electrical connections, breadboards, resistors, and connecting wires are used. Software tools include the Arduino IDE for programming and data acquisition, along with Excel.

## 2.4 Methods

The strain gauge was attached to a plastic ruler, set up as a cantilever beam to create the strain detecting system. The Arduino receives an amplified signal from the Y3 weighing amplifier module, which is connected to the gauge. The strain value was computed by the microcontroller and shown on the LCD. An LED and buzzer have been added to the system to enhance its operation and alert users when crucial strain thresholds are reached. Known weights were used for calibration to create a trustworthy correlation between the strain gauge's output and the strain that the ruler experiences. The calibration procedure guarantees that system readings match theoretical computations obtained from the mechanics of cantilever beams.

A cantilever beam was created for the experiment by clamping a plastic ruler at one end. Gradually, weight tools weighing 50g, 100g, and 150g are placed on the ruler's free end. To guarantee precision and consistency, three readings are made at each load phase. The bending strain formula was used to compute theoretical predictions, which were contrasted with the data gathered from the Arduino-based system. The accuracy of the system was assessed by analysing the relationship between the applied load and the measured strain and comparing the two. To show how strain is distributed across various loads, a graphical plot is made. In real-time monitoring applications, the system's accuracy, affordability, and usability are used to assess its performance. The performance of the strain detection system is evaluated based on key parameters such as accuracy, cost-effectiveness, and usability.

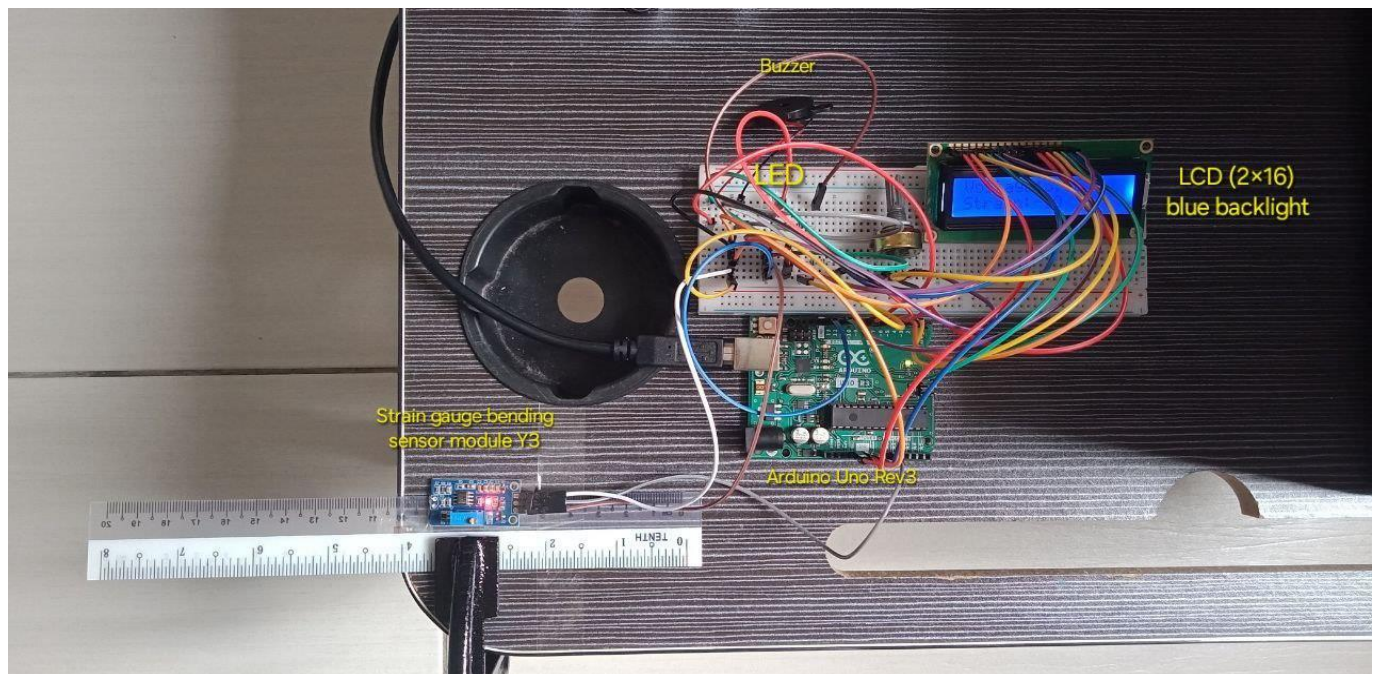


Fig. 4 The system's testing setup

## 3. Results and Discussion

The bending strain of the plastic ruler under different applied loads was calculated using the theoretical bending strain formula:

$$\hat{\mu} = \frac{M \cdot y}{E \cdot I} \quad (1)$$

where  $M$  is the applied moment,  $y$  is the distance from neutral axis,  $I$  is the moment of inertia, and  $E$  is the modulus of elasticity of the ruler material.

