International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(Research Article)

Development of a Goniometer to capture 3D models using Pi Noi camera

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International Journal of Science and Research Archive, 2025, 14(02), 1048-1056

Publication history: Received on 14 December 2024; revised on 10 February 2025; accepted on 13 February 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.14.2.0241

Abstract

This study aims to develop a goniometer for capturing images of a real object placed on the goniometer table and regenerating a 3D virtual model of the same object using a series of captured images. The system captures 100 images of the object while the table rotates 360°. By utilizing images taken with a NoIR camera, a 3D virtual model of the real object can be generated.

A centralized Raspberry Pi board controls all components of the goniometer. The system includes a control interface that connects to a PC via a Wi-Fi network. Using this interface, the rotation angle of the goniometer table can be adjusted with a minimum step size of 0.9°. The table is connected to a stepper motor, which enables rotation up to 360° with 400 steps per full rotation. As the table rotates, the NoIR camera, connected to the Raspberry Pi, captures images of the object.

Additionally, the goniometer includes a rotatable and brightness-adjustable white LED light source. This LED source illuminates the real object on the table and can be controlled via the interface.

Keywords: Development goniometer; Series of images; 3D virtual model generation; 3D virtual model reconstruction

1. Introduction

Goniometers are commonly used in physical therapy to measure a joint's range of motion and measures either an angle. In this research, this technology is applied to rotate the goniometer table in a horizontal plane. 3D virtual models play a crucial role and have broad applications in industrial design, cultural relic restoration, medical diagnosis, and 3D gaming.

There are various methods for generating 3D virtual models, based on different principles, such as laser-based scanning, structured light scanning, contact-based scanning, and image-based photogrammetry. Each of these methods has its own advantages, limitations, and cost differences [1], [2]. However, they share common challenges in object scanning and 3D virtual model reconstruction, such as inconsistent accuracy, lack of repeatability, difficulty of use, and high operational costs [3], [4].

Despite these challenges, 3D virtual models of real objects, generated through various imaging technologies, simplify the measurement of angles with the help of computer software [5].

The objective of this research is to develop an automated goniometer control system that measures the motion of a rotating table from a starting point. The system captures images using a NoIR camera during rotation and reconstructs a 3D virtual model of the real object placed on the goniometer table using an image-based method. Additionally, the system includes a rotatable and brightness-adjustable LED light source to illuminate the object for improved imaging.

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2. Design and methodology

The goniometer unit consists of three subsystems: hardware, a control software interface, and object reconstruction software. Figure 1 shows the complete block diagram of the unit.

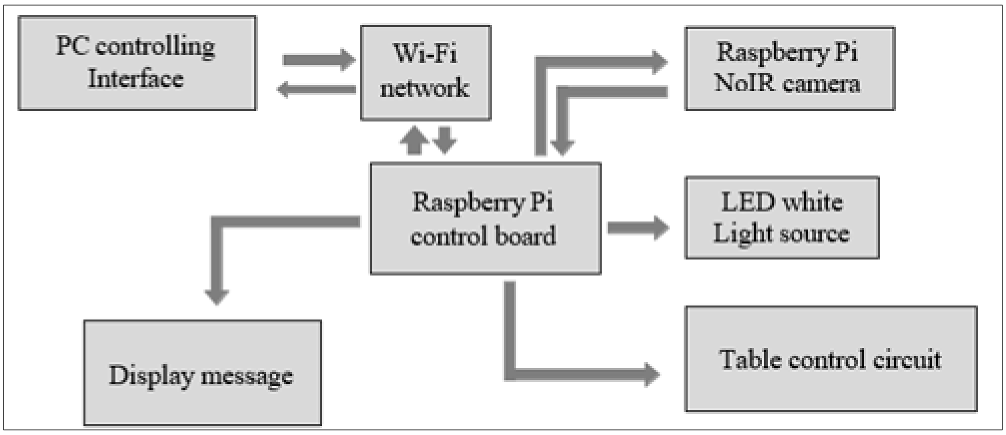

Figure 1 Complete block diagram of the system

The Raspberry Pi is the main controlling board, connecting to a PC over a Wi-Fi network. The Raspberry Pi NoIR camera, LED white light source, and goniometer table control circuit are connected to the Raspberry Pi board. Figure 2 shows the hardware structure of the goniometer system, and Figure 3 presents a real photograph of the goniometer system. The system structure is made of plastic, and the base is designed as an enclosure box to house all circuits along with the main control board. The dimensions of the enclosure are 150 × 65 × 35 mm^3.

