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by Syeda Beena Bukhari

Final Year Project Report

3D Mapping of building For Inspection

B.S. in Computer Engineering, Batch 2020F

Project Advisor
Dr. Rabia Noor Enam
Professor
SSUET

Submitted By:

Ahmed Baseer (GL)	2020F-CE-124
Arbaz Moin	2020F-CE-111
Arisha Fateh	2020F-CE-117
Talha Hussain Khan	2020F-CE-114

DEPARTMENT OF COMPUTER ENGINEERING
Sir Syed University of Engineering & Technology
University Road Karachi - 75300

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Preface

The report presents our Final year project, **"3D Mapping of Building for inspection"**. It represents reconstruction and visualization for building surfaces. Our goal is to revolutionize building assessments with advanced technologies for precise evaluations. By automating manual assessments, we aim to enhance accuracy, efficiency, and quality, reducing the need for specialized personnel. This project has enriched our technical skills and highlighted the importance of innovation. We believe our system will significantly improve building assessment practices, ensuring quality and safety, and paving the way for future advancements.

Acknowledgements

IN THE NAME OF ALLAH [THE MOST GRACIOUS, AND Beneficent of all], Alhamdulillah people who gave us the strength to be able finish our Final Year Project. We have went to great lengths in this project. But without the incredible backing and aid of many individuals, it wouldn't have been possible.We are truly appreciative of them all for the same! We are highly thankful to the teachers for marking their presence with us at every step and for giving them all Project-related information and supporting us in this project. We would also like to present our deepest thanks to our Project Main Supervisor **Prof. Dr. Rabia Noor Enam** and also with **Dr.Santhan Manthavan CEO of Road Level Company(UK)** with our Fyp head **Miss Saba Ahsan**. Thanks a lot as you people who gave us such huge support and hands. We feel motivated and encouraged every time we went to one of their meetings. It is here that without their training and support this have come to fruition without the project We would also like to acknowledge the teaching faculty from Friendly advice, Thank you to everyone in Computer Engineering department and also the University staff for providing us with an opportunity of working lastly to everyone in the cohort for working with us on this project, and providing constant feedback throughout developing of this project. We would also thank the FYPC for giving us this amazing opportunity to do some work on this project, their gentle co-operation and encouragement guided us in attaining the goal of this project. We also thanks and appreciate to all our project partners in developing the part of the project from efforts. The people who are involved in this project whose suggestions, guidance and help was crucial.

Introduction to Group Members

Ahmed Baseer (GL) (2020F-CE-124) Data Collection / System Programmer / 3D Model Designer / Hardware

Contact No: +92 316 3670504

Email: ce20f-124@ssuet.edu.pk

Arbaz Moin (2020F-CE-111)

Data Collection / System Programmer / 3D Model Designer / Hardware

Contact No:+92 334 2652903

Email:ce20f-111@ssuet.edu.pk

Arisha Fateh (2020F-CE-117)

Data Collection / Front End Developer / Database Designer /Technical Documentation

Contact No:+92 318 3043317

Email:ce20f-117@ssuet.edu.pk

Talha Hussain Khan (2020F-CE-114)

Data Collection / Backend Developer / Hardware / Research paper

Contact No: +92 347 2548707

Email:ce20f-114@ssuet.edu.pk

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Chapter 1

Introduction

1.1 Introduction

3D Reconstruction for Buildings leads the 3D mapping industry, specializing in construction and building inspection sectors. Renowned for pioneering, cost-effective solutions, the company transforms traditional building evaluations with state-of-the-art technology. Its innovative approach not only enhances accuracy but also significantly reduces time and costs associated with inspections. Furthermore, the company's commitment to ongoing research and development ensures continuous advancement and adaptation to evolving industry needs.

1.2 Overview

3D Reconstruction for Buildings is a leader in the 3D mapping industry, particularly in the construction and building inspection sectors. The company is celebrated for its groundbreaking and cost-efficient solutions, which revolutionize traditional building evaluations through advanced technology. This innovative approach improves accuracy and significantly cuts down on the time and expenses involved in inspections. Additionally, the company's dedication to continuous research and development fosters ongoing progress and adaptation to the changing needs of the industry.

1.3 Objectives

The objectives of this project are to outline the goals and purposes behind our work on 3D reconstruction for building inspection. Specifically, we aim to:

1. Discover and Prove:

Develop an innovative 3D computer vision approach that integrates 2D-3D methods for accurate building inspections.

2. Problem Focus:

Address the inefficiencies and limitations of traditional inspection methods by leveraging advanced technological solutions.

3. Rationale for Problem:

Recognize the need for enhanced inspection techniques in the construction industry to improve accuracy, reduce costs, and expedite processes.

4. Assigned Problem Justification:

Understand that our advisor assigned this problem to help us learn the application of cutting-edge technologies in real-world scenarios, enhancing our technical and analytical skills.

5. Customer Reviews:

Facilitate a platform for customers to read and leave reviews, helping others make informed purchasing decisions.

6. Multi-Device Compatibility:

Deliver a responsive website design that ensures seamless browsing and uploading of frames, providing point clouds with accurate scale estimation.

1.4 1.1 System Features:

In this section, we approach towards achieving our project goals .

- **Goal:** Our primary endeavor is to pioneer an advanced 3D mapping algorithm, integrating state-of-the-art 2D-3D methodologies. This amalgamation aims to furnish precise reconstructions facilitating thorough building inspections.
- **Problem Significance:** We embark on this endeavor to confront the inadequacies prevalent in conventional inspection techniques. Through the deployment of cutting-edge 3D mapping solutions, our objective is to ameliorate accuracy, efficiency, and cost-effectiveness within the inspection domain.
- **Advisor's Directive:** The assignment of this problem by our advisor serves as a conduit for honing our practical acumen in employing technologies within real world contexts. Our engagement with this project is expected to foster not only technical prowess but also analytical dexterity in the realm of 3D mapping and computer vision.
- **Key Insights for Readers:** Upon perusing our report, readers will attain a comprehensive understanding of the transformation potential inherent in 3D mapping for revolutionizing building inspection paradigms. They will gain nuanced insights into the intricacies of our proposed system, its implications for augmenting operational efficiency, and its pivotal role in advancing industry standards.

1.5 Summary

In the culmination of our project, we've paved new paths in 3D mapping for building inspection. Our efforts led to the development of an advanced algorithm, adeptly merging 2D-3D methodologies. This distinct approach ensures precision and effectiveness, surmounting the traditional constraints of inspection techniques. With guidance from our mentor, we tackled practical challenges while honing our skills in employing state-of-the-art technologies. Our discoveries underscore the transformative potential of 3D mapping, providing valuable insights into its ability to improve accuracy and cost efficiency in construction. As readers explore our report, they'll encounter a narrative characterized by innovation, dedication, and a relentless pursuit of excellence in computer vision and spatial analysis.

Chapter 2

Literature Review

2.1 Introduction

LiDAR (Light Detection and Ranging) technology has been a cornerstone in the field of building inspection, particularly for generating high-resolution 3D models of structures. However, the high cost associated with LiDAR systems has prompted researchers to explore more affordable alternatives that can deliver similar levels of accuracy. This literature review examines various approaches that have been proposed or tested as alternatives to LiDAR, focusing on their potential to reduce costs while maintaining effectiveness in building inspections.

2.2 Integration of Multimodal Imagery Sensors in Robotic Systems

Recent progress in robotic systems for building inspections has emphasized the integration of multiple sensor types. Halder and Afsari (2023) conducted a systematic review that highlights the increasing use of robots equipped with sensors such as RGB cameras, infrared cameras, and LiDAR for monitoring and inspection purposes. Their study underscores the benefits of sensor fusion, where data from different sources are combined to mitigate the limitations of individual sensors, thereby reducing the dependency on LiDAR. This integration supports real-time analysis and geo-registration of defects within 3D models, making the inspection process more cost-effective while retaining accuracy.

2.3 Hand-Held 3D Thermal Mapping Systems

A promising approach to reducing reliance on LiDAR involves the development of hand-held devices that merge RGB-D and thermal cameras. Vidas, Moghadam, and Bosse (2013) introduced a low-cost system capable of generating dense 3D models with integrated thermal data. This system combines color, thermal-infrared, and depth information using affordable hardware, which is particularly useful for energy efficiency assessments and maintenance tasks by vidas 2023. The portability and ability to provide detailed thermal and spatial data without expensive LiDAR equipment make this approach especially attractive for building inspections. While these systems may not yet fully replace LiDAR, their accuracy is sufficient for various applications, particularly in energy assessments and routine maintenance.

2.4 Stereo Vision and Real-Time 3D Reconstruction

Computer vision techniques have been explored as an alternative to LiDAR for 3D reconstruction and visual inspection. Wang and Gan (2023) developed an automated system that combines computer vision and transfer learning for joint 3D reconstruction and visual inspection. Using stereo vision, the system offers a more affordable solution compared to LiDAR while maintaining a high level of detail in the reconstructed models(wang 2023). Although stereo vision systems are generally less accurate than LiDAR, they can be effectively used in building inspections where absolute precision is not critical. The incorporation of machine learning further enhances these systems, making them viable alternatives in certain contexts.

2.5 RGB-D Mapping for Dense 3D Modeling

RGB-D devices, like those utilized in Microsoft's Kinect, have been widely studied for their potential in indoor 3D modeling. Yuan et al. (2021) provided a comprehensive survey on the application of RGB-D devices in indoor 3D modeling, including building inspections. Although these systems are less precise than LiDAR, they offer a cost-effective alternative that can be improved through post-processing and data fusion techniques (yaun 2021). The fusion of RGB-D data with other sensor inputs, such as thermal and infrared cameras, can enhance model accuracy, making this approach suitable for various building inspection tasks.

2.6 Photogrammetry as a Cost-Effective Surveying Tool

Photogrammetry has gained attention as a low-cost alternative to LiDAR, particularly in volumetric surveys and building inspections. Staats (2021) compared photogrammetry with terrestrial LiDAR, showing that while photogrammetry requires more post-processing and is less accurate in capturing fine details, it still provides sufficiently detailed models for many inspection purposes (saats 2021). The affordability of photogrammetry, along with the widespread availability of the required equipment, makes it an attractive option for inspections where cost constraints are a major concern.

2.7 Drone-Based Indoor and Exterior Inspection Systems

Drones have become increasingly popular in building inspections, especially in challenging environments like building exteriors. Huang et al. (2023) explored the use of Building Information Modeling (BIM) to support drone path planning for exterior surface inspections. Drones equipped with cameras and other sensors can autonomously navigate and inspect building exteriors, offering a cost-effective alternative to traditional methods that heavily rely on LiDAR (huang 2023). Although matching the detail and accuracy of LiDAR-based systems is challenging, drones offer a flexible and efficient means of conducting inspections, particularly in hard-to-reach areas.

2.8 Machine Learning and Sensor Fusion for Anomaly Detection

Machine learning is increasingly applied to data from non-LiDAR sensors, such as RGB-D and thermal cameras, for detecting anomalies in building structures. Meng et al. (2020) provided a detailed survey on the role of machine learning in data fusion, highlighting its potential to enhance the accuracy of low-cost sensors for building inspections. The combination of data from multiple sensors with advanced machine learning algorithms enables accurate detection of structural issues, making these systems competitive with LiDAR in specific applications (meng 2023).

2.9 Summary

The reviewed literature indicates that while LiDAR remains the benchmark in building inspections, several viable alternatives exist that can reduce costs without significantly compromising accuracy. These alternatives include multimodal sensor integration, hand-held 3D thermal mapping systems, stereo vision, RGB-D mapping, photogrammetry, and drone-based inspections. Each approach has its own strengths and challenges, and ongoing research is focused on improving their accuracy and reliability to make them more competitive with LiDAR systems. As technology continues to evolve, these alternatives are expected to play a more significant role in building inspections.

Chapter 3

Problem Statement

LIDAR (used for Light Detection and Ranging) is often used in building inspections to model buildings in 3D, but using LiDAR substantially increases the costs since the devices are very costly, and operator-intensive work which is time-consuming and costly. High equipment and labour costs limit the use of LiDAR, making it difficult for smaller companies to adopt it while reducing a building's access to more advanced 3D mapping and inspection, which would decrease its efficiency and reliability.

1. Labor-intensive.

The requirements of the conventional, (manual inspection) that are outlined below makes the process slow hence expensive.

2. Error-prone.

The problems and their possible consequences can be omitted and the results of the assessment could be quite vague if the operation is performed by a human.

3. Expensive.

What must be considered at this stage is that irrespective of whether the manufacturers are applying the present day automated inspection procedures or the conventional are still implemented as manual inspection methods which brings pressure to the exert on budgets which can be really expensive to afford for smaller companies.

3.1 Overview of solutions:

Using ordinary cameras for capturing the images instead of buying expensive LIDAR equiptment, Drone ,labour cost, This project brings technological advancement in deployment to reduce the impact of humans in the Fields taking weeks to do inspection and which includes errors.

Our project aims to:

- Develop a new 3D reconstruction method using standard 2D cameras only.
- Significantly lower inspection costs with affordable camera technology.
- Ensure the new method's accuracy is comparable to LiDAR and is more efficient than it.

We Make advanced 3D mapping accessible to more construction projects, including those with smaller & less budgets. This solution, by reducing costs from expensive and complex LiDAR and specialist labour, uses advancements in computer vision to create high-quality 3D models with a standard camera. Increasing the use of this technology further reduces the cost and time of building inspections, improving the precision, speed, and safety in collection, and allowing for greater widespread adaptive use of state-of-the-art 3D mapping from a variety of different sources.

3.1.1 3D Mapping of building for inspection Impact on society.

"The aim of the project is to estimate various features of a building automation".

- can be said that there will be a huge and positive social impact through better efficiency, precision and accessible insight.The project will also bring about cost-saving, during the entire process of development while being safe and sustainable.The proposed solution will be able to handle and process data for more accurate building assessment, it could provide proper scale estimation with higher accuracy, efficiency with performance measure and it is much faster than a human inspector.It will also provide point cloud with visualization and information about the shape through orientation on the surfaces of 3D space and surface analysis with dimensions and snaging process".

- If the technology progresses and expands as anticipated, its impact on our society will likely increase, and the way we interact with it and govern our physical world will further change. Thanks to this technology, the future of construction and urban infrastructure development could be shaped.

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3.1.2 Project Functional Requirements:

1. 1 Context that relates to the Product and Origin of it.

Our project is associated with the creation of an innovative tool aimed at changing the current ideas of accessibility of hardware solution (lidar). This advanced solution progress the ability of 3D modelling by increasing its precision and efficiency. Utilizing modern approaches to analyze the frames of the videos. Hence, the idea arose from the necessity to enhance Incorporation of several modern technologies in the development of our solution will thus offer a more effective solution to the currently prevailing systems.

1. 2 Product Classification.

Is it the next in a chain of a product series, the new generation of a very mature product line or a new product to replace a new feature to an existing application, or develop a completely new product? This technology is not an improvement of a pre-existing product type but a new category of product all together. Application. This is because it is aimed at meeting a vital void in the market by generating more precise and faster 3D modeling capabilities. Thus, by concentrating only on frame extraction of the video, scale estimation, and converting the frames into 3D point clouds to build meteorological accurate and geometrically very precise 3D models.

3.1.3 1.3 Operating Environment

1. Software Platform:

- Operating Systems: Windows-operated laptops

2. Development Tools:

- Using IDE's including Visual Studio, Open CV, version control Git.

3. Hardware Platform:

- **Laptop**: The primary development and processing platform. Also,
- It can run on intensive computations as well.
- **Mobile Devices:** For video capture to get the frames with imu results.
- **Gimbal**: This is an attachment for smartphones used to ensure stable footage from phone when shooting video footages.

3.1.4 Cross-Platform Compatibility:

Whether having access to the site from a laptop or a cell device, customers can revel in a regular and optimized experience, enhancing accessibility.

3.2 Summary

Only a few years ago, that would have required an extremely lengthy period to complete by hand. Using 3D mapping, engineers, architects, and construction professionals can produce a 3D digital model of a building's exterior and inside. This innovative method speeds up and eliminates errors in building inspections while simultaneously enhancing their precision. Our project's application of innovative computer vision , open fsm and cloud computing technologies with dimensions of real world cordinates , scale estimation , pointcloud visulization provides the construction industry with a scalable and realistic respond with precise building inquiry. The structure is initially captured, after which the video is separated frame by frame and uploaded to Firebase for review. After then, these frames are used for calculating 3D scale estimates, which are necessary for accurate measurements and analysis. We generate a dense point cloud with precise collection of data points that models the building's surface from these approximations. This makes it possible for the building inspectors to examine and assess the building's construction immediately. "

Chapter 4

Technical Documents

4.1 Introduction

Before the development of any system, the selection of its implementation processes, the timeline of executing its different modules, defining the right stakeholders play a crucial part in the development of the proposed project. This chapter consists of technical documents mainly: our system's DFD diagram, name of all stakeholders, stakeholder register, risk register, use case diagram for different actors and Gantt chart for development timeline of the project. These diagrams are necessary for the successful development and completion of our project.

