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Raspberry Pi based 3D scanner for object Reconstruction.

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ABSTRACT :

This paper presents a low-cost, open-source 3D scanning system utilizing a Rasberry Pi and Pi camera. Our system combines structured light scanning and computer vision techniques to reconstruct high-quality 3D models of objects. The proposed system consists of a Raspberry Pi, Pi Camera, and a line laser, which projects vertical line on object The camera captures images of the object under different lighting conditions, and the Raspberry Pi processes these images to generate a 3D point cloud. To test the scanner, objects of different shapes and textures were scanned and compared with reference 3D models. The results show that this system is a budget-friendly alternative to commercial 3D scanners, suitable for small-to-medium-sized objects. It can be used in education, prototyping, and low-cost industrial applications. We evaluate our 3D scanners performance using various metrics and demonstrate its accuracy and robustness in reconstructing complex objects. With low cost our 3D scanner offers a cost-effective alternative to commercial 3D scanners, making 3D scanning accessible to a broader audience.

Keywords: Rasberry Pi, Low cost, Object Reconstruction, 3D Scanning, computer vision, open source etc…

1. INTRODUCTION :

Three-dimensional (3D) scanning has become an essential tool in various fields, including computer-aided design (CAD), 3D printing, and cultural heritage preservation. However, commercial 3D scanners are often expensive and inaccessible to individuals and small organizations. Traditional 3D scanners are often expensive, making them less accessible for small businesses, educational institutions, and individual researchers. To address this issue, this paper presents a low-cost Raspberry Pi-based 3D scanner that can efficiently scan objects and generate accurate 3D models. To overcome this limitation, we developed a low-cost, Raspberry Pi-based 3D scanner. The scanning process includes several steps:
Image Acquisition – The camera captures images of the object from multiple perspectives.
Point Cloud Generation – The depth information is extracted from images and converted into a 3D point cloud.[2]
Mesh Reconstruction – The point cloud is processed, cleaned, and aligned to generate a 3D model. Leveraging the Raspberry Pi's computational capabilities and the Pi Camera's high-resolution imaging, enables accurate object reconstruction through structured light scanning and computer vision techniques also this paper outlines the development and implementation of the Raspberry Pi 3D scanner, highlighting its hardware and software configuration, system performance, and potential advancements, providing a scalable alternative to traditional 3D scanning systems. This study demonstrates that embedded computing with Raspberry Pi can be effectively employed for real-time 3D reconstruction. Future improvements may include higher-resolution cameras, enhanced depth estimation techniques, and AI-based algorithms for better accuracy and automation. [3]A mathematical approach is employed to optimize the accuracy, resolution, and efficiency of the scanner. To validate its performance, multiple objects of different shapes and textures are scanned and compared with reference 3D models. The results show that the Raspberry Pi-based scanner offers a cost-effective alternative to commercial scanners, making it suitable for small-scale applications in education, prototyping, and industrial use. The findings indicate that this low-cost 3D scanner provides an effective alternative for small-scale applications in education, prototyping, and industrial design.[7]

Nomenclature :

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1.1. PROPOSED MODEL

The proposed work can be used by both small- and large-scale application purpose. A Raspberry Pi-based 3D scanner for object reconstruction utilizes a turntable, Pi Camera, and a line laser to capture multiple images of an object, which are later processed to create a 3D model. The scanner works by placing the object on the turntable, which rotates the object in increments (usually 90 degrees) for complete 360-degree coverage. As the object rotates, the Pi Camera captures images from different angles, while the line laser projects straight lines on the object's surface. [1] The laser enhances the surface detail by creating visible contours.

The captured images are then processed using various software tools to convert 2D images into a 3D model. The initial step involves identifying the key features and contours from the images. These images are then stitched together to create a 3D point cloud, which represents the object's surface.

