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IMPLEMENTATION OF A TREE FELLING AGE DETECTION DEVICE USING PIEZOELECTRIC SENSORS IN URBAN FORESTS

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ABSTRACT

This research aims to develop and implement a tree felling age detection device using piezoelectric sensors in urban forests. Urban forests play an important role in maintaining environmental quality and the well-being of urban communities. Despite the many benefits provided by trees, such as oxygen production and carbon dioxide absorption, the health condition of trees is often difficult to identify visually. Traditional methods of determining tree age, such as dendrochronology, are destructive and time-consuming, so a fast and accurate non-destructive method is needed. Piezoelectric sensors offer the potential for non-destructive detection of tree age by measuring the physical characteristics of trees that change with age, such as wood density, hardness and moisture content. The research involved sensor selection and calibration, data collection from trees in an urban forest, and signal processing and analysis to associate the extracted features with tree age. Test results show that the device can provide real-time tree age estimation, supporting sustainable urban forest management. This research also highlights the importance of integrating sensor technology with a comprehensive urban forest management system for better decision-making regarding tree planting, maintenance and felling.

INTRODUCTION

Urban forests play a vital role in maintaining the environmental quality and the well-being of urban communities (Potamitis et al., 2019). Trees in urban forests provide numerous ecological benefits, such as oxygen production, air pollutant absorption, microclimate regulation, water conservation, and wildlife habitat (Savvateeva et al., 2021). In addition, urban forests offer social and economic value, including aesthetic improvements, recreational spaces, and increased property values (Potamitis et al., 2019).

Trees are a very important source of life for the earth and all creatures in it, trees play a role in producing oxygen and absorbing carbon dioxide in the air to improve environmental quality. Indonesia is an archipelago that is geographically located in the equator, where this area is a tropical climate that makes many trees grow. However, it is unfortunate that the care of trees is still very minimal, both in terms of awareness of each individual to insufficient insight into the goodness of trees for life. Trees have many types, shapes and sizes, the ability of trees to absorb carbon dioxide in the air can improve environmental quality and reduce the risk of global warming due to the greenhouse effect, therefore tree conservation is needed to support the growth of these trees. Despite the many benefits of trees that can support human life, trees can also be affected by disease and or can no longer grow because they are old, this condition will cause trees to fall and become a disaster when humans cannot maintain them properly.

The types of damage that cause trees to fall are tree diseases including cancer, advanced rot, open wounds, damaged or dead branches, excessive branching and discolored leaves. In live or standing trees, the health condition is difficult to identify with the naked eye so it is difficult to predict whether the tree should be cut down or left alive, because if not handled quickly and appropriately, cut trees can cause accidents that can even cause incidents that can take lives.

Sustainable management of urban forests requires accurate information about tree conditions, including age. Knowing the age of trees is important for determining their life cycle, predicting growth and structural changes, and planning management activities like planting, pruning, and felling (Goh et al., 2018).

Traditional methods for determining tree age, such as dendrochronology (counting tree rings), are destructive and time-consuming (Goh et al., 2018). Moreover, these methods are impractical for large-scale application in urban forests with numerous trees of various species and sizes. Therefore, there's a need to develop non-destructive, rapid, and accurate methods for determining tree age in urban forests.

Piezoelectric sensors offer potential for non-destructive tree age detection (Zhang, Huang, et al., 2018). These sensors work based on the principle of piezoelectricity, where mechanical stress on a material generates an electrical charge (Paradis et al., 2013). In the context of tree age detection, piezoelectric sensors can measure physical characteristics of trees that change with age, such as wood density, hardness, and moisture content (Zhang, Li, et al., 2018). These physical characteristics affect the speed of acoustic waves in the wood, which can be detected by the sensors (Rovná, 2020).

Research on applying piezoelectric sensors for tree age detection in urban forests is still limited. However, some studies have shown the potential of these sensors for monitoring tree health and detecting wood decay (Zhang et al., 2018). Therefore, this research aims to develop and implement a tree felling age detection device using piezoelectric sensors in urban forests as an innovative solution to support sustainable urban forest management.

