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Tilt Building (TB) Gun-an Arduino Nano Based Device for Detecting Building Inclination

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ABSTRACT

The inclination of a building can be a serious issue with potentially fatal consequences if not addressed correctly from the beginning, as it may lead to the building collapsing. Therefore, a tool is needed to detect the tilt of a building to determine the level of inclination. This research aims to design and build the Tilt Building Gun (TB Gun) as a portable device for detecting building inclination that can be easily used anywhere. The research methodology includes the design of hardware, development of software, and overall testing of the device. A miniature building in the form of a laptop-sized box was also constructed. The components used in this research include Arduino Nano, 2 HC-SR04 ultrasonic sensors, and an OLED display. The test results of ultrasonic sensor 1 for horizontal direction yielded an accuracy value of 99.06% and a relative error of 0.94%. Meanwhile, the testing results of ultrasonic sensor 2, with an additional distance of 13.1 cm (distance between ultrasonic sensor 1 and ultrasonic sensor 2 to the ground surface) for vertical direction, resulted in an accuracy of 96.29% and a relative error of 3.71%. Subsequently, testing the building inclination angle with a horizontal distance of 25 cm for ultrasonic sensor 1 and a vertical distance of 20 cm for ultrasonic sensor 2 yielded an accuracy of 98.86% and a relative error of 1.14%. From these accuracy values, it can be concluded that the prototype has excellent accuracy. The building inclination angle data is then displayed on the OLED.

Introduction

The construction sector in Indonesia can be considered one of the rapidly growing fields, as evidenced by the numerous multi-story building constructions. Multi-story buildings have become a current and future necessity, serving as residences and places for various social, religious, cultural, or other specialized events (Simanjuntak & Bernard, 2013). The increasing demand for space and land limitations drives the construction of multi-story buildings. The inclination of the ground and the foundation of a building must be carefully considered to ensure the safe occupancy of the structure. However, over time, the feasibility of a building tends to decrease, influenced by factors such as natural events like ground movement and earthquakes (Douglas & Edwards, 2016). Monitoring the condition of buildings and structures is very important. People spend 90% of their lives inside buildings (Mobaraki et al., 2021).

The inclination or slope of a building can affect its stability and safety. If the inclination is too steep or uneven, the building may become unstable and at risk of damage or collapse. It is essential to conduct a feasibility test to assess the feasibility of a building. This test ensures that the building structure is in good condition and meets technical standards regarding quality, safety, comfort, and functional needs. One method of testing the feasibility of a building is by measuring its inclination. Building slope measurements have been carried out with various tools, one of which uses variable resistors and sensor

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systems (Pahlevi et al., 2020). The research on ultrasonic sensors was conducted by Sugih et al. (2019) from Pakuan University, West Java, titled prototype digital distance and tilt angle measuring tool using an ultrasonic sensor and accelerometer based on Arduino Nano. Ultrasonic sensors are used to measure changes in distance. These sensors are not directly installed on the building but can be positioned at a certain distance outside the building. One of the advantages of ultrasonic sensors, besides their accuracy and flexibility, is that they allow for contactless measurements.

This measurement aims to determine whether the inclination values are within the tolerance applicable regulations allow. After measuring the inclination, the results can be used to determine the necessary steps to correct the building's inclination and maintain its safety and feasibility. However, some buildings are deliberately arranged at an angle based on carefully calculated architectural techniques (Yiğit & Necdet, 2024). A literature review shows that slopes above 0.005 rad cause people to feel dizzy and have headaches, so the deformation index in the permitted technique is 0.005 rad (McCormick et al., 2008).

Advancements in science and technology, particularly in electronics and instrumentation, allow the realization of a device that can automatically measure the inclination of a surface or building. Such a device is often needed in project environments and civil engineering. For example, during building construction, attention must be paid to the inclination of the ground on which it is erected and the inclination of the building's foundation. The inclination of the ground and foundation must be known to ensure the community can adequately occupy what the contractor builds. Additionally, measuring existing buildings is necessary to determine their level of feasibility. The implementation of this technology is closely tied to the use of sensors and transducers in microcontrollers. Sensors and transducers are currently used for innovation and creativity in experiments (Jayanti et al., 2020).

