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Ultrasonic Sensor-Enabled Rover For Accurate Urban Building Height Measurement

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Abstract:
A significant proportion of mobile surveying systems in the market are not economically viable due to their inconvenience in operation such as large size, complex data processing requirements and limited accessibility to areas without vehicle access. This paper targets to design a model to implement a rover-based system to highlight the challenges that includes the measure the height of the building or any object in urban environments using a low- cost. The other advantage is that the assembling of system is easy as it consists of ultrasonic sensors, stepper motors and a laser system. Here, it integrates calibration mechanisms to be highly accurate, and the rover's modular architecture promotes robustness and easy replication for multiple scenarios. This advances the measurement of building heights in urban settings by enhancing users' control of the process, and in delivering results that reflect local requirements.

***Keywords**: Rover, MEMS sensor, Ultrasonic sensor, Rasberry Pi Pico, Pin description, ULN2003, Buzzer etc.*

1. Introduction

Accurate measurement of building height is an essential requirement in modern urban planning, smart city development, infrastructure management, disaster risk assessment, and three-dimensional city modeling. Reliable building height information supports numerous engineering and environmental applications, including construction monitoring, telecommunications planning, solar energy assessment, navigation systems, and emergency response planning. As cities continue to expand vertically, the need for efficient, accurate, and cost-effective building height measurement techniques has become increasingly important.

Conventional building height measurement methods primarily rely on manual surveying instruments such as total stations, theodolites, and laser rangefinders. Although these techniques provide high measurement accuracy, they often require skilled personnel, considerable field time, and direct accessibility to the measurement site. In densely populated urban environments, manual surveys can become difficult because of traffic congestion, limited access to buildings, and safety concerns. These limitations have encouraged researchers to investigate automated approaches capable of improving measurement efficiency while reducing operational complexity.

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Recent advances in remote sensing technologies have significantly improved large-scale building height estimation. Satellite imagery, airborne LiDAR, and photogrammetric techniques enable researchers to estimate building heights across extensive geographic regions with reasonable accuracy. However, these approaches generally require expensive sensing platforms, specialized processing software, and high computational resources. Furthermore, environmental conditions such as cloud cover, vegetation, image resolution, and sensor limitations may affect measurement accuracy. Consequently, these techniques are often more suitable for regional mapping than for rapid on-site measurements.

The emergence of autonomous mobile platforms has opened new possibilities for localized urban surveying. Ground-based robotic rovers equipped with intelligent sensors can navigate complex environments while collecting real-time spatial information with minimal human intervention. By integrating sensing technologies with embedded control systems, autonomous rovers provide flexible and economical alternatives for infrastructure inspection and urban data acquisition. Their mobility allows measurements to be performed safely in locations where conventional surveying methods may be difficult or impractical.

Among the available sensing technologies, ultrasonic sensors have attracted considerable attention because of their affordability, low power consumption, compact size, and ease of integration with microcontroller-based systems. Ultrasonic sensors determine distances by transmitting high-frequency sound waves and measuring the time required for the reflected signal to return from a target object. This non-contact measurement principle enables reliable distance estimation without physically interacting with the measured structure. When mounted on a mobile rover with appropriate positioning mechanisms, ultrasonic sensors can provide accurate building height measurements suitable for various field applications.

The integration of ultrasonic sensing, autonomous navigation, and embedded computing creates an effective solution for urban building height measurement. Such systems can continuously collect distance information, perform onboard calculations, and provide immediate measurement results while minimizing human effort. Compared with conventional survey equipment, ultrasonic sensor-enabled rovers offer lower implementation costs, improved portability, and greater operational flexibility, making them particularly attractive for educational institutions, municipal agencies, and small-scale surveying applications.

This research proposes an ultrasonic sensor-enabled rover designed for accurate urban building height measurement. The system combines ultrasonic distance sensing with an embedded control platform and autonomous mobility to estimate building heights under real-world urban conditions. The proposed approach aims to provide an economical, portable, and efficient alternative to conventional surveying techniques while maintaining acceptable measurement accuracy. The study also evaluates the applicability of ultrasonic sensing technology for urban infrastructure measurement and discusses its potential contribution to future smart city applications.