LITERATURE REVIEW

Urban forests provide significant ecological, economic, and social benefits to urban communities (Allison et al., 2020; Potamitis et al., 2019). They improve air quality (Савватеева et al., 2021), regulate temperature, reduce noise pollution, and enhance the aesthetic appeal of cities (Potamitis et al., 2019). Trees in urban environments contribute to the well-being of residents by providing recreational spaces and improving mental health. Given these benefits, effective management of urban forests is essential.Traditional methods of assessing tree age and health, such as visual inspection and destructive sampling, have limitations. Visual inspections can be subjective and may not detect internal decay or structural weaknesses (Bagheri & Kafashan, 2025). Destructive methods, like core sampling, can harm trees and are not suitable for large-scale assessments (Goh et al., 2017). Therefore, non-destructive testing methods are crucial for urban forest managers to accurately assess tree conditions without causing harm (Allison et al., 2020).

Piezoelectric sensors offer a promising avenue for non-destructive tree assessment. These sensors can detect changes in the physical properties of wood, such as density, moisture content, and the presence of decay (Zhang, Huang, et al., 2018; Zhang, Li, et al., 2018). The principle behind piezoelectric sensing involves the generation of an electrical charge in response to mechanical stress or vibration (Paradis et al., 2013). By measuring the acoustic properties of wood using piezoelectric transducers, it's possible to infer information about its internal structure and condition (Suchocka, 2020).

Acoustic methods, including those employing piezoelectric sensors, have gained attention for their ability to detect wood decay and assess the structural integrity of standing trees (Goh et al., 2017). These methods involve sending sound waves through the wood and measuring their transmission characteristics. Changes in wave velocity and attenuation can indicate the presence of defects or variations in wood density. Factors such as grain angle and tree ring density can influence acoustic emission detection (Boccacci et al., 2022).

While research on using piezoelectric sensors for tree assessment is growing, there are still gaps in knowledge and practical applications. Studies have explored the use of acoustic methods for detecting wood decay (Goh et al., 2017) and monitoring tree health (Potamitis et al., 2019), but few have focused specifically on age estimation in urban forest

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settings. Furthermore, the integration of piezoelectric sensors with IoT technologies offers opportunities for real-time monitoring and data analysis (Potamitis et al., 2019), but this area requires further exploration. The implementation of a tree felling age detection device using piezoelectric sensors in urban forests holds great potential for improving urban forest management practices. By providing a non-destructive and efficient means of assessing tree age and health, this technology can support informed decision-making regarding planting, maintenance, and removal of trees in urban environments. Future research should focus on refining sensor designs, developing robust data analysis algorithms, and integrating these systems into comprehensive urban forest management platforms.

METHOD

The methodology for this research, "Implementation of a Tree Felling Age Detection Device Using Piezoelectric Sensors in Urban Forests," would likely involve the following stages:

1. **Sensor Selection and Calibration:** Choose appropriate piezoelectric sensors based on their sensitivity to changes in wood density, moisture, and acoustic properties (Zhang, Huang, et al., 2018; Zhang, Li, et al., 2018). Calibrate the sensors to ensure accurate and reliable measurements under varying environmental conditions.
2. **Data Collection:** Collect data from a sample of trees in an urban forest. This would involve attaching the piezoelectric sensors to the tree trunks and recording the acoustic signals generated. It's important to record tree species, diameter at breast height, and any visible signs of damage or decay (Potamitis et al., 2019). You may also want to collect core samples for traditional tree ring analysis to validate the piezoelectric sensor readings, although this is a destructive method (Goh et al., 2017).
3. **Signal Processing and Analysis:** Process the acoustic signals obtained from the piezoelectric sensors to extract relevant features, such as wave velocity, frequency, and amplitude. Use signal processing techniques to filter out noise and enhance the signal quality. Develop a model to relate the extracted features to tree age. This may involve using machine learning algorithms to train a model on a dataset of trees with known ages (Bagheri & Kafashan, 2025).
4. **Device Development:** Integrate the piezoelectric sensors, data acquisition system, and signal processing algorithms into a portable device suitable for field use. The device should be user-friendly and provide real-time age estimates.
5. **Field Testing and Validation:** Test the device in different urban forest settings and validate its accuracy by comparing the age estimates with those obtained from traditional methods or historical records. Evaluate the device's performance under varying weather conditions and tree species.
6. **Data Analysis and Interpretation**: Analyze the collected data to determine the relationship between sensor measurements and tree age. Consider factors such as tree species, environmental conditions, and tree health.
7. **Refinement and Optimization**: Based on the field testing results, refine the device and optimize the signal processing algorithms to improve accuracy and reliability.

