Final Year Project Showcase Batch 2021
Year 2025

Department: Industrial and Manufacturing Engineering

Programme: Industrial and Manufacturing Engineering

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Project Title

Design and Prototyping of 3D Surface Profiling Device Using Optical Imaging.

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Project Idea

The core idea of this project is to revolutionize the paradigm of quality control in manufacturing by developing a 3D surface profiling device that precisely measures surface roughness at the millimeter level. This device envisions a noncontact and nondestructive measurement technique, shifting from traditional linear measurements to precise area measurements. It is motivated by the increasing demand for high product quality and the challenges posed by soft samples and tiny surface features that cannot be inspected with conventional stylus probes. The project aims to automate workflow analysis for surface metrology, ensuring compliance with international standards such as **ISO 4287/4288** for surface roughness measurement and **ISO 16610** for non-contact measurement. It utilizes optical imaging, specifically confocal microscopy, integrated with a 3D scanner and camera for image processing to capture surface characteristics without physical contact. This capability allows manufacturers to identify and correct defects early in the production stage, aiding in the quality assurance of new materials with distinctive surface properties.

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Process

The methodology adopted for this project involved several key stages:

1. Literature Review

A comprehensive review of existing literature, patents, and standards in surface metrology was conducted to identify research gaps. Focus areas included contact and non-contact measurement methods (e.g., White Light Interferometry, Confocal Microscopy), surface parameters, optical principles, structured light, photogrammetry, and related imaging and electrical technologies.

2. Selection of Components

Market research guided the selection of key components for system integration. Major elements included a Raspberry Pi 4B (8GB), 12MP Pi Camera Module 3, linear actuator, HDMI touchscreen, control boards, light sources, and various interfacing modules. A complete Bill of Materials (BOM) was documented.

3. Mechanical Design and Fabrication

The structural design was developed in SolidWorks with three iterations to enhance integration and manufacturability. FEA simulations in Ansys validated structural integrity. Final construction used ASTM A36 Carbon Steel, with 3D-printed components and assembled hardware.

4. System Integration

The system was electrically and mechanically integrated. Raspberry Pi controlled the actuator via a dual-relay H-bridge and interfaced with the camera through CSI. Manual push buttons and isolated power supplies ensured safe operation. Assembly involved welding, soldering, and adhesives.

	5. Software Development A Python-based "Surface Analysis Tool" was created with real-time and offline modes. It computes roughness parameters (Ra, Rq, Rz, Rt), detects peaks, and estimates surface angles using OpenCV, NumPy, SciPy, Matplotlib, and Tkinter. The pipeline includes edge detection, profile extraction, smoothing, and interpolation. ***6. Experimental Validation*** The system was tested on various material surfaces (flat, textured, patterned) to optimize parameter extraction and verify functional performance. ***7. Accuracy Evaluation*** Device outputs were benchmarked against commercial systems (Mitutoyo SJ-410 and handheld testers). Accuracy was evaluated using statistical metrics such as correlation analysis, MAE, and residual error.
4	**Outcome** The project successfully developed a working prototype of a 3D Surface Profiling Device using Optical Imaging. The device is capable of: • Visualizing surface features not visible to the naked eye. • Measuring surface parameters such as roughness and waviness in millimeters. • Protecting delicate samples from destruction through non-contact measurement • measurement. • Real-time monitoring of surface parameters on an integrated touchscreen display. • Adaptability to work with different types of surfaces and materials. • Achieving precision in millimeters, accounting for environmental fluctuations. • Complying with ISO standards for surface roughness measurement (ISO 4287/4288) and non-contact measurement (ISO 16610). • Automating workflow analysis for surface metrology. • Capturing real product previews with up to 10x magnified imaging without needing CAD models for inspection. The accuracy evaluation showed a 55% accuracy gap when compared against the Mitutoyo SJ410 and a 63% accuracy gap with a handheld surface roughness tester, with excellent agreement for Ra and Rq parameters and identifiable differences for Rz due to the optical differences for Rz due to the optical system's higher sensitivity to extreme topographical features. The measurement errors were found to be random and centered at zero, indicating a well-calibrated system free from systematic bias.
5	**Evidence (Theoretical Basis)** This project focuses on surface metrology and optical imaging. Surface metrology is the field of measuring and analyzing small 3D surface structures like waviness and roughness in order to support quality control in an organization's engineering processes. The system employs contactless optical measurement techniques to capture high-resolution, non-destructive measurements. Core methods include: • ***Confocal Microscopy:*** High-resolution 3D imaging is performed with selective focus in complex geometries using lasers, beam splitters, and pinholes, which is beneficial for intricate surfaces. • ***Interferometry:*** Measures displacements on the surface of an object using the interference of light waves (WLI, PSI). • ***Structured Light Scanning:*** Projects structured patterns to capture 3D surfaces and uses distortions to reconstruct them.