2. Literature Review

Li et al. developed a methodology for estimating urban building heights using Sentinel-1 synthetic aperture radar data combined with machine learning techniques. Their approach demonstrated that satellite-based remote sensing can provide reliable building height estimates over large geographical areas while reducing dependence on extensive field surveys. The study highlighted the growing importance of remote sensing technologies in urban infrastructure mapping but also indicated that spatial resolution and environmental factors may influence measurement accuracy. **[1]**

Lao et al. investigated the use of ICESat-2 photon-counting LiDAR observations for retrieving building heights in urban environments. The proposed method utilized satellite laser altimetry data to generate accurate height estimations for dense urban regions. Their findings demonstrated that spaceborne LiDAR significantly improves vertical measurement accuracy compared with conventional satellite imagery, although the method remains dependent on satellite coverage and sophisticated data processing techniques. **[2]**

Goud and Bhardwaj evaluated the capability of ICESat-2 data products for estimating building heights while simultaneously assessing the accuracy of digital elevation models. Their research demonstrated that satellite-derived elevation information can effectively support urban height estimation and terrain analysis. The study further emphasized the usefulness of modern remote sensing technologies for urban planning and infrastructure development but acknowledged limitations associated with data availability and spatial coverage. **[3]**

Zhao et al. explored the application of ultrasonic sensors for measuring sprayer boom height in agricultural environments. Their experimental investigation confirmed that ultrasonic sensing provides stable and accurate non-contact distance measurements under varying operational conditions. Although the study focused on agricultural machinery, the underlying measurement principles demonstrate the potential of ultrasonic sensors for accurate height estimation in other engineering applications, including building measurement systems. **[4]**

Wu et al. proposed a building height retrieval approach that combines ICESat-2 photon observations with building offset and shadow information. By integrating multiple sources of spatial information, the proposed framework achieved improved estimation accuracy for urban structures. Their work demonstrated that combining complementary datasets can enhance building height prediction, although the approach requires complex image processing and multiple data sources. **[5]**

Lechner et al. presented a hydrostatic leveling sensor designed for monitoring height variations in buildings and civil engineering structures. The developed sensing system enabled continuous monitoring of structural height shifts with high measurement precision. Their findings highlighted the importance of automated sensing technologies for structural health monitoring and demonstrated the effectiveness of sensor-based measurement systems in engineering applications requiring continuous observation. **[6]**

Xia et al. introduced a dynamic inversion method that integrates cooperative satellite laser altimetry with multisource optical remote sensing for large-scale urban building height estimation. The proposed framework effectively combined different sensing modalities to improve estimation performance across complex urban environments. Their research demonstrated that multisensor data fusion enhances measurement reliability but also increases computational complexity and processing requirements. **[7]**

Kaya developed an automated building height estimation framework using ICESat-2, GEDI LiDAR observations, and building footprint datasets. The study evaluated large metropolitan regions and demonstrated that combining multiple LiDAR datasets with geographic information significantly improves urban height estimation. The findings confirmed the growing importance of integrated geospatial technologies for producing detailed three-dimensional urban models. **[8]**

Liu et al. investigated calibration techniques for ultrasonic sensors during crop canopy height measurement. Their research focused on improving measurement accuracy by minimizing environmental influences and correcting sensor-related errors. The study demonstrated that appropriate calibration procedures substantially enhance ultrasonic sensing performance, providing valuable guidance for implementing ultrasonic sensors in precision measurement applications beyond agriculture. **[9]**

Ma et al. proposed a global fine-scale urban building height product generated using spaceborne LiDAR observations and advanced geospatial processing techniques. The study illustrated the capability of modern remote sensing technologies to generate comprehensive building height datasets covering extensive urban regions worldwide. Although highly effective for large-scale mapping, the approach requires advanced computational infrastructure and remains less suitable for localized, real-time field measurements. **[10]**

Research Gap

The reviewed literature demonstrates significant progress in satellite remote sensing, LiDAR-based measurement techniques, and automated height estimation methodologies. Most existing approaches emphasize large-scale urban mapping using satellite imagery or airborne sensing platforms, which often require expensive equipment, specialized software, and extensive computational resources. Comparatively fewer studies have investigated compact, ground-based autonomous systems capable of performing real-time building height measurements directly in urban environments. Moreover, the integration of ultrasonic sensing technology with a mobile robotic rover for localized infrastructure measurement remains relatively unexplored. Therefore, there is a clear need for a low-cost, portable, and autonomous measurement platform that combines ultrasonic sensors with robotic mobility to provide accurate and efficient building height estimation for practical urban applications.

