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Design and Development of a GUI-Based Remote Limb Measurement Platform and COMSOL- Assisted Material Analysis for Affordable Lightweight Transradial Prosthetic Arms

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Received: 02/06/2026
Approved: 26/06/2026
Published: When it happens

Abstract

Background: Normal transradial prosthetic fabrication involves regular clinical visits for anthropometric measures and customization, which prolongs the rehabilitation process and contributes to higher rehabilitation expenses. Furthermore, it is difficult to select lightweight materials with adequate mechanical strength for prosthetic fabrication. **Objective:** This study was designed to create and test a Graphical User Interface (GUI) based system for remotely measuring the length of a limb and to determine the best material for lightweight transradial prosthetic arms through the use of finite element analysis performed in COMSOL. **Methods:** An applied engineering design approach was adopted and consisted of two phases. In Phase I, a graphical user interface (GUI) was created in Python with the help of MediaPipe, OpenCV, CVzone, and NumPy Libraries, along with the Kivy application to estimate hand and arm dimensions from a distance. The system was tested with 23 subjects: 10 subjects with unilateral transradial amputation and 13 healthy subjects. In Phase II, three candidate materials (PLA, PETG and Polysulphone) were tested with COMSOL Multiphysics. **Results:** The developed GUI achieved an average measurement accuracy of 94.91% in healthy participants and 98.23% in participants with unilateral transradial amputation, with a maximum measurement error below 2.1%. The simulation results showed that the Polysulphone material has the highest thermal stability, excellent stress resistance and lowest structural deformation of the material tested. PETG demonstrated good structural properties, while PLA was appropriate for lightweight, non-load-bearing parts. **Conclusion:** The proposed framework is efficient and works well when combining remote anthropometric measurement with simulation-based material optimization in order to develop a transradial prosthetic arm that is more affordable, lightweight and customizable. The study proves the feasibility of a computer vision-assisted Finite Element Analysis (FEA) system to improve prosthetic design, minimize clinical dependency and enable tele-rehabilitation applications.

Keyword: Biomedical Engineering, Computer Vision, COMSOL Multiphysics, Graphical User Interface (GUI), Remote Limb Measurement, MediaPipe, Transradial Prosthetic Arm.

1. Introduction

The functional independence, productivity, and quality of life of individuals with upper-limb amputation are significantly affected. One of the most prevalent forms of upper-limb amputation, transradial amputation affects the person's ability to manipulate objects, write, lift, and perform a variety of other routine tasks. **[4]** In the last ten years, prosthetics technology has come a long way, from the addition of Myoelectric Control to Artificial Intelligence, Additive Manufacturing, and Advanced Lightweight Materials. In spite of these technologies, intelligent prosthetic arms are not widely accessible, especially in developing countries like India, where limited customization facilities, reliance on foreign-made arms, and high cost of arms are still hindering the arm's spread. **[7, 8]**

Accurate anthropometric measurements for custom-made fabrication of the socket and alignment of the prosthesis are one of the significant difficulties in prosthetic rehabilitation. Traditional measurement procedures involve a number of clinical visits for measurement, fitting, and adjustments, adding to the rehabilitation time and cost of treatment. Patients living in rural and remote areas are especially affected by these challenges because fewer centres with expertise are available in these areas. **[12, 13]** In recent years, image processing methods have been shown to have the potential to provide contactless anthropometric measurements, showing promising results in the field of computer vision and machine learning. **[9]** Apart from correct anthropometric dimensions, appropriate materials are also vital for ensuring the comfort, longevity and performance of prosthetic arms. The ideal prosthetic device should be lightweight, durable, thermally stable and be biocompatible to allow for long term use on a daily basis without causing user discomfort. It is important to systematically evaluate the materials used in additive manufacturing, including common materials like polylactic acid (PLA), polyethylene terephthalate glycol-modified (PETG) and polysulphone, at the design stage due to the different mechanical and thermal properties they possess. Finite Element Analysis (FEA) using COMSOL Multiphysics enables systematic evaluation of these materials. **[5, 6]**

The current research aims to solve these problems by introducing an integrated engineering approach to designing a GUI-based remote limb measurement platform and deriving an optimized material for designing a low-cost lightweight transradial prosthetic arm using COMSOL-based simulation. **[1]** The developed application is based on computer vision algorithms for remote estimation of anthropometric dimensions of the upper-limb, which can decrease the number of repeated hospital visits and help in the design of a personalized prosthesis. Then finite element simulations are used to evaluate candidate materials according to thermal, mechanical and durability properties and select the most suitable material for the prosthetic manufacture. **[4, 5]** This study aims to combine the advantages of digital anthropometry and material optimization through simulation, thereby paving the way for an accessible, cost-effective, and locally available prosthetic solution that can be adopted in the Indian healthcare landscape and for further developments in tele-rehabilitation and personalized assistive technologies.

2. Research Gap

There has been extensive research on myoelectric prosthetic arms, computer vision-based limb measurement and finite element analysis of prosthetic material but these have been studied to a large extent independently. **[11]** Current research is largely restricted to either prosthetic control methods or anthropometric measurement methods or material performance assessment, and very little work is done on bringing them together in a comprehensive way for prosthetic development. In addition, many commercially available systems for prostheses require multiple face-to-face clinical sessions to measure and customize the limb, thereby requiring more rehabilitation time and more rehabilitation costs. **[13]** Furthermore, there is a lack of indigenous solutions that are cost-effective, have user-friendly graphical interfaces and have the capability of simulating materials specific to the Indian healthcare environment for remote limb measurement. Thus, there is a great research gap for creating an integrated digital platform to achieve accurate anthropometric assessment from a distance, which can also determine the most suitable lightweight materials for low-cost custom-designed transradial prosthetic arms. In the present study, a computer vision-based GUI system is developed to complement the finite element analysis (FEA) tools with COMSOL to enable efficient, economical, and patient-centered prosthetic design, which is a major missing element in current studies.

a. Problem Statement

Although great progress has been made in myoelectric prosthetic technology, the use of intelligent transradial prosthetics is still not widespread, with issues of access, cost, customization and materials all playing a role. **[11]** Traditional prostheses construction involves several visits to the clinic for anthropometric measurements, fitting, and adjustment, which consumes rehabilitation time, increases the cost of the procedure, and decreases its accessibility, especially for patients living in rural areas. **[12]** Besides, the commercially available high-tech prosthetic arms are mostly imported and costly which is not available to the majority of the developing countries like India and its amputees. Another challenge is picking materials that are lightweight, strong, and comfortable for the patient, since the device needs to be both durable and comfortable for extended periods of time. **[7]** Previous research has focused on either remote sensing technologies or the optimization of materials, but few efforts have been made to incorporate these two. Most previous work related to remote sensing technologies or optimization of materials has been studied separately, and not with a focus on an integrated prosthetic development system. Thus, it is required to build an inexpensive, human-friendly measurement system that integrates the accurate measurement of remote limbs by GUI and simulation-based material optimization for achieving personalized lightweight and economic design of transradial prostheses.

b. Objective of Study

- Develop and validate a GUI-based remote limb measurement platform.