The method would aim to provide a non-destructive and efficient means of estimating tree age, which can help urban forest managers make informed decisions about tree maintenance and removal (Allison et al., 2020). Note that knowledge of applicability of selected methods is crucial, as without proper interpretation of the obtained results may lead to wrong conclusions (Suchocka, 2020). lead to wrong conclusions (Suchocka, 2020).

This research employs an experimental methodology, focusing on direct field measurements to gather data. The experimental setup utilizes an Arduino UNO microcontroller, based on the ATMega328, as the primary control system. Piezoelectric sensors are used to detect pressure variations within the tree trunk."

- **Piezoelectric Sensors for Pressure Detection:** You're using piezoelectric sensors to measure pressure changes or vibrations within the tree trunk. The pressure variations can be related to tree's physiological processes or structural characteristics (Zhang et al., 2018).

In essence, you are building a system to measure pressure changes in the tree using piezoelectric sensors, controlled by an Arduino, and recording the data in the field. As (Suchocka, 2020) notes, without proper interpretation, the data may lead to wrong conclusions.

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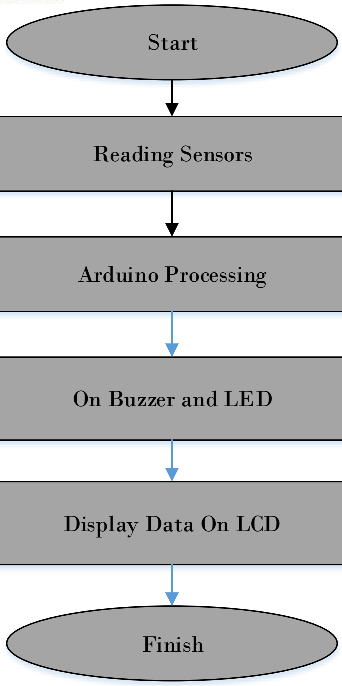

Figure 1. Flowchart System

The flowchart of the tool can be seen in Figure 1 the process begins with reading and activating the sensor, Arduino and other sensor components are activated when the electric current is applied, after initialization is complete, the piezoelectric sensor will read the pressure on the tree trunk, after the pressure data is obtained, the data will be sent back to the Arduino and Arduino gives the command so that the buzzer and led light up as an initial indicator that the sensor has finished reading and the data has been sent to the Arduino, and the last process is the data obtained will appear on the 16x2 LCD screen to measure and assess the pressure reading by the piezoelectric sensor on the tested tree trunk.