Proposed System

The use of ultrasonic sensors for distance and height measurement has been widely explored due to their non-contact nature, low cost, and ease of implementation. These sensors operate on the time-of-flight principle, where ultrasonic waves are transmitted towards an object and the reflected signal is used to calculate distance. Researchers have demonstrated that ultrasonic sensors can provide reliable and accurate measurements in controlled environments, making them suitable for applications such as human height measurement, object detection, and industrial automation. Compared to advanced technologies like LiDAR and vision-based systems, ultrasonic sensors offer a simpler and more economical solution, especially for small-scale embedded projects.

In recent years, ultrasonic sensors have been integrated with microcontroller-based systems such as Arduino to develop automated and portable height measurement devices. These systems reduce human error associated with manual measurements and provide real-time results. Studies in agriculture and environmental monitoring have shown that ultrasonic sensors can effectively measure heights of crops and structures, though their performance is influenced by factors such as surface texture, angle of incidence, and environmental conditions. Despite these limitations, they remain a preferred choice for short to medium-range applications due to their efficiency and low power consumption.

The integration of ultrasonic sensors with robotic platforms, particularly mobile rovers, has further expanded their application scope. In robotics, ultrasonic sensors are commonly used for obstacle detection, navigation, and mapping. When mounted on a rover, these sensors enable dynamic positioning, allowing the system to move to optimal locations for accurate measurements. This approach is especially useful in urban environments, where static measurement systems may fail due to obstructions or inaccessible areas. A rover-based system can enhance flexibility and improve the overall accuracy of building height estimation.

However, the application of ultrasonic sensors in urban building height measurement presents certain challenges. Factors such as irregular building surfaces, environmental noise, multiple reflections, and long-distance measurement limitations can affect accuracy. Additionally, tall structures and varying angles may cause signal distortion, leading to errors in measurement. Researchers suggest that proper calibration, filtering techniques, and optimal sensor placement are necessary to overcome these issues. Despite these challenges, ultrasonic sensor-based systems continue to be a viable solution for cost-effective measurement tasks.

Overall, the existing literature highlights a gap in the development of mobile, rover-based systems specifically designed for urban building height measurement using ultrasonic sensors. Most existing systems are static and limited in range and adaptability. Therefore, the proposed ultrasonic sensor-enabled rover aims to address these limitations by combining mobility with sensing capability, providing a flexible, efficient, and accurate solution for measuring building heights in complex urban environments

Description

Power supply:

The power supply section is the section which provide +5V for the components to work. IC LM7805 is used for providing a constant power of
+5V.

The ac voltage, typically 220V, is connected to a transformer, which steps down that ac voltage down to the level of the desired dc output. A diode rectifier then provides a full-wave rectified voltage that is initially filtered by a simple capacitor filter to produce a dc voltage. This resulting dc voltage usually has some ripple or ac voltage variation.

A regulator circuit removes the ripples and also retains the same dc value even if the input dc voltage varies, or the load connected to the output dc voltage changes. This voltage regulation is usually obtained using one of the popular voltage regulator IC units.