- Identify the most suitable lightweight material using COMSOL simulations.

c. Review of Literature

Biomedical engineering technologies, such as computer vision, AI, additive manufacturing, and digital design, have greatly enhanced the design and manufacture of upper-limb prosthetic devices in recent years. Recent research has focused on the ability of additive manufacturing to produce lightweight, custom-made, and cost-effective prosthetics sockets and the need for suitable materials and mechanical properties for clinical use over extended periods of time **[1]**. The use of digital template libraries and computer-aided prosthetic design has also increased the efficiency and personalization of transradial prosthetic socket manufacturing, minimizing time and providing better patient specific customization **[2]**.

Likewise, low-cost 3D printed prosthetic sockets have shown that the production of affordable prostheses is possible and that they are equally functional **[3]**. Computer vision has proven to be a successful method for contactless anthropometric measurement & intelligent prosthetic control. The grasp recognition and interaction with objects has been improved by vision-based sensing of the hand **[4]**, and the grasp assistance and the control of the hand by the hand is enhanced by the sensorized prosthetic system **[5]**. Moreover, human pose estimation, a technique from MediaPipe, and hand landmark detection have been found to be quite accurate in identifying anatomical landmarks for real-time measurements and gesture recognition **[6,7]**. The MediaPipe framework has also built a solid foundation for real-time computer vision applications **[8]**, and has been successfully used in rehabilitation systems, showing its potential for remote patient evaluation **[9]**.

All of these studies confirm that computer vision technologies could offer reliable contactless anthropometric measurements for prosthetics. The ability to predict the thermal and mechanical behavior of prosthetic components prior to manufacture has become essential and finite element analysis (FEA) is now a vital tool for this. FEA has proven to be a valuable tool in simulation that can help increase structural reliability, optimize prosthetic design and aid in material selection in the development of additive manufactured prosthetic devices **[10]**. Moreover, systematic reviews have highlighted the need for biomechanical assessment and interface pressure evaluation to enhance the comfort and functionality of the prosthetics **[11]**. More recent research has also focused on the development of engineering simulations for the evaluation of prosthetic socket characteristics, design and fabrication **[12]**. Customization, manufacturing flexibility and accessibility of prosthetic devices have also been improved, thanks to the application of additive manufacturing and multi-material fabrication techniques **[13,14]**.

Although these developments have taken place, previous research has largely been conducted in isolated research fields of computer vision, prosthetic design, finite element analysis and material optimization. There is limited evidence in the current literature regarding the development of an integrated framework for remote anthropometric measurement using the GUI and material optimization using COMSOL for customized prosthetic development. Furthermore, there are still limited numbers of digitally customized affordable prosthetic solutions that are specifically designed for resource challenged healthcare systems like India **[15]**.

Hence, the present study suggests an integrated approach, which involves computer vision based remote measurement of limbs and finite element analysis-based material optimization, for the development of lightweight, customized, and affordable transradial prosthesis for tele-rehabilitation and indigenous manufacturing of prostheses.

3. Materials and Methods

a. Research Design

In the present study, the method of applied engineering design and development research was used and the experimental validation and simulation-based material optimization were used to create an affordable lightweight transradial prosthetic arm. The research was given two integrated phases. The initial phase consisted of designing and testing a GUI-based computer vision system to remotely measure anthropometric parameters of the upper limb. The second phase involved analyzing different candidate prosthetic materials using finite element analysis (FEA) with COMSOL Multiphysics to determine which material was best suited for the application based on its thermal and mechanical properties and its biocompatibility. The methodology was software development, experimental validation, CAD modeling and engineering simulation, which led to an optimal prosthetic design.

b. Study Workflow

The study was conducted following systematic engineering design procedure from the identification of a problem to requirement analysis. A graphical user interface (GUI) was then designed to aid in the remote measurement of the upper-limb using computer vision techniques. The system developed was tested by comparing the anthropometric data obtained from the remote location and the anthropometric data obtained manually. After successful validation, three-dimensional CAD models of the prosthetic components were created and introduced to COMSOL Multiphysics software for finite element simulation. Candidate materials were tested for their thermal and mechanical characteristics, and the best material was chosen for the final prosthetic design.

The steps of the workflow were:

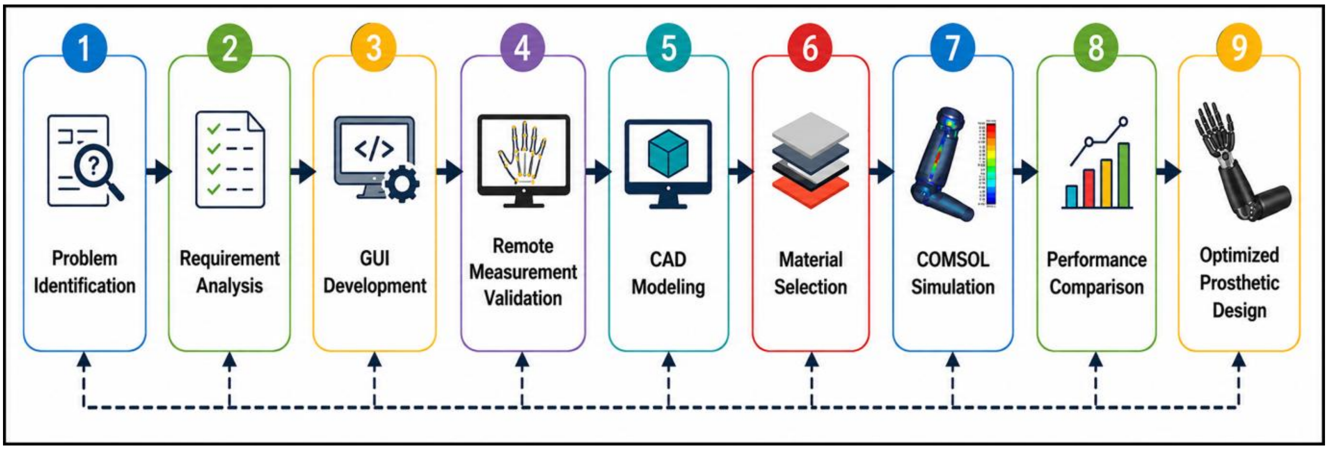

Figure 1: Study Work Flow

c. Study Area

The study was done in India as investigation of engineering design and validation. Healthy volunteers and people with upper-limb amputation were used to validate the developed remote measurement platform with anthropometric measurements.