	• ***Photogrammetry:*** Creates 3D models using triangulation and images with known coordinates. • ***Image Processing:*** Applies noise and edge preserving filters (Bilateral, Anisotropic Diffusion) to slice images and turn them into 3D data. • ***Visualization:*** Real-time rendering of 3D surfaces. • ***Key Surface Parameters:*** The equipment measures and evaluates standard parameters of surface roughness, Arithmetic Mean Deviation (Ra), Root Mean Square Deviation(Rq), and Maximum Height (Rz).
6	**Impact on Sustainability of Urban Regions or SDG-11 "Sustainable Cities and Communities"** While SDG-11 focuses on "Sustainable Cities and Communities" through aspects like safe housing and sustainable transport, the project's primary contribution to sustainability, as articulated in the sources, is more directly aligned with sustainable production and consumption patterns that underpin resilient urban development. The device contributes by Reducing Energy Consumption: By ensuring minimal surface roughness, the device helps reduce rework time in manufacturing processes, which in turn leads to a direct reduction in the energy consumption of mechanical machines. This efficiency gain in industrial production indirectly supports more sustainable resource use within urban industrial zones. Promoting Efficient Resource Use: Its ability to identify and correct defects early in the production stage directly minimizes waste and enhances material efficiency in manufacturing. This aligns with the broader goals of sustainable industrial practices that reduce the environmental footprint of production within urban and regional contexts. The project represents an "upgraded solution for surface metrology and testing with alignment of selected sustainable development goals", aiming to improve the sustainability of manufacturing practices that are often concentrated in or supply urban regions.
7	**Competitive Advantage or Unique Selling Proposition** The 3D Surface Profiling Device offers several compelling advantages and unique selling propositions for the industry: • Our 3D Surface Profiling Device, developed at a cost of PKR 90,000, offers a non-contact, optical measurement solution using confocal imaging integrated with Raspberry Pi. • Unlike traditional stylus-based systems, it avoids damage to soft or delicate materials and supports real-time surface visualization. • Commercial systems like Olympus OLS5100 and Nanovea PB1000 cost several million PKR, making our device a cost-effective alternative for academic and SME use. • It features a user-friendly interface, live monitoring, and adaptability to various surface types without the need for CAD models. • The system ensures compliance with ISO 4287/4288 and ISO 16610 standards for surface roughness and non-contact metrology. • With modular architecture and open-source software, it offers flexibility for customization and further research. • Compared to stylus profilometers, our device provides higher usability, faster operation, and eliminates destructive testing. • This prototype bridges the gap between low-cost basic tools and high-end industrial systems, making precision metrology more accessible. • Its portability, automation, and visualization features position it uniquely in the affordable optical metrology space.

