Brilliance
Research of Artificial Intelligence

E-ISSN : 2807-9035
Volume 5, **Number** 2, November 2025
https://doi.org/10.47709/brilliance.v5i2.7324

TreeRTTSys: A Low Cost Sensor To Measure Tree Trunk Quality Using Strain Gauge Sensors

Rudi Arif Candra[1*], Dirja Nur Ilham[2*], Arie Budiansyah[3]
[1,2]Politeknik Aceh Selatan, Indonesia
[3]Universitas Syiah Kuala, Indonesia
[1]rudiarifcandra@gmail.com, [2]dirja.poltas@gmail.com, [3]arie.b@usk.ac.id

open access

***Corresponding Author**

Article History:
Submitted: 17-11-2025
Accepted: 09-12-2025
Published: 15-12-2025

Keywords:
TreeRTTSys ; Arduino; Sensor Strain gauge; Data Acquisition.

ABSTRACT

Tree health monitoring is essential to ensure environmental safety, sustainability, and the prevention of hazards caused by structurally weakened trees. Visual inspection alone is often insufficient to detect internal defects such as decay or reduced mechanical strength within tree trunks. This study presents the design and implementation of **TreeRTTSys**, a low-cost sensor-based system for evaluating tree trunk quality using strain gauge and load cell sensors integrated with an Arduino microcontroller. The proposed system aims to measure tensile force characteristics of tree trunks as an indicator of structural integrity and mechanical performance. The experimental method was employed by conducting tensile tests on five different types of tree trunks, namely Meranti, Beringin, Rambutan, Durian, and Kapok. A load cell sensor combined with an HX711 signal conditioning module was used to acquire force data, which were processed and recorded in real time by an Arduino-based data acquisition system. The applied tensile load and resistance duration were analyzed to evaluate the strength and deformation behavior of each wood type. The results show significant variation in tensile strength and load resistance among the tested tree species. Meranti wood exhibited the highest tensile strength of 11.13 kN and the longest resistance time of 151 seconds, indicating superior load-bearing capacity and stability. Rambutan wood demonstrated high ductility, sustaining tensile loading for 149 seconds despite a lower maximum force. In contrast, Kapok and Durian woods showed relatively low tensile resistance and shorter failure durations.These findings confirm that the proposed TreeRTTSys is capable of accurately capturing the mechanical behavior of tree trunks in real time. The system offers a reliable, cost-effective solution for tree health assessment, with potential applications in urban forestry management, environmental monitoring, and preventive safety inspections.

INTRODUCTION

Trees play a fundamental role in maintaining environmental balance and supporting life on Earth by producing oxygen and absorbing carbon dioxide, thereby reducing greenhouse gas concentrations. In tropical countries such as Indonesia, the equatorial climate supports high biodiversity and the growth of various tree species in both natural forests and urban environments. Despite their critical ecological function, public awareness and systematic efforts related to tree maintenance and conservation remain limited, particularly in urban areas where trees are exposed to environmental stress, aging, and human activities.

Structurally, trees are perennial woody plants composed of roots, trunks, branches, and leaves, with the trunk serving as the primary load-bearing component. Over time, internal deterioration such as decay, voids, or material weakening may occur due to biological factors, environmental conditions, or aging. These internal defects often cannot be detected through visual inspection, increasing the risk of unexpected tree failure that may endanger public safety and infrastructure. Therefore, reliable assessment of tree structural health is essential, especially in public green spaces, in accordance with Indonesia's Law No. 26 of 2007 on Spatial Planning, which emphasizes the role of green open spaces in ensuring environmental safety and comfort.

Recent advances in sensor-based monitoring systems have provided promising solutions for non-destructive tree health assessment. Piezoelectric sensors integrated with microcontroller platforms have been employed to detect hollow or decayed trees by analyzing vibration or voltage responses (Sujadi et al., 2018). In parallel, strain gauge sensors have been widely applied in structural health monitoring, load measurement systems, and material characterization due to their high sensitivity to small deformations (Adamo et al., 2015)(Kamnik et al., 2015); These sensors have demonstrated effectiveness in monitoring wood behavior and deformation in real time, making them suitable for forestry and conservation applications (Anaf et al., 2020).

Brilliance
Research of Artificial Intelligence

E-ISSN : 2807-9035
Volume 5, **Number** 2, November 2025
https://doi.org/10.47709/brilliance.v5i2.7324

Furthermore, strain gauge technology has been extensively used in composite material analysis and mechanical testing, including polymer–metal systems and wood–steel composites, providing accurate representations of stress–strain behavior under applied loads (Satyarno et al., 2017)(Putra & Rahman, 2016;(Gruionu et al., 2019). Data acquisition systems commonly utilize Arduino-based platforms combined with Wheatstone bridge configurations and signal conditioning modules such as HX711 to achieve low-cost yet reliable measurement performance(Ayu et al., 2017)(Bagenda et al., 2018);(Live et al., 2019).

Based on these considerations, the development of a low-cost, strain gauge–based data acquisition system for evaluating tree trunk mechanical behavior is both relevant and necessary. Such a system can support preventive tree maintenance, enhance public safety, and provide quantitative data for urban forestry and environmental management applications(Pratama et al., 2025). Force sensor utilizing stiffness change of shape-memory polymer based on temperature (Takashima et al., 2017).