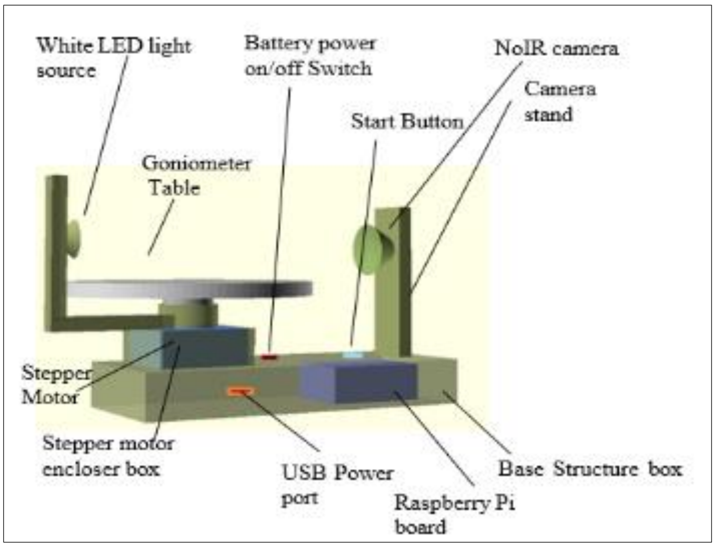

Figure 2 Structure of the goniometer system

The goniometer structures a disk-shaped plastic table with a diameter of 60 mm and a thickness of 5 mm, connected to a stepper motor housed inside the enclosure box. The system includes a camera stand and a rotating arm with an LED light. Both the stepper motor enclosure and the camera stand are securely fixed to the goniometer base.

The LED light source is fixed on the rotating arm and can move up and down along the arm, as well as rotate around the table also. The LED light source controller and the goniometer table controller are separate circuits, both of which are controlled by the Raspberry Pi board based on commands from the control interface.

A control interface is included, allowing users to manage these components through the main board. While the goniometer system operates, relevant feedback messages are also displayed on the interface. By using a control interface, the brightness of the LED white light source and the rotation angle of the table can be adjusted. While the table is rotating, images of the real object are captured by the Raspberry Pi NoIR camera.

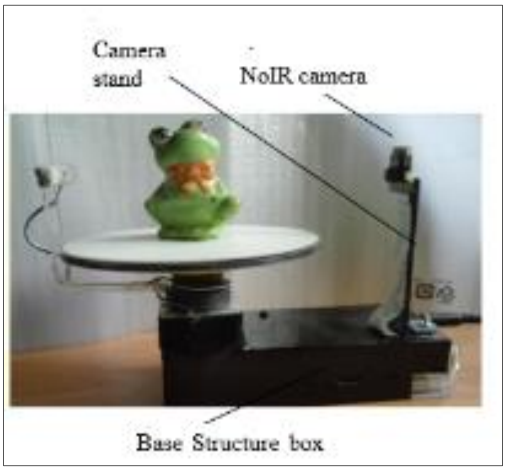

Figure 3 Real photograph of the goniometer system

2.1. Raspberry Pi board

The Raspberry Pi 3 Model B is a centralized, single-board computer including a 1.2 GHz 64-bit quad-core processor, on-board 802.11n Wi-Fi and USB ports. A 16GB SD card with the Raspbian operating system should be inserted into the Raspberry Pi board for it to operate. Raspbian is an open-source operating system, which can be downloaded from the official Raspberry Pi website. The operating system should be installed on the SD card as bootable. Insert the SD card into the Raspberry Pi board, connect the USB power, and the Raspberry Pi will boot from the SD card.