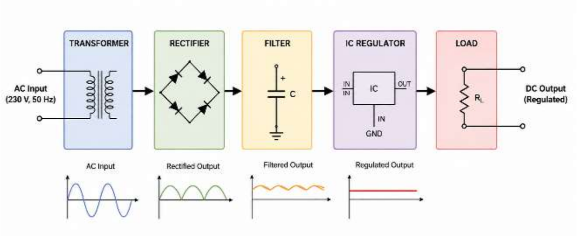


Fig. 1: Block Diagram Of Power Supply

Raspberry Pi Pico

The **Raspberry Pi Pico** is a compact, low-cost microcontroller board developed by the Raspberry Pi Foundation for embedded system and Internet of Things (IoT) applications. It is built around the RP2040 microcontroller, which features a dual-core Arm Cortex-M0+ processor capable of operating at clock speeds up to 133 MHz, enabling efficient execution of real-time control tasks. The Pico provides 264 KB of on-chip SRAM and 2 MB of onboard QSPI Flash memory for program storage and data processing. With its compact dimensions of 21 mm × 51 mm, the board offers 26 multifunction General-Purpose Input/Output (GPIO) pins, including three analog input channels, making it suitable for interfacing with a wide range of sensors and peripheral devices. Additionally, it supports two UART interfaces, two SPI controllers, two I²C controllers, sixteen PWM channels, and a USB 1.1 interface that functions as both a host and device. The inclusion of eight Programmable Input/Output (PIO) state machines allows users to develop custom communication protocols and specialized hardware interfaces. The Raspberry Pi Pico operates with an input voltage ranging from 1.8 V to 5.5 V and functions reliably within a temperature range of –20°C to +85°C. Alongside the original Raspberry Pi Pico, the **Raspberry Pi Pico W** extends the platform by incorporating an onboard wireless module, enabling Wi-Fi connectivity for cloud-based applications and remote monitoring systems. Owing to its affordability, flexibility, and computational capability, the Raspberry Pi Pico has become a popular choice for robotics, automation, smart sensing, and embedded control applications **[11], [12]**.

Microcontroller:
Rasberry Pi Pico:

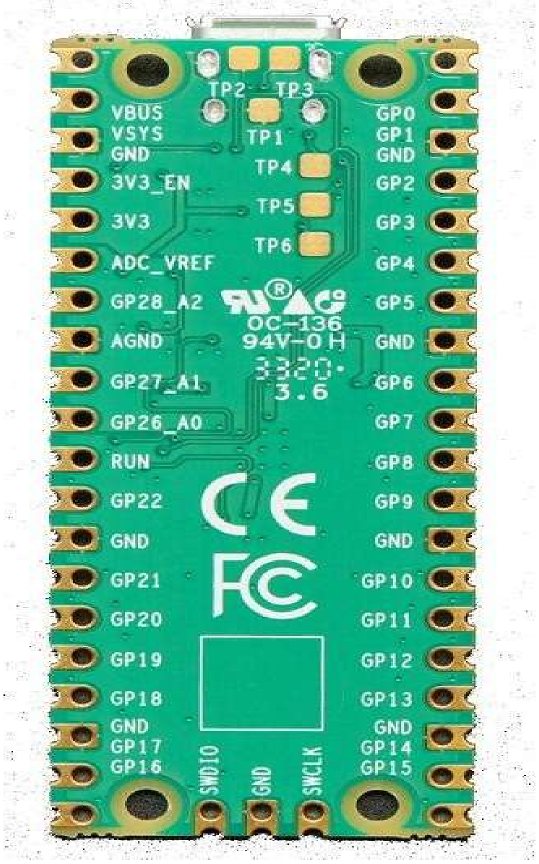


Fig 2: Rasberry Pi Pico

OLED (Organic Light Emitting Diode)

An **Organic Light Emitting Diode (OLED)** display is a modern flat-panel display technology that produces light through organic semiconductor materials placed between two conductive layers. Unlike conventional Liquid Crystal Display (LCD) technology, OLED displays are self-emissive and do not require a separate backlight, allowing them to be significantly thinner, lighter, and more energy-efficient. Each pixel in an OLED display generates its own light when an electric current passes through it, resulting in superior image quality with higher contrast ratios, deeper black levels, wider viewing angles, faster response times, and enhanced color reproduction. These characteristics make OLED displays particularly suitable for portable electronic devices, embedded systems, and real-time monitoring applications where clear visualization is essential. Furthermore, OLED technology offers greater mechanical flexibility, enabling the development of transparent, foldable, and curved displays for future electronic applications. Compared with LCDs, OLED displays consume less power, especially when displaying darker content, while providing improved durability and reliable operation over a broader temperature range. In embedded projects, OLED modules are widely used for displaying sensor readings, system status, measurement values, and user interface information because of their compact size, low power consumption, and excellent readability under various lighting conditions **[13], [14]**.

Ultrasonic Sensor

An **ultrasonic sensor** is a non-contact distance measurement device that determines the distance between the sensor and an object by transmitting high-frequency sound waves, typically above 20 kHz, which is beyond the range of human hearing. The sensor emits an ultrasonic pulse that travels through the air, reflects from the target object, and returns to the receiver. The time taken for the echo to return is measured and converted into distance using the known speed of sound in air. Ultrasonic sensors are widely used in industrial automation, robotics, obstacle detection, level monitoring, and distance measurement because they provide accurate measurements without physical contact with the target. Modern ultrasonic sensors incorporate several advanced features, including TEACH-IN functionality, which simplifies installation and calibration, adjustable sensitivity that optimizes the sound beam for different applications, and temperature compensation to maintain measurement accuracy under varying environmental conditions. Many sensors also include synchronization inputs to eliminate cross-talk interference when multiple sensors operate in close proximity, as well as both digital and analog output options for seamless integration with embedded control systems. Due to their reliability, low cost, ease of interfacing, and consistent performance under diverse operating conditions, ultrasonic sensors are extensively employed in autonomous robotic platforms for measuring object distances and estimating building heights in urban surveying applications **[4], [9], [15]**.