LITERATURE REVIEW

The TreeRTTSys is a low-cost sensor system designed to measure tree trunk quality using strain gauge sensors. This system is particularly useful in precision agriculture and forestry, where monitoring tree trunk diameter can provide insights into tree health, water stress, and structural stability. The use of strain gauges allows for accurate and continuous measurement of trunk diameter changes, which are critical indicators of tree health and environmental conditions. The following sections detail the key aspects of the TreeRTTSys system. Low-Cost and Accurate Measurement The TreeRTTSys employs strain gauges configured in a Wheatstone bridge, which are sensitive to minute deformations, allowing for precise measurement of trunk diameter changes (Pavelyev et al., 2023). The system is capable of detecting changes as small as 1μm, making it highly sensitive and suitable for monitoring diurnal changes in tree trunk diameter (Dietrich et al., 2018)(Khairi et al., 2012). Real-Time Monitoring and Data Transmission The system includes a control software that autonomously acquires and processes data, providing real-time monitoring capabilities(Subedi et al., 2023) (Chimarro & Freire, 2023). Data can be transmitted wirelessly to a cloud server, enabling remote monitoring and timely interventions to prevent potential risks such as tree breakage (Zhuoping et al., 2018). Application in Precision Agriculture and Forestry By continuously monitoring trunk diameter, the system helps in assessing water stress and other environmental factors affecting tree health (Subedi et al., 2023). The strain gauge technology has been validated against other measurement techniques, demonstrating its effectiveness in capturing diurnal changes in tree trunk diameter. While the TreeRTTSys offers a cost-effective and precise solution for monitoring tree trunk quality, it is important to consider the potential limitations such as environmental factors that might affect sensor accuracy and the need for regular calibration to maintain measurement precision. Additionally, integrating this system with other environmental sensors could provide a more comprehensive understanding of tree health and environmental interactions (Pratama et al., 2025). Numerical and experimental analysis in the manipulation of the mechanical properties for enhancing the mechanical resistance of a material (Urriolagoitia-Sosa et al., 2011). Experimental Analysis of Eccentric Compression Performance of Larch Wood-Steel Composite Columns (Wang et al., 2019).

METHOD

The research method used an experimental method by taking the average of the research results directly from field experiments. This study used a sampling method with a main control system using Arduino Uno based on the ATMega328 microcontroller and a Load Cell sensor in detecting tensile tests on tree trunks. Due to its low cost, the use of Arduino microcontrollers has been discussed in engineering applications that generally involve instrumentation, machine and structure monitoring, and mechanical system control. Arduino microcontrollers are used in conjunction with low-cost sensors for vibration instrumentation. For example, Arduino microcontrollers are used for vibration instrumentation in systems with various degrees of freedom using Arduino Uno R.3.

Table 1. Hardware Requirements

No	Name	Function
1	Laptop THOSIBA windows 10	As a place to run applications in Tool Design
2	Load Cell Sensor	A sensor designed to detect the pressure or weight of a load, a load cell sensor is generally used as the main component in a digital weighing system and can be applied to a weighing bridge.
3	Mikrokontroler (Arduino Mega)	an electronic circuit that is open source, and has hardware and software that easily functions as a digital control
4	Modul HX711	an amplifier module (signal amplifier) and an Analog to Digital Converter (ADC) module which functions to condition the analog signal from the load cell sensor and convert it into a digital signal.
5	Breadboard	Assembling and connecting electronic components.
6	Jumper cable	Used to connect components

Brilliance
Research of Artificial Intelligence
E-ISSN : 2807-9035
Volume 5, Number 2, November 2025
https://doi.org/10.47709/brilliance.v5i2.7324

7	Power Supply	Used to supply power to all components in the system

In designing and implementing research entitled Designing a tool to detect rotting tree trunks using a load cell sensor, the following software is required:

Table 2. Software Requirements

No	Name	Function
1	IDE Arduino	Used to write program code, compile, and upload programs to the Arduino board
2	Library Arduino	Used to facilitate Arduino programming
3	Elektronics Simulator	Used to design and simulate electronic circuits before implementation.
4	Compiler	Programming and loading program code onto the Arduino board

Stages of Research

1. Preparation Stage
   In this preparation stage, we will prepare the tools and materials needed to create this proposal, such as a PC, Arduino Uno, jumper cables, a 50 kg load cell sensor, and a breadboard.
2. Design Stage
   In this design stage, we will connect one device to another to form a unified whole.
3. Program Writing Stage
   This program writing stage involves writing the program syntax into the Arduino IDE software.
4. Testing Stage
   After completing the previous steps correctly, the next step is to connect the laptop to the assembled device and upload the program.

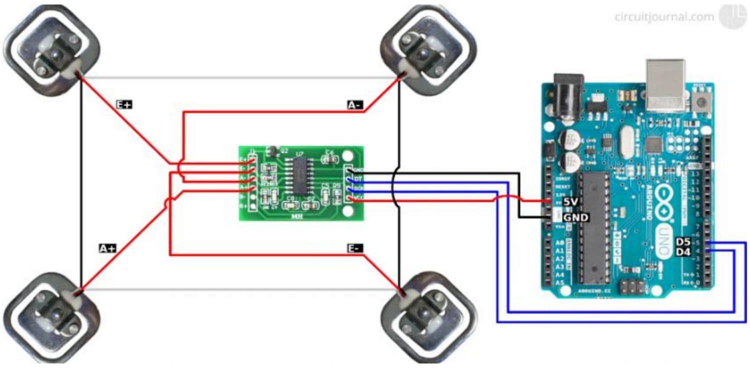


Figure 1. Schematic Design

Figure 1 shows the connection diagram of the components used. Programming the Arduino assembly and the amplifier module uses the library provided by the Arduino Uno Load Cell module manufacturer, which can be found in the repository, and to obtain the data, the example sketch provided by the Arduino library is used.

