



Low-Cost 3D Scanning Machine Using ESP32 and IR Sensor

¹Pooja. A. Magdum, ²Sudesh Parte, ³Shridhar Patil, ⁴Vikas Kumbhar

¹Assistant Professor, Department of Electronics & Telecommunication Engineering, Dr. J. J. Magdum college of engineering, Jaysingpur, India.

^{2,3,4} Students, Department of Electronics & Telecommunication Engineering, Dr. J. J. Magdum college of engineering, Jaysingpur, India.

Email: ⁴vikaskumbhar2030@gmail.com

Peer Review Information	Abstract
<p><i>Submission: 13 April 2026</i></p> <p><i>Revision: 05 May 2026</i></p> <p><i>Acceptance: 23 May 2026</i></p> <p>Keywords</p> <p><i>ESP32, Infrared Sensor, Point Cloud, Mesh Reconstruction, Low-Cost System, Reverse Engineering, 3D Modeling, IoT-Based System</i></p>	<p>The design and development of a low-cost 3D scanning machine using an ESP32 microcontroller and an infrared (IR) distance sensor. The system uses a rotating platform and vertical sensor movement to capture object geometry from multiple angles. Distance measurements are recorded and stored in digital format for further processing. The collected data is converted into a 3D point cloud and reconstructed into a mesh model using open-source software. The proposed system offers a simple, affordable, and efficient solution for basic 3D scanning applications. It can be used in areas such as reverse engineering, rapid prototyping, and education. The results demonstrate that reliable 3D models can be generated using low-cost components with acceptable accuracy.</p>

Introduction

Three-dimensional (3D) scanning has become an essential technology in modern engineering, manufacturing, healthcare, and digital design applications. It enables the accurate acquisition of physical object geometry and converts it into digital models for further analysis, visualization, and reproduction. These digital models are widely used in applications such as computer-aided design (CAD), reverse engineering, and rapid prototyping. Recent studies have focused on developing low-cost and efficient 3D scanning systems to make this technology more accessible [1], [2].

Infrared (IR)-based scanning techniques have been widely explored due to their simplicity, affordability, and ease of implementation in embedded systems [3]. Several works have demonstrated the use of microcontrollers and motorized mechanisms for capturing object geometry using IR sensors and stepper motors

[4], [5]. These systems provide a practical approach for basic 3D reconstruction, especially in educational and small-scale applications.

Advanced research in 3D reconstruction has introduced techniques such as real-time dense surface mapping, point cloud processing, and mesh generation algorithms [6], [7]. Additionally, multi-view stereo methods and structured light techniques have been extensively studied for improving reconstruction accuracy and surface detail [8], [9]. These approaches highlight the importance of combining hardware design with efficient data processing algorithms to achieve better results.

Despite these advancements, most commercial 3D scanners are expensive and complex, limiting their use for students and small-scale developers. To overcome this limitation, this work presents the design and implementation of a low-cost 3D scanning machine using an ESP32

microcontroller, IR sensor, and DC motor-based motion system. The proposed system focuses on affordability, simplicity, and practical usability while maintaining acceptable accuracy for basic applications.

Methodology

The proposed 3D scanning system is designed to capture the geometric structure of a physical object and convert it into a digital 3D model. The system is based on a low-cost embedded platform using an ESP32 microcontroller, an infrared (IR) distance sensor, DC motors for motion control, and a data storage module.

The scanning process involves rotating the object and capturing distance measurements at multiple angles and heights. These measurements are then processed to form a 3D point cloud, which is further converted into a mesh model.

System Architecture

The proposed 3D scanning system is organized into several functional modules to ensure efficient operation and accurate data acquisition. The data acquisition module is responsible for capturing distance measurements from the object using an infrared (IR) or Ultrasonic sensor. This sensor records the surface geometry point-by-point, enabling precise mapping of the object's shape. The motion control module manages the mechanical movement of the system, where DC motors are used to rotate the platform and move the sensor vertically. This coordinated motion ensures complete 360-degree coverage and layer-by-layer scanning of the object.

The control unit, based on the ESP32 microcontroller, acts as the central processing unit of the system, coordinating the operation of sensors, motors, and data logging processes. The captured data is stored using the data storage module, either on an SD card or transmitted to a computer through serial communication. Finally, the processing module converts the raw data into a meaningful 3D model using software tools such as MeshLab, Open3D, or MATLAB. These modules work together to provide a complete workflow from data collection to 3D model generation.