After installing the OS, Wi-Fi connectivity needs to be set up for the Raspberry Pi board. To do so, navigate to the "/etc" directory, open the terminal, and access it as a super user by typing the command "su", then entering the password "root". Use the command "nano /etc/wpa_supplicant/wpa_supplicant.conf" to open the configuration file and enter the Service Set Identifier (SSID) "ssid="YourNetworkName"" and Pre-Shared Key (PSK) "psk="YourWiFiPassword"" to set up Wi-Fi.

Press "Ctrl+X" to exit the edit mode and confirm saving the changes by typing "Yes". To configure the network interfaces, use the "nano /etc/network/interfaces" command to edit the IP address, subnet mask, and default gateway. Follow the above same procedure to save the changes. Finally restart the Raspberry Pi, it will start and automatically connect to the Wi-Fi network.

2.2. Raspberry Pi NoIR Camera

The Raspberry Pi NoIR Camera features a high-quality 8-megapixel Sony IMX219 image sensor, specifically designed for the Raspberry Pi board. It is capable of capturing static images at a resolution of 3280 × 2464 pixels, and its dimensions are 25 mm × 23 mm × 9 mm [5]. The NoIR camera connects directly to the camera port on the Raspberry Pi board.

2.3. Stepper motor

The Stepper motor has a unique structure for the rotation of forward and backward in small "steps" with high accuracy and it is used for rotated the goniometer table. The stepper motor is controlled through ULN2003A IC and it connects to the Raspberry Pi digital pins 7, 11, 13 and 15 as shown in Figure 4. Stepper motor is in the encloser box which dimension is 40 × 40 × 20 mm and it is fixed on the base.

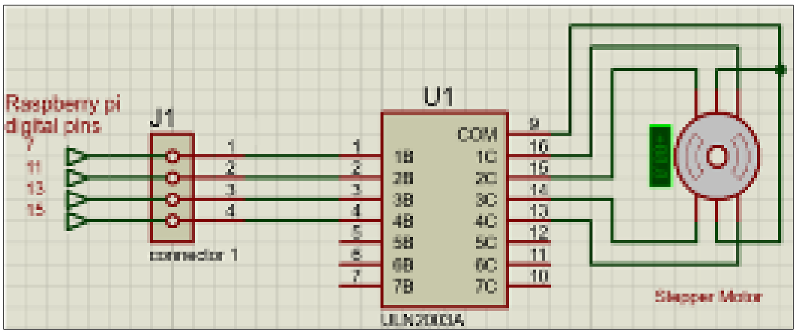

Figure 4 Stepper motor control schematic diagram

2.4. White LED source

The 1W white LED light is used to illuminate the real object on the goniometer table. The brightness of the LED light is controlled through a transistor circuit, and it is connected to the Raspberry Pi's digital pin 18. The LED light brightness can be adjusted using a PWM (Pulse Width Modulation) signals, ranging from 0 to 100, which is provided by the Raspberry Pi.

2.5. Power supply unit

An internal 3.7V/5000mA Li-ion battery with a separate USB charging port is used to power up all components without relying on external power.

2.6. Control interface

There is a command line interface control interface that manages all components of the unit. This procedure is used to log into the Raspberry Pi board from a PC or Mobile phone over a Wi-Fi connection. As shown in Figure 5, open the terminal on the PC and enter the SSH command: ssh pi@192.168.43.3 (IP address is depend on Raspberry Pi board) with the default password "raspberry" to log into the Raspberry Pi through the Wi-Fi network.

Figure 5 Raspberry Pi logging command line interface

A control code program written in Python is located in the project directory.
To access this directory, use the command: “cd project/”
Then, to execute the goniometer control code, use the command: “python goniometer.py”.