For this research, an easy-to-use measuring tool is needed to read and use the results. Existing building inclination detection tools are often expensive, complex to install, require specialized skills, and cannot be easily moved to another building if needed. This research aims to design a building inclination detection tool that can be used as a Tilt Building Gun (TB Gun), making it easy to use anywhere using two HC-SR04 ultrasonic sensors. Sudarmanto et al. (2023) highlight the advantages of the HC-SR04 ultrasonic sensor, stating that it is accurate and affordable. The HC-SR04 ultrasonic sensor module has a transmitter and receiver circuit that provides distance information. The sensor measures the distance and detects objects by sending a signal from the transmitter. The receiver receives the reflected signal and then sent to the microcontroller for processing to calculate the distance to an object in front of it (Yunardi, 2017). Microcontroller technology allows digital measurement results to be directly displayed on an LCD screen (Jayanti et al., 2020). The Arduino Nano microcontroller is used in this design due to its small construction (Kiri & Lapono, 2018), making it more practical. Using Arduino Nano as the central controller, the device can be easily adjusted and calibrated, saving time with automatic measurements displayed directly on the screen. The display screen in this study uses OLED (Organic Light-Emitting Diode), which is smaller and thinner than LCD screens, with sharp contrast for easy readability. Based on this background, this research is expected to contribute to the development of a portable, efficient, and user-friendly building inclination detection tool.

Methods

The research was conducted at the Faculty of Science and Technology Physics Laboratory, Universitas Islam Negeri Walisongo Semarang. The activities included designing hardware, developing software, and overall testing of the device. A miniature building in the form of a laptop-sized box was also constructed. The components used in this research include Arduino Nano, 2 HC-SR04 ultrasonic sensors, and an OLED display.

Functional Design

The software design in this research utilizes the Arduino IDE (Integrated Development Environment). Arduino IDE is employed to compose code that will be uploaded to the Arduino module, which contains a text editor for code or command programs. The hardware in this study employs two HC-SR04 Ultrasonic sensors to detect changes in horizontal and vertical distances from the building, thereby obtaining the building's inclination angle. Arduino Nano is used as the data processor for the building's inclination angle, and OLED serves as the display screen for the processed data by Arduino Nano. The prototype of the tool can be seen in Figure 1.

Data Collection and Analysis

Data collection in this study used comparative data in the form of a ruler and a protractor installed on the miniature building. The ultrasonic sensor testing was conducted with 7 (seven) variations of horizontal and vertical distances, and the results were compared with a ruler. The overall testing of the device included 6 (six) variations of angles, and the results were compared with a protractor. The sensor readings for the distance to the building and the distance to the ground were converted into inclination angles. The data collection process can be seen in Figure 2. Building Inclination Distance is determined using Equation 1.

Figure 1
Prototype TB Gun Hardware

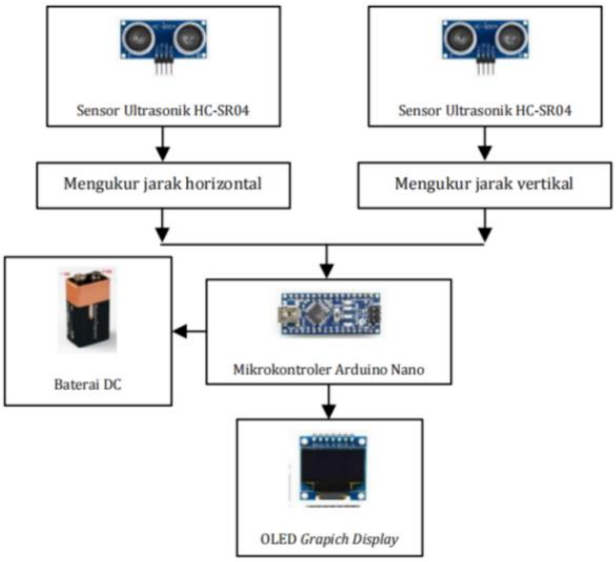
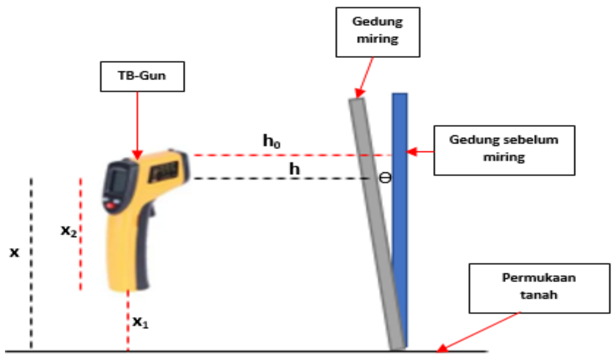