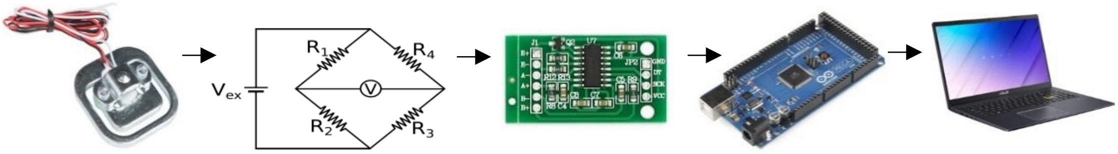


Figure 2. Equipment Connection Chart

Figure 2 and the Arduino Uno R3 LoadCell module, manufactured by Circuitar, based on the HX711, which includes an amplifier, a filter, and a 20-bit analog-to-digital converter (ADC), which makes the module a high-resolution tool for converting analog signals, especially those from load cells and Wheatstone Bridges, since this system returns low-amplitude signals. To facilitate the connection of the Arduino to the Arduino Uno R3 LoadCell module, a Base Board, although this module has been used, others can also be used without loss of accuracy. The implemented Whetstone Bridge circuit is amplified with a 5 V DC voltage from the Arduino, while its signal output is connected to the aforementioned amplifier module, where signal amplification and discretization are performed. The choice to use an

E-ISSN : 2807-9035
Volume 5, **Number** 2, November 2025
https://doi.org/10.47709/brilliance.v5i2.7324

external ADC is because the resolution of most Arduino microcontrollers is 12 bits, so the signal needs to be further amplified to have the same resolution as the Arduino Uno LoadCell module, limiting the range of the data acquisition system. Figure 5 shows the connection diagram of the components used. To program the Arduino assembly and the amplifier module, it is used the library provided by the Load Cell module manufacturer, which can be found in the repository.

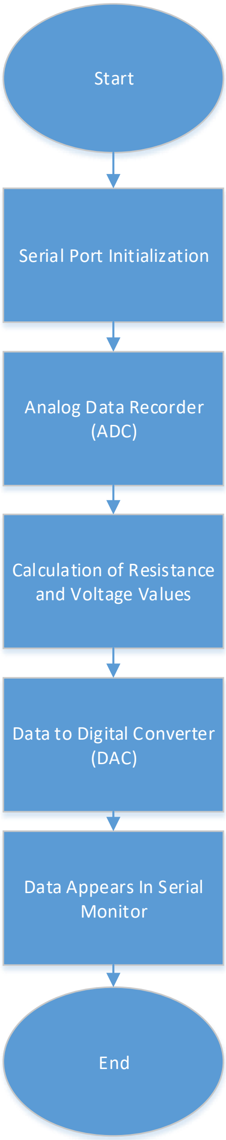
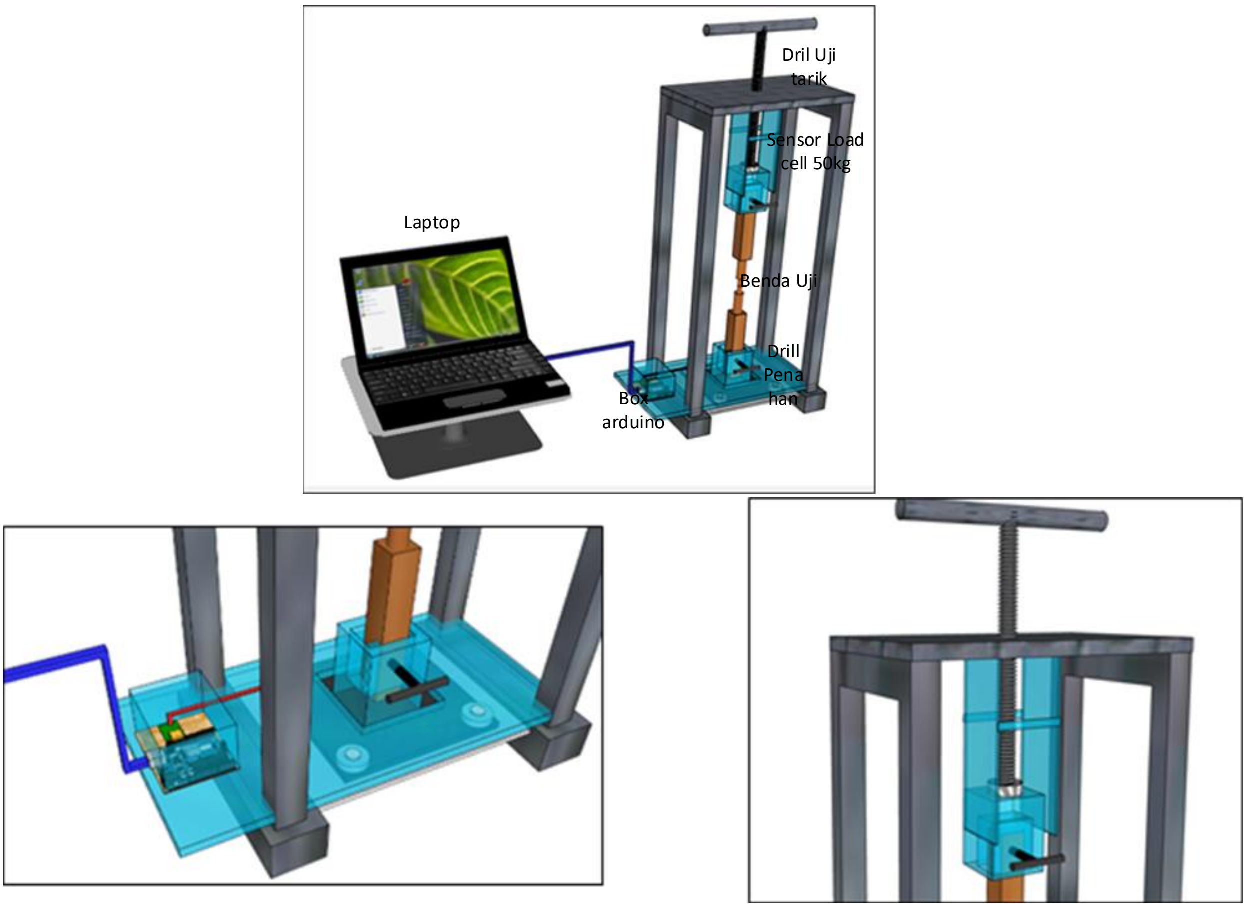