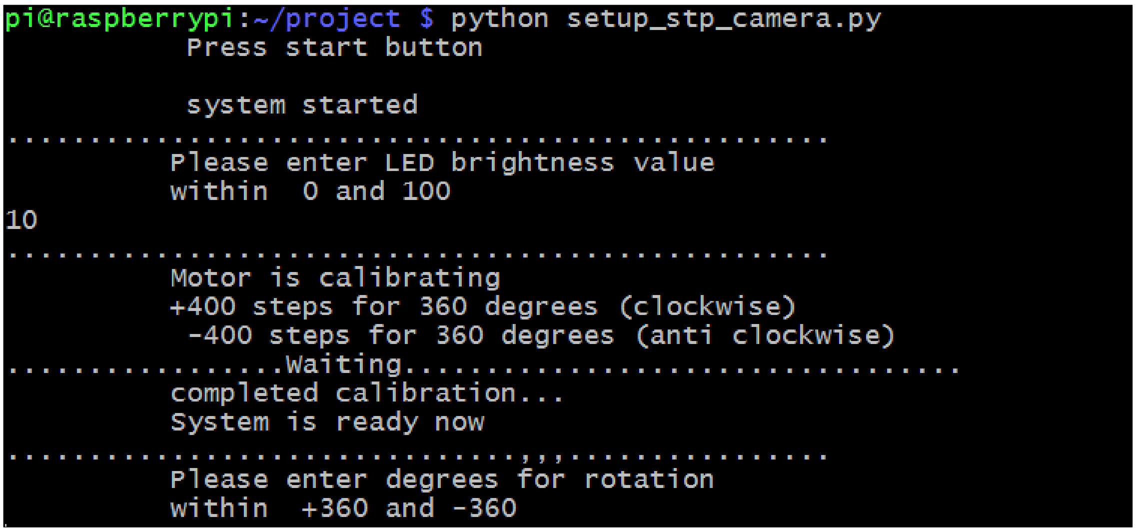

Figure 6 Goniometer control command line interface

As shown in Figure 6, the system is ready to operate, and the message "Please enter degrees for rotation within -360° to 360°" will be displayed. The user can enter the desired rotation angle for the goniometer table, which can rotate both clockwise and counterclockwise within the range of -360° to +360°.

Place the real object on the goniometer table, enter the rotation angle, and press the Enter button. The goniometer table will begin rotating, and as it rotates, the NoIR camera will capture images of the real object. The table rotates in steps of 0.9°, and the camera will take a photo every 4 steps. The rotation angle and the number of images saved are displayed on the interface. Once the rotation is complete, the goniometer table stop at the final position and the message "One rotation finished" will be displayed. 100 images of the object captured per rotation.