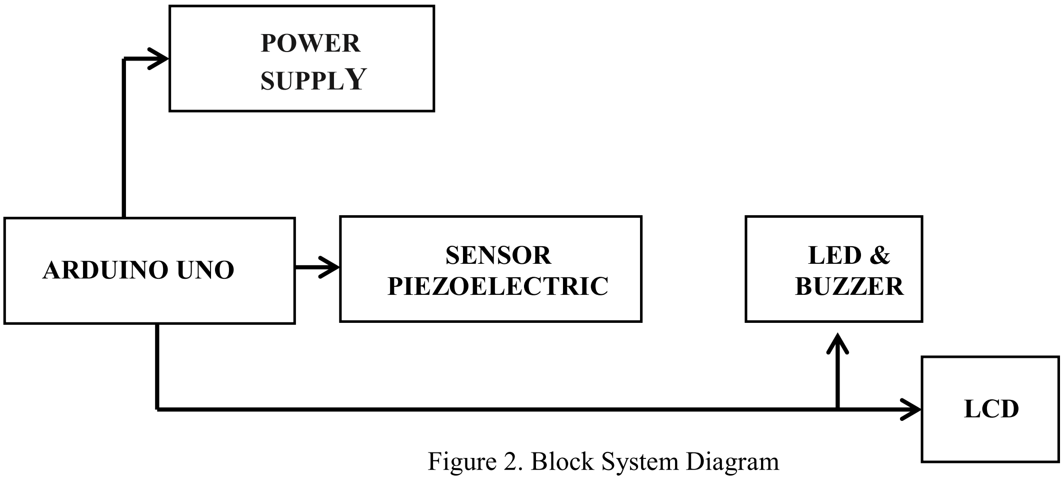

Figure 2. Block System Diagram

The design of this Tree Felling Age Detection Tool uses an arduino-based ATMega328 microcontroller, so software is needed so that the system can work as it should. Information obtained from piezoelectric sensors will be processed by a microcontroller which will be forwarded to the LCD, LED and Buzzer to provide information related to the data obtained. The design of the tool becomes an important stage so that the purpose of making the tool can be achieved properly. For this reason, a block diagram of the tool design must be compiled. The block diagram can be seen in Figure 2 below: After the piezoelectric sensor reads and detects the pressure value of a tree, the results of the reading

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will be processed by Arduino to be forwarded to the LCD as the output interface in this tool circuit so that it can be seen and concluded that the pressure of the object is measured in the form of numbers, and also forwarded to the LED and buzzer as an indicator on the tool.

RESULT

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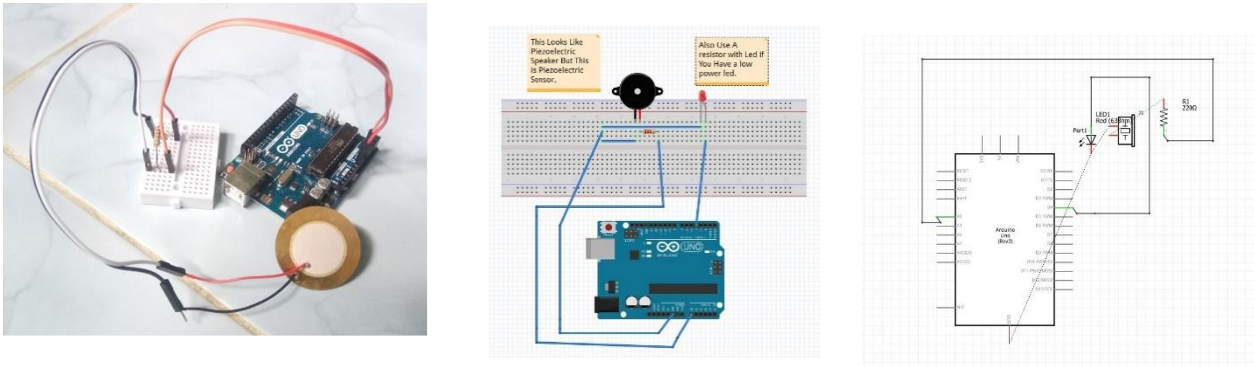

(a) (b) (c)

Figure 3. Results of the Tree Felling Age Detection Tool Range

In the Arduino circuit and piezoelectric sensor, the GND pin and Output pin on the piezoelectric sensor are connected first to the resistor, then the GND pin is forwarded to the GND pin on the Arduino board and the Output pin is connected to pin A0 on the Arduino board. In the Arduino circuit and piezoelectric sensor, the positive and negative pins on the sensor must be connected to a resistor with a resistance value of 220/320. For more details, it can be seen in Figure 3(a) Scheme of piezoelectric sensor and LED. Figure 3(b) Schematic of Piezoelectric Sensor and LED

In the Arduino and LED circuit, the foot on the LED must be adjusted accordingly, it must not be reversed, if it is reversed, the LED will burn out. For the negative leg on the LED is connected to the GND pin on the Arduino board, while the positive leg on the LED is connected to pin D4 on the Arduino board, and it should also be noted, in the installation of the connector between the Arduino and the LED must be connected using a resistor, with a resistance value of 220/330.