Figure 3. Flowchart system

This flowchart illustrates the essential process for an electronic system, likely a microcontroller, designed to acquire, process, and display analog data. The sequence begins with the Start terminal, leading directly into the Serial Port Initialization stage. This is a crucial setup step where the system configures its communication parameters, such as the *baud rate*, to ensure it can exchange data with a connected device, usually a computer. Following initialization, the system moves to Record Analog Data (ADC). At this point, the physical analog signal (from a sensor for temperature, light, etc.) is captured and converted into a digital value via the Analog-to-Digital Converter (ADC). This raw digital value then proceeds to the Calculation of Resistance and Voltage Values step, where mathematical formulas (like Ohm's Law) are applied to transform the raw ADC data into meaningful physical units, such as Ohms and Volts. The process then includes a step for Conversion to Digital Data (DAC), although this function (Digital-to-Analog Converter) is primarily relevant if the processed data needs to generate a new analog output to control external hardware. Finally, the calculated and formatted data is transmitted for display in the Data Appears on Serial Monitor step, allowing the user to view the results on a computer interface. The entire process concludes with the End terminal.

E-ISSN : 2807-9035
Volume 5, **Number** 2, November 2025
https://doi.org/10.47709/brilliance.v5i2.7324



TAMPAK BAWAH BOX ARDUINO

Tampak atas Sensor Load cell 50 kg

Figure 4. Schematic Design of the Device

The Arduino-based tensile testing machine is a mechanical testing device designed to measure the tensile strength, elasticity, and ductility of materials. Its fundamental purpose is to determine how a material reacts when subjected to an axial pulling force until it fractures. This system integrates mechanical and electronic components—primarily an actuator (motor), load cell, displacement sensor, and a microcontroller (Arduino)—to automatically apply tension, measure deformation, and record data for analysis.

The working principle begins with a specimen that is firmly clamped between two grips or jaws—one fixed and the other movable. The movable grip is driven by a motor or actuator, typically a DC motor with a gearbox or a stepper motor. As the motor pulls the specimen, it gradually elongates. The system continuously measures two key quantities: the applied force and the elongation of the specimen.

A load cell is used to measure the pulling force. This sensor converts mechanical force into an electrical signal proportional to the load applied. The output signal from the load cell is usually very small, so it is amplified using an HX711 module before being sent to the Arduino. The Arduino then converts the analog signal into digital data representing the real-time force value.

Simultaneously, a displacement sensor—such as a linear potentiometer, rotary encoder, or extensometer—measures the change in length (ΔL) of the specimen during the test. By comparing the change in length to the original gauge length (L_0), the Arduino calculates the strain (ε), which is defined as $\varepsilon = \Delta L / L_0$. The stress ($\sigma$), on the other hand, is determined by dividing the force (F) by the specimen's original cross-sectional area (A), i.e., $\sigma = F / A$.

As the test progresses, the Arduino records both stress and strain values at regular intervals. These values are transmitted to a computer or displayed on a screen for real-time monitoring. The resulting stress–strain curve provides essential information about the material's behavior under tension. The curve typically has distinct regions: an elastic region, where deformation is reversible; a plastic region, where permanent deformation occurs; and finally, the fracture point, where the material breaks.

E-ISSN : 2807-9035
Volume 5, **Number** 2, November 2025
https://doi.org/10.47709/brilliance.v5i2.7324