Figure 2
Illustration of Determining the Inclination Angle



$$\Delta h = h_0 - h \tag{1}$$

notes:

Δh : is Building Inclination Distance (cm)

h_0 : is distance of the sensor to the building before tilting (cm)

h : is the distance of the sensor after the building tilts (cm)

To determine the measurement height with ultrasonic sensor 2 relative to the ground surface, the reading of ultrasonic sensor 2 is obtained by adding the distance between ultrasonic sensor 2 and ultrasonic sensor 1, which is 13.1 cm, with the following Equation (2).

$$\Delta x = x_1 + x_2 \tag{2}$$

notes:

Δx : is measurement height (cm)

x_1 : is the distance of ultrasonic sensor 2 to the ground surface (cm)

x_2 : is the distance between ultrasonic sensor 2 and ultrasonic sensor 1 (cm)

To determine the conversion from distance to inclination angle in the ultrasonic sensor, trigonometric calculations are used with Equation (3).

$$\theta = \arctan \frac{\Delta h}{\Delta x} \tag{3}$$

To express the arctangent of the angle in radians as degrees, it is multiplied by $180/\pi$ as in Equation (4) below.

$$\theta = \frac{\left(\arctan\frac{\Delta h}{\Delta x}\right) x\ 180}{\pi} \tag{4}$$

Where Δx is the distance of ultrasonic sensor 2 to the ground surface (cm), Δh is the distance of ultrasonic sensor 1 to the building after tilting (cm), to express the arctangent in degrees, it is multiplied by $180/\pi$, and θ represents the inclination angle of the building (degrees).

The data analysis technique in this study involves two stages. The first stage consists of testing the sensors and the entire device and analyzing the data by calculating relative error and accuracy. The error value can be calculated using the following Equation (5).

$$\text{Error} = \frac{x_i}{x_M} x\ 100\% \tag{5}$$

The accuracy value of the sensor can be calculated using the following Equation (6).

$$\text{Accuracy} = 100\% - \text{Error} \tag{6}$$

Notes:

X_i : The difference in distance measured by the sensor and the ruler or protractor.

X_M : Measurement using a ruler or protractor

X_S : sensor measurements (cm)

Result and Discussions

The results obtained from this study are the prototype form of components such as Arduino Nano, Ultrasonic Sensor, and OLED that have been assembled and programmed into an integrated device, as seen in Figure 3. The prototype can be used to measure changes in horizontal distance and the inclination angle of the building. The design results in the form of the prototype can be seen in Figure 3 and Figure 4.

Figure 3
Implementation of the Hardware Circuit Design of TB

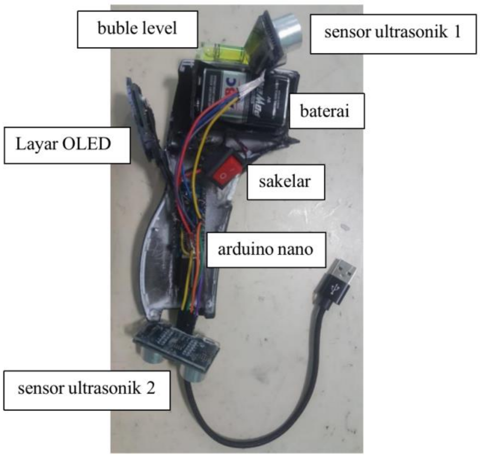
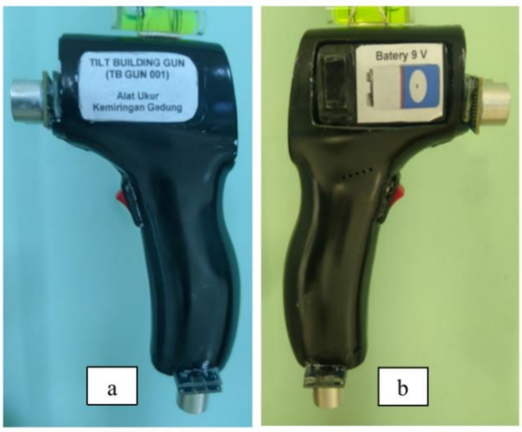