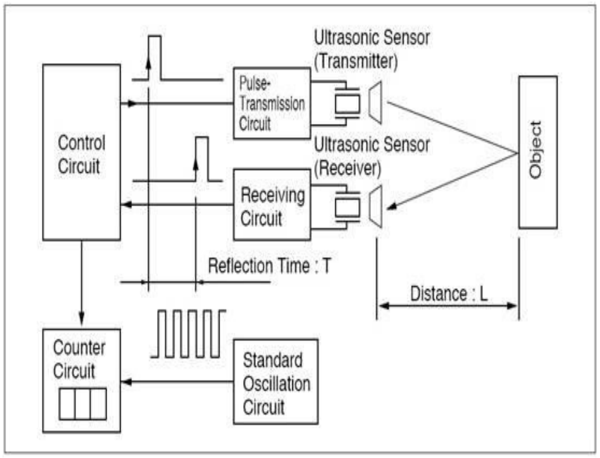
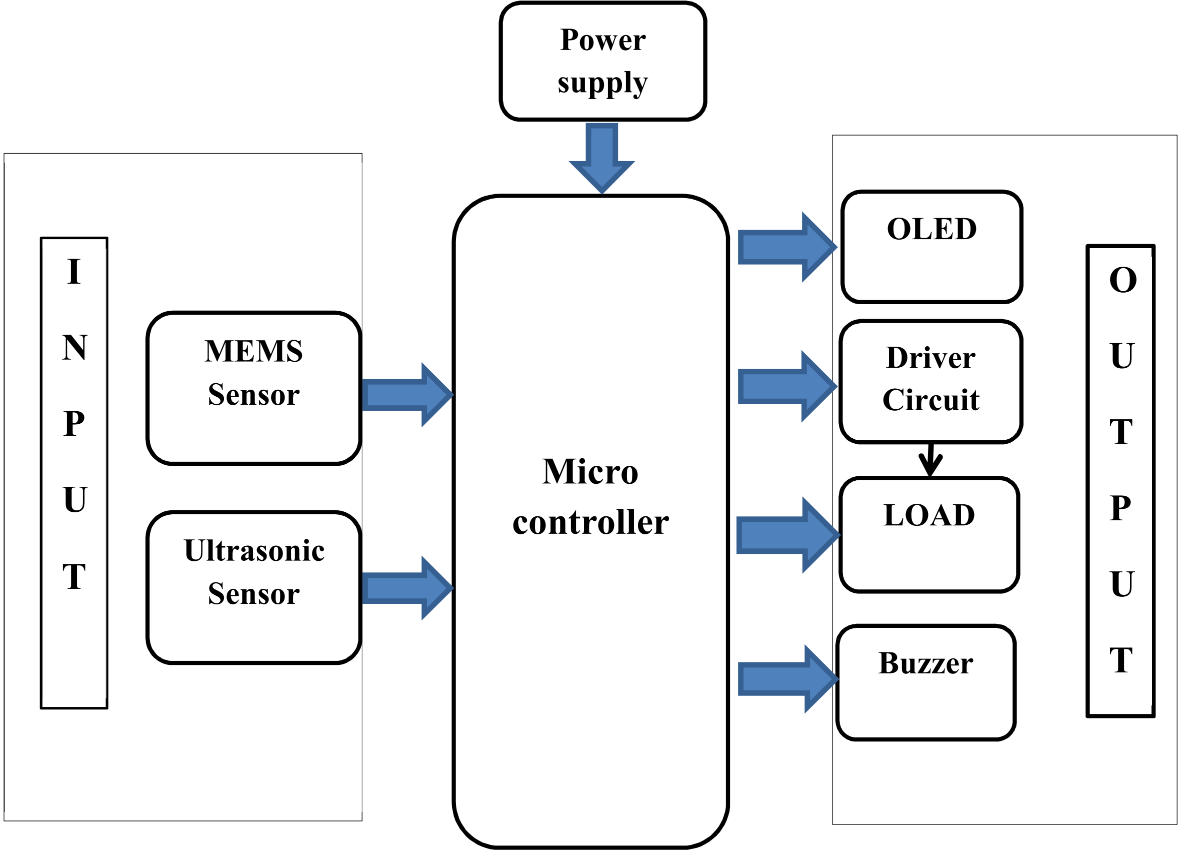