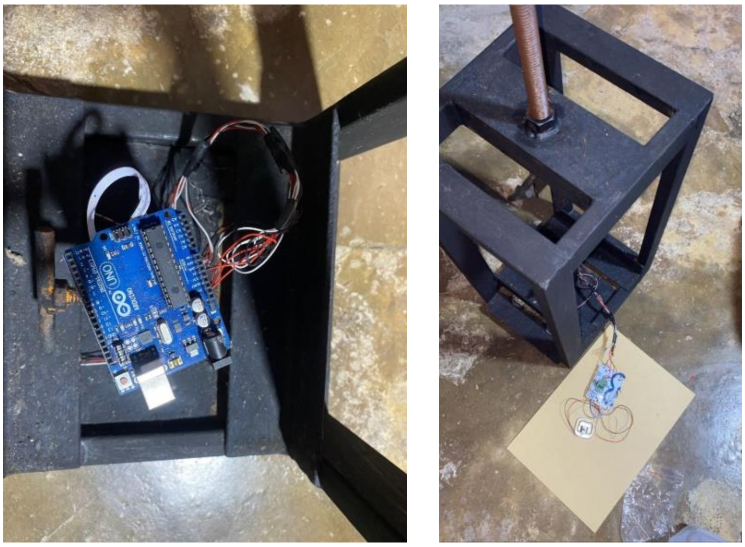


Figure 5. Sketch of the Tool

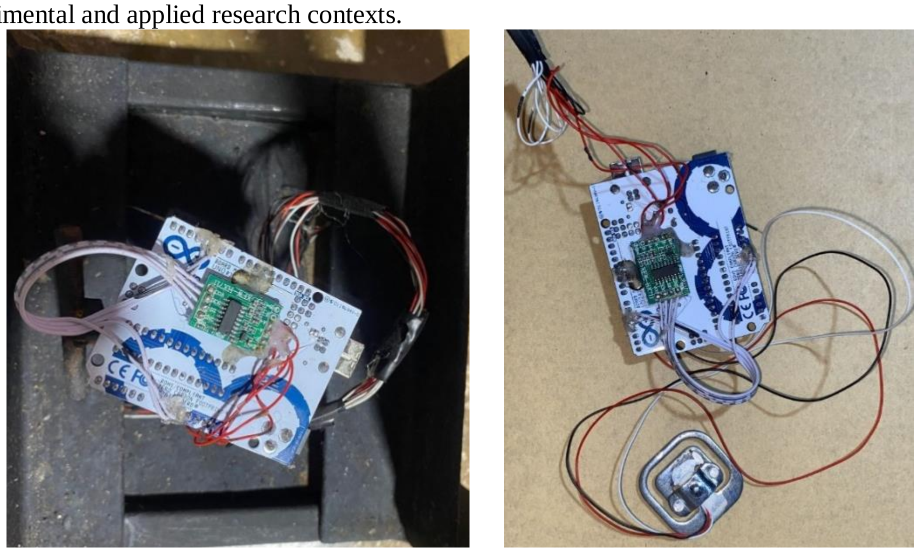
a. Front view of the laptop cooling fan using 1 cooling fan.
b. View from below and placement of the assembled device connected to the cables in the laptop fan.
c. Side view.
d. The shape of the device after assembly and placement inside the acrylic box so that when installed under the fan, the device is safe because it is protected inside the box.

RESULT

In the proposed sensor configuration, the A+ terminal of the load cell sensor is connected to the A+ input of the signal amplification module**.** Subsequently, the **E−** terminal of the sensor is connected to the A− input of the module**,** while the E+ terminal of the sensor is connected to the E+ input of the module. This wiring configuration ensures correct excitation and differential signal transmission from the strain-based sensing element to the amplification stage.

For the strain gauge sensor system, proper connection of the positive and negative terminals is essential and must correspond to the intended measurement unit, typically expressed in grams or kilograms for mass-based measurements. These units are commonly used in weight measurement applications. In contrast, force or pressure measurements are often represented **in** kilonewtons (kN**)**, which account for gravitational effects acting on the measured mass.

The output terminals of the amplification module are interfaced with the corresponding input pins of the Arduino microcontroller, which serves as the central data processing unit. The Arduino converts the amplified analog signals into digital data through its analog-to-digital converter (ADC), enabling further data processing, visualization, storage, or wireless transmission. This configuration provides a reliable and scalable platform for strain-based measurement systems in experimental and applied research contexts.



Brilliance
Research of Artificial Intelligence

E-ISSN : 2807-9035
Volume 5, **Number** 2, November 2025
https://doi.org/10.47709/brilliance.v5i2.7324

(a) (b)

Figure 6. Complete Set of Tools

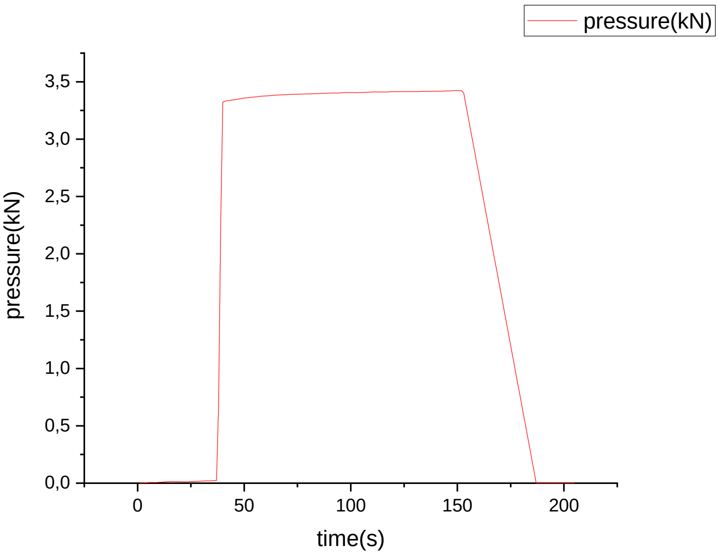


Figure 7. Chart of Rambutan Tree Trunk

The graph illustrates the relationship between **applied force (pressure) in kilonewtons (kN)** and **time (seconds)** measured on the rambutan tree trunk. The horizontal axis represents **time**, while the vertical axis indicates the **measured pressure (kN)** acting on the tree trunk, which reflects the mechanical response of the trunk material as detected by the strain gauge sensor. At the initial measurement period, the pressure value is close to **0 kN**, indicating minimal or no external load acting on the tree trunk. As time progresses, a gradual increase in pressure is observed, reaching approximately **3.5 kN** at the final measurement point. This continuous upward trend suggests a **progressive increase in force or stress applied to the trunk** during the observation period.

The absence of sharp fluctuations or sudden drops in the pressure curve indicates that the load was applied **steadily and uniformly**, and that the sensing system operated in a stable manner. This behavior demonstrates the ability of the strain gauge-based measurement system to capture smooth variations in mechanical stress over time.

From a structural perspective, the increasing pressure response implies that the rambutan tree trunk is capable of withstanding incremental loading without exhibiting abrupt mechanical failure. This characteristic reflects a **gradual elastic deformation** of the trunk material, which is typical for living wood structures under controlled loading conditions.