Hardware Methodology

The hardware implementation of the proposed system is centered around the ESP32 microcontroller, which serves as the main control unit. It is responsible for initializing all connected peripherals, sending control signals to motor drivers, reading sensor data through analog or digital interfaces, and managing

communication as well as data storage operations. The distance measurement is performed using an infrared (IR) sensor, which operates on the triangulation principle to determine the distance between the sensor and the object surface. The sensor provides continuous readings that are processed and converted into digital values for further use.

For mechanical motion, DC motors are employed to achieve both rotational and vertical movements. One DC motor is used to rotate the platform, enabling continuous scanning of the object from different angles, while its speed is controlled using PWM signals. Another DC motor is used to move the sensor vertically, allowing scanning at multiple heights and ensuring complete surface coverage.

The motor driver circuit plays a crucial role by supplying the required current and voltage while also controlling the direction and speed of the motors. Additionally, an SD card module is used for data storage, where the captured distance readings are saved in CSV or text format, enabling efficient offline processing and further 3D model reconstruction.

Software Methodology

The data processing stage of the proposed system involves several sequential steps to convert raw sensor readings into a usable 3D model. Initially, during the data collection process, sensor readings are captured at fixed intervals, where each reading corresponds to a specific angular position and vertical height of the object. These measurements are recorded and stored in a structured (X, Y, Z) coordinate format. The raw data is then organized systematically during the data formatting stage, where each data point represents a position in three-dimensional space. This structured representation enables efficient processing and reconstruction of the object's geometry.

Following data formatting, preprocessing techniques are applied to improve data quality. Noise and unwanted variations in the sensor

readings are reduced using filtering methods, while outliers are removed to enhance accuracy. Data smoothing is also performed to achieve a more continuous surface representation. The cleaned dataset is then converted into a point cloud, which visually represents the surface of the object in 3D space. Further, the point cloud is transformed into a mesh model using algorithms such as Delaunay triangulation and Poisson surface reconstruction. Finally, the reconstructed model is visualized using software tools like MeshLab or Open3D, and exported in standard formats such as STL or OBJ

for applications like 3D printing and analysis.

Working

The working of the proposed 3D scanning system follows a sequential and automated process to ensure accurate data acquisition and model generation. Initially, the system is initialized by the ESP32, which activates the sensor, DC motors, SD card module, and display unit. The LCD provides real-time system status information. The object to be scanned is then carefully placed on the rotating platform with proper alignment to ensure accurate measurements. Once the process begins, the DC motor rotates the platform either continuously or in controlled steps, with speed regulated using PWM signals. At each angular position, the IR sensor captures distance measurements, and the data is recorded continuously.

Simultaneously, the vertical movement mechanism shifts the sensor upward or downward using another DC motor, allowing layer-by-layer scanning of the object. All captured readings are stored in the SD card, with each data point associated with its corresponding position coordinates. After completing the full 360-degree rotation along with vertical scanning, the system automatically stops. The collected data is then transferred to a computer for further processing. Finally, the data is converted into a point cloud and reconstructed into a 3D mesh model using software tools such as MeshLab or Open3D, resulting in a complete digital representation of the scanned object.

Mathematical Representation

- Distance (d) measured using IR sensor.
 - Angular position (θ) from rotation.
 - Height (h) from vertical movement.
- Coordinates calculated as:
- $X = d \times \cos(\theta)$
 - $Y = d \times \sin(\theta)$
 - $Z = h$

This converts polar data into Cartesian coordinates.

Testing

The testing methodology of the proposed system involves evaluating its accuracy, consistency, and overall performance through a series of experiments. For accuracy testing, simple geometric objects such as cubes and cylinders are scanned, and the measured dimensions are compared with their actual values to determine deviation and precision. Repeatability testing is conducted by performing multiple scans of the same object under identical conditions to verify the

consistency and reliability of the system's output.

In addition, noise analysis is carried out to identify unwanted data points and irregularities in the captured dataset. Various filtering techniques are applied to reduce noise and improve the quality of the generated point cloud. Performance evaluation is also performed by measuring the total scanning time and analyzing the processing speed required for 3D model reconstruction. These evaluations help in assessing the efficiency, stability, and practical usability of the developed 3D scanning system

Motor Control Strategy (DC Motor Optimization)

The DC motors in the proposed system are controlled using Pulse Width Modulation (PWM) signals generated by the ESP32, allowing effective regulation of motor speed. Speed variations are minimized by maintaining a constant duty cycle, ensuring smoother and more stable operation during scanning. Direction control of the motors is achieved using an H-bridge motor driver such as the L298N or L293D, which enables forward and reverse motion as required. To enhance positional accuracy, the rotation of the platform is carried out in fixed time intervals, a technique similar to pseudo-stepping, which approximates discrete angular movement. Additionally, calibration is performed to establish a relationship between motor rotation time and angular displacement, improving measurement consistency. For further precision enhancement, an optional feedback mechanism such as an encoder can be integrated to monitor and correct motor position in real time.