Figure 4
Side View of TB Gun Prototype



Results of Ultrasonic Sensor for Horizontal and Vertical Directions

Testing of the HC-SR04 ultrasonic sensor aims to determine its functionality. Ultrasonic sensors usually measure distance in robotics (Zhmud et al., 2018). The HC-SR04 ultrasonic sensor is designed to measure distance, which Arduino Nano then processes. Testing of the HC-SR04 ultrasonic sensor for horizontal and vertical directions can be seen in Figure 5 and Figure 6.

Figure 5
Data Acquisition of Ultrasonic Sensor 1 Horizontally

Figure 6
Data Acquisition of Ultrasonic Sensor 2 Vertically

The testing data results for ultrasonic sensor 1 horizontally and ultrasonic sensor 2 vertically are compared with a ruler. The data collection for ultrasonic sensor 1 varies at 20 cm, 25 cm, 30 cm, 35 cm, 50 cm, 75 cm, and 100 cm. Meanwhile, the data for ultrasonic sensor 2 varies at 10 cm, 20 cm, 25 cm, 40 cm, 65 cm, 80 cm, and 100 cm. The testing results for both sensors can be seen in Figure 7 and Figure 8.

The testing of ultrasonic sensor 1 to measure horizontal distance resulted in a relative error of 0.94%, and the accuracy value of the sensor is 99.06%. Meanwhile, testing of ultrasonic sensor 2 for vertical distance measurement resulted in a relative error of 3.71%, with an accuracy value of 96.29%. In Figure 7 and Figure 8, it is observed that the readings of both ultrasonic sensors, when compared with the ruler, are not significantly different, indicating excellent accuracy. This is consistent with Equations 1 for horizontal and 2 for vertical ultrasonic sensors.

Figure 7
Comparison Graph of Ultrasonic Sensor 1 and Ruler Horizontally

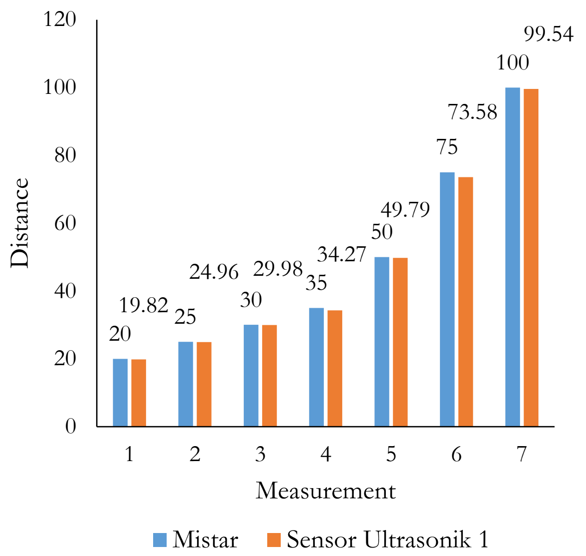
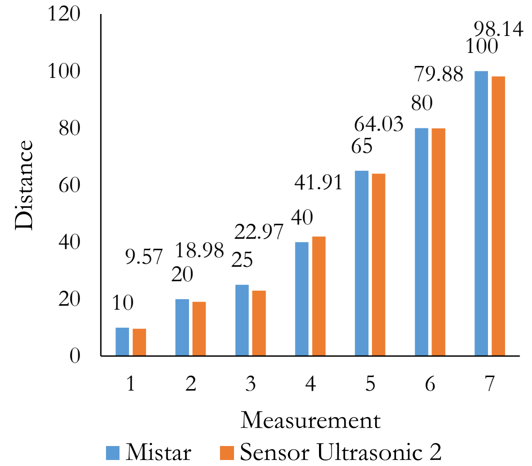