3. Generate 3D object

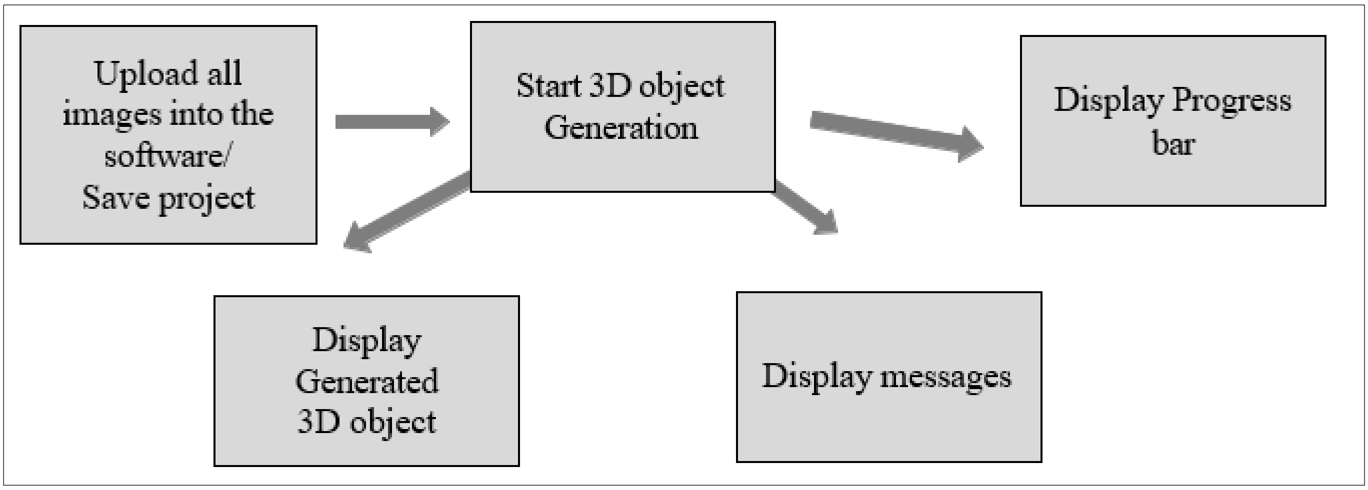

Figure 7 Block diagram of 3D object generation from series of image

Figure 7 shows the block diagram of the 3D model generation process by the software. The entire set of images captured by the camera, copied to the PC from the Raspberry Pi over Wi-Fi. the images can also be transferred to the PC using a USB. Several free and opensource software tools are available for generating virtual 3D objects from a series of images. "Meshroom" and "VisualSFM" are commonly used software that can generate high-quality 3D models.

3.1. Meshroom software

As shown in Figure 8, import images into the Images pane on the left side of the Meshroom software. Save the project and click the Start button. While running, a progress bar appears at the top of the software. If any issue occurs, it will be indicated in red on this bar. Sometimes, an error message may appear during processing, which can happen if the PC is under heavy load or experiencing performance issues.

Figure 8 Meshroom software interface

After the process will complete successfully, the progress bar will be displayed entirely in green. As shown in Figure 9, the software will then begin generating the 3D virtual object in the 3D viewer of Meshroom.

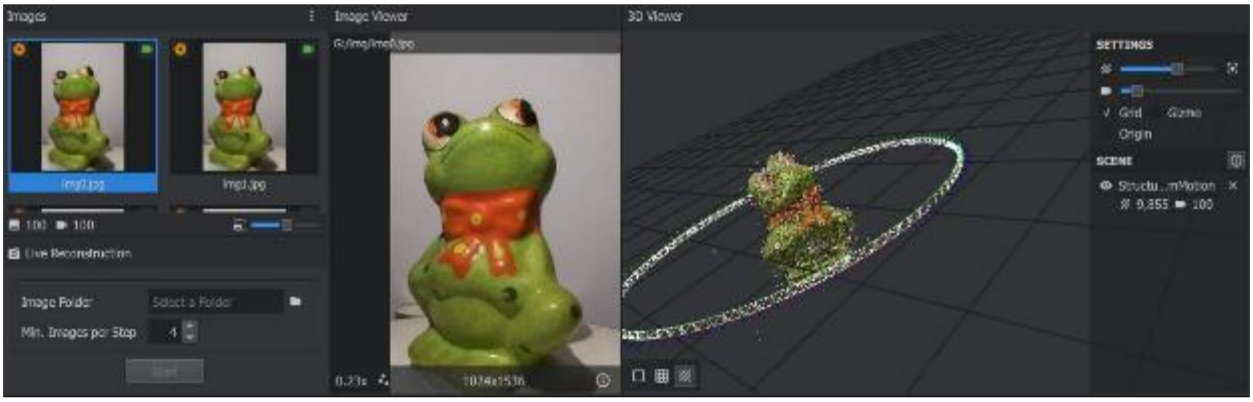

Figure 9 Interface of generating the 3D object

4. Results and discussion

The goniometer table is horizontally connected to a stepper motor, allowing it to rotate both clockwise and counterclockwise in a horizontal plane. The maximum rotation angle is 360°, while the minimum rotation angle is 0.9°. The stepper motor moves in discrete steps, with a minimum step size of 0.9°, which defines its smallest possible rotation.