d. Study Participants

In the validation study, a total of 23 participants (13 healthy volunteers and 10 patients with unilateral transradial amputation) were enrolled. The healthy participants were used to validate the measurement algorithm under normal anatomical conditions, while the amputee participants were recruited for the purpose of evaluating the applicability of the proposed system in the area of prosthetic rehabilitation.

e. Sampling Technique

The participants were selected through purposive sampling because the inclusion of other people was not necessary to assess the performance of the developed measurement system. Intentionally, both healthy volunteers and amputees were chosen as the intended user population of the proposed prosthetic platform.

f. Software and Tools

This GUI application was created in Python, with the help of the PyCharm Integrated Development Environment (IDE). MediaPipe, OpenCV, CVzone and NumPy were used for computer vision tasks like landmark detection and image processing, and Kivy was used to create the graphical interface. Three-dimensional prosthetic models were developed and analysed with COMSOL Multiphysics, used to perform finite element simulations for thermal and mechanical evaluation of candidate materials.

3.1 Phase I

A GUI was created to estimate the dimensions of the upper limbs remotely using a standard digital camera with the help of anthropometric dimensions. The application took a photograph of the hands and arms and used MediaPipe to detect anatomical landmarks on the hands and arms. The extracted landmark coordinates were then used to calculate the Euclidean distance between the known anatomical landmarks. A calibration procedure was then conducted with a reference object with known dimensions that would allow converting the distances measured in pixels to real distances, measured in centimeters. The GUI showed the real-time calculation of the hand height, hand width and arm length.

Mathematical Formulation

Equation (1)

$$D_{pixel} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

where,

x_1, y_1 = First landmark
x_2, y_2 =Second landmark
D_{pixel} = Euclidean distance between the two landmarks in pixels.

Equation (2)

$$CF = \frac{L_{known}}{D_{Pixel}}$$

where,

L_{known}= Known reference length (e.g., calibration object) in millimetres (mm).
D_{pixel} = Pixel distance corresponding to the known reference.
CF = Calibration factor (mm/pixel), used to convert pixel measurements into real-world dimensions.

Equation (3)

$$L=D_{pixel} \times CF$$

where,
D_{pixel} = Measured distance between landmarks in pixels.
CFCFCF = Calibration factor (mm/pixel).
L = Actual distance between the landmarks in millimetres (mm).

Equation (4)

$$Accuracy= (1-\frac{/M_{manual}-M_{GUI}/}{M_{manual}}) \times 100$$

where,
M_{manual} = Measurement obtained using the manual method.
M_{GUI} = Measurement obtained using the GUI-based system.
Accuracy = Percentage accuracy of the GUI measurement with respect to the manual measurement.

Equation (5)

$$Error= (\frac{/M_{manual}-M_{GUI}/}{M_{manual}}) \times 100$$

M_{manual} = Measurement obtained using the manual method.
M_{GUI} = Measurement obtained using the GUI-based system.
Error = Percentage error between the GUI measurement and the manual measurement.

3.2 Algorithm

a. GUI-Based Remote Limb Measurement Algorithm

Figure 2 illustrates the complete workflow of the proposed GUI-based remote limb measurement system developed for estimating upper-limb dimensions from a single captured image. The process begins by acquiring an RGB image through the graphical user interface (GUI), ensuring a user-friendly and contactless measurement procedure. The captured image is processed using the MediaPipe hand landmark detection framework, which accurately identifies key anatomical landmarks of the hand and forearm.

Once the landmark coordinates are extracted, Euclidean distance calculations are performed to determine the pixel-based distances between the selected anatomical points. These pixel measurements are then converted into real-world dimensions using a predefined pixel-to-centimeter calibration factor, enabling accurate estimation of physical measurements irrespective of image resolution. Based on the calibrated distances, the system computes essential anthropometric parameters, including hand height, hand width and arm length. Finally, all calculated measurements are presented through the GUI, allowing users to obtain instant and reliable limb dimensions. The proposed algorithm offers a simple, efficient and non-invasive approach for remote anthropometric assessment and provides a practical foundation for applications such as customized transradial prosthetic arm design.