Figure 8
Comparison Graph of Ultrasonic Sensor 2 and Ruler Vertically



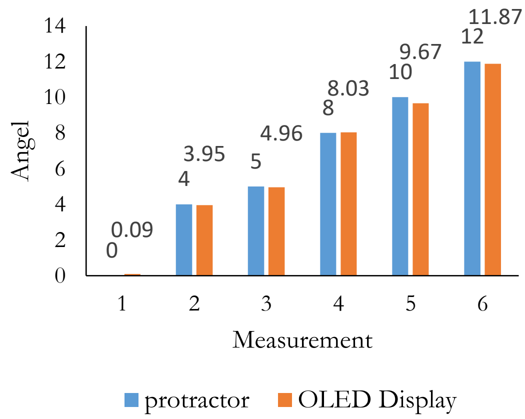
Results Overall Prototype Testing and Discussion

The overall prototype testing includes ultrasonic sensors to obtain the inclination angle values, and the results are displayed on the OLED screen. Equation 4 is utilized, and then the results are compared with the protractor to get the inclination angle values. The inclination angle testing can be seen in Figure 9.

Figure 9
Inclination Angle Data Acquisition

The building inclination angle was tested with the sensor placed on the side of the building at various angles: 0°, 4°, 5°, 8°, 10°, and 12°. Ultrasonic sensors 1 and 2 were positioned at a sensor height of ±20 cm and a distance from the building of ±25 cm. The prototype has a bubble level to determine the tool's horizontality. The data results of the inclination angle values compared with the protractor can be seen in Figure 10.

Figure 10.
Comparison Graph of Inclination Angle Values and Protractor



From Figure 10, the inclination angle values obtained an accuracy of 98.86% and a relative error of 1.14%. The overall prototype testing results indicate that the received data aligns with expectations. The data displayed on the OLED screen includes the inclination angle. The results of the inclination angle testing displayed on the OLED screen show values that are not significantly different from those read on the protractor.

Measuring the slope of a building is very important because it can indicate a danger alarm for the loss of stability of the slope on which the building is being built (Ślusarek & Łupieżowiec, 2020). Using the Tilt Building (TB) Gun-an Arduino Nano Based Device effectively measures the slope of buildings. Slope detection can also be applied to slope monitoring. Slope monitoring is important in Opencast mining operations for worker safety and smooth production (Mittapally & Marichamy, 2023).

This TB Gun tool can be used both vertically and horizontally. Horizontal use can be applied to measure the slope of the floor. It is imperative to calculate the slope of the floor because an inadequate slope can cause surface damage and the formation of water pockets. Similar tool development has also been carried out by developing the 3D Cloude data system. This system produces the slope value of the room being examined and the direction of the slope to determine the correct direction of floor drainage, which is essential for accessing bathrooms or balconies in residential buildings (Peansupap & May, 2024). So that the development of the TB gun is very related to the needs in the industrial and building world. Further development certainly needs to be carried out so that the accuracy of the measurement results of this tool can be improved.

Conclusions

This research involves designing and building a Tilt Building Gun (TB Gun) prototype to detect building inclination using HC-SR04 ultrasonic sensors based on Arduino Nano. The results show that the change in distance values for ultrasonic sensor 1 in the horizontal direction has an accuracy of 99.06% with an error of 0.94%. In contrast, ultrasonic sensor 2 in the vertical direction has an accuracy of 96.29% with an error of 3.71%. As for testing building inclination angles, an accuracy of 98.86% and an error of 1.14% were obtained. From these accuracy values, it can be concluded that the prototype has excellent accuracy. Based on the results of this prototype, it is expected that it can be implemented on buildings or structures to detect whether the building or structure is experiencing tilt.

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