4.2 The Data Flow Diagrams (DFDs)

provided illustrate the overall workflow and data exchange within a system designed to process video and IMU (Inertial Measurement Unit) data from a client. Below is a description of the key components and processes depicted in the diagrams:

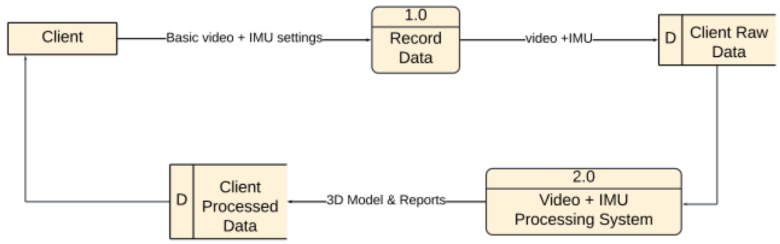


Figure 4.1: DFD Diagram

Figure 4.1 Description

1. Client:

The process begins with the client who provides basic video and IMU settings. This data is essential for configuring the subsequent processes.

2. Record Data (Process 1.0):

This process is responsible for capturing the video and IMU data as specified by the client. The data is then sent to the "Client Raw Data" store.

3. Client Raw Data (Data Store D):

The raw video and IMU data are stored in this data store after being recorded. This data store holds the unprocessed data until it is needed for further processing.

4. Video + IMU Processing System (Process 2.0):

This system takes the raw video and IMU data and processes it to generate a 3D model and reports. The processed data is then sent back to the client.

5. Client Processed Data (Data Store D):

This data store holds the processed data, which includes the 3D model and reports, ready for the client's review or further analysis.

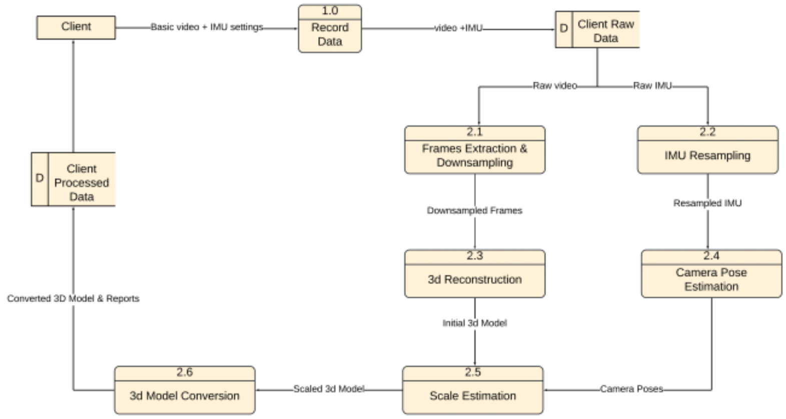


Figure 4.2: Description for the second figure

Figure 4.2 DFD Diagram

1. Frames Extraction and Downsampling (Process 2.1):

- The raw video is first broken down into individual frames.
- These frames are then downsampled to reduce the amount of data that needs to be processed, making the system more efficient.

2. IMU Resampling (Process 2.2):

- The raw IMU data undergoes resampling to align it with the video frames, ensuring synchronized data for further processing.

3. 3D Reconstruction (Process 2.3):

- Using the down sampled frames, this process reconstructs a 3D model.
- This initial model serves as the foundation for the subsequent steps.

4. Camera Pose Estimation (Process 2.4):

- This process estimates the camera's position and orientation based on the IMU data, which is critical for accurately scaling the 3D model.

5. Scale Estimation (Process 2.5):

- Using the estimated camera poses, this process determines the scale of the 3D model, ensuring that it accurately represents real-world dimensions.

6. 3D Model Conversion (Process 2.6):

- Finally, the scaled 3D model is converted into a format suitable for generating the final reports, which are then stored in the "Client Processed Data" store for the client's use.

4.3 ERD

The entity-relationship diagram (ERD) is a visual database structure for the "3D Mapping of Building for Inspection" which shows the entities, attributes, relationships, and constraints of the project

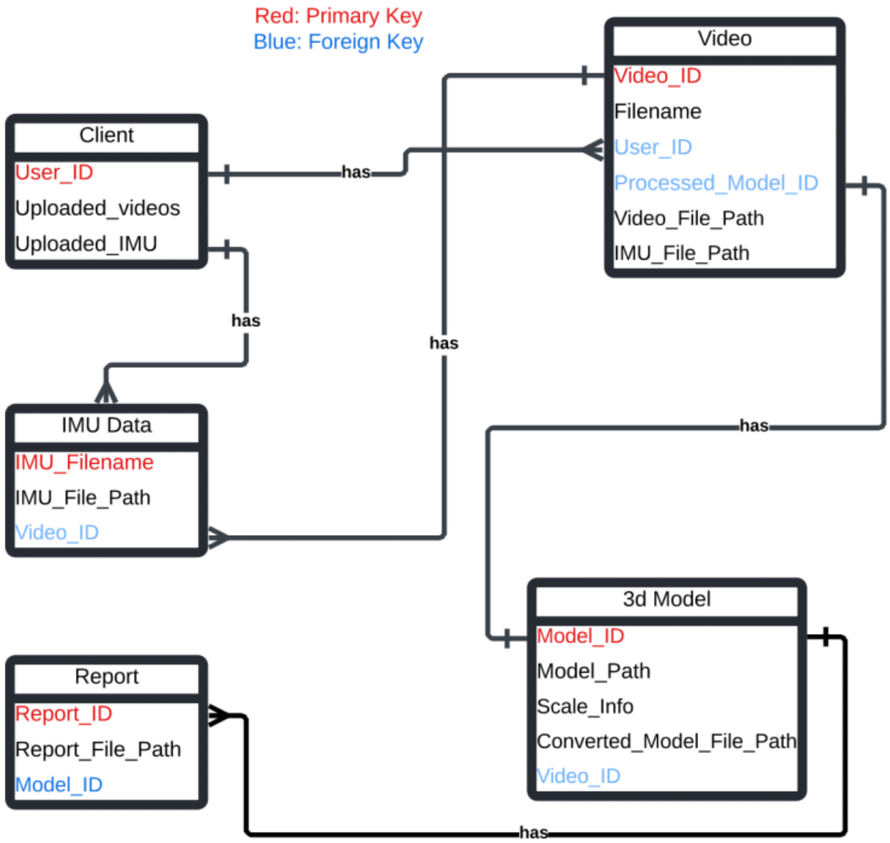


Figure 4.3: Description for the second figure

4.4 "3D Mapping Of Building For Inspection"

Use Case Diagram:

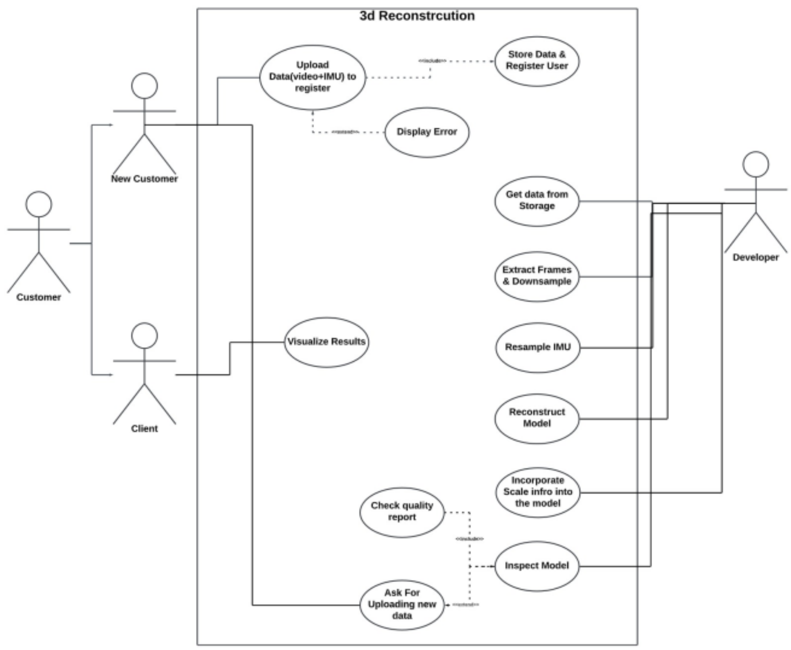


Figure 4.6

The Use Case Diagram for the 3D Mapping of Building for Inspection system effectively represents the interaction between the Users' with system developmental functionalities, including Inspectors and System Administrators. From user capturing video and then making frames with IMU data, through building data entry towards the database for storage, uploading to Firebase, having scale estimation, and then point cloud generation and visualization with calculated dimensions, then goes to 3D model. It gives a thorough overview of the procedure analysis of data with scale estimated factors. With this thorough illustration, all essential features and possible outcomes are guaranteed to be taken into consideration, improving the system's growth and understanding.

4.5 Gantt chart

Gantt chart is a project management tool that shows the duration of different activities (tasks, events) during the development of the whole project. On the left side, there is a task list, along the top is a suitable time scale and on the right side, project timeline is displayed. Each activity or task is represented by a bar. The position of the bar shows the start date of that task and length of the bar shows the duration and the end date of that particular task. This is the Gantt chart for our project

4.5.1 The Gantt Chart's components include:

- **Activities and Tasks:**

Everything that is needed in order to complete the 3D Mapping Of building for inspection project, in terms of tasks and activities, is enlisted on the Gantt chart. Requirements gathering, design, development, testing, deployment, and post-launch maintenance are a few examples of these tasks.

- **Timetable:**

The Gantt chart's horizontal axis will indicate the project timeline which can be divided into days or weeks or months depending on how long the project is supposed to take. From the beginning day till end day for every task each of them are plotted along the timeline.

- **Bars:**

In a Gantt chart, tasks represent as horizontal bars whose lengths show a duration for each one of them. Hence this means that all tasks will last different periods with respect to their time frames among others besides their respective start and finish dates provided by the location of a bar across its timeline.

- **Achievements:**

These are those important components of an event that either completing a phase, when any feature is turned on or releasing some heavyweight product etc. it can be the major features which engineer might have developed during Sprint for months "Milestones in project Each of these had a diamond icon assigned on the Gantt chart both to indicate their importance and as checkpoints".

4.5.2 Advantages of Gantt Chart Use:

- **Showcase:**

The Gantt chart makes it simple and clarifies the order of tasks and their dependencies. It shows visually the project schedule .

- **Organizing and Timetable:**

Gantt chart: To divide the work for project planning and scheduling break down into common components and give deadlines to everything.

- **Resource Allocation:**

The Gantt chart allows project managers to assign resources (including money) The number of workers, labor hours and required materials were adjusted as needed for all work tasks within the project timeline

- **Tracking and Observation:**

Gantt charts Ideal for process tracking and showing task progression throughout. the project life cycle. When bottlenecks occur, delays happen or in the case of a slight deviation from schedule With this the project managers can easily recognize them and take the necessary corrective measures.

- **Conversation:**

Project status and time lines with a view of the Gantt chart accelerate communication and technology exchange for all parties involved in the project.

- **Conclusion:**

The project's milestones are those crucial occasions or actions that include finishing a phase, estimating results easy to understand, releasing a noteworthy product, or turning on any feature. On a Gantt chart, these have been designated with diamond-shaped marks that serve as both indicators of importance and progress checks.

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
1			**Phase 1 : Planing**	**12 days**	**Wed 11/15/23**	**Thu 11/30/23**	
2			Make the flow of project for better understanding	2 days	Wed 11/15/23	Thu 11/16/23	
3			Meet with External + Internal for getting Roles definition	1 day	Fri 11/17/23	Fri 11/17/23	2
4			Visited market to check the feasibility & possibility of implementing exact hardware	3 days	Mon 11/20/23	Wed 11/22/23	3
5			Choosing appropriate database	2 days	Thu 11/23/23	Fri 11/24/23	4
6			Implement basic frontend for uploading dataset	3 days	Mon 11/27/23	Wed 11/29/23	5
7			Milestone: Basic Understanding on how to get started	0 days	Wed 11/29/23	Wed 11/29/23	6
8			**Phase 2 : Research**	**75 days**	**Mon 11/20/23**	**Fri 3/1/24**	
9			Understand concepts of sfm & look for implemented approach	18 days	Mon 11/20/23	Wed 12/13/23	3
10			Research on how to show point clouds on wesbite as output	4 days	Mon 11/20/23	Thu 11/23/23	3
11			Research on implementation for 3d reconstruction and compare which is better	3 days	Thu 12/14/23	Mon 12/18/23	9,10
12			Document the previous work that has been done on this	8 days	Thu 12/14/23	Mon 12/25/23	9
13			Understand concepts of IMU and find extraction app	10 days	Tue 12/19/23	Mon 1/1/24	11

Project: 3d Recon Gantt chart Date: Mon 8/12/24	Task	Manual Task	Deadline
	Split	Duration-only	Critical
	Milestone	Manual Summary Rollup	Critical Split
	Summary	Manual Summary	Baseline
	Project Summary	Start-only	Baseline Milestone
	Inactive Task	Finish-only	Baseline Summary
	Inactive Milestone	External Tasks	Progress
	Inactive Summary	External Milestone	Manual Progress

Figure 4.4: 1. Gantt Chart

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
14		Researching hardware options	6 days	Tue 1/2/24	Tue 1/9/24	13
15		Conduct comprehensive review of prior research work	8 days	Wed 1/10/24	Fri 1/19/24	14
16		Research on Resampling techniqu	2 days	Mon 1/22/24	Tue 1/23/24	15
17		Research for Camera pose estimation	15 days	Wed 1/24/24	Tue 2/13/24	16
18		Research on how to estimate scales using IMU	12 days	Wed 2/14/24	Thu 2/29/24	17
19		Meeting with External For getting idea about scales	1 day	Fri 3/1/24	Fri 3/1/24	18
20		Milestone: Complete Research done and now we can	0 days	Fri 3/1/24	Fri 3/1/24	19
21		**Phase 3 : Implementation**	**170 days**	**Mon 11/20/23**	**Fri 7/12/24**	
22		Develop code for frames extarction & downsampling	4 days	Mon 11/20/23	Thu 11/23/23	3
23		Resampling IMU data	5 days	Wed 1/24/24	Tue 1/30/24	16,22
24		Connecting DB with Frontend	2 days	Thu 11/30/23	Fri 12/1/23	6
25		Implement Sfm algorithm	28 days	Wed 1/31/24	Fri 3/8/24	23
26		Improvise Sfm algorithm	55 days	Mon 3/11/24	Fri 5/24/24	25
27		Implement Camera pose estimation algorithm	20 days	Mon 5/27/24	Fri 6/21/24	26,17
28		Develop Code for Estimating Scal	15 days	Mon 6/24/24	Fri 7/12/24	27,19
29		Implement Complete frontend with multiple pages	30 days	Mon 12/4/23	Fri 1/12/24	24

Figure 4.5: 1. Gantt Chart

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
30		Milestone: Near to Complete the project	0 days	Fri 1/12/24	Fri 1/12/24	29
31		**Phase 4 : Mid-Year Evaluation**	**12 days**	**Mon 3/11/24**	**Tue 3/26/24**	
32		Preparing material for evaluation	10 days	Mon 3/11/24	Fri 3/22/24	25
33		Evaluation	2 days	Mon 3/25/24	Tue 3/26/24	32
34		Milestone: Got Appreciation From Committe	0 days	Tue 3/26/24	Tue 3/26/24	33
35		**Phase 5 : Hardware Integration**	**17 days**	**Mon 3/11/24**	**Tue 4/2/24**	
36		Hardware Designing	10 days	Mon 3/11/24	Fri 3/22/24	25
37		Implement hardware and check compatibility	4 days	Mon 3/25/24	Thu 3/28/24	36
38		Develop code for hardware	3 days	Fri 3/29/24	Tue 4/2/24	37
39		Milestone: Developed working hardware	0 days	Tue 4/2/24	Tue 4/2/24	38
40		**Phase 6 : Documentation + Final Results**	**43 days**	**Wed 6/19/24**	**Fri 8/16/24**	
41		SRS Report	15 days	Mon 6/24/24	Fri 7/12/24	27
42		Testing +Fixing Bugs	5 days	Mon 7/15/24	Fri 7/19/24	28
43		Checking Accuracy of Estimated Data	15 days	Mon 7/22/24	Fri 8/9/24	42
44		Documentation	20 days	Mon 7/22/24	Fri 8/16/24	42
45		Milestone: Finaly completed the project	0 days	Fri 8/16/24	Fri 8/16/24	44