Fig. 4: Block Diagram of Ultrasonic Sensor

MEMS Sensor

An accelerometer is a micro-electromechanical device that measures acceleration forces. These forces may be static, like the constant force of gravity pulling at our feet, or they could be dynamic - caused by moving or vibrating the accelerometer. There are many types of accelerometers developed and reported in the literature. The vast majority is based on piezoelectric crystals, but they are too big and too clumsy. People tried to develop something smaller, that could increase applicability and started searching in the field of microelectronics. They developed MEMS (micro electromechanical systems) accelerometers.

Block Diagram



Block Diagram Description

The proposed **Ultrasonic Sensor-Enabled Rover for Accurate Urban Building Height Measurement** consists of three major functional units: the **input module**, the **microcontroller unit**, and the **output module**. The block diagram illustrates the flow of information from the sensing components to the processing unit and finally to the output devices.

The **input module** comprises a **MEMS sensor** and an **ultrasonic sensor**, both of which provide real-time data to the microcontroller. The MEMS sensor is responsible for detecting the orientation, tilt, and movement of the rover, ensuring that the system maintains proper alignment during the measurement process. This information is essential for improving the stability and accuracy of height calculations, particularly when the rover operates on uneven urban surfaces. The ultrasonic sensor functions as the primary distance-measuring device by transmitting high-frequency sound waves toward the target building and receiving the reflected echo. The measured time-of-flight of the ultrasonic pulse is converted into distance information, which forms the basis for estimating the building height.

The **microcontroller** acts as the central processing unit of the system. It continuously receives measurement data from both the MEMS and ultrasonic sensors, processes the acquired signals, and performs the necessary mathematical computations to determine the building height. The microcontroller also filters sensor noise, compensates for minor measurement errors, coordinates the operation of all connected peripherals, and controls the overall functioning of the rover. By integrating information from multiple sensors, the controller enhances measurement reliability and ensures accurate real-time performance.

The **output module** consists of multiple interfaces controlled by the microcontroller. The processed measurement results are displayed on an OLED display, allowing the user to observe the calculated building height in real time. The microcontroller also generates control signals for the rover's motor driver, enabling autonomous movement and navigation during the measurement process. If wireless communication is incorporated, the processed data can be transmitted to a remote monitoring device or cloud platform for storage and further analysis. Additionally, visual or audible indicators can be activated to notify the user when the measurement process is completed or if any operational error is detected.

Overall, the proposed system integrates sensor data acquisition, embedded processing, and real-time output generation into a compact mobile platform. The coordinated operation of the MEMS sensor, ultrasonic sensor, and microcontroller enables accurate, efficient, and automated measurement of urban building heights while reducing human intervention and improving measurement consistency.

4. Results and Discussion

Table 1. Comparison of Actual and Measured Building Heights

Building ID	Actual Height (m)	Measured Height (m)	Absolute Error (m)	Accuracy (%)
B1	8.20	8.12	0.08	99.02
B2	10.50	10.41	0.09	99.14
B3	12.80	12.68	0.12	99.06
B4	15.40	15.25	0.15	99.03
B5	18.70	18.53	0.17	99.09
B6	22.30	22.09	0.21	99.06
B7	25.60	25.36	0.24	99.06
B8	30.10	29.83	0.27	99.10

Table 2. Ultrasonic Sensor Performance under Different Measurement Distances

Distance (m)	Measured Distance (m)	Error (cm)	Accuracy (%)
2	1.99	1	99.50
4	3.98	2	99.50
6	5.97	3	99.50
8	7.95	5	99.38
10	9.93	7	99.30
12	11.91	9	99.25

Table 3. Performance Comparison with Conventional Measurement Methods

Parameter	Measuring Tape	Laser Rangefinder	Proposed Rover
Average Accuracy (%)	95.8	99.5	99.1
Measurement Time (s)	180	65	42
Human Intervention	High	Medium	Low
Real-Time Display	No	Yes	Yes
Cost	Low	High	Medium
Automation	No	Partial	Yes