The total number of steps required for a full 360° rotation is calculated as follows:

$$\text{Total steps} = 360° / 0.9°$$

$$= 400$$

Table 1 Calculated step size for rotation angle of stepper motor

Start location	**0°**	**0°**	**0°**	**0°**	**0°**	**0°**	**0°**
Expected angle (θ°)	30°	45°	60°	90°	180°	270°	360°

No of rotation steps Theoretical	33.33	50	66.66	100	200	300	400
Theoretical angle (θ°)	29.7°	45.0°	59.9°	90.0°	180.0°	270.0°	360.0°
Actual angle value (θ°)	29.5° ± 0.5°	45°± 0.0°	60° ± 0.5°	90°± 0.0°	180°± 0.0°	270°± 0.0°	360°± 0.0°

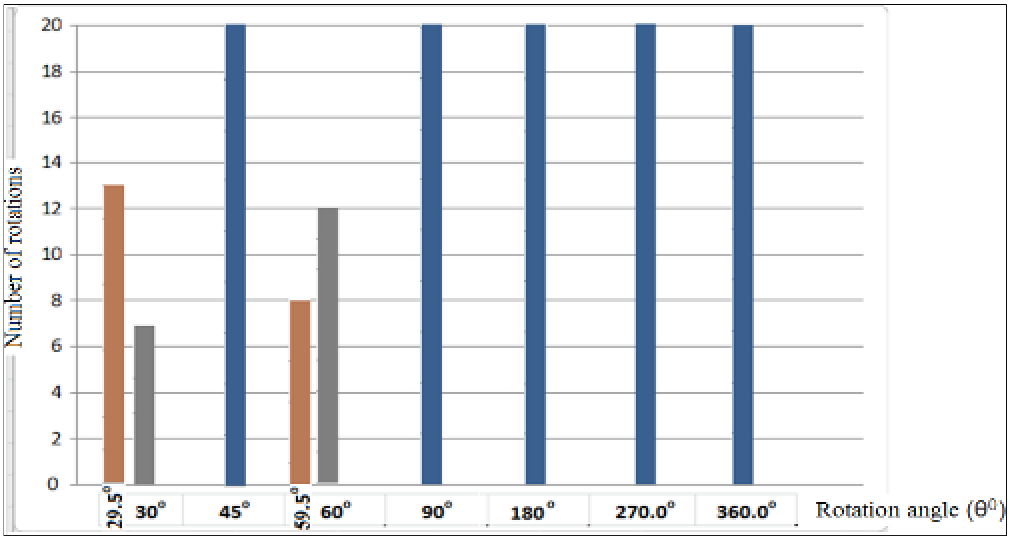

Figure 10 The graph of actual rotation values of goniometer table Vs rotation angle

While the goniometer table rotates, Figure 10 shows the graph of the actual rotation values of the goniometer table versus the rotation angle, and the NoIR camera captures 100 images of the real object placed on the rotating table. Figure 11 shows the series of images captured during one rotation.