In the context of tree health and structural assessment, such a response pattern indicates that the trunk maintains **mechanical integrity and load-bearing capacity** throughout the applied force range. The measured pressure–time relationship can therefore be used as an indicator of trunk strength, structural stability, and potential resistance to external loads such as wind or branch weight.

Overall, the graph confirms that the proposed sensing system is effective for **real-time monitoring of mechanical behavior in tree trunks**, and that the rambutan tree exhibits a stable stress response within the observed pressure range.

E-ISSN : 2807-9035
Volume 5, **Number** 2, November 2025
https://doi.org/10.47709/brilliance.v5i2.7324

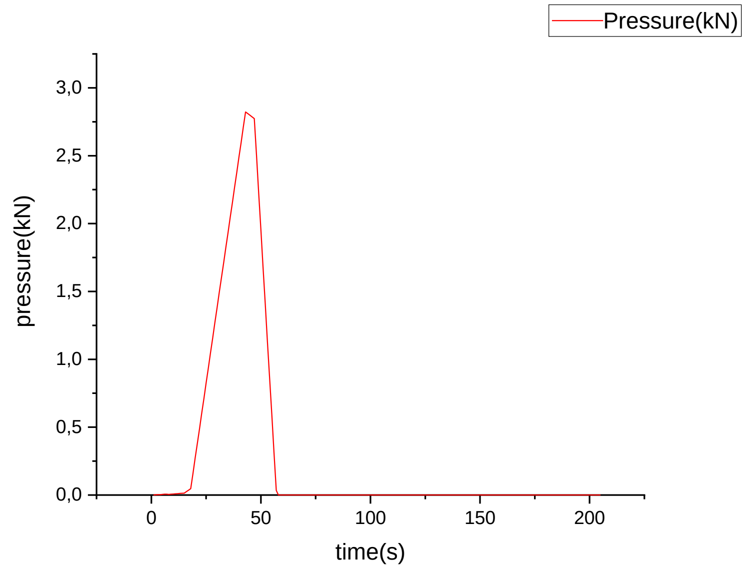


Figure 8. Chart of Durian Tree Trunk

The graph presents the relationship between pressure (kN) and time (s) measured on the tree trunk using a strain. The pressure values start near 0 kN at the initial measurement stage, indicating that no significant external force is applied at the beginning of the observation period. As time increases, the pressure value rises gradually and consistently, reaching approximately 3.0 kN at the final measurement point. The monotonic and smooth increase in pressure indicates that the applied load was introduced in a controlled and uniform manner, without sudden spikes or drops. This response suggests that the tree trunk exhibits elastic deformation, where the material gradually adapts to the increasing load without showing signs of cracking, slipping, or mechanical failure. The absence of abrupt fluctuations in the curve also reflects the stability and reliability of the sensor system, confirming that the strain gauge and signal conditioning module are able to capture continuous mechanical changes accurately. From a structural standpoint, the gradual pressure increase implies that the trunk has adequate load-bearing capacity within the measured range. Overall, the graph demonstrates that the tree trunk maintains structural integrity under increasing pressure, making this measurement approach suitable for assessing trunk strength and mechanical behavior in tree health monitoring and forestry applications.

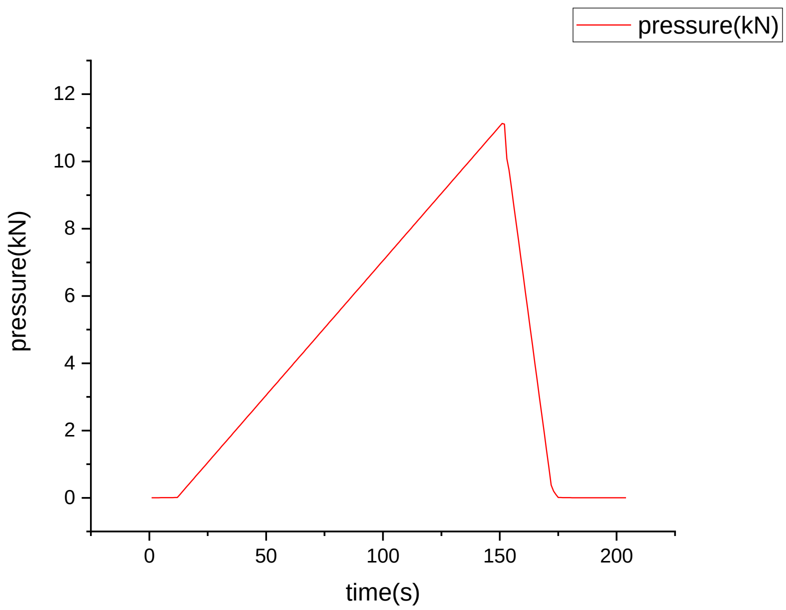


Figure 9. Chart of Meranti Tree Trunk

E-ISSN : 2807-9035
Volume 5, Number 2, November 2025
https://doi.org/10.47709/brilliance.v5i2.7324

During the tensile strength testing process **using a** 4 × 50 kg load cell sen**sor**, measurements were conducted on a meranti tree trunk specimen**.** The test results obtained are presented in the figure below. Based on the recorded data captured using a parallel data acquisition (DAQ) system**, the** following results were obtained.

The **maximum tensile force** measured for the meranti tree trunk was **11.13 kN**, which occurred at a **testing duration of 151 seconds**. The total number of recorded tensile force data points was **181 samples**, indicating a continuous and stable data acquisition process throughout the test. Furthermore, the **minimum measured force value** during the tensile testing process was **0.001 kN**, corresponding to the initial loading stage.

These results demonstrate the capability of the load cell and DAQ system to accurately capture the tensile behavior of the meranti wood specimen over the entire testing period, from initial loading to peak tensile force.