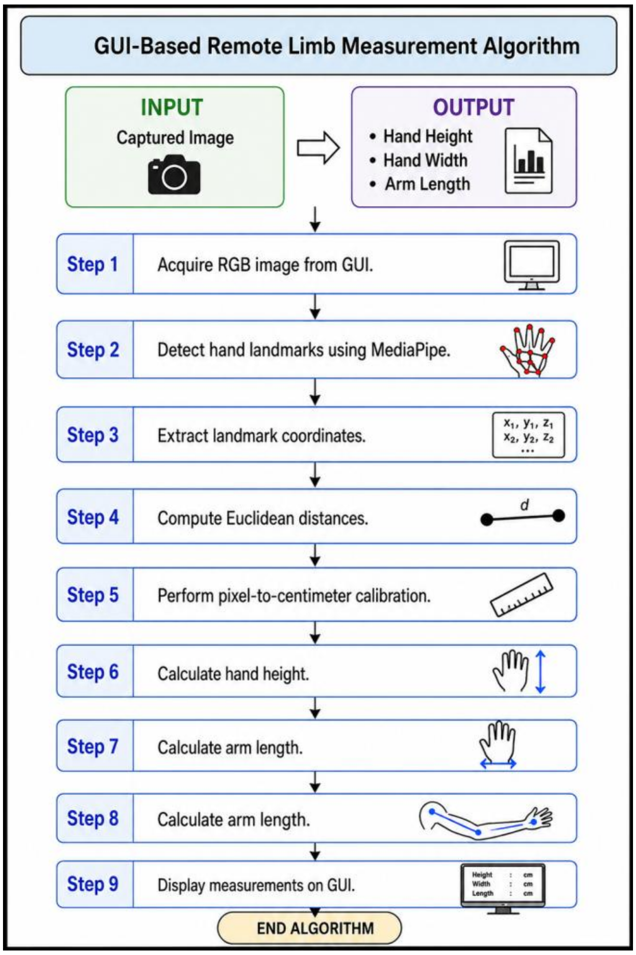

Figure 2: GUI-Based Remote Limb Measurement Algorithm

b. Validation Procedure

The developed GUI was tested by comparing the anthropometric measurements taken remotely with the anthropometric dimensions that are measured manually with the help of a measuring tape. The accuracy of the proposed system and percentage error were calculated for each participant to evaluate the reliability of the proposed system.

3.3 Phase 2

Engineering analysis was performed using three-dimensional CAD models of the prosthetic fingers, palm, wrist and supporting assembly. This was followed by the selection of 3 candidate materials namely Polylactic Acid (PLA), Polyethylene Terephthalate Glycol-Modified (PETG), and Polysulphone, which have been commonly used in the manufacturing of prosthetics and additive manufacturing technologies.

Finite Element Analysis (FEA) was carried out for the same thermal and mechanical loading conditions in COMSOL Multiphysics. The performance of the material was assessed in terms of thermal conductivity, maximum operating temperature, stress distribution, deformation, tensile properties, environmental resistance and biocompatibility. Comparative analysis was then conducted to obtain the most appropriate material in the various prosthetic parts.

3.4 Outcome Measures

The main outcome measures were the accuracy of the remote arm length measurement, hand height measurement, hand width measurement and the percentage measurement error of all three measurements. Secondary outcomes were thermal conductivity, tolerable maximal temperature, stress distribution, deformation of the structure, durability of the material, resistance to the environment, and overall suitability of candidate materials for the production of prostheses.

3.5 Statistical Analysis

Descriptive statistical techniques, including mean, standard deviation, measurement accuracy, and percentage error, were used to analyse the anthropometric measurement data obtained in Phase I. Comparative analysis was performed using the calculated measurement accuracy and percentage error to evaluate the performance of the proposed GUI-based measurement system.

In the second phase, the results from the simulation performed in COMSOL Multiphysics were analysed by comparative engineering analysis. The thermal behavior, mechanical strength, deformation and overall material performance were compared amongst PLA, PETG and Polysulphone to select the best material for the lightweight fabrication of Transradial Prosthetic Arms.

4. Results

Section 1: The principles of GUI Development and Performance Evaluation.

The remote limb measurement system was successfully developed and implemented using Python programming language and integrated with several libraries such as MediaPipe, OpenCV, CVzone, NumPy and Kivy.

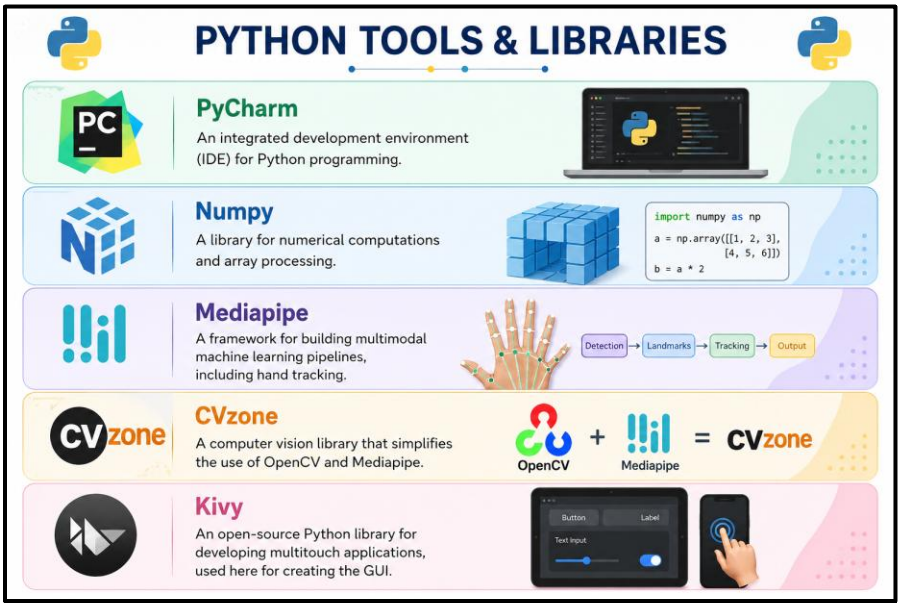

Figure 3: Software Environment for GUI

The application offers an easy-to-use interface to perform remote image acquisition of the upper limbs, real-time detection of landmarks and automatic anthropometric measurements.

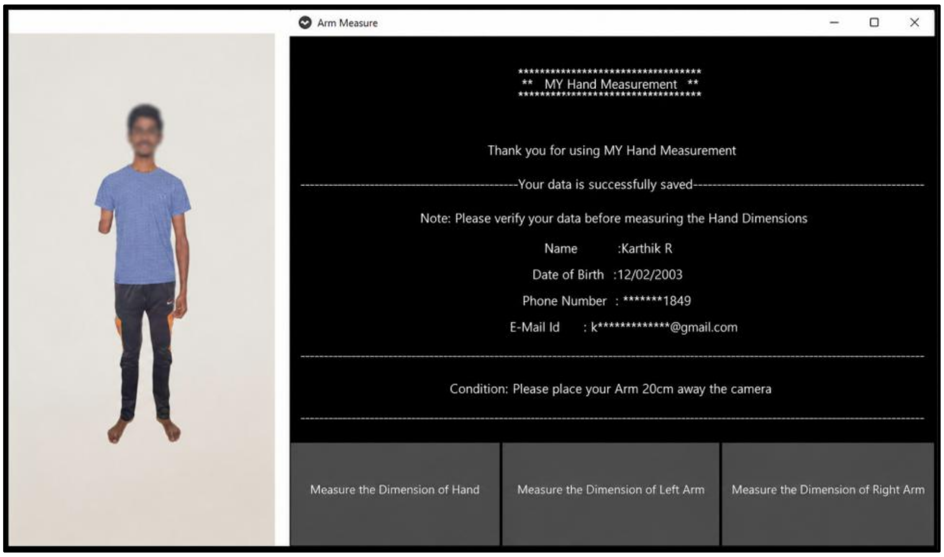

Figure 4: Architecture of the GUI-based remote limb measurement system

The GUI provides a means to take pictures with an ordinary camera, which are then fed into the system, which automatically detects anatomical landmarks of the hand and upper limb using the MediaPipe framework. The landmark coordinates extracted from the extracted data are then passed through a calibrated distance estimation algorithm to provide measurements in centimeters.