a	**Attainment of any SDG** ***SDG 3: Good Health and Well-being*** This device advances SDG 3 by enhancing surface quality control of medical devices using non-contact, non-destructive techniques. It inspects critical biocompatible components such as prosthetic and implant devices and ensures that their surfaces exceed minimal acceptance levels which improves the safety and performance. Its adaptability to new materials facilitates the construction of more sophisticated and health-oriented materials. ***SDG 9: Industry, Innovation, and Infrastructure*** This device catalyzes industrial innovations since it will permit a fast and non-contact inspection of the quality of surfaces using QR codes giving an early warning of defects and better tool use. It improves performance, facilitates precision production and diminishes faults, which leads to economies of scale. Being a new metrology solution, it fills the gaps in the surface measurement and reinforces the industrial infrastructure. ***SDG 12: Responsible Consumption and Production*** The device produces minimum waste since its non-destructive testing uses less rework and energy. It encourages effective using the resources, sustainable production, and profitable production and reduces environmental burdens along the production chain.
b	**Environmental Aspect** The device promotes energy efficiency by reducing rework time in manufacturing, thereby decreasing the energy consumption of decreasing the energy consumption of mechanical machines. This directly contributes to a reduction in the carbon footprint associated with industrial processes.
c	**Cost Reduction of Existing Product** The ability to "identify and correct defects early in the production stage" translates into significant cost savings by reducing rework and waste. A higher production rate with fewer defects leads to lower unit costs due to economies of scale.
d	**Process Improvement which Leads to Superior Product or Cost Reduction, Efficiency Improvement of the Whole Process** The device offers "super-fast" quality checks and non-destructive sample testing, which are substantial improvements over traditional contact methods. It aids in "optimizing the manufacturing processes and in the optimizations of SOPs" and enhances the "productivity of manufacturing firms" by streamlining quality control.
e	**Expanding of Market share** This PKR 90,000 optical profiling system targets academia, R&D labs, and SMEs requiring affordable, ISO-compliant surface metrology. • Its non-contact, real-time imaging meets the growing demand for non-destructive testing in materials, biomedical, and precision manufacturing sectors. • The device's modularity and open-source architecture enable integration into educational curricular and applied research projects. • Limited availability of cost-effective alternatives positions our device to replace imported systems in developing regions. • Collaborations with universities and incubation centers can drive early adoption and local industry awareness. • Scalability, customization, and academic partnerships will support sustained growth in the affordable metrology segment.

f	**Capture New Market** The device addresses the unmet demand for noncontact and nondestructive measurement techniques for soft samples, films, and surface features smaller than stylus probes. This opens up niche markets for quality assurance of "new materials with distinctive surface properties" and applications in areas like "agriculture or field inspection", dermatology, tissue analysis, and food quality control. It also provides features for mapping precision across diverse materials and applications.	
g	**Any Other Aspect (Please tag it like above options)** Superior Performance: Offers "clear, high-contrast images" with "high XY resolution" and "high angle detection" for steeply inclined slopes.	
8	**Target Market** The target market for this 3D Surface Profiling Device is broad and includes various industries, groups, and individuals requiring precise surface characterization: • ***Manufacturing and Engineering Firms:*** Especially those focusing on quality assurance, precision manufacturing (e.g., making dyes and molds), and process optimization. • ***Materials Science:*** For characterization and analysis of new and existing materials. • ***Quality Control Departments:*** Across various sectors for ensuring product compliance with industry regulations and standards. • ***Aerospace and Automotive Industries:*** Where surface finish significantly impacts performance, safety, and aesthetics. • ***Medical Device Manufacturers:*** For checking the smooth curves of prosthetics and ensuring biocompatibility. Potential for use in dermatology or tissue surface analysis. • ***Research and Development Laboratories:*** In academic institutions and industrial settings, for studying new materials, technologies, and analyzing material behavior (e.g., fatigue resistance, corrosion resistance, adhesion). • ***Educational Institutions:*** As a tool for students to understand and experiment with optical-based metrology. Industries requiring non-contact and non-destructive testing: Especially for delicate or soft samples like films, or those with small surface features. • ***Archaeology and Reverse Engineering:*** For studying surface patterns on rocks or analyzing existing equipment. • ***Agriculture and Field Inspection:*** For portable, on-site analysis (future work). • ***Food Quality Control:*** For analyzing surface properties of food products (future work).	
9	**Team Members** (Names along with email address	1) Muhammad Mubashir Aftab (mubashiraftab27@gmail.com) 2) Anusha Ahmed(anushaahmedbaig@gmail.com) 3) Muhammad Abdullah Sikandar(mabdullahsikandar@gmail.com) 4) Muhammad Zohaib Siddiqui(zohaibsiddiqui754@gmail.com)
10	**Supervisors Name** (along with email address)	1) Dr. Muhammad Wasif (mwasif80@gmail.com) 2) Mr. Danish Saleem (mdanishsaleem@cloud.neduet.edu.pk)
11	**Video (If any)**	https://drive.google.com/file/d/1Dn1k9TFNRRfIdTkbpodTCWPhxmcJ8RDK/view?usp=drivesdk