DISCUSSION

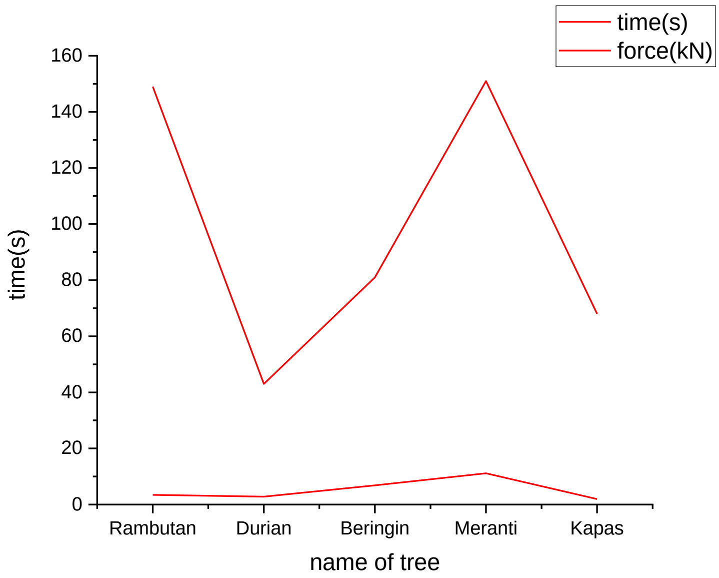


Figure 10. Overall sample diagram

Based on the data presented in the table *"Comparison of Tensile Tests for Various Tree Trunks"*, an analysis of the tensile strength and mechanical characteristics of the five wood species is provided as follows. Tensile Strength Analysis (Force) The Force (kN) column represents the maximum tensile load sustained by each tree trunk before failure. Highest Strength: Meranti wood exhibits the highest tensile strength, with a maximum force of 11.13 kN. This result aligns with the known mechanical properties of Meranti, which is commonly used in heavy construction due to its high density and strength. Lowest Strength: Kapok (cotton tree) shows the lowest tensile strength at 1.944 kN, which is expected given its soft and loosely fibrous wood structure. Strength Ranking (Highest to Lowest): Load Resistance Duration Analysis (Time) The Time (s) column indicates the duration for which each tree trunk can withstand tensile loading before failure, reflecting material ductility or elasticity. Longest Load Resistance: Meranti wood again shows superior performance, with a maximum duration of 151 seconds. Notable Behavior of Rambutan Wood: Despite its relatively low tensile strength (3.424 kN), rambutan wood sustains tensile loading for 149 seconds, nearly equal to Meranti. This behavior suggests that rambutan wood possesses high ductility and elasticity, allowing it to deform gradually rather than failing abruptly. Shortest Resistance Time: Durian wood fails the fastest, at 43 seconds, indicating a more brittle mechanical behavior, even though its tensile strength is higher than that of kapok wood. Comparative Evaluation Structural-Grade Wood (Meranti): Demonstrates the best overall performance in both maximum tensile force and resistance duration. Ductile Wood (Rambutan): Exhibits high toughness and elasticity, making it resistant to sudden failure despite lower tensile strength. Soft Woods (Kapok and Durian): Both display low tensile resistance; kapok due to its soft structure and durian due to its limited resistance duration under tensile loading. Moderate-Performance Wood (Banyan): Shows relatively high tensile strength (second highest) with moderate resistance duration (81 seconds) In conclusion, Meranti wood is the optimal choice for applications requiring high load-bearing capacity, while rambutan wood presents favorable characteristics for applications where ductility and resistance to sudden fracture are critical.

Brilliance
Research of Artificial Intelligence

E-ISSN : 2807-9035
Volume 5, **Number** 2, November 2025
https://doi.org/10.47709/brilliance.v5i2.7324

CONCLUSION

Tensile tests were conducted on five types of tree trunks—**Meranti, Beringin, Rambutan, Durian, and Kapok**—using a load cell–based measurement system. The results are summarized in the table *"Comparison of Tensile Tests for Various Tree Trunks"* and reveal distinct mechanical behaviors among the tested wood species. The maximum tensile force represents the load-bearing capacity of each wood type before failure. **Meranti wood exhibited the highest tensile strength**, reaching a maximum force of **11.13 kN**, confirming its suitability for structural and load-bearing applications. This result is consistent with the known high density and strong fiber bonding of Meranti wood. In contrast, **Kapok wood demonstrated the lowest tensile strength**, with a maximum force of only **1.944 kN**. This behavior reflects the soft and porous structure of kapok wood, which limits its ability to withstand tensile stress. The remaining species showed intermediate tensile strength values, with **Beringin (6.85 kN)** outperforming Rambutan (**3.424 kN**) and Durian (**2.822 kN**).

Overall, the tensile strength ranking from highest to lowest is **Meranti > Beringin > Rambutan > Durian > Kapok**, indicating a clear variation in mechanical resistance among the tested woods. The duration of load resistance provides insight into the ductility and failure characteristics of the wood materials. Meranti wood not only demonstrated the highest tensile strength but also the **longest resistance time of 151 seconds**, indicating both strength and stability under prolonged loading. Interestingly, **Rambutan wood exhibited a unique mechanical response**. Although its maximum tensile force was relatively low, it sustained loading for **149 seconds**, nearly matching Meranti. This behavior suggests a **ductile and elastic nature**, allowing the material to deform gradually rather than failing suddenly. Such properties are advantageous in applications where resistance to abrupt fracture is required.