The developed interface consists of three main functional modules:

1. Image acquisition
2. Landmark detection and processing
3. Measurement display.

While the image is being captured, the GUI shows the captured image with the detected landmarks on the hand and arm and shows the calculated hand height, hand width, and arm length. Measurement output is produced in real time after the pixel to centimeter calibration, and eliminates manual calculation.

The proposed GUI-based remote measurement application was evaluated using anthropometric data collected from 13 healthy subjects. The experimental results demonstrate consistent and reliable measurement performance across all participants. The system achieved a mean measurement accuracy of 94.91% with a mean measurement error of 1.59%, indicating good agreement between the remotely estimated anthropometric dimensions and the corresponding manual reference measurements. These results validate the effectiveness and reliability of the proposed system for remote anthropometric assessment.

Table 1: Without Amputation Individuals Readings

Sl. No.	Name	Age	Hand Height (cm)	Hand Width (cm)	Left Arm (cm)	Right Arm (cm)	Accuracy (%)	Error (%)
1	Subject 1	36	20	6	26	33	92.04	1.05
2	Subject 2	26	19	8	25	25	92.04	1.05
3	Subject 3	44	15	6	21	23	93.68	1.02
4	Subject 4	50	21	8	25	32	95.10	1.90
5	Subject 5	43	18	7	27	28	93.20	1.80
6	Subject 6	41	19	9	26	31	97.90	2.10
7	Subject 7	45	22	10	29	30	98.30	1.70
8	Subject 8	46	20	8	25	25	96.00	2.00
9	Subject 9	56	23	9	30	31	95.50	1.50
10	Subject 10	51	22	10	27	28	95.30	1.50
11	Subject 11	32	21	8	26	27	95.40	1.60
12	Subject 12	40	20	9	29	27	94.30	1.50
13	Subject 13	69	18	7	23	24	95.10	1.90

Table 2: Readings of Amputees

SL.No.	Name	Age	Hand Height (cm)	Hand Width (cm)	Arm Length (cm)	Accuracy (%)	Error (%)	Unavailable Arm
1	Subject 1	30	20	9	28	98.0	2.0	Left
2	Subject 2	35	18	8	27	98.1	1.9	Left
3	Subject 3	40	19	9	26	98.2	1.8	Left
4	Subject 4	45	21	8	29	98.3	1.7	Left
5	Subject 5	50	22	10	30	98.4	1.6	Right
6	Subject 6	29	19	9	27	98.1	1.9	Right
7	Subject 7	33	18	8	25	97.9	2.1	Right
8	Subject 8	38	20	9	26	98.2	1.8	Right
9	Subject 9	43	21	10	28	98.5	1.5	Right
10	Subject 10	48	22	10	30	98.6	1.4	Right

The developed GUI successfully automated the complete anthropometric measurement process, from image acquisition to dimensional estimation, demonstrating its practical applicability for remote prosthetic assessment.

Section 2: Validation Results

a. Participant Characteristics

The developed GUI-based measurement system is validated with 23 participants of which 13 are healthy and 10 are people with unilateral transradial amputation. The ages of the participants ranged from 26 to 69 years.

Table 3. Demographic and Participant Characteristics

SL.No.	Variable	Healthy (n=13)	Amputees (n=10)	Total (n=23)
1	Participants	13	10	23
2	Age Range (years)	26–69	29–50	26–51
3	Assessment Method	GUI	GUI	GUI

b. Measurement Results

The developed application was able to accurately predict the height of the hands, hand width, and arm length for all the participants. The measured arm lengths ranged from 21 to 31 cm, hand heights ranged from 15 to 23 cm, and hand widths ranged from 6 to 10 cm.

Table 4. Summary of Anthropometric Measurements

SL.No.	Parameter	Minimum (cm)	Maximum (cm)
1	Hand Height	15	24
2	Hand Width	6	10
3	Arm Length	21	31

c. Measurement Accuracy

The proposed GUI-based measurement system demonstrated a high level of accuracy when evaluated on healthy individuals. The measurement accuracy ranged from 92.04% to 98.30%, with an average accuracy of 94.91% across the 13 subjects. For amputee participants, the proposed system exhibited excellent measurement performance. The accuracy ranged from 97.90% to 98.60%, resulting in an average measurement accuracy of 98.23%.

d. Measurement Error

The measurement error observed for healthy individuals was relatively low, ranging from 1.02% to 2.10%, with an average error of 1.59%. The low error values indicate that the proposed system closely matches manual anthropometric measurements and maintains consistent performance across subjects of different ages and body dimensions.

The proposed system also achieved a low measurement error for amputee subjects. The error values varied between 1.40% and 2.10%, with an average measurement error of 1.77%. Despite the absence of one upper limb, the system maintained stable and accurate measurements using the available anatomical features

Section 3: COMSOL Simulation Results

To evaluate the suitability of candidate materials for prosthetic arm fabrication, COMSOL Multiphysics was employed to perform Finite Element Analysis (FEA). A three-dimensional CAD model of the prosthetic component was imported into COMSOL, where identical thermal and mechanical boundary conditions were applied to each material. The simulations were carried out using PLA, PETG, and Polysulphone to investigate their thermal and structural performance. The materials were compared based on temperature distribution, maximum temperature resistance, thermal conductivity, stress distribution, deformation, and environmental resistance to identify the most suitable lightweight material for prosthetic arm development.

a. Temperature Distribution

The COMSOL thermal analysis showed that there were perceptible differences in the temperature profiles of the materials studied. Polysulphone had the highest max temp resistance at 400K followed by PETG 380K and PLA 350K. The temperature contours showed that the temperature in the prosthetic parts under the simulation operating conditions was stable.

b. Stress Distribution

Stress analysis showed that Polysulphone is the material with the highest stress (110 MPa), followed by PETG (80 MPa) and PLA (60 MPa). Stress distribution showed that Polysulphone had better load bearing properties than the other materials.