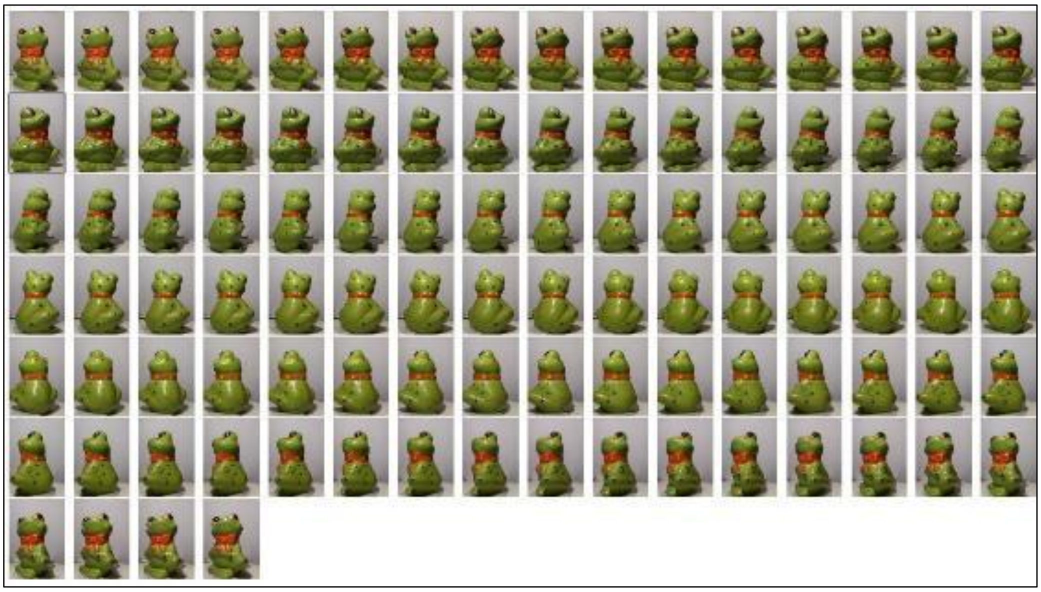

Figure 11 Series of images taken from NoIR camera

Meshroom and VisualSFM are open-source software, the regenerated 3D object created from a series of images are shown in Figure 12 and Figure 13.

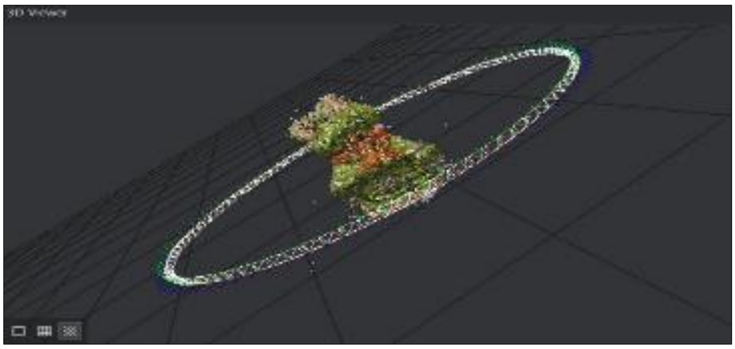

Figure 12 Virtual model of the object-1 generated by using Meshroom software

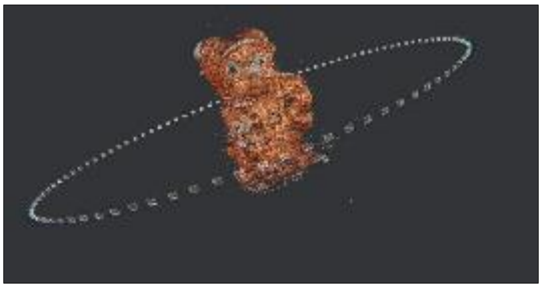

Figure 13 Virtual model of the object-2 generated by using VisualSFM software

5. Conclusion

This study developed a goniometer system that captures 100 images of a real object as it rotates 360°, using a NoIR camera and a Raspberry Pi to generate a 3D virtual model. The system allows for precise table rotation with a minimum step size of 0.9° and includes an adjustable LED light source for optimal illumination. By offering real-time control via a Wi-Fi interface, this system provides an efficient, scalable solution for 3D modeling, advancing imaging techniques for both medical and industrial applications.

The goniometer table has been successfully rotated to angles of 45°, 90°, 180°, 270°, and 360° without any errors. Generally, the goniometer table rotates with an accuracy of ±0.5°.

The integration of image capturing using the NoIR camera during each rotation allows for detailed 3D object reconstruction, enhancing the utility of the goniometer for various imaging and modeling tasks.

Compliance with ethical standards

Disclosure of conflict of interest

There is no conflict of interest to be disclosed.

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