Experimental results obtained from the Arduino-based strain sensing system show consistent performance in measuring strain on cantilever beams using a plastic ruler. Strain data were recorded for three load conditions: 50g, 100g, and 150g, with three readings taken at each load. The average strain values for each load condition show a strong correlation with the theoretical predictions, confirming the reliability of the system. The following results were obtained for the three load conditions:

**Table 1** Theoretical bending strain values

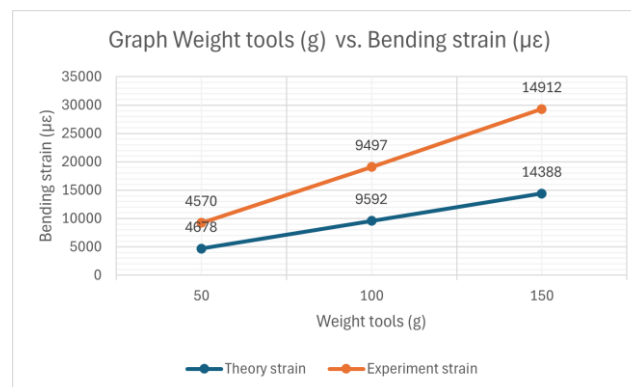
Weight load (g)	Bending strain ( $\mu\epsilon$ )
50	4678
100	9592
150	14388

The strain data was measured experimentally using the Arduino-based strain sensor system and compared with the calculated values. The average experimental readings showed strong agreement with theoretical predictions, validating the system's accuracy and reliability.

**Table 2** Experimental bending strain values

Weight load (g)	Average bending strain ( $\mu\epsilon$ )	Percentage errors (%)
50	4570	2.3
100	9497	1.2
150	14802	2.9

For 50g load, the theoretical value was 4678  $\mu\epsilon$  and the average experimental value was 4570  $\mu\epsilon$ , with a percentage error of 2.3%. For 100g load, the theoretical value was 9592  $\mu\epsilon$  and the average experimental value was 9497  $\mu\epsilon$ , with a percentage error of 1.2%. For 150g load, the theoretical value was 14388  $\mu\epsilon$  and the average experimental value was 14802  $\mu\epsilon$ , with a percentage error of 2.9%.



**Fig. 5** Graph for theoretical data and experimental data

The results show a linear relationship between applied load and bending strain, as expected for a cantilever beam under bending stress. This consistency highlights the effectiveness of the Arduino-based strain sensor system in accurately capturing strain data. Small discrepancies between experimental and theoretical values have been observed and are likely due to factors such as imperfect adhesion of the strain gauge to the plastic ruler, weight tools that may not be perfectly aligned or centered on the cantilever beam and misalignment or incorrect positioning of the strain gauge relative to neutral axis of the beam.

The performance of the strain sensing system was assessed based on key parameters. In terms of accuracy, the measured strain values closely matched the theoretical calculations, with an average error of 2.1%. The system was cost-effective, with all components, including the Arduino and strain gauge, sourced for a total cost of approximately 170.00 MYR. Furthermore, the system demonstrated excellent usability, providing real-time strain monitoring with visual and audible alerts, making it a practical solution for structural health monitoring applications.

The successful detection of strain at different load levels and activation of the buzzer and LED upon critical strain thresholds are reached demonstrate the practicality of the system for real-time monitoring. These features make the system particularly suitable for educational settings, offering a direct approach to understanding strain distribution and structural behaviour under loading conditions.

Although the system works well within the scope of this study, further improvements could include exploring wireless data transmission for remote monitoring and extending the experiments to other materials and load ranges. This will increase the applicability of the system for broader structural health monitoring and educational applications.

#### 4. Conclusion

In conclusion, this project effectively illustrated its ability to use plastic rulers to measure and evaluate strain in a cantilever beam configuration under various load scenarios. Real-time strain readings were recorded and shown on the LCD by the system, which combines an Arduino microcontroller with a strain gauge bending sensor module Y3. When crucial strain levels were met, the LED and buzzer also gave instant feedback. Results from the experiment demonstrated a distinct linear relationship between the applied load and the measured strain, confirming the precision and dependability of the system in strain detection. The system's repeatability was confirmed by the three consistent readings that were acquired for each of the three load conditions: 50g, 100g, and 150g. This project demonstrates how low-cost strain sensor devices can be developed for real-time structural health monitoring. However, limitations were recognized, including the strain gauge's fragility and wireless communication limits. Future work could solve these difficulties by enhancing sensor robustness, adding wireless data transfer for remote monitoring, and expanding the system to measure strain in a wider variety of materials and structural configurations.

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#### Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

#### Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design, methodology, data collection, analysis and interpretation of results, draft manuscript preparation:** Nur Amirah Amran and Ahmad Hadi Ali. All authors reviewed the results and approved the final version of the manuscript.*

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