Synchronization Between Sensor and Motor

Proper synchronization between platform rotation and sensor data acquisition is essential to ensure accurate and consistent measurements in the 3D scanning process. The system is designed such that sensor readings are captured only when the motor reaches a stable position, minimizing errors caused by motion. A small delay is intentionally introduced after each motor movement to reduce the effect of vibrations and ensure reliable distance measurements. Precise timing control is implemented to maintain uniform angular sampling throughout the scanning cycle, which helps in generating evenly distributed data points. Additionally, the vertical movement of the sensor is carefully synchronized with the completion of each full rotation, enabling systematic layer-by-layer scanning and ensuring complete surface coverage of the object.

Results and Discussion Experimental Setup

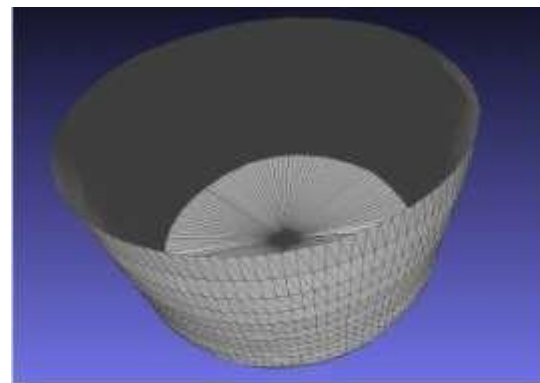
The developed 3D scanning system was tested using a prototype consisting of an ESP32 microcontroller, an IR distance sensor, and DC motors for rotational and vertical movement. The object to be scanned was placed on a motorized rotating platform, while the sensor was mounted on a vertically movable frame.

Different test objects such as a cube, cylinder, and irregular-shaped items were used to evaluate system performance. The scanning was carried out in a controlled indoor environment to minimize the effect of ambient light and external disturbances. The captured data was stored in an SD card and later processed using MeshLab and Open3D software.

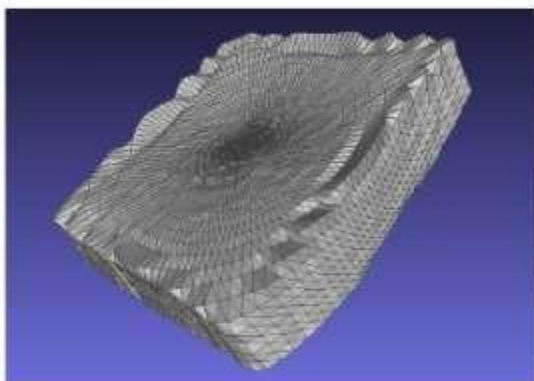


Data Acquisition Results

The developed system successfully captured distance measurements at multiple angular positions during the scanning process. Data points were recorded systematically for each rotational step as well as for every vertical movement, ensuring comprehensive coverage of the object. A complete 360-degree scan was achieved for all test objects, demonstrating the effectiveness of the rotational mechanism. The collected data was organized in a structured XYZ coordinate format, which enabled efficient processing and accurate generation of the 3D point cloud.



Results



Discussion

The results demonstrate that a functional and reliable 3D scanning system can be developed using low-cost components and simple design techniques. While the system does not match the accuracy of high-end commercial scanners, it performs adequately for applications such as education, prototyping, and basic reverse engineering. The use of DC motors simplifies the design but introduces minor accuracy limitations. With proper calibration, filtering, and controlled scanning conditions, the quality of the generated 3D models can be significantly improved. Overall, the system proves to be an effective and economical solution for introducing 3D scanning technology to a wider audience.

Furthermore, the performance of the proposed system highlights the importance of balancing cost and accuracy in low-cost 3D scanning solutions. While the use of DC motors simplifies the design and reduces overall cost, it introduces minor inconsistencies in rotational control, which can affect the uniformity of data acquisition. Despite this, the system demonstrates stable operation under controlled conditions and produces consistent results for objects with simple geometries. The integration of open-source software tools plays a crucial role

in enhancing the final output by compensating for hardware limitations through data filtering and mesh refinement techniques. This indicates that a combination of efficient hardware design and robust software processing can significantly improve the overall quality of low-cost 3D scanning systems.