Figure 4.6: 2. Gantt Chart

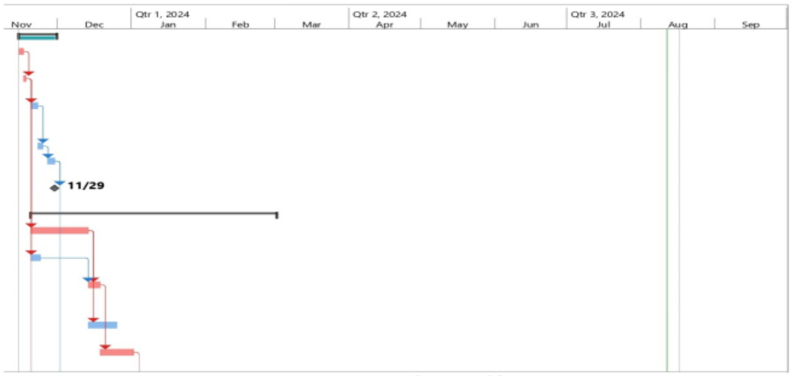


Figure 4.7: 1. Gantt Chart

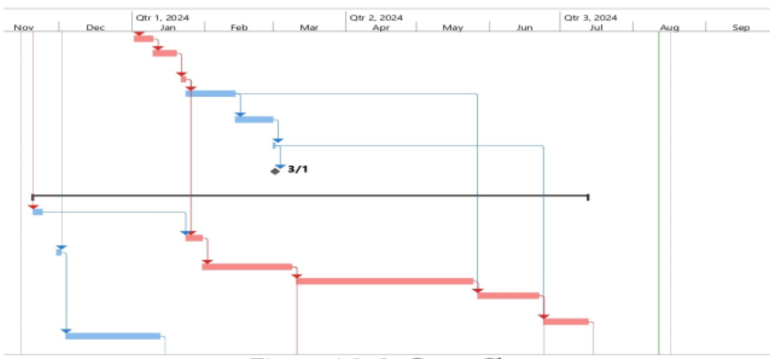


Figure 4.8: 2. Gantt Chart

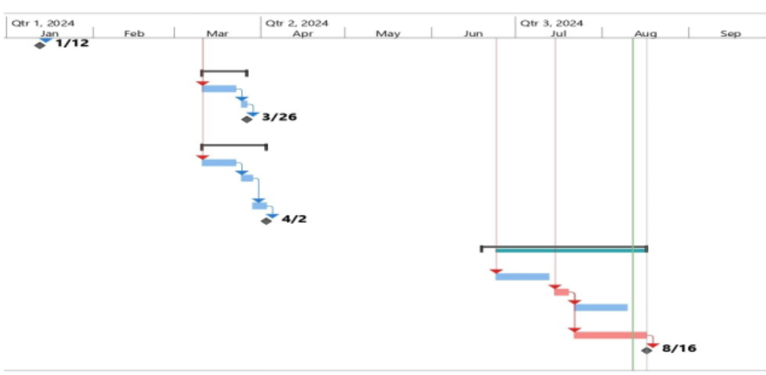


Figure 4.9: 3. Gantt Chart

4.6 Risk Register

Risk register is a risk management tool that identifies potential setbacks within the given project. Identifying potential setbacks includes identifying, analyzing, and solving risks before they turn into problems. The risk register document contains the list of risks associated with the different team members of the project. The document also includes information about the likelihood and priority of the risks. A risk register, along with identifying and analyzing the risks, also provides mitigation measures for the defined risks. This is the risk register for our project:

Risk ID	Risk Owner	Name	Description	Impact	Probability	Risk Level (Impact x Likelihood)	Mitigation Strategy
1	Ahmed Baseer, Talha Hussain khan	Device Compatibility Issues	Compatibility Issues with choosing optimize storage as cloud(firebase).	Medium	Medium	low	Research & test on a variety of devices. Prioritize widely-used platforms.
2	ALL	Technical challenges	Unforeseen technical issues difficulties during 3d modeling.	Critical	Medium	Medium	Conducted technical feasibility study. Allocated additional time for unforeseen technical challenges.
3	Arisha, Arbaz Talha,	Technology obsolesces	Regularly update the technology stack and stay with latest versions.	Medium	Medium	Medium	Updated with time studied latest version and implemented in our code.
4	Ahmed Baseer	Bugs & Technical issues	Conduct thoroughly Testing, used fixing tools and have also got a rapid response from team members for technical issues.	Medium	Medium	Medium	Research for finding ways to fix bugs & did testing to avoid any further technical issues.
5	ALL	Budget Control	Conducted Market search to get hardware things under a specific budget.	Medium	High	Medium	Implement strict budget controls.
6	Arisha Fateh, Arbaz Moin	Succession Planning	Lack of knowledge about the 3D inspection with photo geometry & point cloud visualization.	High	Medium	High	Develop a succession plan, cross-train team members Implemented sessions for guidance about the innovative technology of 3D mapping of building for inspection
7	Ahmed Baseer	Inadequate Scale estimation results	Poor quality of camera affecting images caused bad quality of point cloud.	Medium	Low	Medium	Implement a robust Calibration process. Choose a camera with better quality conducted testing of 3d model and got accurate results.

Figure 4.10: Figure 4.8

4.7 Stakeholder Register

Description:

Project stakeholders are individuals who have an interest in the project and have something to gain (or lose) from the project's outcome. These are the stakeholders of our project.

"3D Mapping of Building for Inspection"

The stakeholders included in the Stakeholder Register for the project are those who supported our efforts, such as **"Sir Syed University of Engineering and Technology (SSUET)"**, and the project sponsor, **"Round Gauge Company (UK)"**, which also contributed resources and support. Under the direction and expertise of **"Prof. Rabia Noor Enam"**, we students actively participated in the project creation process. The FYP Committee assesses the results of the projects. This project will appeal to the average person or investor willing to invest their money.

Project Sponsor	❖ **SIR SYED UNIVERSITY OF ENGINEERING & TECHNOLOGY** ❖ **Road Gauge Company (UK)**
Stakeholders	**Students: Responsible for developing and designing the project.** 1.Ahmed Baseer 2.Arisha Fateh 3.Arbaz Moin 4.Talha Hussain Khan **Professor. Dr. Rabia Noor Enam:** Responsible for supervising the project. **Responsibilities**: Guidance, oversight, and evaluation of the project's progress and quality. **Professor Dr. Senthan Mathavan:** Responsible for Assist with overcoming challenges and technical difficulties in the project. **Final Year Project Committee:** Responsible for evaluating the project. **Responsibilities**: Review and approval of project milestones, ensuring the project meets academic and industry standards.

Figure 4.11: Stakeholder Register Diagram

4.8 Summary

In this chapter, we included some important technical documents and diagrams. These technical documents and diagrams include Data flow diagram (DFD), Use case diagram, name of stakeholders, stakeholder and risk register and Gantt chart. DFD shows the basic process flow of 3D Mapping of building for inspection website is divided into easy steps to go through. Stakeholders are the group of individuals that are interested in the outcome of the project. They continuously monitor the progress of the project. In stakeholder register, we defined the roles, concerns and contact information of different stakeholders of our project. Use case diagram shows the different roles of students, instructors, and system admin with the app. In risk register section, the potential risks and challenges are defined that can be faced by each member of the FYP team and their mitigation strategies are also defined. Gantt chart provides a visual representation of the whole project timeline. These technical documents were very crucial for the successful implementation and completion of our project.

Chapter 5

Methodology

The development process for 3D Mapping of Building for inspection is based on the innovative use against the "expensive lidar" to improve old traditional method with the concept of photo-geometry learning by placing realistic 3D computer components models on the specific video which converts the synchronized video into frame by frame than upload data on (firebase), store data pre-process apply reconstruction and then accurate scale estimation is done after that that estimated data goes through the process of 3d Model converter to get the visualization of data. This entire process involve Python , CSS, JavaScript, Xampp, Firebase, open Cv ,openfsm and Visual Studio, were used for the implementation of the Website. The primary software tool is open cv and openfsm , on which interesting, 3d model can be smoothly implemented without any hassle that are present in the PDF lectures. The project planning, requirements analysis, design, implementation, testing, and deployment phases are all included in the methodology.

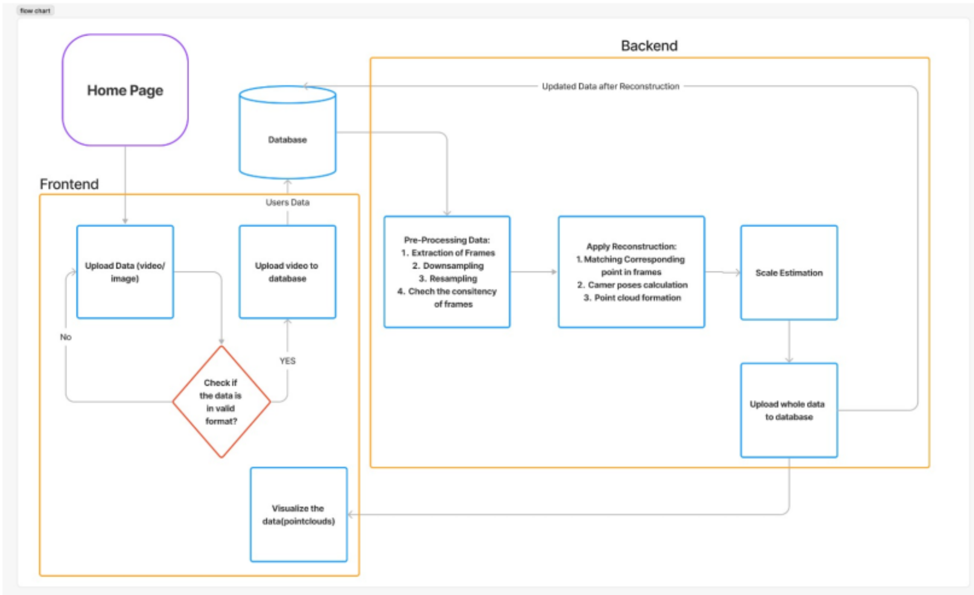


Figure 5.1: Methodology of 3D Mapping of Building for Inspection

5.1 Front-end development:

5.1.1 Project Structure:

- A JavaScript user interface library, is used to develop 3D Mapping of building front end. In accordance with recommended practices for component-based architecture, components are arranged in a structured hierarchy.
- HTML builds the structure and content.
- CSS styles and lays out the content.
- These three technologies work together to create responsive, interactive, and visually appealing web applications.

Required Technologies

- **Development Environment**: Visual Studio Code was selected due to its comprehensive support for multiple programming languages and adaptability.

- **Firebase** is the storage solution preferred due to its reliable and expandable database services.
- **Programming Language:** JavaScript is used for frontend development and client-side interactivity, while (.ply) extension polygon format is used for mathematical calculations and image processing due to its broad support.

5.2 System Diagram of 3D Mapping of Building for Inspection

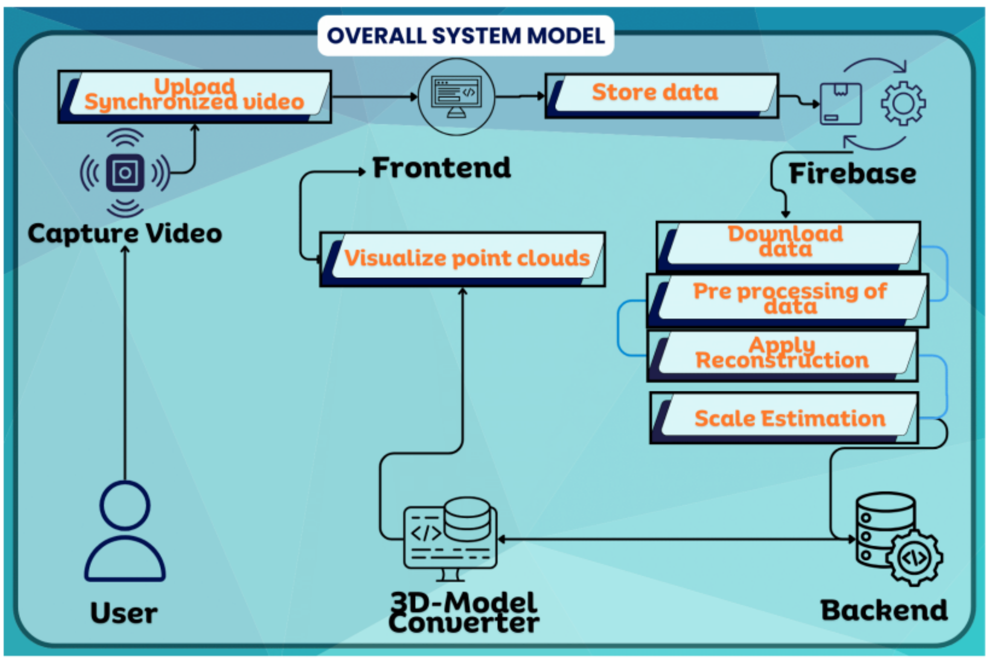


Figure 5.2: System diagram

Our innovative "3D mapping technology" has been used in our project to establish an innovative approach toward building inspection. It makes a consistent integration of the most exact scale figure computations with the most advanced methods.

5.3 UI Prototype for 3D Mapping Solution for Building Inspection.

1. Overview

The UX prototype aims to provide a graphical layout of the system's front-end and back-end interfaces, enabling visualization of how the system will be presented to users. This can be hand-drawn or created using a proper tool.

2. Features and UI Components

Description:

Interface for managing and viewing different datasets used in 3D reconstruction.

UI Elements:

Thumbnails of datasets, description texts, and dataset management buttons.

3 .Point Cloud Result

Description:

Display of point cloud data generated from datasets providing a visual representation

UI Elements:

Graphical visualization of point clouds, analysis options, and data interaction tools.

4. Analysis Section

Description:

Section dedicated to analyzing the data collected from inspections.

5. Image Upload and Reconstruction Description:

Interface for uploading images and initiating the 3D reconstruction process.

UI Elements:

Upload buttons, progress bars, and display of reconstructed 3D models.

4. 3D Reconstruction Visualization

Description:

Visual representation of the 3D reconstruction.

UI Elements:

Interactive 3D models, navigation controls, and detailed view options.

5.3.1 Frameworks and Libraries

- **OpenCV:** For processing images and extracting video frames.
- **Firebase:** Used for storage and real-time management of databases.
- **NumPy:** For computing with numbers. Arrays and matrices, which are crucial to computational image processing and 3D model computations, are handled by NumPy.
- **Pandas:** To alter and examine data.
- **XAMPP:** XAMPP is used for local testing and development of database-driven applications, providing an all-in-one solution for setting up a development environment.
- **scipy:** For calculating Euclidean distances, interpolation, and filtration.
- **OS:** For handling command line functionalities.
- **matplotlib:** For generating interactive graphs, visuals, and reports.
- **multiprocessing:** For achieving parallelism.
- **setuptools:** For packaging the project.
- **exifread:** For extracting EXIF information from images.
- **PIL:** Used to handle and interact with PNG images within the PIL (Python Imaging Library).
- **json:** For handling JSON data.

5.3.2 User Interface Design:

Users can plan the area for which he wants point-cloud and scale estimated data after that capture video upload frames and after that he will get the point cloud visualization with accurate measurement with photo geometry Each point in a point cloud has a specific X, Y, and Z coordinate in 3D space, representing its location. which is made to be visually appealing, responsive, and intuitive.

- **Adaptive Web Design:** The user interface layout is designed to be responsive to varying screen sizes and devices, guaranteeing consistent usability on tablets, smartphones, and desktop computers.
- **Themes for Material Design:** It is possible to use material design principles to produce a contemporary and eye-catching user interface. In order to improve the user experience overall, this includes the use of typography, color schemes, icons, and motion effects.

5.3.3 Data Fetching and Management:

To retrieve and display dynamic content from the backend APIs, components make use of asynchronous data fetching techniques.

Integrating API:

In order to retrieve data from the back end APIs, including product, HTTP requests are made using the Fetch API and also used three.js.

Recent State Updates:

Context API are used to store the retrieved data in the application state. To guarantee that the user interface displays the most recent data from the backend, state updates cause the impacted components to be re-rendered.

Tools used for frontend development :

We have used various tools to design and developed the frontend for our project. These are the best tools and technologies for the frontend development.

VS code:

The front-end development team used Visual Studio Code (VS Code) as their main integrated development environment (IDE) when 3D Mapping of Building for inspection was being created. The development process was streamlined by its many features, which included integrated version control with Git, debugging capabilities, and Intelligence for code completion. Because VS Code is lightweight and highly configurable, developers can add extensions and themes to customize their workspace, which improves teamwork and productivity. VS Code offered a sustainable and reliable and effective environment which included writing, editing, and debugging our code in HTML, CSS, JavaScript, code because of its strong easy to usable user friendly platform with scalability and regular updates.

HTML and CSS:

The 3D Mapping of Building for Inspection user interface design was built on the foundation of HTML (Hypertext Markup Language) and CSS (Cascading Style Sheets). Web page content was organized using HTML, which established the elemental hierarchy and layout. The HTML elements were styled using CSS, which provided specifications for visual elements like color, font, spacing, and placement. The organization and management of style sheets was made easier by the use of CSS pre-processors like Sass, which made it possible to write modular and maintainable CSS code. The front-end team employed HTML and CSS to create visually appealing and responsive web pages to have best user experience.

JavaScript:

JavaScript was essential to the addition of dynamic functionality and interactivity to the 3D Model of Building for inspection website. JavaScript is a flexible programming language that can be used to manage user interactions, manipulate HTML and CSS elements, and carry out client-side validation.JavaScript's event-driven architecture improved the web application's overall responsiveness and performance by enabling real-time updates and asynchronous server communication.