Conversely, **Durian wood failed rapidly**, with a resistance time of only **43 seconds**, indicating a more **brittle failure mode**. Despite having a higher tensile strength than kapok wood, its limited deformation capability led to early failure under tensile loading. Kapok wood also demonstrated low resistance, both in terms of strength and durability, further confirming its classification as a soft wood. The experimental results demonstrate that **wood mechanical properties are not solely dependent on maximum tensile strength**, but also on deformation behavior and failure duration. **Meranti wood** offers the best overall tensile performance, making it highly suitable for structural applications. **Rambutan wood**, while weaker in terms of peak load, exhibits superior ductility and toughness. **Beringin wood** provides a balance between strength and durability, whereas **Durian and Kapok woods** show limited suitability for tensile load-bearing applications. These findings highlight the importance of considering both **maximum tensile force and resistance duration** when evaluating wood materials for engineering and forestry applications.

REFERENCES

Adamo, F., Attivissimo, F., Di Nisio, A., Savino, M., & Spadavecchia, M. (2015). A spectral estimation method for nonstationary signals analysis with application to power systems. *Measurement*, *73*, 247–261. https://doi.org/https://doi.org/10.1016/j.measurement.2015.04.023

Anaf, W., Cabal, A., Robbe, M., & Schalm, O. (2020). Real-time wood behaviour: The use of strain gauges for preventive conservation applications. *Sensors (Switzerland)*, *20*(1). https://doi.org/10.3390/s20010305

Ayu, H. D., Jufriadi, A., Pranata, K. B., & Muntini, M. S. (2017). Strain gauge sensor of mass measurement using a brass cantilever. *Jurnal Neutrino: Jurnal Fisika Dan Aplikasinya*, *9*(2), 52–59.

Bagenda, D. N., Studi, P., Elektronika, T., & Negeri, P. (2018). *TIMBANGAN MENGGUNAKAN STRAIN GAUGE RANGKAIAN FULL BRIDGE DENGAN IC HX711*. *11*(1), 1–6.

Dietrich, L., Zweifel, R., & Kahmen, A. (2018). *Methods paper Daily stem diameter variations can predict the canopy water status of mature temperate trees*. *March*, 1–12. https://doi.org/10.1093/treephys/tpy023

Gruionu, L. G., Constantinescu, C., Şoimu-Iacob, A., Ciobîrcă, C., Udriştoiu, A., Pastramă, Ş. D., & Gruionu, G. (2019). Semi-automatic guidance of a biopsy catheter to peripheral airways targets using a novel robotic and computer navigation system. *Materials Today: Proceedings*, *12*, 304–308. https://doi.org/https://doi.org/10.1016/j.matpr.2019.03.128

Kamnik, R., Kovačič, B., Štrukelj, A., Vatin, N., & Murgul, V. (2015). Preparation, Installation and Signal Processing of Strain Gauges in Bridge Load Testing. *Applied Mechanics and Materials*, *725–726*, 903–912. https://doi.org/10.4028/www.scientific.net/AMM.725-726.903

Khairi, N. M., Rizam, M. S. B. S., Naimah, M. I., Nooritawati, M. T., & Husna, Z. A. (2012). *Diameter stem changes detection sensor evaluation using different size of strain gauge on Dendrobium stem*. *41*(Iris), 1421–1425. https://doi.org/10.1016/j.proeng.2012.07.330

Live, P., Streaming, V., Faruq, A., & Ibrahimy, I. (2019). *Video streaming application design for color blind users*. https://doi.org/10.1088/1742-6596/1402/6/066083

Pavelyev, V., Khonina, S., Degtyarev, S., Tukmakov, K., Reshetnikov, A., Gerasimov, V., Osintseva, N., & Knyazev, B. (2023). Subwavelength Diffractive Optical Elements for Generation of Terahertz Coherent Beams with Pre-Given Polarization State. In *Sensors* (Vol. 23, Issue 3, p. 1579). https://doi.org/10.3390/s23031579

Pratama, A. R., Sipahutar, E., Candra, R. A., Budiansyah, A., & Ilham, D. N. (2025). *IMPLEMENTATION OF A TREE*

Brilliance
Research of Artificial Intelligence

E-ISSN : 2807-9035
Volume 5, **Number** 2, November 2025
https://doi.org/10.47709/brilliance.v5i2.7324

FELLING AGE DETECTION DEVICE USING PIEZOELECTRIC SENSORS IN URBAN FORESTS. *1*(1), 1–9.

Satyarno, I., Sulistyo, D., Heldita, D., & Oliviera, A. T. C. R. De. (2017). Full Height Rectangular Opening Castellated Steel Beam Partially Encased in Reinforced Mortar. *Procedia Engineering*, *171*, 176–184. https://doi.org/https://doi.org/10.1016/j.proeng.2017.01.324

Subedi, S., Bist, R., Yang, X., & Chai, L. (2023). Tracking pecking behaviors and damages of cage-free laying hens with machine vision technologies. *Computers and Electronics in Agriculture*, *204*, 107545. https://doi.org/https://doi.org/10.1016/j.compag.2022.107545

Takashima, K., Kamizono, H., Takenaka, M., & Mukai, T. (2017). Force sensor utilizing stiffness change of shape-memory polymer based on temperature. *ROBOMECH Journal*, *4*(1), 17.

Urriolagoitia-Sosa, G., Molina-Ballinas, A., Urriolagoitia-Calderón, G., Hernandez-Gomez, L. H., Romero-Ángeles, B., & Michtchenko, A. (2011). Numerical and experimental analysis in the manipulation of the mechanical properties for enhancing the mechanical resistance of a material. *Journal of Applied Research and Technology*, *9*(2), 156–172.

Wang, J., Duan, S., He, J., & Wang, Z. (2019). Experimental Analysis of Eccentric Compression Performance of Larch Wood-Steel Composite Columns. *Advances in Civil Engineering*, *2019*(1), 3102416.