In the overall circuit, all of the above components will be connected and work in 1 coding command, when the piezoelectric sensor reads the pressure on the tree trunk generated from the tin suction device, the LCD will display the reading from the sensor which will be used to make a conclusion, whether the tree is worth cutting or not. When the tree pressure value is considered a healthy tree, the buzzer and LED will not turn on, while if the tree is considered porous, the buzzer and LED will be active indicating that the tree is porous.

The design of this tree cutting age detection system consists of several components, starting from the microcontroller that regulates the work of the tool, piezoelectric sensors as output value readers from tree pressure, output devices, such as LCD, buzzer, and LED, as well as pressure devices, which are used to apply pressure to trees. In the tests carried out, the pressure exerting device used was a tin suction device. By applying pressure using a tin suction tool, the piezoelectric sensor attached to the side of the tree trunk will read the reading results of the pressure applied by the tin suction tool, which is then taken as test data in distinguishing which trees are healthy and porous trees, and by using a tin suction tool, it can produce the same pressure when applying pressure to both healthy and porous trees.

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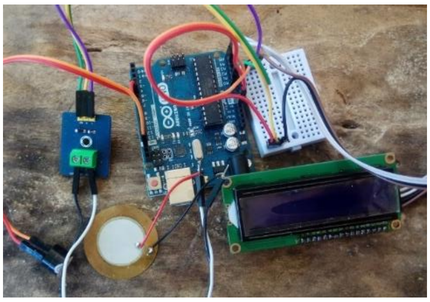

Figure 4. Overall Tool Set

The design of this tree cutting age detection system consists of several components, starting from the microcontroller that regulates the work of the tool, piezoelectric sensors as output value readers from tree pressure, output devices, such as LCD, buzzer, and LED, as well as pressure devices, which are used to apply pressure to trees. In the tests carried out, the pressure exerting device used was a tin suction device. By applying pressure using a tin suction tool, the piezoelectric sensor attached to the side of the tree trunk will read the reading results of the pressure applied by the tin suction tool, which is then taken as test data in distinguishing which trees are healthy and porous trees, and by using a tin suction tool, it can produce the same pressure when applying pressure to both healthy and porous trees.

Figure 5. Tree Samples Used

In testing this tree cutting age detection tool, testing is not done directly, but only done and formed in a prototype. In this test, the samples used are obtained directly by searching and sorting the types of samples to be used. In this study, the samples used consisted of 3 types of trees, including Spruce trees, Tamarind trees, and Trembesi trees. Each tree trunk of the 3 types of trees mentioned above will be cut from the original trunk and then tested at home, from each type 3 samples will be taken for each condition, both healthy trees and porous trees, which then the research will be carried out at home to get the pressure value given by the tree. In the miniature there will only be a few samples that will be tested to show the results of the tool's performance. The testing process is carried out starting from collecting each sample needed, which then prepares the hardware and software that will be used to conduct tests on the tree trunk. After the sample is obtained and the tool can be used, the next process is to conduct a trial to get the pressure value of the tree, by applying pressure to each test sample using a tin suction tool, which will then be seen the value of the pressure given from healthy trees and porous trees. After obtaining data on the difference between healthy and porous trees, the next step is to rebuild the system to provide an automated system when used directly. When the sensor reads the tree pressure assisted by applying pressure using a tin suction tool, then when the resulting byte value is a healthy tree value, the LCD will display that it is a healthy tree and if the resulting byte is a porous tree value, the LCD will display that the tree is a porous tree.