5.4 Visual Representation of 3D Mapping of Building for inspection.

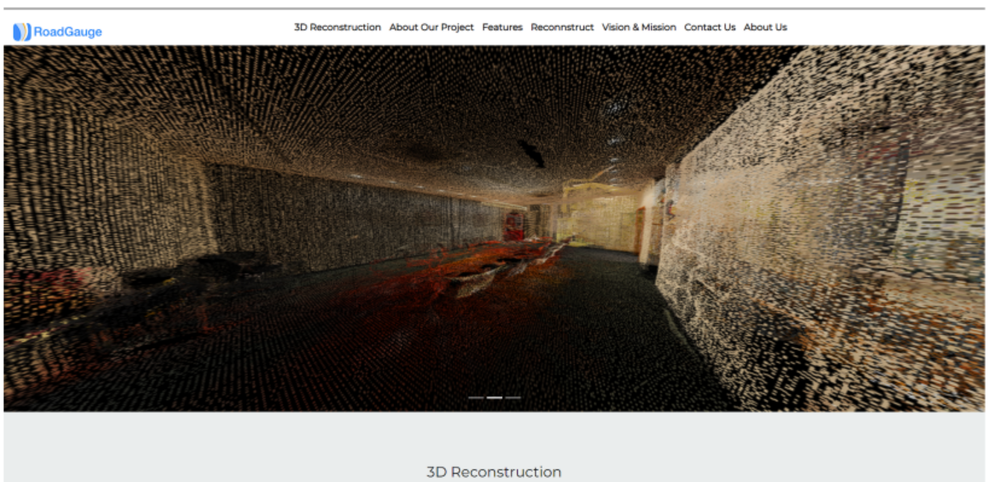


Figure 5.3: 1.Front-end visuals

Figure 5.4: 2.Front end visuals

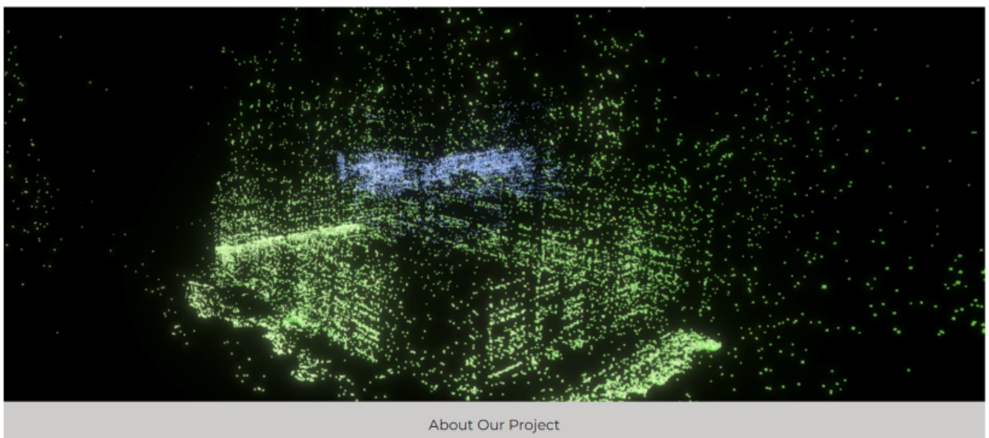


Figure 5.5: 3.front end visuals

Component Structure: The modular and reusable nature of UI components encourages the reuse and maintainability of code. Based on their roles and functionalities, components are arranged into functional units.

State Administration: Data flow and application state are managed in the front-end using Context API. Data inconsistencies and race conditions are less likely to occur when components are consistent and synchronized thanks to centralized state management.

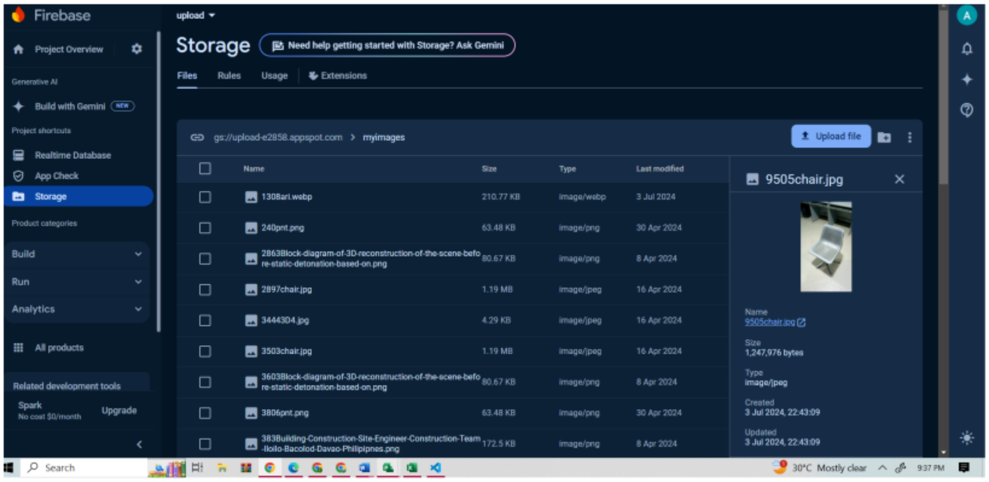


Figure 5.6: 4. Firebase visual

Figure 5.7: 5. Front end visuals

5.5 Backend development:

During 3D Mapping of building for inspection backend development, we made use of the potent combination of three.js and Express.js to build a stable server environment. We used three.js's flexibility to run JavaScript code on the server side, and made it easier to create RESTful APIs. This made it possible for us to manage HTTP requests and responses quickly and effectively, which made it easier for the frontend and backend parts of our e-commerce platform to communicate with each other.

5.5.1 Configuring the server:

We started working on Firebase to save images from website to directly and upload it on Firebase and npm was used (Node Package Manager) on our development environment as part of 3D Model server setup process. Firebase is a great option for developing scalable and fast web applications because it offers a runtime environment for server-side JavaScript code execution in Firebase environment. In contrast, npm acts as a package manager to install .

5.5.2 Integration of Databases:

Includes ply polygon file format . That provided to db then at frontend convert it into .html file format to visualize it on web portal For that we using multiple js libraries and APIs.

5.6 Algorithm Used

- step 1: PnP with RANSAC
- step 2: Triangulation
- step 3: SIFT and KNN
- step 4: EKF

- step 5: ZUPT
- step 6: bandpass filter (unused) Rest development is logic-based not a specific algo

5.7 Backend Visuals

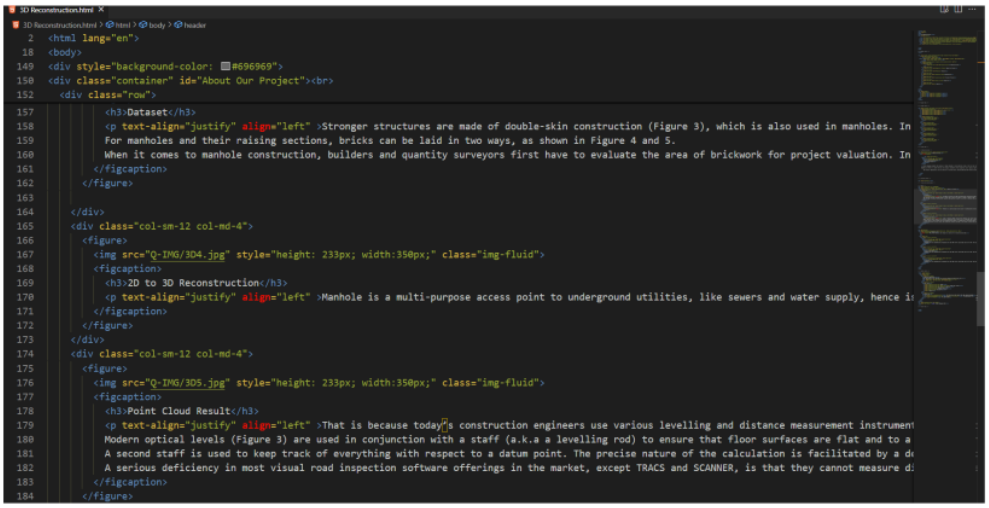


Figure 5.8: 1. Back end visuals

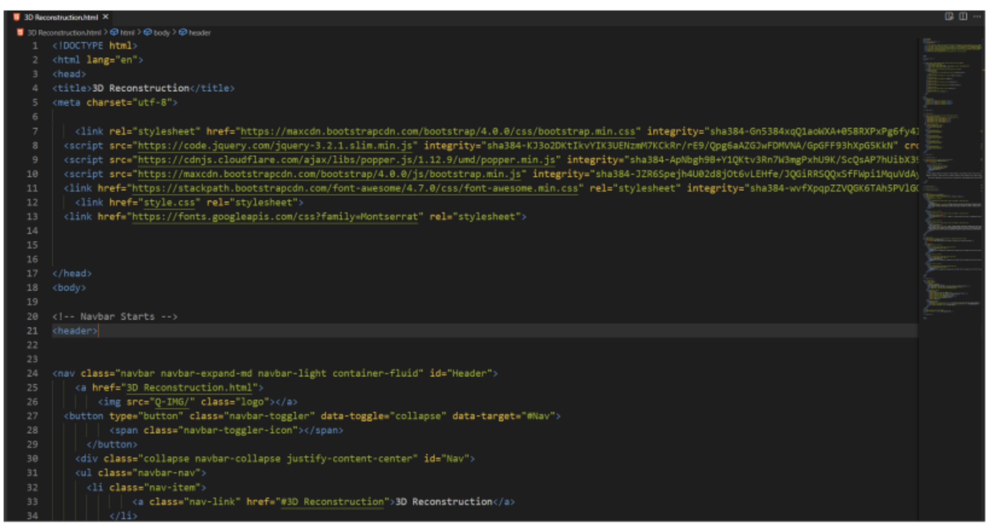


Figure 5.9: 1. Back end visuals

5.8 Hardware Diagram of 3D Mapping of Building for Inspection

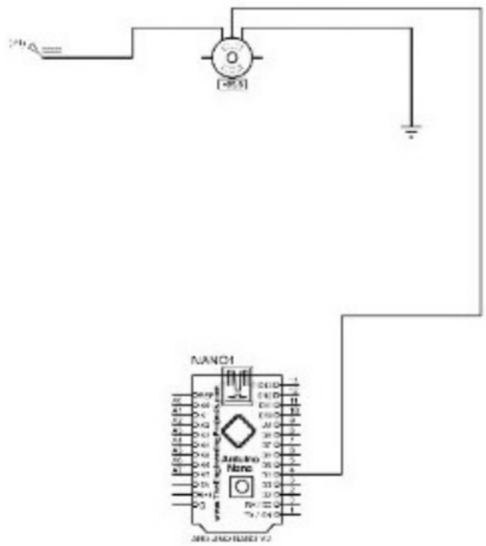


Figure 5.10: Arduino Nano-Based Motor Control Circuit with Buck Converter

Diagram Detailed Description

This diagram shows a basic control circuit with an Arduino Nano microcontroller and a DC motor powered by the buck converter.

Arduino Nano

The Arduino Nano is the main microcontroller in this circuit. The device is likely used to command the DC motor, for example, to turn it on or off, control its RPM, or change its direction.

DC Motor

A DC motor might be connected to the circuit and controlled by the Arduino Nano. It will be managed by the Arduino through appropriate signals, which may include triggering a relay or a transistor depending on the motor's power requirements.

Buck Converter

The buck converter is used to reduce the input voltage (12V) to a level more suitable for the Arduino Nano and potentially the motor. The output voltage of the buck converter can be adjusted to suit all the components on the board.

Functionality

Power Supply: The circuit is powered by a 12V source, which is regulated by the buck converter. The buck converter provides the necessary voltage for both the Arduino Nano and the motor.

Control:

The Arduino Nano takes the input and performs control actions based on its programmed instructions, which may include running a PID loop or any other additional features. This can range from controlling the speed of the motor to simply switching it on and off.This setup is common in projects where a small micro controller (like an Arduino Nano) controls a higher power device, such as a motor, and therefore needs to be powered by an additional voltage regulator (buck converter) to ensure smooth operation.

5.9 Workflow of the project "3D Mapping of Building for Inspection"

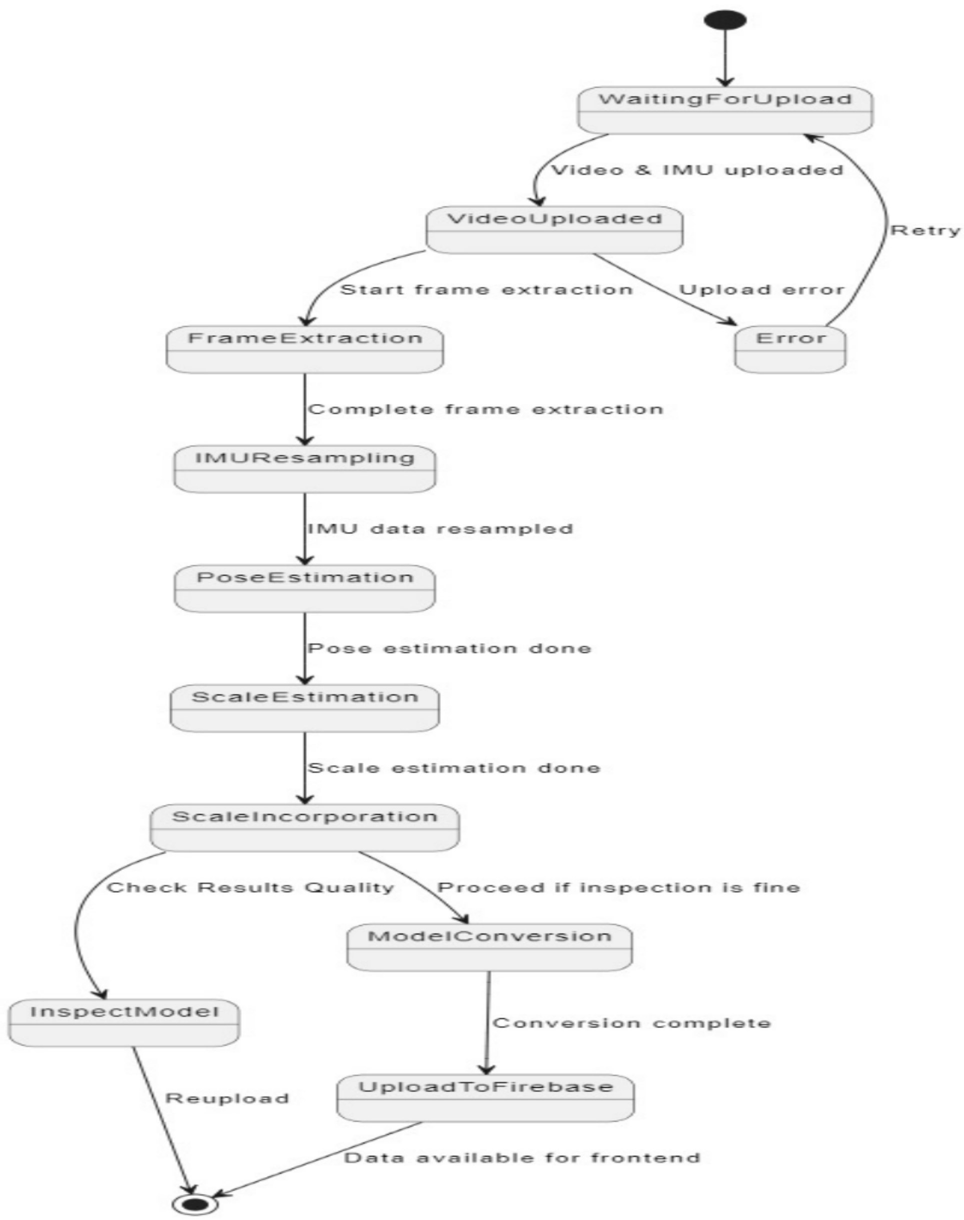


Figure 5.11: Workflow of the project "3D Mapping of Building for Inspection"

5.10 "End-to-End Process for 3D Building Inspection and Analysis"

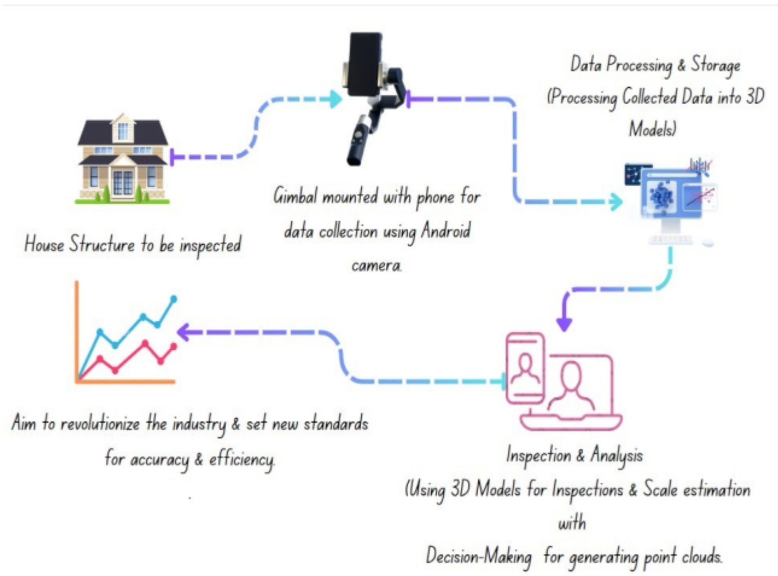


Figure 5.12: Workflow of the project "3D Mapping of Building for Inspection".