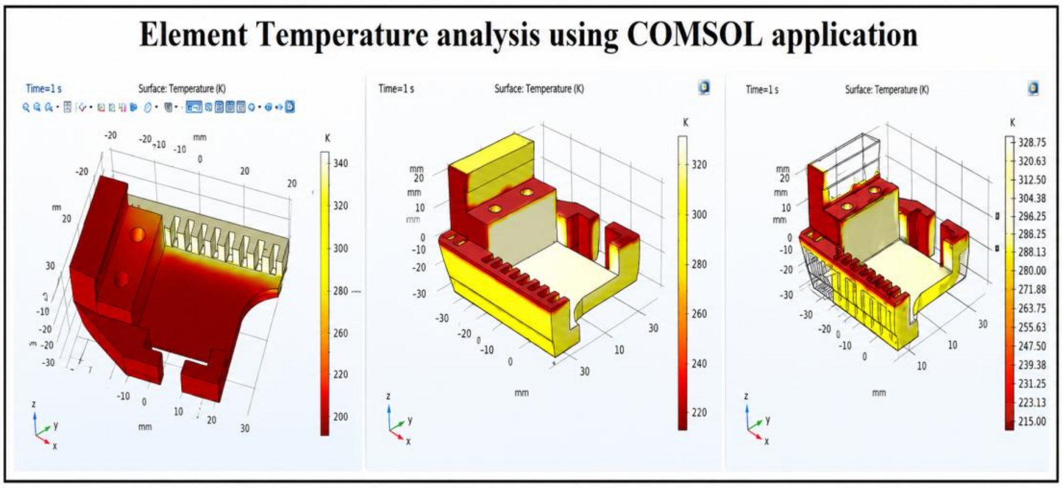

Figure 5: Illustrates the temperature distribution obtained from the COMSOL thermal analysis of the prosthetic component under the specified operating conditions.

Figure 5 illustrates the COMSOL-based thermal analysis of the prosthetic component fabricated using PLA. The temperature distribution ranges from 300 K to 400 K, where the red region represents the lower temperature zone and the white region represents the higher temperature zone. The simulation demonstrates the thermal behaviour of the prosthetic component under the applied operating conditions and assists in evaluating the thermal suitability of the selected material.

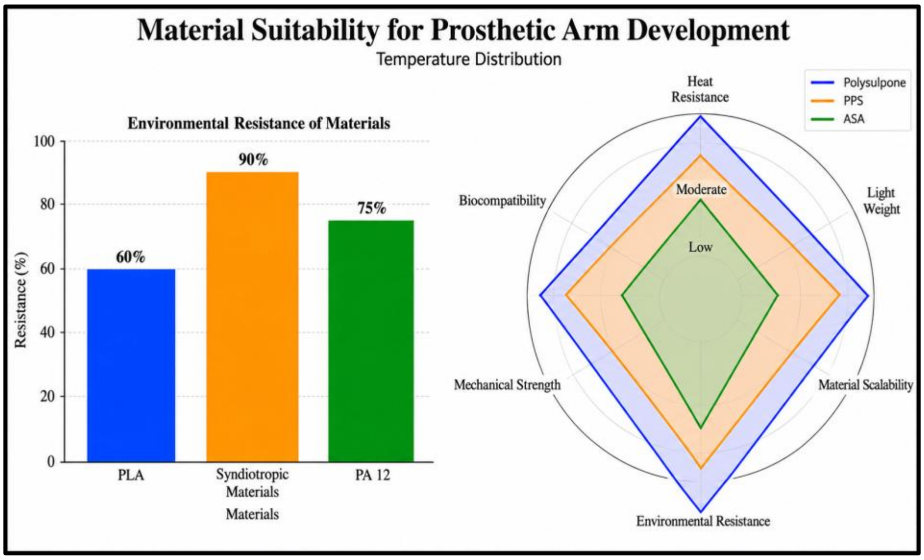

Figure 6: Environmental Resistance of Materials

c. Deformation Analysis

From the results of the deformation analysis, the lowest structural deformation was observed in Polysulphone (0.5 mm), where PETG showed 1.0 mm and PLA showed 1.8 mm indicating that the Polysulphone had the highest dimensional stability under the mechanical loading applied.

d. Thermal Conductivity

From the simulations, the thermal conductivity values were found as 0.13 W/m·K for PLA, 0.22 W/m·K for Polysulphone, and 0.24 W/m·K for PETG. The simulated results showed that there are heat transfer differences between the materials selected.

Table 5. COMSOL Simulation Results of Candidate Materials

SL.No.	Material	Thermal Conductivity (W/m·K)	Maximum Temperature (K)	Stress (MPa)	Deformation (mm)	Environmental Resistance (%)
1	PLA	0.13	350	60	1.8	60
2	PETG	0.24	380	80	1.0	75
3	Polysulphone	0.22	400	110	0.5	95