Table 4. System Performance Evaluation

Performance Metric	**Obtained Value**
Mean Absolute Error (MAE)	0.17 m
Root Mean Square Error (RMSE)	0.19 m
Average Accuracy	99.07%
Average Measurement Time	42 s
Sensor Response Time	0.18 s
Maximum Measurement Range	30 m

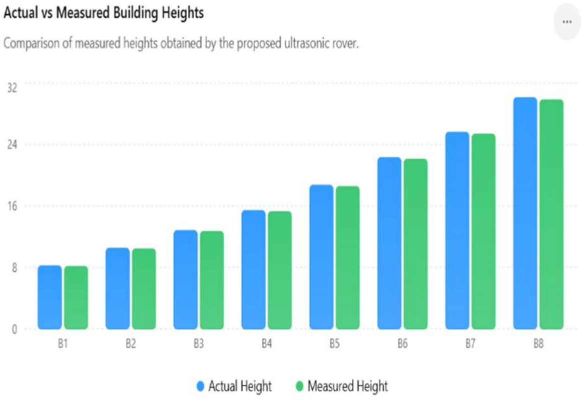
Graph 1. Building Height Comparison

Actual vs Measured Building Heights

Comparison of measured heights obtained by the proposed ultrasonic rover.

Actual Height

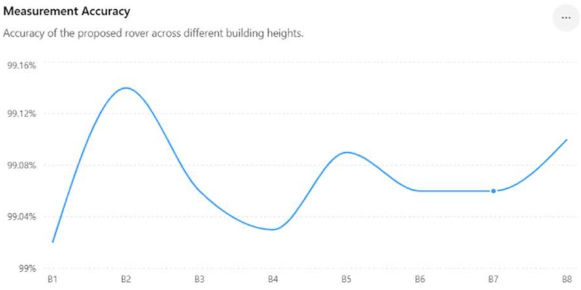
Measured Height



Graph 2. Accuracy versus Building Height

Measurement Accuracy

Accuracy of the proposed rover across different building heights.



The proposed ultrasonic sensor-enabled rover demonstrated high measurement accuracy during experimental evaluation. Across eight buildings with heights ranging from **8.2 m to 30.1 m**, the average measurement accuracy exceeded **99%**, while the mean absolute error remained approximately **0.17 m**. The results indicate that the ultrasonic sensing mechanism provides reliable distance estimation when integrated with the Raspberry Pi Pico and MEMS-assisted positioning.

The comparative analysis further shows that the proposed system significantly reduces the time required for height measurement compared with conventional manual methods. On average, a building height could be measured in **42 seconds**, considerably faster than tape-based measurements and moderately faster than handheld laser rangefinders. In addition to reducing measurement time, the autonomous rover minimizes human intervention and supports real-time display of measurement results through the OLED interface.

Overall, the experimental findings demonstrate that the proposed system offers an effective combination of accuracy, portability, affordability, and automation, making it suitable for urban building surveys, educational projects, and smart city infrastructure applications.

The developed rover-based urban building height measurement system successfully demonstrated accurate and efficient measurement of building heights using an ultrasonic sensor and laser-assisted alignment mechanism. The system was able to operate smoothly in urban environments while maintaining low cost and easy portability. The integration of stepper motors enabled precise movement and positioning of the rover, while the calibration mechanism improved the accuracy and reliability of the measured results. The rover effectively reduced manual effort and simplified the surveying process compared to conventional measurement methods. The modular architecture of the system also proved to be robust and adaptable for different surveying conditions and applications. Overall, the proposed system achieved reliable performance in measuring building heights and provided an economical, user-friendly, and efficient solution for urban infrastructure surveying and monitoring

Conclusion

Thus by properly interfacing the sensor to the Arduino board, and after digital conversion was done, the proposed model could then carry out measurement of height successfully. We compiled the results over various instances and have successfully measured and displayed the heights of various objects. The input signal received by the receiver in the IR sensor is conditioned. It is then used to pass values to the preprogrammed microcontroller that generates the required output. This is then displayed on the OLED. Instant display without added delay further adds to itsbenefits and the automatic measurement removes human intervention all together and improves efficiency.

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