"This title emphasizes the comprehensive nature of the workflow, from data collection to final analysis, highlighting the entire process involved in the project."

5.11 Summary

This project was to develop a 3D mapping solution targeted for building inspections (point clouds) via photogrammetry concept and 3D Mode instead of costly LiDAR technology. Simply put, this required getting the video feed to be converted into frames and then pushed up along with extracted frames data (to Firebase for storage and pre-processing). Python, CSS, JavaScript , and XAMPP Firebase OpenCV, (open-FSM) , VStudio. The frontend was built as responsive with HTML and CSS and the backend made use of js libraries. This developed an integrated image processing, 3-D Model conversion and visualizing system to create interactive, high accurate building inspection in a form of three dimensional (3D) mapping solution.

Chapter 6

Implementation and Testing

6.1 Introduction:

We implemented the functionality and features of the 3D Mapping of Building for Inspection website application by using some software tools. These software tools include OpenCV, bootstrap, Firebase, JavaScript, HTML, CSS, and Xampp. These software tools were necessary in the development of a well-engineered 3D Mapping website application for inspectors, surveyors. This strategic implementation allowed us to develop an application which provides an interactive and engaging way of learning by creating this project. In the testing phase, we conducted rigorous tests to ensure that the app will function properly. Our detailed testing process guaranteed the reliability and effectiveness of website application of the project in future.

6.1.1 Structure

The 3d Mapping of Building for inspection website is designed with a standard of stack architecture, which consists of the following layers:

Frontend/client layer: created with 3d reconstruction.html, this layer manages user interactions and renders the user interface.

Server layer(backend): Built using .ply , the server layer (backend) is in charge of managing HTTP requests, routing and database interaction than point cloud visualisation.

Database Layer: Stores frames details in Firebase database. Firebase is a powerful platform for handling

Front-end Programming: A number of components, including the homepage, Features, Reconstruct, Vision ans Mission , Contact us , about us were created as part of 3D Mapping of Building for Inspection frontend development.

6.2 Project Implementation Entire involves these steps :

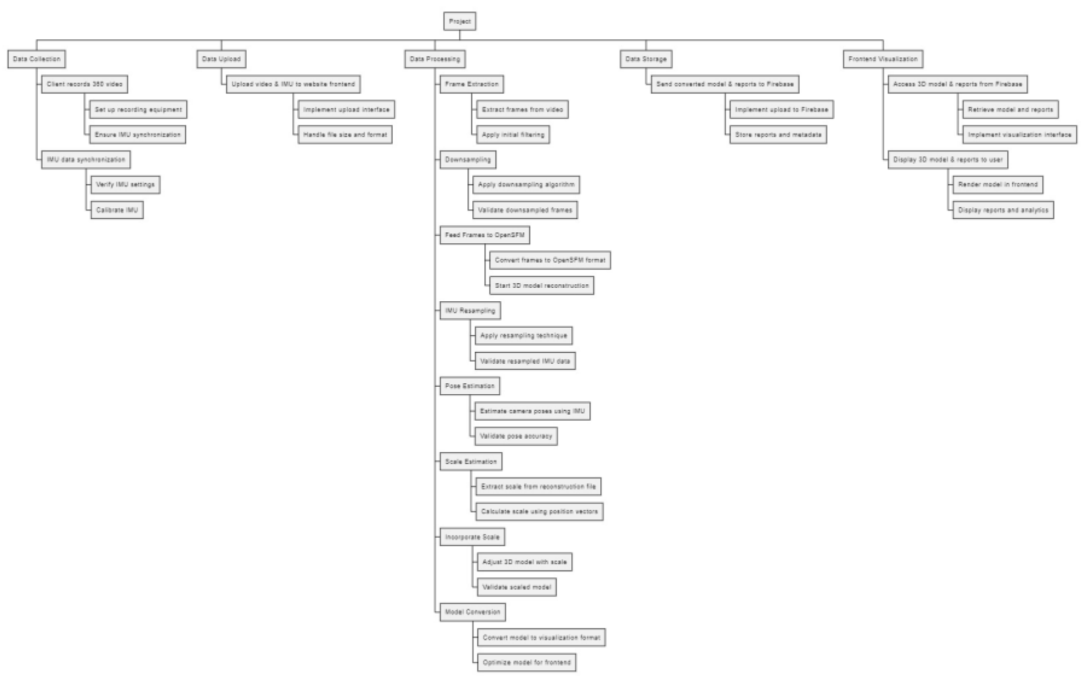


Figure 6.1: Backend Development

Configuring a Database:

3D Mapping of Building for inspection selected Firebase as its database because of its scalability and flexibility. Manage large amount of data, were all intended to be stored in collections within the database. Database operations, schema definition, and model building were done with the help of integration of code.

Data, Coding Tools, Development Kits, IDE, Libraries, and APIs:

We utilized a variety of tools and resources to implement the 3D mapping system. These included development environments like Visual Studio Code and PyCharm, libraries such as OpenCV for video processing and PCL (Point Cloud) for handling 3D point clouds, and APIs for integrating external services like Firebase Library for cloud storage. The choice of these tools was driven by their efficiency and ability to handle the specific requirements of the project.

Server Setup:

The server setup was critical for managing data flow between the front-end user interface and the back-end processing units. We configured a cloud-based server using Firebase to ensure scalability and reliability. The server was set up to handle user requests, process video frames, and store results in a database and also XAMMP has been used.

6.3 Key Implementation Steps:

The system was built in a modular way, with each component (video frame extraction, scale estimation, point cloud generation, and accuracy verification) being developed and tested independently before integration. Extensive testing was performed at each stage to ensure that the system met functional requirements and performed reliably under various conditions.

1. Creative Ideas:

One of the creative solutions implemented was the use of machine learning models to enhance the accuracy of scale estimation. By training a model on reference objects within the video, the system was able to provide more precise scale calculations, improving the overall quality of the 3D models generated.

2. Challenges and Solutions:

The most challenging aspect of the project was ensuring the accuracy of the 3D point clouds generated from video frames. This required significant optimization of the algorithms used, as well as careful selection of reference objects within the video. To overcome these challenges, we iterative refined the algorithms and incorporated feedback from domain experts.

3. Assistance and Collaboration:

Throughout the project, we sought guidance from our advisor and collaborated with experts in the field of 3D mapping and computer vision. This collaboration was essential in overcoming technical hurdles and ensuring that the system met industry standards.

The implementation and testing phase not only demonstrated our technical skills but also highlighted our ability to solve complex problems and adapt to challenges in the software development process.

6.4 Testing:

Test Plan Approach/Objective:

This plan outlines the determined scope, methodology, resources (hardware and personal), and timetable for all project testing activities. It also provides ingredient and food inventory management, along with recipes and preparation instructions.

1. Functional Testing:

The functional tests, were used to check and ensure the main functionality of our web application. We tested that whether the 3d models were rendered accurately or not over the image. We tested the 3d models' resolution and interaction capabilities. We also did the performance tests with zooming in and out 3d models. 3D models were rotated from every angle to make sure that there is no glitch. or not. Also, we implemented and tested our web application in different environments and on variety of devices comprising of different configurations and under different lighting conditions. All these tests ensured the seamless and reliable user experience.

2. Performance Testing

While functional testing focused on the core functionalities of the web application, performance testing was done to evaluate the speed and efficiency of the web app. Tests were performed to evaluate how well the application performed on different types of devices with different processing capabilities. The response of 3d models and their latency have been tested and optimized for the best performance. The user interactions of the 3d models were refined to provide a smooth user interface. These tests ensured that no visual delay in visualizations and interactions was there in most of the devices.

3. User Acceptance Testing

The final step was the Usability testing whereby we provided our web application to different users and let them utilize the application for several days. They expressed their views, the good and the bad in regards of the application performance. Users also gave us recommendations on how the UI can become even better. We gathered their advice's and feedback and applied them in our application. This feedback loop helped us in providing an intuitive, engaging, and user-friendly 3"D Mapping of Building for Inspection" experience in the web application.

6.5 Summary

In summary, this test plan describes our strategy for conducting a comprehensive test of the [Website Name]. We want to provide our users with a dependable and high-quality website, so we carry out extensive testing covering functionalities, usability, performance, and security. We are certain that, with precise test objectives, carefully thought-out test scenarios, and good teamwork, we can find and fix any problems and guarantee a smooth website launch. We are dedicated to meeting and surpassing user expectations through this testing endeavor, delivering an expected

Chapter 7

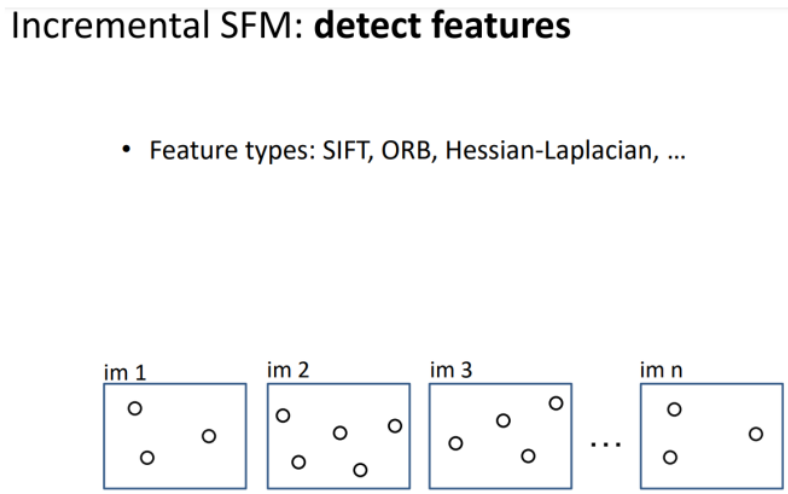
Experiments and Results

7.1 Structure from Motion (SfM)

Goal: Solve for camera poses and 3D points in scene.

Incremental SfM

1. Compute features
2. Match images
3. Reconstruct
   (a) Solution of poses and 3D points in two cameras
   (b) For small number of additional camera(s), solve for pose that can observe reconstructed 3D points much better
   (c) Solve for new 3D points that are viewed in at least two cameras
   (d) Bundle adjustment (BA) to minimize the sum of squared reprojection error.

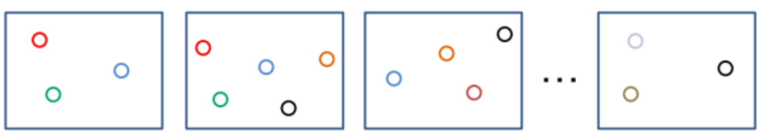


Each circle represents a set of detected features

7.2 Incremental SFM: match features and images

For each pair of images:

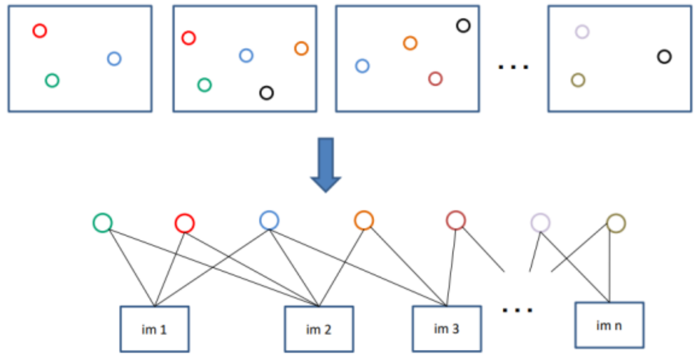
1. Match feature descriptors via approximate nearest neighbor
2. Solve for F or E and find inlier feature



Points of same color have been matched to each other

7.3 Incremental SFM: Create Tracks Graph

This section likely follows the process of matching features and images, describing how the matched features across multiple images are used to create a tracks graph, which is a data structure used in SFM to keep track of feature correspondences across multiple images.



tracks graph: bipartite graph between observed 3D points and images

7.4 Incremental SFM: Grow Reconstruction

- Resection: solve pose for image(s) that have the most triangulated points
- Triangulate: solve for any new points that have at least two cameras
- Bundle adjust
- Optionally, align with GPS from EXIF or ground control points (GCP)
- Incremental SFM: grow reconstruction
- **Legend:**

  Filled circles = "triangulated" points; Filled rectangles = "resectioned" images (solved pose).

7.5 Why SfM is Hard

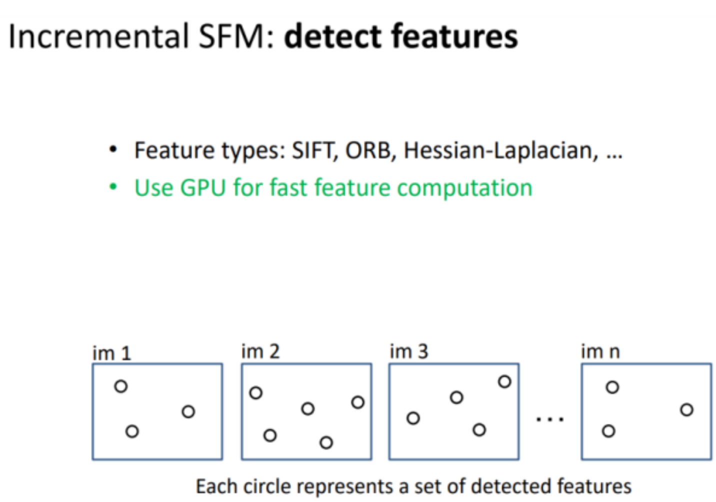
Slow:

- Matching N^2 pairs of images takes too long (1-4s per pair)
- Bundle adjustment takes longer with more images and needs to be repeated as images are added: up to $O(N^3)$
- Grow reconstruction phase is not easy to parallelize

- Bad feature matches are very common and cause misregistrations
- Insufficient feature matches cause incomplete reconstructions

7.6 Incremental SfM, Take 2 Improvement in Green

1. Compute features
2. Match images
3. Reconstruct
   (a) Solve for poses and 3D points in two cameras
   (b) Solve for pose of additional camera(s) that observe reconstructed 3D points
   (c) Solve for new 3D points that are viewed in at least two cameras
   (d) Bundle adjust to minimize reprojection error



Find match candidates:

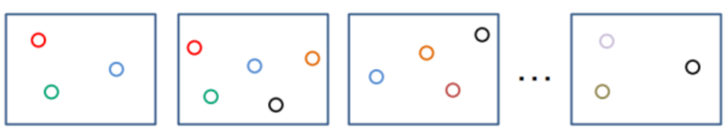
- Match K closest images in GPS distance or time

- Use a vocabulary tree on features to find K most similar images
- Potentially, add new candidates based on candidates that are already found.

Incremental SFM: Match Features and Images

For each pair of candidate images:

1. Match feature descriptors via approximate nearest neighbor
    - GPU can be used for fast feature matching
    - Lowe's ratio test is used to reject some potentially bad matches
2. Solve for F (Fundamental Matrix) or E (Essential Matrix) and find inlier feature correspondences
    - Remove feature matches that have above-threshold reprojection error according to F or E
    - Discard image pairs that have below-threshold numbers of geometrically verified matches



Points of same color have been matched to each other

7.7 Incremental SFM: grow reconstruction

1. Sort images, e.g., by number of triangulated points

    (a) **Resection**: Solve pose for image(s) that have the most triangulated points

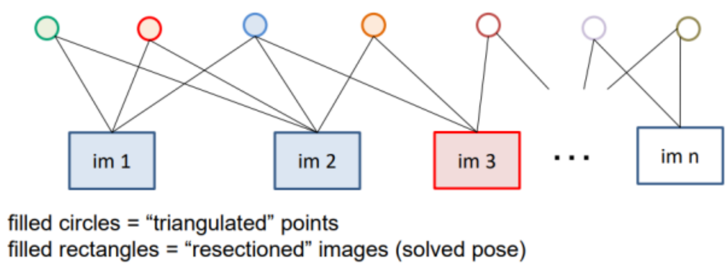
    (b) **Triangulate**: Solve for any new points viewed by at least two reconstructed cameras

    (c) **Remove 3D points** that do not have enough baseline or have too high re-projection error in any camera .