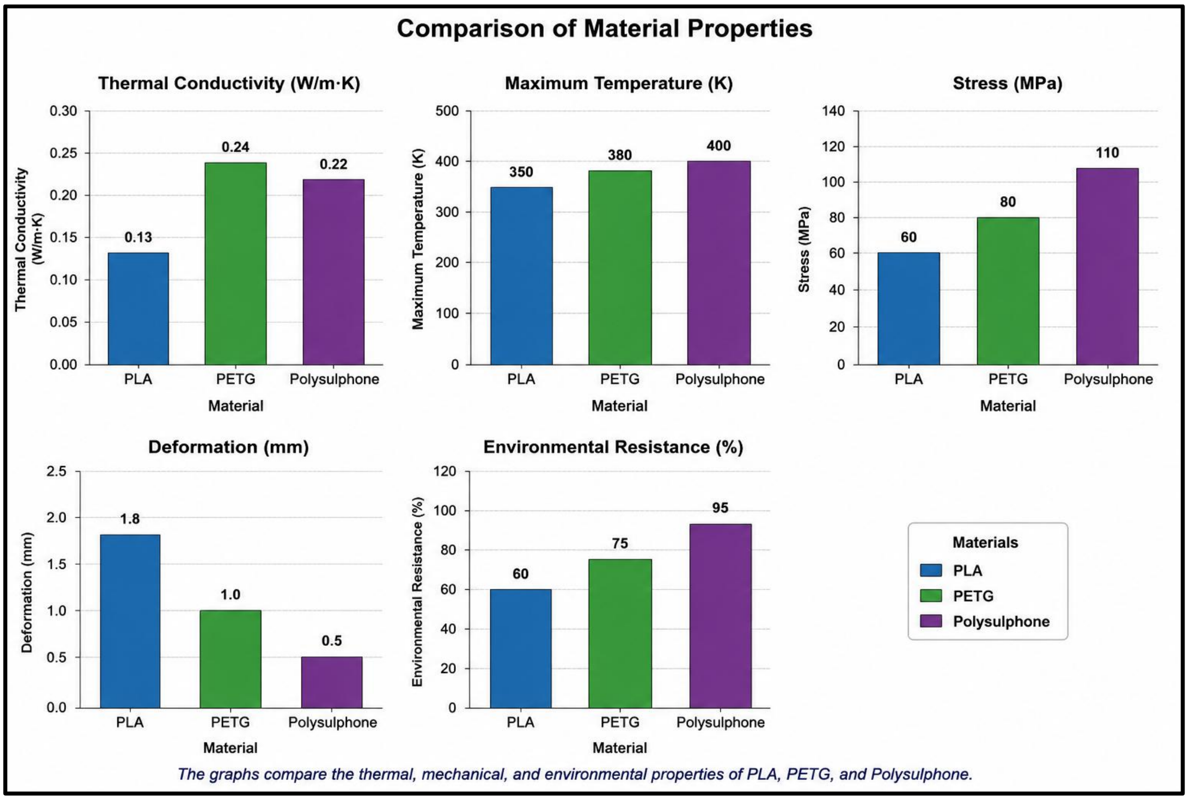

Figure 7: Comparison of Thermal, Mechanical, and Environmental Properties of PLA, PETG and Polysulphone

e. Material Comparison

The comparative analysis of the simulation results showed that Polysulphone was the most appropriate material for the critical parts of the prostheses based on the following parameters: stress resistance, deformation, temperature resistance and environmental durability. PETG had medium mechanical properties and thermal properties, and PLA was more suitable for non-load-bearing and cosmetic parts. The results of the evaluated materials in terms of their comparative properties are given in below table.

Section 4: Final Material Selection

The materials were compared and ranked based on the results of the comparative evaluation of the thermomechanical and biocompatibility properties. Polysulphone performed best in all areas of testing, with excellent stress resistance, minimal deformation, excellent temperature resistance and high environmental durability.

The second best was PETG, with a moderate thermal and mechanical performance, which is ideal for structural parts. Despite being a relatively weak and poor thermal resistance material, PLA was still well suited for lightweight, non-load bearing and cosmetic prosthetic components. The summary of the final material ranking is:

1. Polysulphone (Most Preferred)
2. PETG
3. PLA

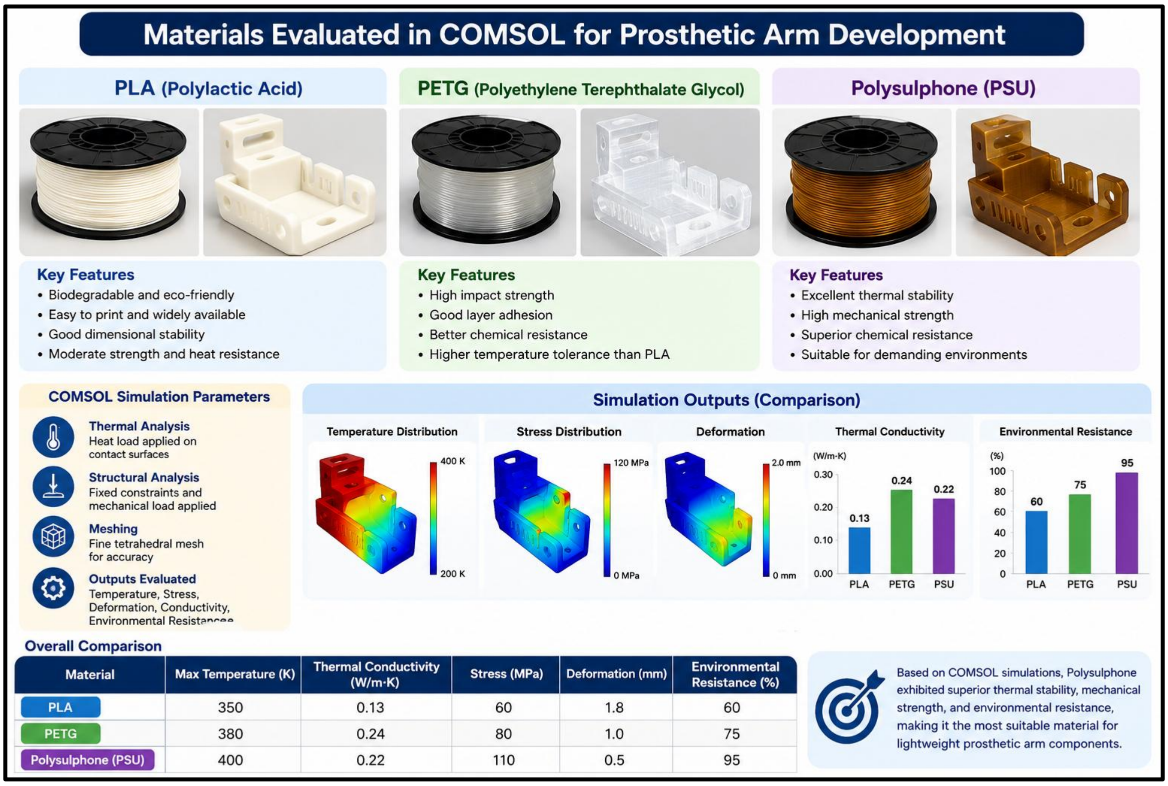

Figure 8: COMSOL-Based Comparative Analysis of Candidate Prosthetic Materials

Table 6. Final Ranking of Candidate Materials for Prosthetic Fabrication

Rank	Material	Key Characteristics	Recommended Application
1	Polysulphone	High stress resistance, low deformation, excellent thermal stability, high durability	Socket, wrist, fingers, motor mounts
2	PETG	Moderate thermal and mechanical performance	Structural frame and assembly
3	PLA	Lightweight, biodegradable, lower mechanical strength	Cosmetic covers and non-load-bearing components