To convert the point cloud into a 3D model, the data is processed into an STL (Stereolithography) file, a widely used format for 3D printing. Finally, the STL file is refined and reconstructed into a detailed 3D mesh using MeshLab, an open-source tool for editing and processing 3D models. Depth information is extracted from multiple images using stereo vision or structured light techniques. A 3D point cloud is generated, representing the object's surface geometry. [3]

The point cloud undergoes alignment, filtering, and noise removal to refine the data. Using MeshLab, the processed point cloud is converted into a 3D mesh through triangulation. This project provides an affordable and flexible solution for creating high-resolution 3D scans, leveraging the Raspberry Pi's versatility and the precision of the Pi Camera and line laser setup. The resulting 3D models can be used for various applications, including digital archiving, reverse engineering, and 3D printing.[6]

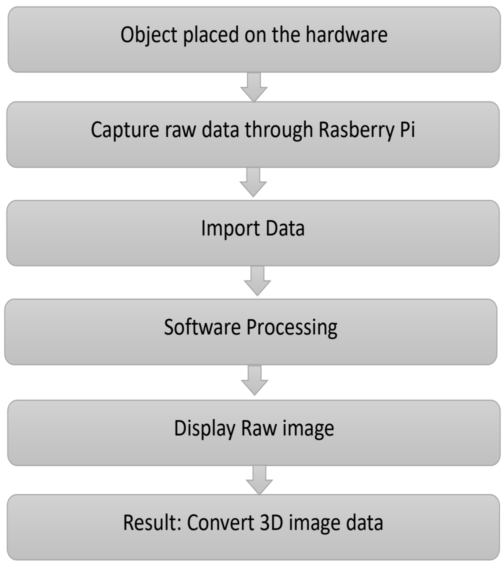


Fig. 1 - Process flow block diagram of proposed module

1.2. Methodology

The proposed system consists of hardware and software both. The methodology outlines the system design, calibration, data acquisition, and 3D reconstruction processes.

Hardware Components includes

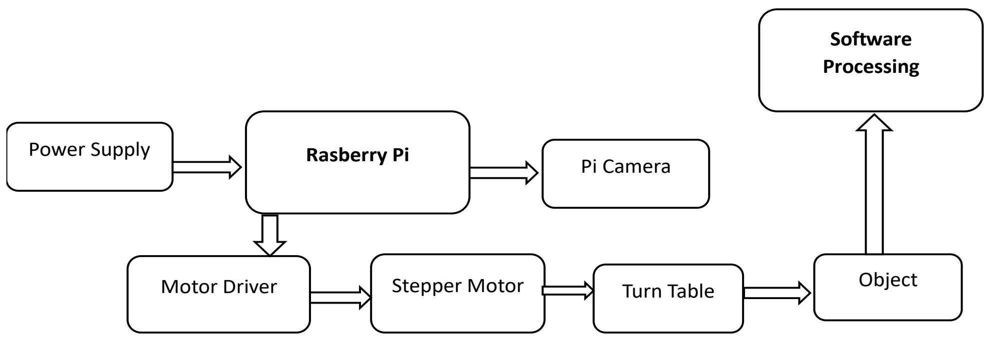
1.Raspberry Pi 4 Model B
2. Raspberry Pi Camera Module v2
3. Line laser
4. Object rotation stage (optional)

Software needed:

1. Raspberry Pi OS (Raspbian)
2. Custom Python scripts for system control
3. Meshlab

1.3. Block Diagram:

Fig.2- Block diagram of proposed module.



1. Structured Light Scanning: The projector casts a sequence of sinusoidal the object.
2. Image Acquisition: The Raspberry Pi Camera captures images of the object under different lighting conditions.

The simulation of the 3D Scanner product replicates the operational dynamics of the system within a virtual realm. It commences with the Raspberry Pi, serving as the core of the simulation, overseeing the entire process. The Pi Camera V2, virtually represented, captures images of the target object from diverse angles for scanning. Simulated stepper motors precisely guide the virtual camera to ensure comprehensive data capture. Within the virtual domain, a structured or laser light source is utilized to illuminate the virtual object, facilitating the scanning process.

Calibration: Camera Calibration-Intrinsic and extrinsic parameters are estimated using OpenCV's camera calibration toolkit.

Data Capturing:

1. 1.Object Rotation: The object is rotated using the rotation stage.

2. 2.Image Capture: Images are captured at each rotation step.