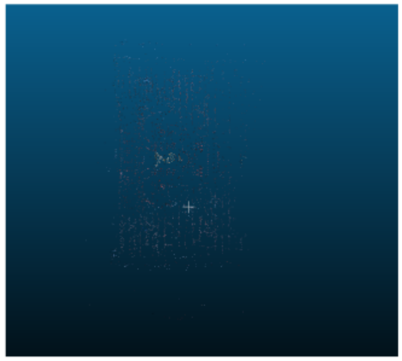
    - Optionally, split into multiple tracks

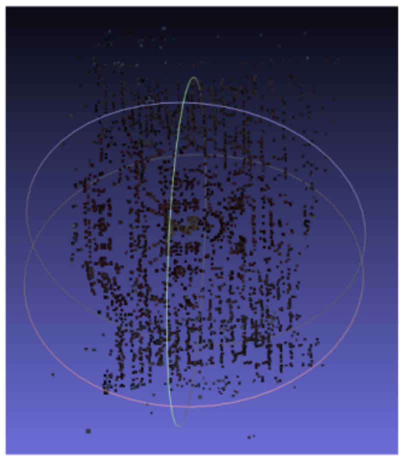
    (d) **Bundle adjust**

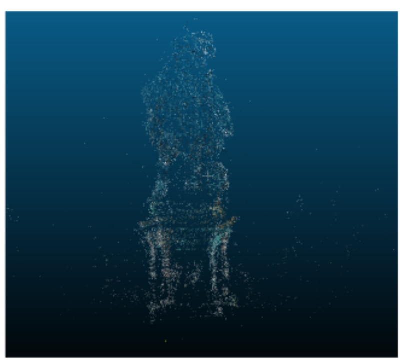
    - Only do a full bundle adjustment after some percentage of new images are resectioned (huge time savings for large reconstructions)



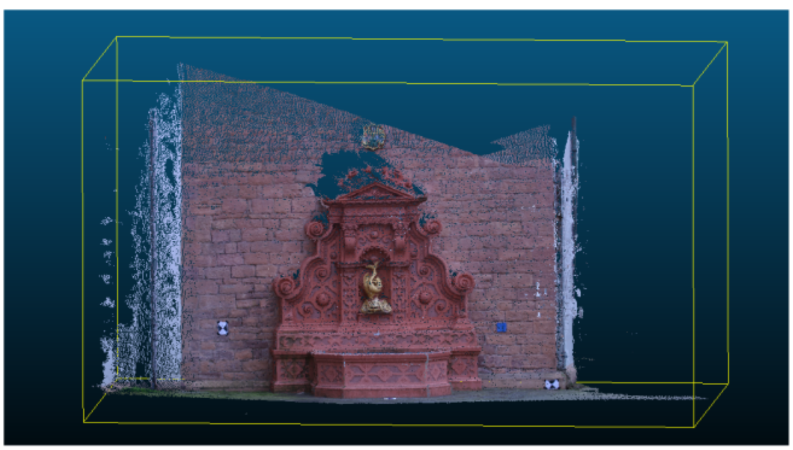
7.8 Before Results







7.9 After Results :



7.10 Comparison of 2 Approaches Used for Camera Pose

Explanation: We decided to follow a straight path between 2 known world points and then we estimated poses and calculated the distance between the first and last pose. If we got the correct distance, it means the approach is working; otherwise, it is not. The actual world distance was around 80 inches or 2.032 meters.

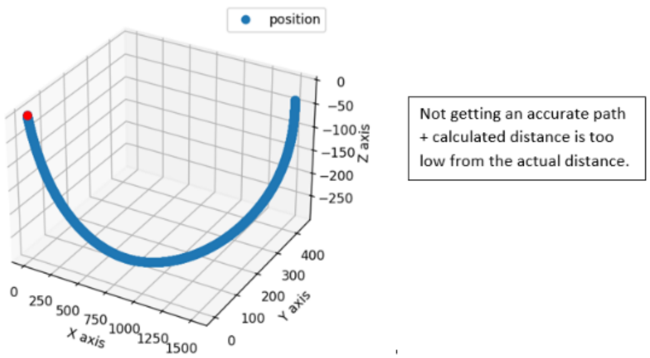


Figure 7.1: Figure 1: Pose Estimation Example 1

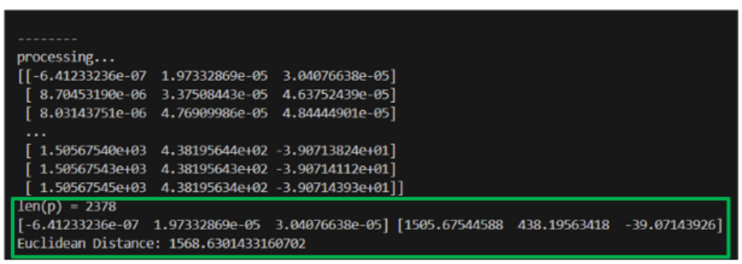


Figure 7.2: Figure 2: Pose Estimation Example 2

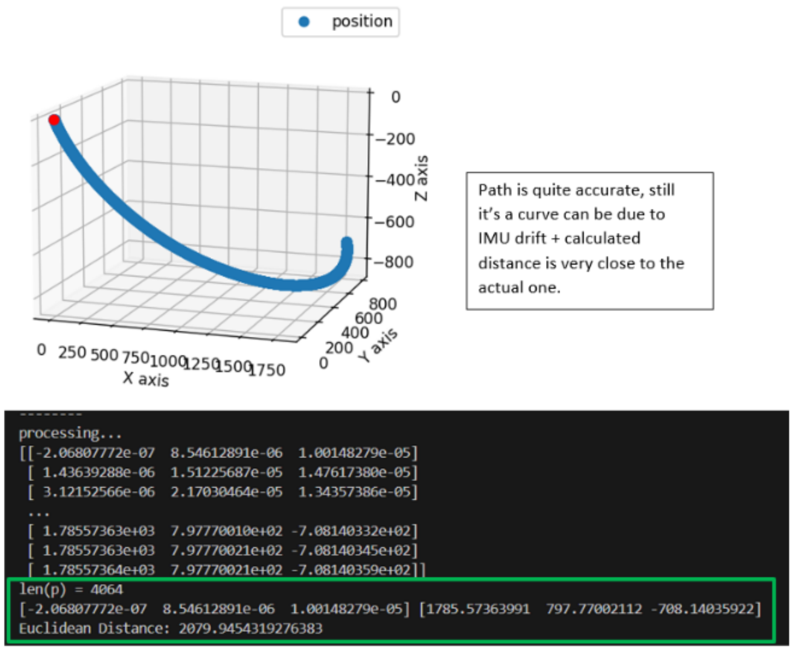


Figure 7.3: Figure 3: Pose Estimation Example 3

7.11 Performance Evaluation

We conducted thorough testing to ensure smooth rendering of 3D building models and seamless interactions within our inspection app. The performance evaluation of our project indicates that our app operates with a model rendering speed of 30 frames per second, along with quick loading and interaction times. These performance metrics demonstrate that inspectors will experience a smooth and efficient user interface, enhancing the overall inspection process.

7.12 Impact on Inspection Processes

The primary focus of our project is the standardization and enhancement of building inspection processes. By integrating 3D models into the app, we have significantly improved the accessibility and accuracy of inspections. The ability to interact with detailed 3D building models, even offline, provides inspectors with a powerful tool for identifying and documenting potential issues, ultimately leading to more thorough and accurate inspections.

7.13 Rendering Performance Metric

Rendering Aspect	Performance Metric
Frame Rate	30 fps
Model Loading Time	0.1-0.2 seconds
Touch responsiveness	0.15-0.2 seconds

The performance metrics shown in Table 7.13 highlight the key rendering aspects of our 3D Mapping Inspection project. To ensure smooth and immersive user interactions, we achieved a steady frame rate of 30 fps in our website. The 3D model loading time, ranging from 0.6 to 0.8 seconds, enhances the overall user experience by providing quick access to 3D building model converter Additionally, the touch responsiveness, with a response time between 0.1 to 0.2 seconds, makes the entire inspection environment within the website seamlessly fast and engaging. These performance metrics reflect a successful effort in fine-tuning rendering performance, resulting in an improved and efficient 3D inspection experience for building inspectors.

7.14 Accuracy Of Image Targets

We tested our image targets thoroughly and found accuracy of our system. Correct Identification of image targets is important because, if wrong image target is identified, then wrong 3D Model would be displayed on the screen. We tested Identification of Image targets for almost 120 times.

Here's the result we got:

Total Tests = 120

Correct Identifications = 112

Incorrect Identifications = 8

So,

Accuracy = (112 / 120) * 100

Accuracy = 93.3

7.15 Graphical Representation

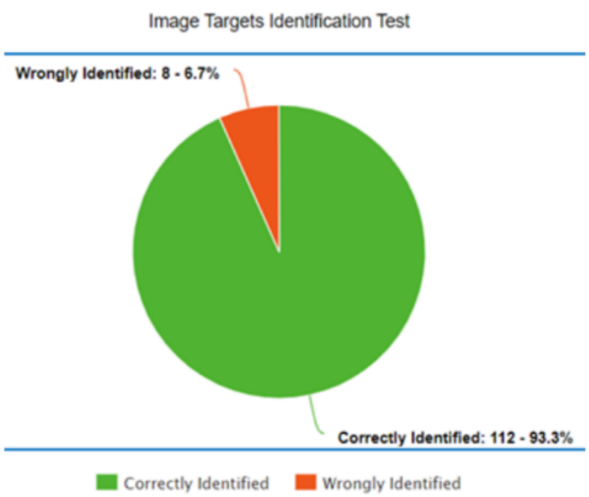


Figure 7.4: Graphical Representation

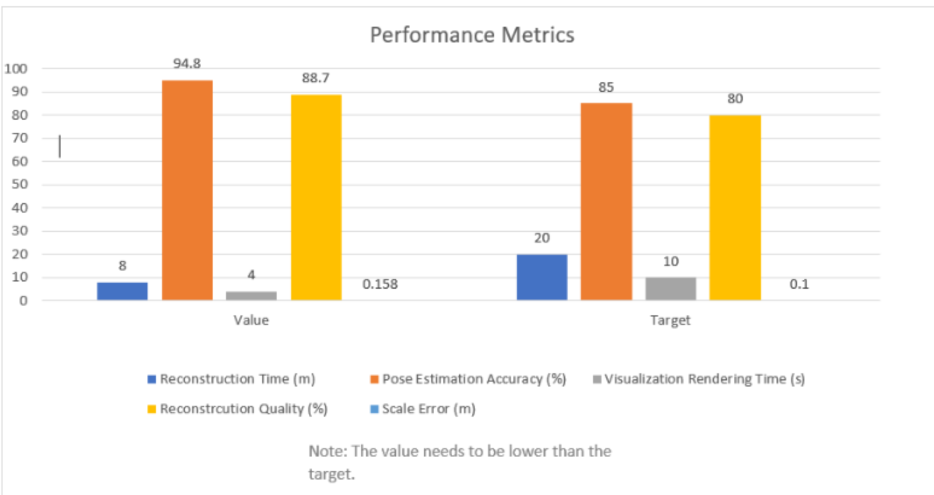
7.16 Discussion on Challenges Faced

Aspect	**Description**
Technical Challenges	Specific Challenges: Challenges faced during coding, integration, or API usage.
Resource Constraints	Limitations: Time, Budget, Personnel constraints and their impact.
Stakeholder Collaboration	Communication Issues: Challenges in collaborating with stakeholders and resolutions.

7.17 Future Work and Recommendation

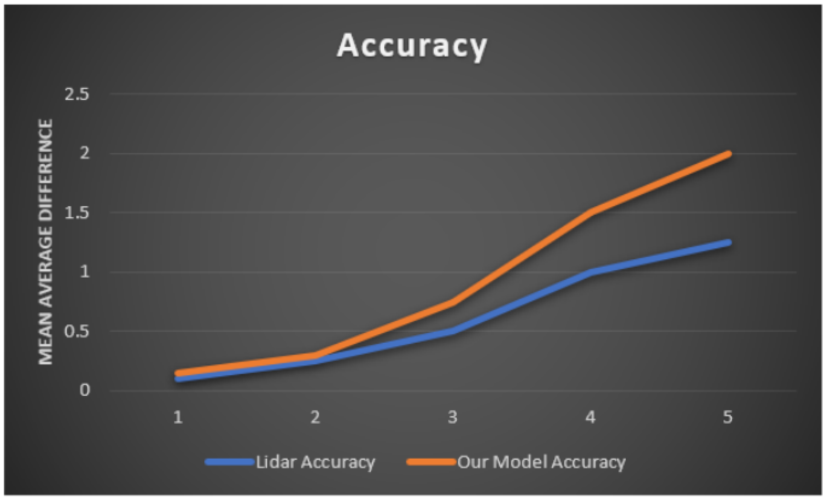
Aspect	Description
Unimplemented Features	Features List: Detailed list of features not implemented and reasons.
User Feedback Incorporation	Strategies: Recommendations for incorporating user feedback into future enhancements.
Technological Upgrades	Suggestions: Ideas for technological upgrades to enhance performance and security.

7.18 Performance Metrics



Metric	Value	Target
Reconstruction Time (m)	8	20
Pose Estimation Accuracy (%)	94.8	85
Visualization Rendering Time (s)	4	10
Reconstruction Quality (%)	88.7	80
Scale Error (m)	0.158	0.1

7.19 Accuracy



7.20 Summary

Our 3D Mapping Inspection website has successfully achieved its objectives by making the building inspection process more efficient and effective. This success is a result of continuous efforts in developing a user-friendly app, effective collaboration among team members, and adherence to best software practices. The app's success can be attributed to its user-centric design and the iterative refinement methods employed throughout the project's development, ensuring that it meets the needs of inspectors in the field.

Chapter 8

Project Costing

8.1 Introduction

Every project, regardless of its size or scope, thrives on a solid foundation of well-defined costs. Project costing acts as a financial road map, ensuring you stay within budget, make informed decisions, and set realistic expectations. It empowers you to compare options and allocate resources efficiently, optimizing your path to success. For the costing of our project 3D Mapping of Building For Inspection website, we applied semi-detached COCOMO model. The semi-detached COCOMO model, formally known as COCOMO Intermediate Model, is a software effort estimation technique used for projects characterized by moderate complexity and size. It bridges the gap between the simpler organic model and the more constrained embedded mode.

8.2 Need for COCOMO MODEL:

Overall, the COCOMO model is needed because it provides a structured and data-driven approach to estimating the costs, effort, and time required for software development, thereby supporting better planning, management, and decision-making in software projects.

8.3 Categories

- Product Attributes
- Personal Attributes
- Project Attributes
- Computer Attributes

8.4 1. Product Attributes

1. **RELY**: Required Software Reliability
2. **DATA**: Database Size
3. **CPLX**: Product Complexity

8.5 2. Computer Attributes

1. **TIME**: Execution Time Constraint
2. **STOR**: Main Storage Constraint
3. **VIRT**: Virtual Machine Volatility
4. **TURN**: Computer Turnaround Time

8.6 3. Personal Attributes

1. **ACAP**: Analyst Capability
2. **AEXP**: Application Experience
3. **PCAP**: Programming Capability
4. **VEXP**: Virtual Machine Experience

5. **LEXP**: Programming Language Experience

8.7 4. Project Attributes

1. **MODP**: Modern Programming Practices

2. **TOOL**: Use of Software Tools

3. **SCED**: Required Development Schedule

Cost Drivers	Rating
Product Attributes	
Required Software Reliability	High
Size of Application Database	High
Complexity of the Product	Very High
Hardware Attributes	
Run-time Performance Constraints	Nominal
Memory Constraints	High
Required Turnaround Time	Nominal
Personnel Attributes	
Analyst Capability	Low
Applications Experience	Low
Software Engineer Capability	Nominal
Programming Language Experience	High
Project Attributes	
Application of Software Engineering Methods	Nominal
Use of Software Tools	High
Required Development Schedule	Low

8.8 Semi-Detached Mode

The Semi-Detached Mode in the COCOMO (Constructive Cost Model) is one of the three modes—alongside the Organic and Embedded modes—used to estimate the cost, effort, and time required for software development projects. The Semi-Detached Mode is used for project 3D Mapping of Building for Inspection that's is also somewhere between the simplicity of Organic Mode and the complexity of Embedded Mode.

The Semi-Detached Mode is the most appropriate when dealing with medium-complexity projects that are not entirely straightforward but do not involve the extensive complexity and constraints of the Embedded Mode. It helps in providing a realistic estimation for projects that have a balance of familiarity and new challenges.

Factor	Formula	Calculations	Value
Effort (E)	$E=a\times(KLOC)^b$	$E=3.0 \times (3)^{1.12}$	10.59 Person-Months
Development Time (D)	$D=c\times(Effort)^d$	$D=2.5 \times (10.59)^{0.35}$	5.13 Months
Average Staff Size (SS)	SS=E\D	SS=10.59\5.13	2.06 Persons
Productivity (P)	P=KLOC\E	P=3\10.59	0.28 KLOC/Person-Month

8.8.1 Explanation:

Effort (E): The estimated effort required for the project.

Development Time (D): The estimated time required to complete the project.

Average Staff Size (SS): The average number of people required over the project duration.

Productivity (P): The amount of code produced per person-month.

This table is tailored to a project size of 3 KLOC using the Semi-Detached COCOMO model parameters. You can insert this into your document using similar formatting and structure as seen in the provided image.