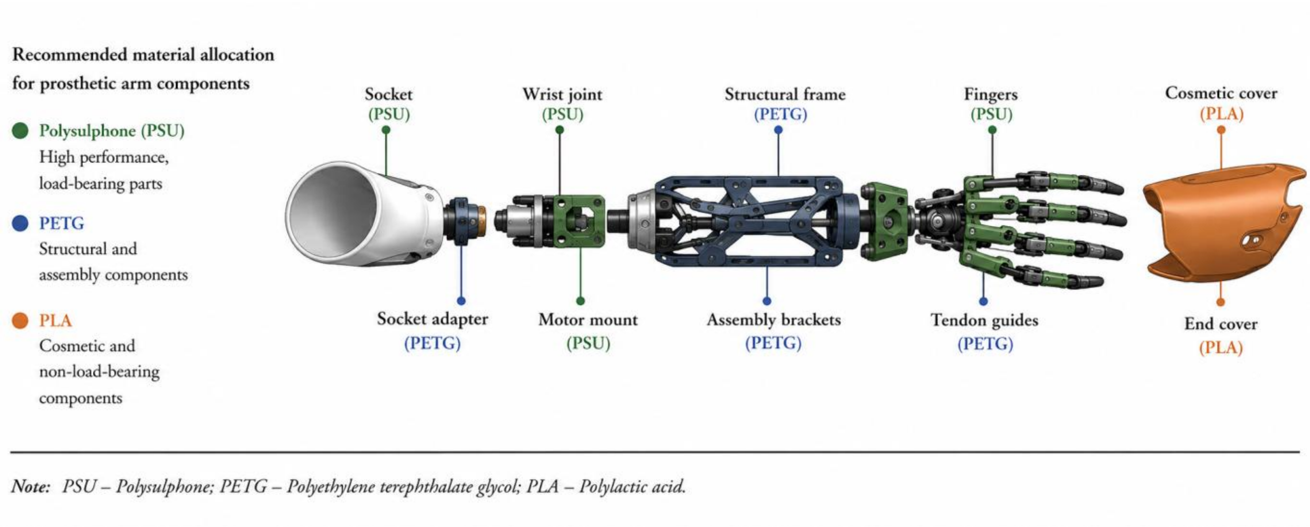

Figure 9: Material Selection and Component-Wise Allocation for the Proposed Transradial Prosthetic Arm

5. Discussion

The measurement accuracy of the developed GUI-based remote limb measurement system was also found to be very high, showing a negligible error, which indicated that the developed system for remote measurement of the upper limbs is reliable for anthropometric measurement of the upper limbs. The results are in agreement with the previous studies which reported the effectiveness of computer vision techniques for the non-contact measurement. By combining MediaPipe and image-processing algorithms, it was made possible to accurately estimate hand and arm dimensions by means of an intuitive interface. The clinical benefit of the proposed system can lead to fewer visits to the hospital for repeated measurements and customization of prosthetics, can facilitate the application of tele-rehabilitation, and can enhance access to prosthetic services, especially for persons living in distant areas.

The COMSOL simulation results showed that the thermal and mechanical properties of Polysulphone were better than those of PETG and PLA. It is used for load-bearing and skin-contact prosthetics due to its higher temperature tolerance, stress level resistance, and low deformability. PETG had good structural properties, while PLA was suitable for lightweight cosmetic applications. Polysulphone is a little more costly but it has got greater durability and safety making it a better choice for critical use in prosthetic applications. In conclusion, the results of the simulation support a material selection approach based on mechanical properties, thermal protection, and cost that can be used to create lightweight, transradial prosthetic arms.

The integration of computer vision-based anthropometric measurement with COMSOL-assisted material evaluation provides a comprehensive framework for the design and development of customized transradial prosthetic arms. The proposed methodology not only improves measurement accuracy but also enables informed material selection by simultaneously considering thermal stability, mechanical strength, structural deformation, and environmental durability. Such an integrated approach minimizes design iterations, reduces fabrication time, and enhances the overall reliability of prosthetic devices. Furthermore, the modular architecture of the developed GUI allows future integration with additive manufacturing (3D printing), cloud-based patient databases, and artificial intelligence-based prosthetic design optimization. These capabilities support rapid customization, cost-effective production, and remote clinical services, making the proposed system a promising solution for next-generation prosthetic rehabilitation, particularly in resource-constrained and rural healthcare environments.

6. Conclusion

The present study proposed an integrated transradial prosthetic arm development model by using a material optimization system with COMSOL software and a GUI-based remote limb measurement system to develop an affordable lightweight transradial prosthetic arm. The designed GUI was able to reliably measure and estimate anthropometric dimensions of the upper-limb with high measurement accuracy and a minimal error, thus successfully establishing the potential of remote assessment and customization of prosthetic devices. A comparative study of PLA, PETG, and Polysulphone has also been conducted and this was possible thanks to the finite element analysis. Polysulphone had the best overall results and was the material of choice for critical components of prostheses. The proposed framework provides a practical solution to decrease clinical dependency, aids in personalized design of the prostheses and encourages cost-effective indigenous development of prostheses in India. The integration of computer vision-based anthropometric measurement with COMSOL-assisted material optimization demonstrates a promising approach toward next-generation digital prosthetic design. Furthermore, the proposed framework has the potential to improve accessibility, reduce fabrication time and support personalized prosthetic rehabilitation in resource-constrained healthcare settings.

7. Future Scope

The proposed framework can be further improved by the addition of the image acquisition from the smart phone and sharing of data using cloud technology, for real time tele-rehabilitation. Machine learning and artificial intelligence algorithms could be included in future studies to enhance measurement precision and automate the prosthetic customization process. The developed system may further be combined with 3D printing to achieve the rapid manufacturing of personalized prosthetics.

Future work may also incorporate digital twin technology, IoT-enabled remote monitoring and advanced biomechanical simulations to further enhance prosthetic performance and patient-specific customization. Additionally, clinical validation involving a larger and more diverse amputee population will improve the reliability and translational potential of the proposed system for real-world rehabilitation applications.

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