Pictures (If any)

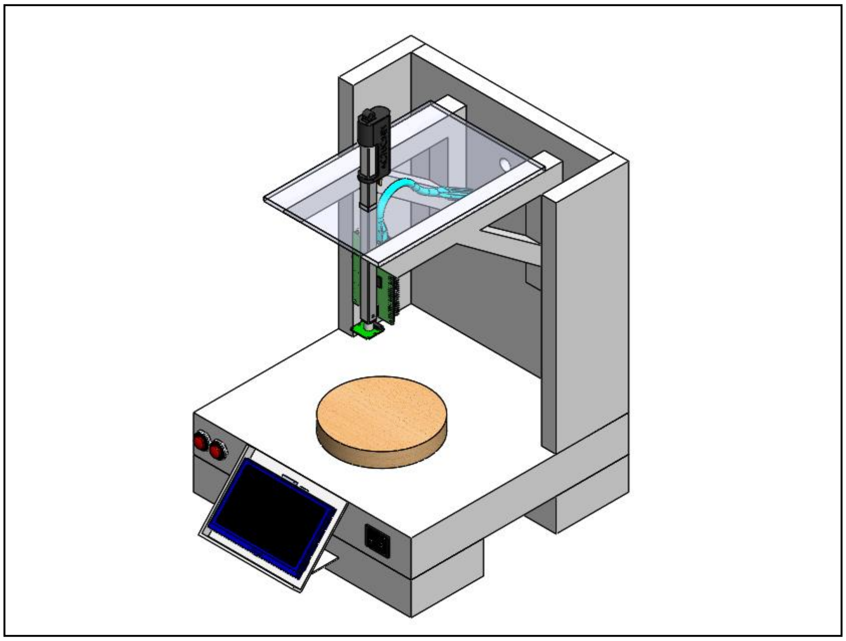

Figure 1: CAD model of 3D surface profiling device

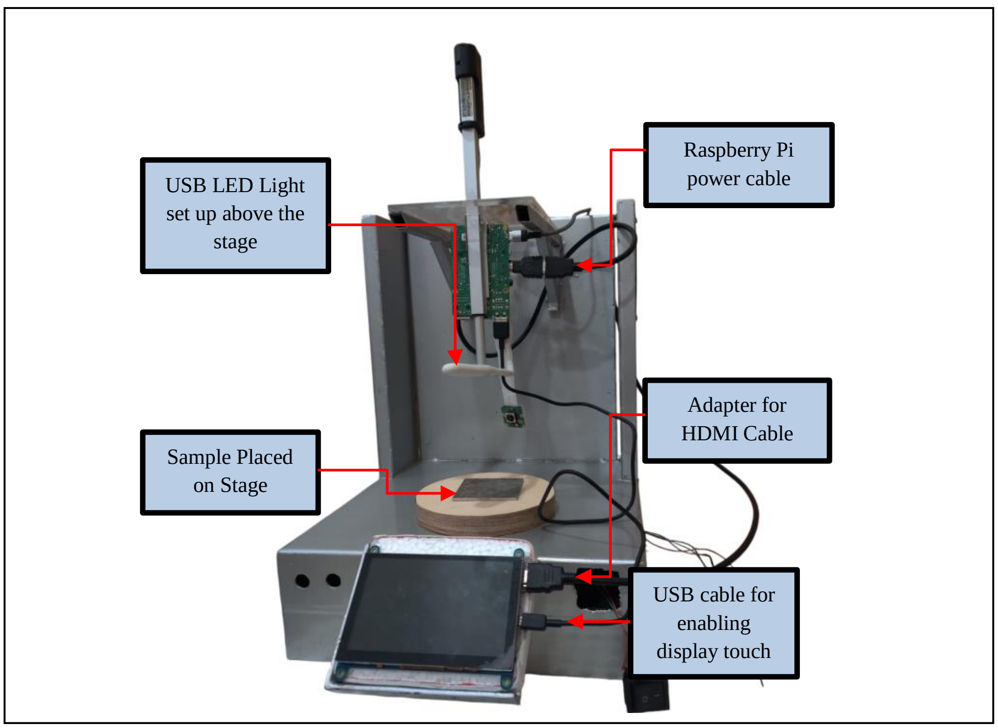

Figure 2: Working Prototype of 3D Surface Profiling device

Results