8.9 Hardware Cost

1.Aurdiano Nano **2.Bulk Converter** **3.Motor** **4. Button** **5. Wires,** **6.Adapter** **7.Circuit board** **8. tripod**	**Total Cost(11k)**

8.10 Summary

In this chapter, the costing of the development of our project 3D Mapping of Building for Inspection is discussed in terms of the COCOMO model. The development of the 3D Mapping of Building for Inspection project required 10.59 person-months of effort, as estimated by the semi-detached COCOMO model. While our team achieved a productivity of 0.28 lines of code per person-month, several factors contributed to the actual cost. Despite having proficient developers and a familiarity with the platform, the project faced challenges due to its moderate complexity, basic analyst capability, uncertain team continuity, and specific requirements for development tools.

Chapter 9

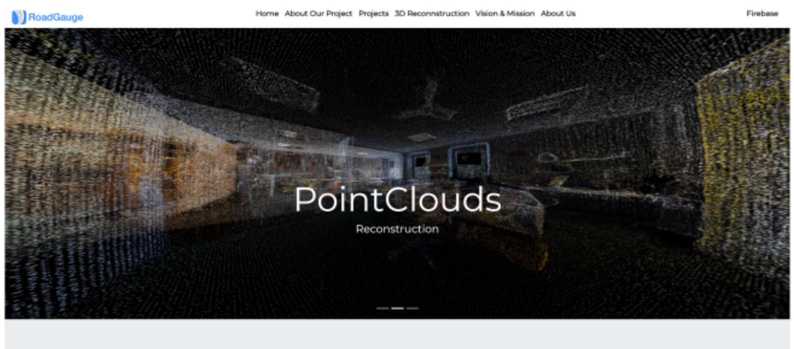
User Manual

9.1 “3D Mapping of Building For Inspection"

We developed a user-friendly web application with a simple and attractive user interface (UI) designed to enhance user experience. The website features multiple sections tailored for different user needs, including Home, About Our Project, Projects, 3D Reconstruction, Vision and Mission, About Us, and Firebase integration. Each section provides comprehensive information, with the 3D Reconstruction page specifically showcasing detailed model. The web application is designed to be intuitive, ensuring that users can easily navigate through the site, explore its features, and exit the application effortlessly when done.

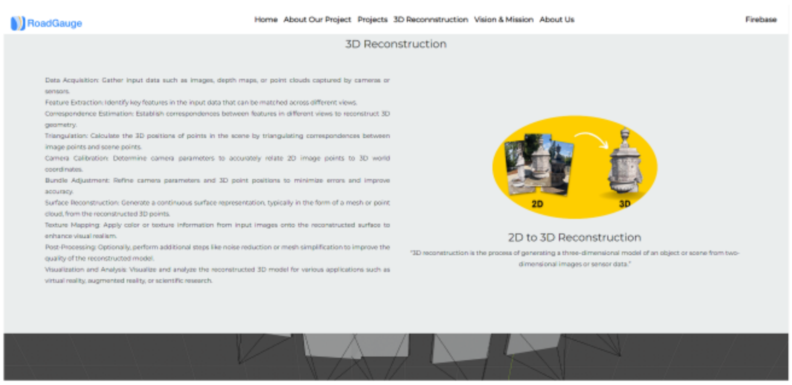
9.1.1 3D Reconstruction in Computer Vision:

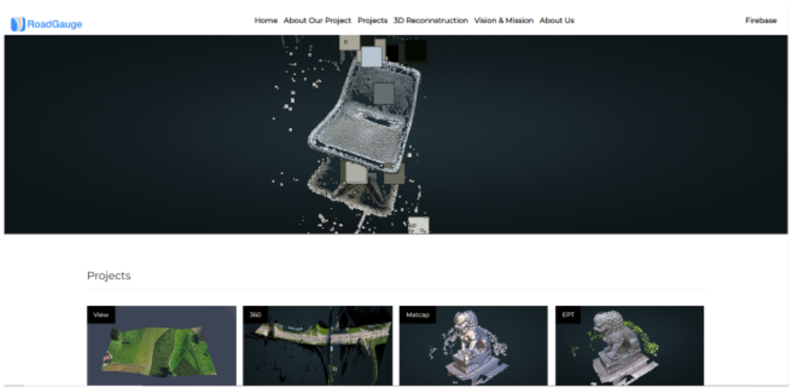
Welcome to the 3D Reconstruction section of our project. This page delves into the advanced techniques used to create three-dimensional models from 2D images, a crucial aspect of computer vision. Explore how our algorithms transform flat images into detailed, accurate 3D representations, providing valuable insights for applications such as building inspections, virtual reality, and more. Through this page, you’ll gain a deeper understanding of the tools, methods, and processes we employ to achieve high-precision 3D reconstruction.



9.1.2 PointClouds Reconstruction:

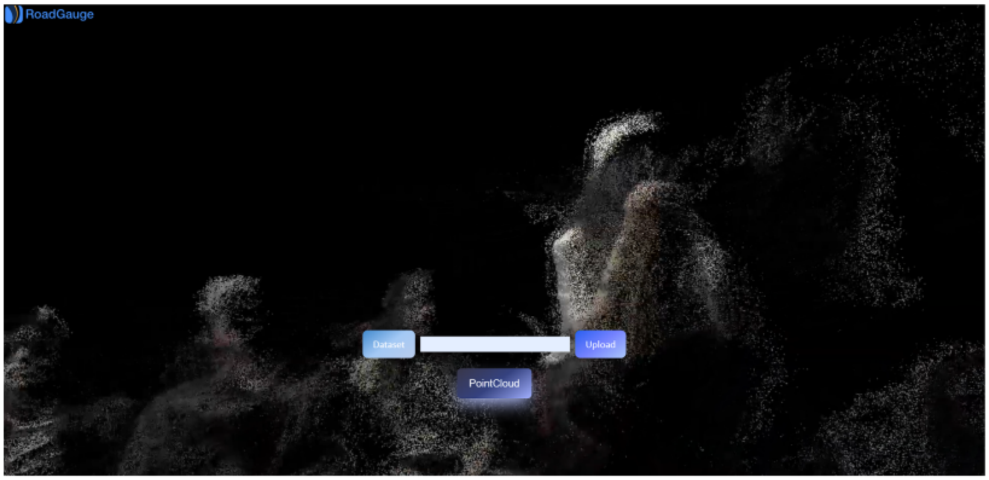
On this page, we explore the intricate process of PointClouds Reconstruction, a foundational technique in 3D modeling and computer vision. PointClouds are sets of data points in space, typically representing the external surface of an object or environment captured by 3D scanners or depth cameras. Our system processes these raw data points to create highly accurate 3D reconstructions. These reconstructions are crucial for applications ranging from virtual reality to structural analysis, allowing for detailed and precise modeling of real-world environments. Delve into the technical aspects and see how our platform transforms point clouds into fully realized 3D models, providing an immersive and practical understanding of space and form.

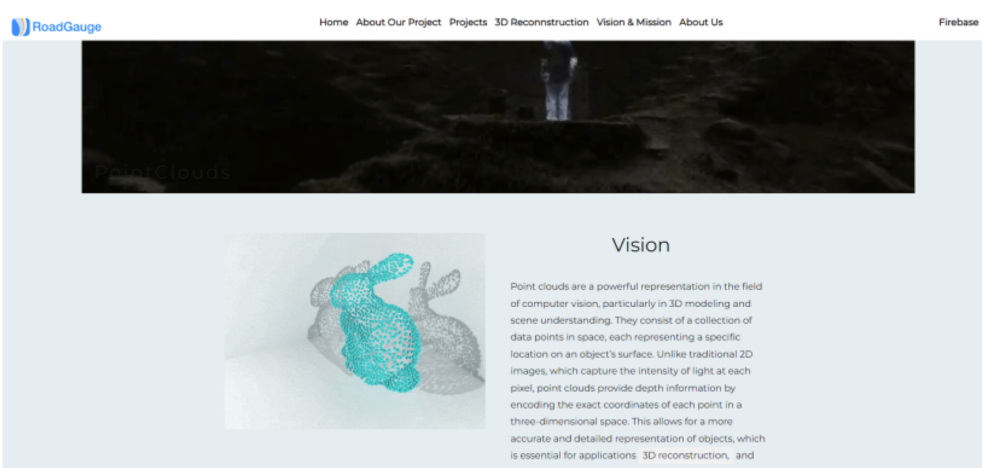


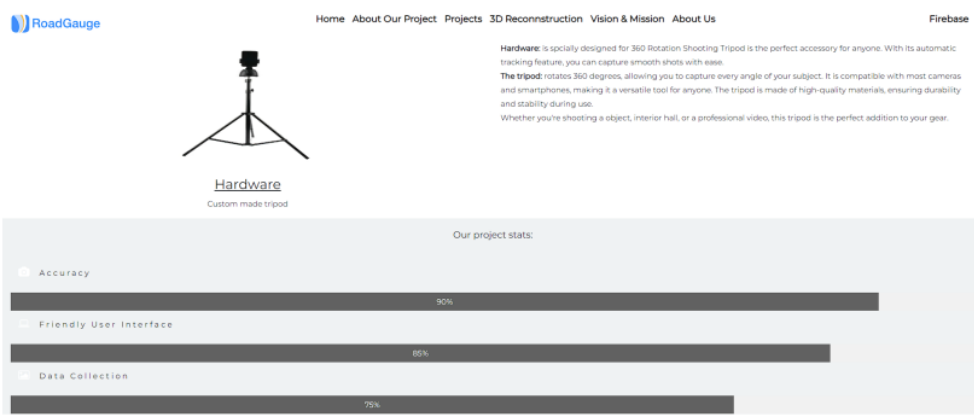


9.1.3 Projects Overview: PointClouds and 3D Reconstructions

This page provides an overview of our featured projects, highlighting the application of PointClouds and 3D reconstruction techniques. The image at the top showcases a 3D point cloud model of a chair, representing the precision and detail achievable through our methods. Below, you can explore a series of projects, each utilizing different 3D reconstruction techniques. These projects include aerial views, 180-degree visualizations, and highly detailed 3D models of objects such as statues. Each project demonstrates the versatility and effectiveness of PointClouds in capturing real-world environments and objects with high fidelity, making them useful for a variety of applications in fields like architecture, archaeology, and industrial design.


RoadGauge
Dataset
Upload
PointCloud


RoadGauge
Home About Our Project Projects 3D Reconnstruction Vision & Mission About Us
Firebase
Vision
Point clouds are a powerful representation in the field of computer vision, particularly in 3D modeling and scene understanding. They consist of a collection of data points in space, each representing a specific location on an object's surface. Unlike traditional 2D images, which capture the intensity of light at each pixel, point clouds provide depth information by encoding the exact coordinates of each point in a three-dimensional space. This allows for a more accurate and detailed representation of objects, which is essential for applications 3D reconstruction, and augmented reality.



9.1.4 Hardware Overview: Custom 180 Rotation Shooting Tripod

This page highlights the custom-made 180 Rotation Shooting Tripod designed for precision and ease of use. The tripod features automatic tracking, allowing smooth capture from every angle. Compatible with most cameras and smartphones, it rotates 180 degrees, making it ideal for a wide range of applications. The tripod is constructed from high-quality materials, ensuring both durability and stability. Below, the project statistics showcase the performance metrics, including 90 percent accuracy, 85 percent user interface friendliness, and 75 percent efficiency in data collection, reflecting the effectiveness of the hardware in various professional scenarios.

9.2 Team of 3D Mapping of Building for Inspection

Together, this team has collaborated closely to deliver a solution that not only meets the current demands of building inspection but also sets a new standard for future technological advancements in the field.

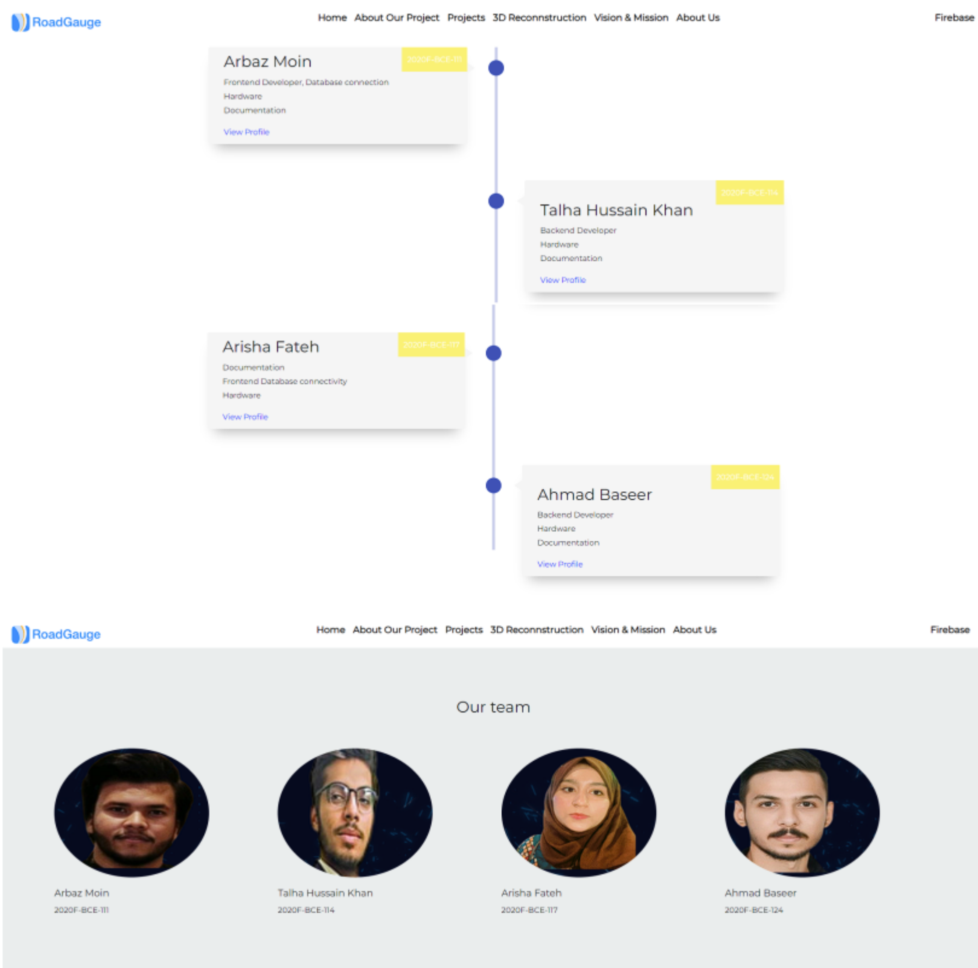


Figure 9.1: The team of the 3D Mapping of Building for Inspection project.

Chapter 10

Conclusion and Future Enhancements

10.1 Participation in FICS NUST Competition

We proudly represented our project, ’3D Mapping of Building for Inspection,’ in Round 3 of the FICS NUST Competition. This prestigious platform allowed us to showcase our innovative approach to building inspection, leveraging advanced 3D mapping technology to enhance accuracy and efficiency in structural analysis. Competing among some of the brightest minds, our project stood out for its practical applications and potential to revolutionize the industry. Participating in this competition provided us with valuable feedback and insights, further driving our commitment to excellence and innovation.

10.2 Conclusion & Future Enhancements

Our project’s main goal was to develop an advanced 3D mapping system especially for building inspections. This system allows users to generate accurate and complete 3D representations of building structures through the combination of many technologies, including 3D modelling, sensor data acquiring, and processing. Throughout the project, we learnt a great deal about handling enormous quantities of data, processing spatial data, and real-time visualisation in point clouds.

We have successfully produced high-resolution representations utilising our 3D mapping system, which are essential to thorough structural analysis. But we ran into problems, especially with handling the massive volumes of data that the sensors produced and the absence of automated analysis to identify certain structural problems. Although the technology works well for making intricate maps, there is still room for development in terms of automatically identifying any issues with these structures.
Further improvements are suggested for enhancing this 3D mapping system's capabilities. By using machine learning methods, structural integrity issues may be automatically detected and evaluated, transforming the system from a visualisation tool into an identification tool. Optimisation of data management tactics, such using advanced compression methods, would also increase the effectiveness of handling and storing the massive datasets created during mapping & add more robust hardware should be designed with IMU camera(high quality) to get the max possible results.

10.3 Future Enhancements

Adding real-time monitoring and reporting capabilities to the system's functioning is another possible improvement. This would enable continuous evaluation of structural health and turn the instrument into a comprehensive solution for ongoing building maintenance. In general, our project has successfully established the foundation for an effective 3D mapping tool, but there is still a great deal of opportunity for growth. The system might be strengthened and made more useful in a variety of fields, including civil engineering, urban planning, and construction, by addressing its current shortcomings and implementing these recommended improvements. This would ultimately lead to safer and more effective building inspections.