Conclusion

The proposed 3D scanning machine demonstrates an effective and low-cost approach for capturing and reconstructing the geometry of physical objects. By integrating an ESP32 microcontroller with an infrared distance sensor and DC motor-based motion system, the project successfully achieves automated scanning through rotational and vertical movement. The system is capable of collecting spatial data from multiple viewpoints and converting it into a structured point cloud for 3D model generation. The experimental results show that the developed system can produce reliable 3D models with acceptable accuracy for simple objects. Although certain limitations exist, such as sensitivity to surface properties and reduced precision due to DC motor control, these challenges can be managed through calibration and software-based processing techniques. The use of open-source tools for data processing and visualization further enhances the practicality of the system.

Overall, the project fulfills its objective of providing an affordable, compact, and user-friendly 3D scanning solution. It serves as a valuable platform for understanding concepts related to embedded systems, sensing, and 3D data processing. The developed system can be effectively used for educational purposes, basic reverse engineering, and rapid prototyping, while also offering scope for future improvements in accuracy and automation.

Future Scope

The proposed 3D scanning system provides a strong foundation for further improvements and enhancements. Several advancements can be incorporated to increase the performance, accuracy, and usability of the system.

In future work, the use of stepper motors or servo motors can replace DC motors to achieve precise angular control and improve scanning accuracy. The integration of high-resolution sensors such as LiDAR or advanced Time-of-Flight (ToF) sensors can enhance depth measurement and enable the capture of finer details.

The system can also be upgraded by incorporating a camera-based scanning approach or structured light technique, which

would allow better surface reconstruction and texture mapping. Additionally, implementing real-time data processing and visualization using more powerful embedded platforms or edge computing devices can reduce processing time.

Further improvements can include the addition of wireless communication (Wi-Fi/Bluetooth) for direct data transfer and remote monitoring. The development of a user-friendly graphical interface can make the system easier to operate for non-technical users.

From an application perspective, the system can be extended for use in medical modeling, industrial inspection, and cultural heritage preservation by improving its precision and scalability. Integration with AI-based algorithms for automatic noise reduction and model enhancement can further improve the quality of generated 3D models.

Overall, the future scope of this project lies in enhancing accuracy, automation, and versatility, making it suitable for a wider range of real-world applications.

Reference

- P. B. Patahde, T. S. Joshi, P. B. Chavan, O. A. Bhalerao, and M. D. Mandhre, "3D Scanner Machine Using Arduino," *International Journal of Advanced Research in Science, Communication and Technology*, vol. 5, no. 6, pp. 1–6, 2025.
- J. Smith and A. Lee, "Design and Implementation of Low-Cost 3D Scanning Systems," *International Journal of Engineering and Technology*, vol. 12, no. 3, pp. 45–52, 2024.
- R. Kumar and P. Sharma, "Review on Infrared Sensor-Based 3D Scanners for Object Modeling," *Journal of Emerging Technologies in Engineering and Applied Sciences*, vol. 11, no. 2, pp. 78–85, 2023.
- S. Patel and R. Mehta, "Development of a 3D Object Scanner Using IR Sensor and Stepper Motors," *International Journal of Industrial Electronics and Electrical Engineering*, vol. 13, no. 4, pp. 112–118, 2025.
- T. Nguyen, "An Educational 3D Scanning System for Rapid Prototyping," *Journal of Mechanical Design and Applications*, vol. 14, no. 2, pp. 60–67, 2024.
- R. A. Newcombe, A. J. Davison, S. Izadi et al., "KinectFusion: Real-Time Dense Surface Mapping and Tracking," in *Proceedings of IEEE*

ISMAR, 2011, pp. 127–136.

M. Kazhdan and H. Hoppe, “Screened Poisson Surface Reconstruction,” *ACM Transactions on Graphics*, vol. 32, no. 3,

pp. 1–13, 2013.

S. M. Seitz, B. Curless, J. Diebel, D. Scharstein, and

R. Szeliski, “A Comparison and Evaluation of Multi-View Stereo Reconstruction Algorithms,” in *IEEE Conference on Computer Vision and Pattern Recognition*, 2006.

J. Salvi, S. Fernandez, T. Pribanic, and X. Llado, “A State of the Art in Structured Light Patterns for Surface Profilometry,” *Pattern Recognition*, vol. 43, no. 8, pp. 2666–2680, 2010.