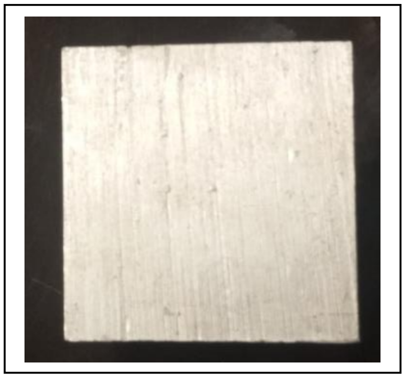

Figure 3: A sample tested

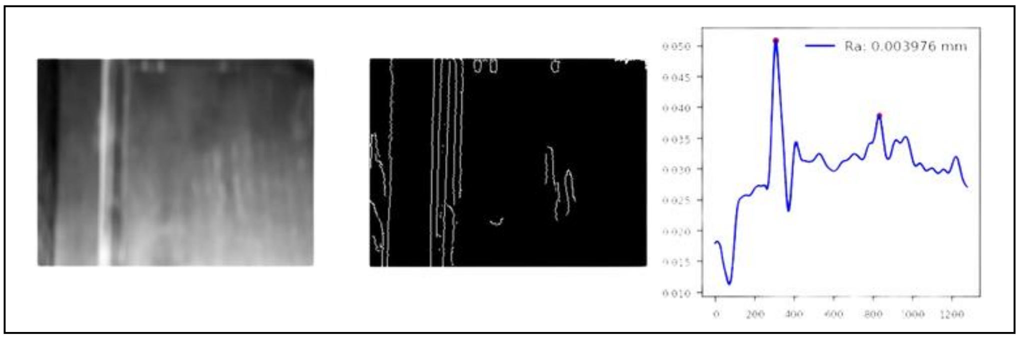

Figure 4: Image captured in Main tab for sample

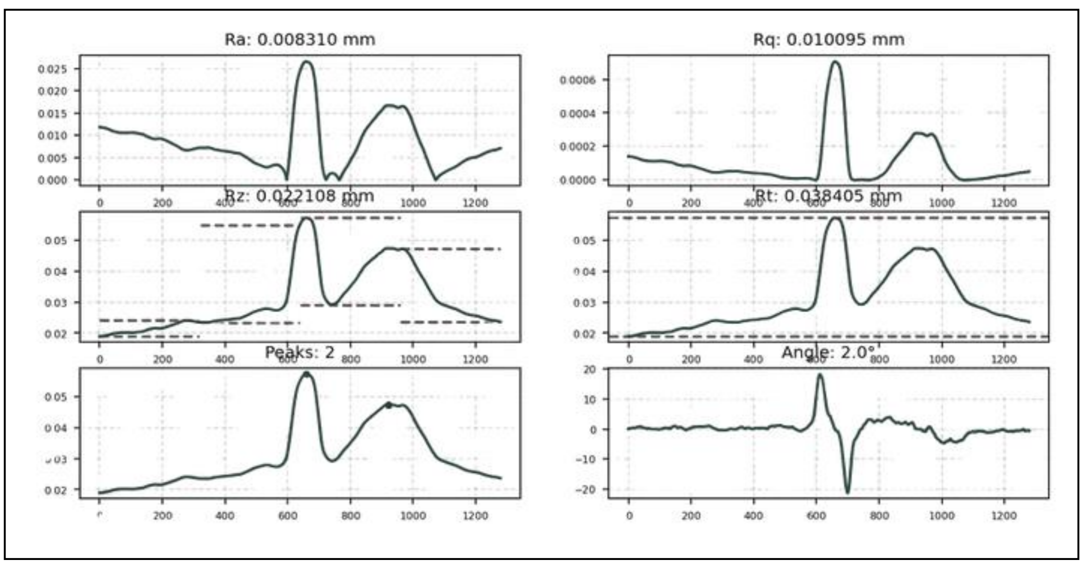

Figure 5: Roughness Parameters in Readings Tab for sample