3. 3.Pattern Projection: Structured light patterns are projected onto the object.[2]

3D Reconstruction:

1. Point Cloud Generation: PCL is used to generate a 3D point cloud from the captured images.
2. Mesh Reconstruction: A 3D mesh is reconstructed from the point cloud using PCL's mesh reconstruction algorithms.

Evaluations Metrics:

- Accuracy: Measured using root mean square error (RMSE) between ground truth and reconstructed models.
- Completeness: Measured using the percentage of reconstructed surface area.
- Computational Efficiency: Measured using processing time.

1.4 Experimental Setup

Object Selection: Various objects with complex geometries are selected for testing. The system is tested in a controlled environment with minimal lighting variations.

This provides a comprehensive overview of the system's design, calibration, and operation.[4] The implicit 3D representation uses functions to express the 3D scene. By modelling the space occupation of the 3D object, the explicit 3D scene can be obtained by post rendering and other processing, but no intermediate 3D scene reconstruction process is required. Because the implicit 3D representation uses the neural network method to solve the problem of many holes in the traditional 3D reconstruction, the difference between the implicit 3D representation and the traditional 3D reconstruction method is that the expression is continuous. Common implicit 3D expression functions include Occupancy Function, Signed Distance Field (SDF) and NeRF.[8]

MeshLab is a free, open-source software for editing, processing, and viewing 3D models. Developed by the Visual Computing Lab, it was first released in 2005. It offers tools for fixing, cleaning, and improving 3D meshes, along with features like texture mapping, colour processing, and measurement tools.

Some of its key functions include aligning and merging 3D scans, filling holes, smoothing, simplifying models, and reconstructing surfaces using algorithms like Marching Cubes and Screened Poisson. These tools help in preparing 3D models for different applications.

MeshLab is widely employed in 3D scanning, 3D printing, CAD, research, cultural heritage preservation, architecture, gaming, and virtual/augmented reality. It supports formats like OBJ, STL, PLY, and VRML.[9]

To run MeshLab smoothly, a 64-bit CPU, 8GB+ RAM, and an OpenGL-compatible graphics card are recommended. It works on Windows, macOS, and Linux. Released under the GNU General Public License (GPLv2), MeshLab is regularly updated and has an active community for support.

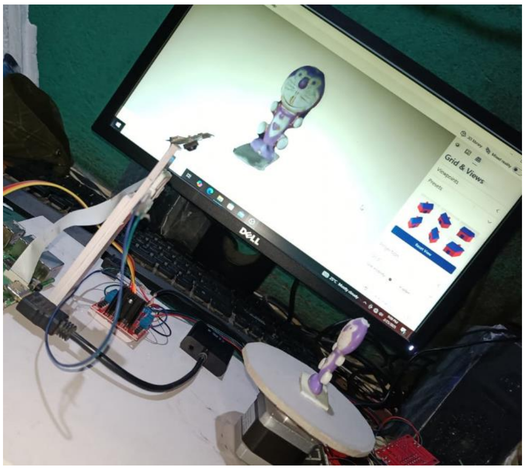


Fig. 3- Result of proposed module

Result:

In this we have created 3D model of some sample object. First, we take sample images from the hardware further this gets into the point data for the software processing.

1. As per the application involved 3D model can be rendered, we can calculate the dimensional analysis for the studying purpose.
2. The algorithm provided a smooth surface reconstruction, while Screened Poisson delivered more detailed features. Minor deviations were observed in complex geometries due to noise in point cloud data.
3. The final model was optimized and exported in STL format for further applications.
4. As shown in the figure we get the images of the sample object.

Conclusion :

In this paper, development of a Raspberry Pi-based 3D scanner for object reconstruction represents a significant advancement in the field of affordable and accessible 3D scanning technology. By leveraging the capabilities of the Raspberry Pi, along with complementary components such as the Pi Camera V2, stepper motors, this system successfully captures detailed 3D models of physical objects. The integration of real-time visual feedback through an LCD display enhances user interaction and ensures a seamless scanning experience1. This innovation not only bridges the gap between the physical and digital worlds but also opens up new possibilities for applications in 3D printing, design, and immersive experiences. As technology continues to evolve, the potential for further enhancements and broader applications of this 3D scanner is vast, making it a promising tool for both hobbyists and professionals alike.

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