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Figure 6. Testing Process and Value Capture on samples

DISCUSSION

Testing and analysis of system work is a combination of software and hardware that has been realized. Testing the tool provides accurate results, where when the piezoelectric sensor reads the pressure on the tree coupled with the pressure exerted by the tin suction tool and produces a reading of <=200 then the tree is a healthy tree, and if the sensor reading produces a reading of >=200 then the tree is a porous tree. In testing this tree cutting age detection tool, the tree samples used are 3 different types of trees, including Fir trees, Tamarind trees, and Trembesi trees. These three types of trees are trees that are often found living on the side of the vehicle traffic road, and often endanger motorists when the tree suddenly collapses. Of the 3 samples used, each 1 type of tree was taken 3 samples of healthy trees of that type, and 3 samples of porous trees, so in this study 9 samples of healthy trees were used from 3 types of trees and likewise for porous tree samples, 9 samples were used, and the total samples used were 18 samples.

Table 1. Testing on Healthy Stems

No	Jenis Pohon	Percobaan 1	Percobaan 2	Percobaan 3	Rata-rata
1	Pohon Cemara	126	98	149	124.3
2	Pohon Asam	176	188	152	172
3	Pohon Trembesi	164	197	183	181

In table 1, it can be seen the reading results of piezoelectric sensors on healthy tree trunks after pressure exertion using a tin suction tool, it can be seen that the average results of healthy tree samples <=200, so these results can be used as a reference in coding for automation in tree cutting age detection tools.

Table 2. Testing on Porous Rods

No	Jenis Pohon	Percobaan 1	Percobaan 2	Percobaan 3	Rata-rata
1	Pohon Cemara	231	256	228	238.3
2	Pohon Asam	248	261	278	262.3
3	Pohon Trembesi	325	287	290	300.6

As for the results of the test on the porous tree trunk, the results of the piezoelectric sensor readings after applying pressure using a tin suction tool on the porous trunk, it can be seen that the average reading results show results > = 200, so these results can be used as a reference in the coding for further testing. For trials that produce test results in tables 1 and 2, only piezoelectric sensors and tin suction tools are used, and the readings are only monitored through a serial monitor to facilitate data collection, because testing tools are used with readings and a delay of 100 milliseconds. After the results are obtained as in tables 1 and 2, it can be concluded that healthy trees have a byte value <=200 and while

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porous trees >=200, after obtaining the conclusion as above, it can be inputted in coding and retesting with the parameters of the success rate when testing. Testing and analysis of system work is a combination of software and hardware that has been realized. Testing the tool provides accurate results, where when the piezoelectric sensor reads the pressure on the tree coupled with the pressure exerted by the tin suction tool and produces a reading of <=200 then the tree is a healthy tree, and if the sensor reading produces a reading of >=200 then the tree is a porous tree.

CONCLUSION

After designing and testing this tree cutting age detection tool, it can be concluded that:

1. Piezoelectric sensor is a sensor that is quite sensitive to vibration and pressure, and its use is quite difficult because it is based on the few sources that can be taken in the testing process.
2. In testing and to get the results of piezoelectric sensor readings, a place must be made to put the sensor and it must always be ensured that the place of laying the sensor is dry without wetness from tree sap.
3. The tool runs according to what is expected.

Effectiveness of Piezoelectric Sensors: The piezoelectric sensor has proven to be highly sensitive to vibrations and pressure, making it a valuable tool for detecting tree health and age. However, its application can be challenging due to the limited sources available during the testing process.

Sensor Placement Considerations: For accurate readings from the piezoelectric sensors, it is crucial to ensure that the sensor is placed in a dry area, free from moisture caused by tree sap. Proper placement is essential for reliable data collection.

Operational Success: The developed tree felling age detection tool operates as intended, successfully providing real-time assessments of tree health and age based on pressure readings. The results indicate that the tool can effectively differentiate between healthy and porous trees, contributing to better urban forest management practices.

Overall, the research demonstrates the potential of using piezoelectric sensors for non-destructive testing of trees, paving the way for improved decision-making in urban forestry. Future work should focus on refining the technology and expanding its applications in various urban forest settings.

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