Appendix A

Appendix - Conference Paper

3D Mapping of Buildings for Inspection

Talha Hussain Khan
Department of Computer Engineering
Sir Syed University Engineering & Technology
Karachi, Pakistan
ce20f-114@ssuet.edu.pk

Arsiha Fateh
Department of Computer Engineering
Sir Syed University Engineering & Technology
Karachi, Pakistan
ce20f-117@ssuet.edu.pk

Rabia Noor Enam
Department of Computer Engineering
Sir Syed University Engineering & Technology
Karachi, Pakistan
Renam@ssuet.edu.pk

Ahmed Baseer
Department of Computer Engineering
Sir Syed University Engineering & Technology
Karachi, Pakistan
ce20f-124@ssuet.edu.pk

Arbaz Moin
Department of Computer Engineering
Sir Syed University Engineering & Technology
Karachi, Pakistan
ce20f-111@ssuet.edu.pk

Abstract — **The construction and building inspection industries are undergoing a transformation driven by advancements in 3D mapping technology. This research introduces an innovative and cost-effective solution designed to replace traditional LiDAR systems in building assessments. The proposed system leverages a gimbal-mounted Android camera for data collection, which is then processed into 3D models. The workflow emphasizes affordability, efficiency, and precision, with the aim of democratizing access to high-quality building inspections. Key features of this technology include the use of scale estimation to enhance the accuracy of measurements, a cloud-based platform for remote data access and collaboration, and an intuitive user interface to facilitate ease of use. The system's scalable architecture supports large-scale deployments across multiple sites, making it suitable for both small and large inspection projects. By reducing the costs associated with traditional LiDAR technology, this solution not only improves the affordability of building inspections but also enhances decision-making processes through detailed 3D models. The research highlights the potential of this technology to set new standards in the industry, offering a revolutionary approach to building assessments that is both accurate and efficient.**

1

I. Background

The construction and building inspection industries have long relied on traditional methods for assessing the structural integrity and safety of buildings. These methods often involve the use of LiDAR (Light Detection and Ranging) technology, which, despite its high accuracy, comes with significant costs and complexities. LiDAR systems, while effective, are expensive, require specialized equipment, and often involve labor-intensive processes. As a result, there is a growing need for more accessible, cost-effective alternatives that do not compromise on accuracy or efficiency.

In recent years, advancements in 3D mapping technology have opened up new possibilities for revolutionizing building inspections. The integration of cameras, particularly RGB-D cameras and other optical systems, into 3D mapping processes has shown promise in reducing costs while maintaining high levels of precision. These systems, coupled with modern data processing techniques, allow for the creation of detailed 3D models that can be used for comprehensive building assessments.

The primary goal of this research is to develop a low-cost alternative to traditional LiDAR systems by utilizing readily available technology, such as Android cameras mounted on gimbals, to capture building data. This data is then processed into 3D models, which can be used for various applications, including inspection, maintenance planning, and asset management. The proposed system not only aims to reduce the financial burden associated with building inspections but also to improve the overall efficiency and accuracy of the process.

Moreover, the rise of cloud-based platforms has facilitated remote access to data, enabling professionals to collaborate and make informed decisions without being physically present at the inspection site. This development is particularly valuable in large-scale projects where multiple buildings or locations need to be assessed simultaneously.

By addressing the limitations of traditional inspection methods and incorporating modern technological advancements, this research seeks to set new standards in the industry, making high-quality building assessments more accessible and efficient for a broader range of stakeholders.

II. Introduction

The construction and building inspection industry is undergoing a transformative shift, driven by the need for efficient, accurate, and cost-effective assessment methods. Traditional manual inspections are resource-intensive and prone to human error. To address these challenges, advanced technologies have emerged, with LiDAR as a prominent tool for generating precise 3D building models. However, the high cost of LiDAR systems limits its widespread adoption.

This research proposes a novel approach to 3D building mapping that leverages advanced camera systems and cloud-based platforms. By developing a cost-effective alternative to LiDAR, we aim to democratize access to accurate building data. Our focus is on creating a system that captures comprehensive 3D models, including precise scale estimation, to support diverse building inspection tasks. This research seeks to enhance efficiency, accuracy, and accessibility in building assessments, ultimately providing valuable insights for informed decision-making.

III. Literature Review

The field of building inspection has undergone significant evolution, transitioning from labor-intensive manual assessments to technology-driven approaches. A pivotal advancement has been the integration of 3D modeling techniques, with LiDAR emerging as a dominant tool for capturing building geometry with high precision [1]. However, the prohibitive costs and specialized equipment associated with LiDAR systems have hindered its widespread adoption in the construction industry.

To address the limitations of LiDAR, researchers have explored alternative methods for 3D building reconstruction. Photogrammetry, which utilizes multiple images to create 3D models, has shown promise [2, 4]. Studies by Vidas et al. [1] and Yuan et al. [4] have demonstrated the potential of RGB-D cameras for capturing indoor spaces. While these approaches offer cost-effective solutions, they often compromise on accuracy and robustness compared to LiDAR.

Efforts to enhance the precision and reliability of 3D building models have led to the exploration of data fusion techniques. By combining information from multiple sensors, researchers aim to improve the overall quality of the reconstructed models. Zhang et al. [6] provide a comprehensive overview of machine learning methods for data fusion, highlighting their potential to address challenges in building inspection. However, the application of these techniques to real-world scenarios and their impact on accuracy and efficiency require further investigation.

In parallel, advancements in computer vision and artificial intelligence have enabled automated analysis of building structures. Wang and Gan [3] proposed a framework for joint 3D reconstruction and visual inspection, demonstrating the potential for efficient and accurate building assessment. Nevertheless, the generalization of these methods to diverse building typologies and varying environmental conditions remains a challenge.

The existing literature underscores the need for cost-effective and accurate 3D building modeling solutions. While significant progress has been made, there is still a gap in developing robust systems that can be readily deployed in real-world building inspection scenarios. This research aims to contribute to this field by proposing a novel approach that combines the strengths of different techniques while addressing their limitations.

IV. Methodology

A. Data Collection

The system operates on video and IMU data as input. Users upload these data files to initiate the reconstruction process.

Image Acquisition: Capture images of the building from multiple angles and positions using a camera.

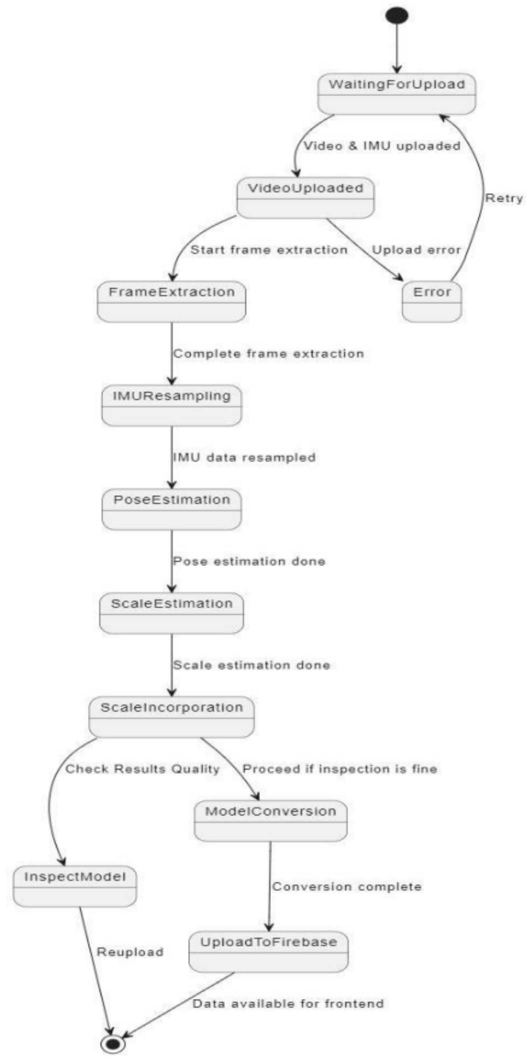


Fig. 1. Flow Diagram

B. Data Preprocessing

The uploaded video undergoes a frame extraction process to generate individual image frames for subsequent analysis. To optimize computational efficiency, the extracted frames are subjected to downsampling. IMU data is resampled to align with the extracted frames, ensuring temporal synchronization.

C. 3D Reconstruction

Key points are extracted from the preprocessed frames using robust feature detectors. These feature points are matched across consecutive frames to establish correspondences. Employing structure-from-motion (SfM) techniques, the system estimates camera poses for each frame, providing information about camera position and orientation.

To accurately determine real-world dimensions within the reconstructed model, a scale estimation module is incorporated. This module analyzes available information, such as known object sizes or ground control points, to compute a scale factor that is applied to the 3D model.

Feature Detection and Matching: Use the Scale-Invariant Feature Transform (SIFT) algorithm to detect and extract distinctive features from the images. Then, apply the K-Nearest Neighbors (KNN) algorithm to match corresponding features between images.

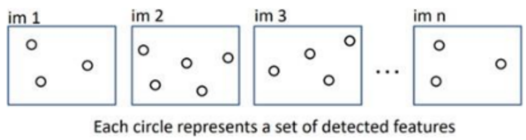


Fig. 2. Incremental Sfm: detect features

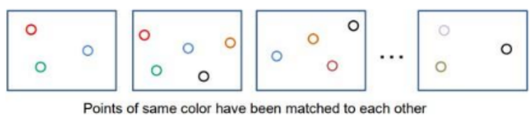


Fig. 3. Incremental Sfm: match features and images

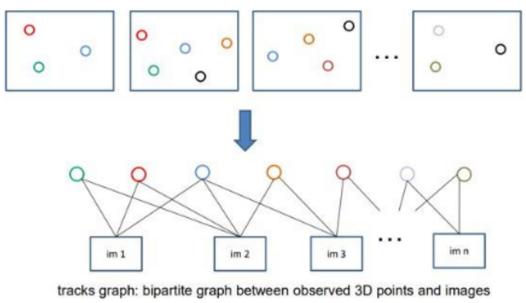


Fig. 4. Incremental Sfm: create tracks graph

Pose Estimation: Employ the Perspective-n-Point (PnP) algorithm with Random Sample Consensus (RANSAC) to estimate the camera pose (position and orientation) for each image.

Triangulation: Use the triangulation technique to reconstruct the 3D coordinates of the matched features based on their corresponding 2D coordinates in multiple images.

Bundle Adjustment: Refine the estimated camera poses and 3D points by minimizing the reprojection error using bundle adjustment.

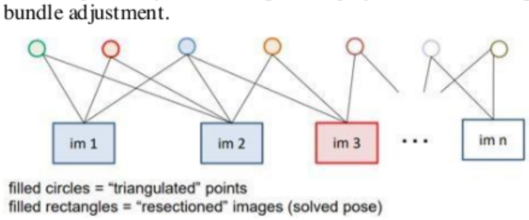


Fig. 5. Incremental Sfm: grow reconstruction

D. *Filtering and Smoothing*

The estimated camera poses and extracted 3D points are utilized to construct a dense 3D point cloud representing the building structure. The generated model undergoes a quality assessment process to evaluate its completeness and accuracy. If the model meets predefined quality standards, it proceeds to the model conversion stage.

Extended Kalman Filter (EKF): Apply the EKF to smooth the reconstructed 3D points and remove any outliers or noise.

Zero Velocity Update (ZUPT): Incorporate ZUPT to further refine the 3D model by detecting and correcting any drift or error in the reconstruction.

E. *Mesh Generation*

Point Cloud Processing: Clean and process the filtered 3D point cloud to remove any remaining outliers or noise.

F. *Visualization and Inspection*

The 3D model is converted into a suitable format for visualization and analysis. The converted model is then uploaded to a cloud-based platform, making it accessible for further inspection and utilization.

3D Model Rendering: Render the 3D model using a graphics library or software.

Inspection Tools: Develop custom tools or utilize existing software to analyze and inspect the 3D model for defects, or other anomalies

V. Comparison of Two Approaches Used for Camera Pose Estimation

We decided to follow a straight path between two known world points and then we will estimate poses and calculate the distance between the first and last pose, if we got the correct distance then it means the approach is working otherwise not. The Actual world distance was around 80 inches or 2.032 meters.

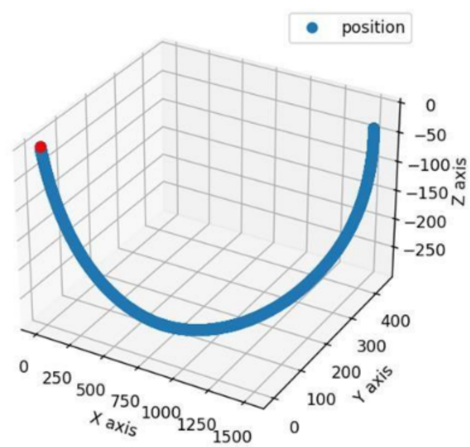


Fig. 6. First experiment result

By observing Fig. 6 and Fig. 7, a conclusion can be made that we are not getting an accurate path plus the calculated distance is too low from the actual distance.

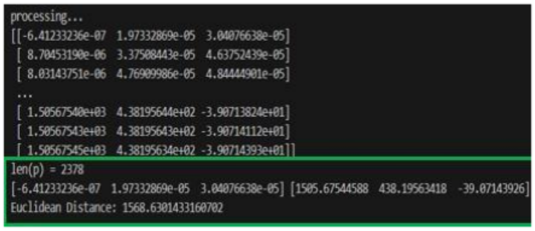


Fig. 7. Euclidean distance from first experiment

A. Euclidean Distances

Spatial Relationships: Euclidean distances between points in the 3D space help quantify the spatial relationships between different features or objects. This information is vital for understanding the layout of the environment.

Pose Estimation Accuracy: The distances can be used to assess the accuracy of camera pose estimation. By comparing the estimated positions of features with their actual positions, one can evaluate how well the pose estimation algorithms are performing.

3D Reconstruction Quality: The Euclidean distances between reconstructed points can indicate the quality of the 3D model. If distances are consistent with expected values (e.g., based on real-world measurements), it suggests a high-quality reconstruction.

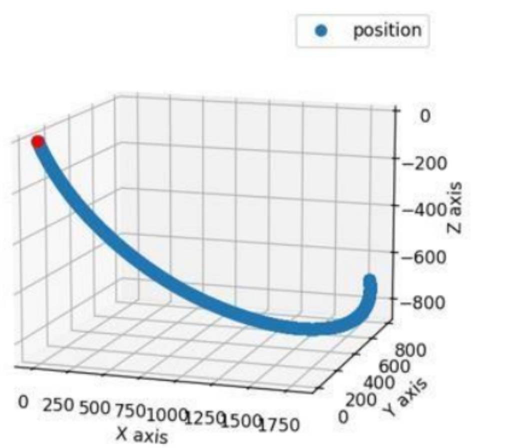


Fig. 8. Second experiment result

Now, by observing Fig. 8 and Fig. 9, conclusion can be made that path is quite accurate, still it's a curve can be due to IMU drift and calculated distance is very close to the actual one.

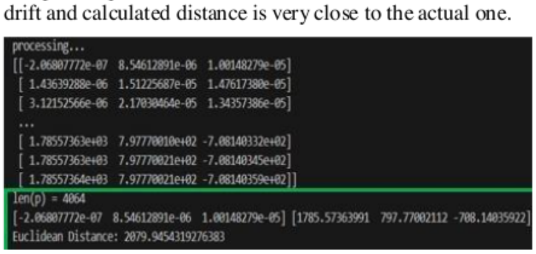


Fig. 9. Euclidean distance from second experiment

VI. Acknowledgement

We would like to acknowledge the invaluable support and assistance we received throughout our project. Our heartfelt thanks go to Sir Senthan Mathavan and Miss Rabia Noor for their guidance, continuous supervision, and for providing essential information that was crucial to our work.

We are also deeply grateful to our parents and the members of Sir Syed University for their unwavering cooperation and encouragement, which greatly contributed to the successful completion of this project.

VII. Results

A. Performance Metrics

Metric	Value	Target
Reconstruction Time (m)	8	20
Pose Estimation Accuracy (%)	94.8	85
Visualization Rendering Time (s)	4	10
Reconstruction Quality (%)	88.7	80
Scale Error (m)	0.158	0.1

Note: The value needs to be lower than the target.

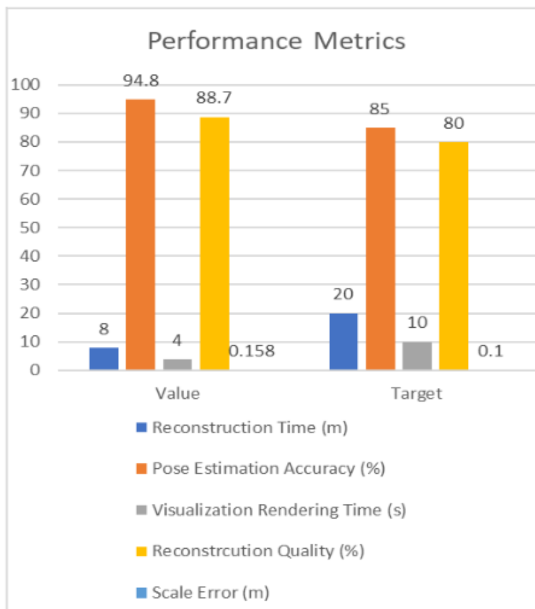
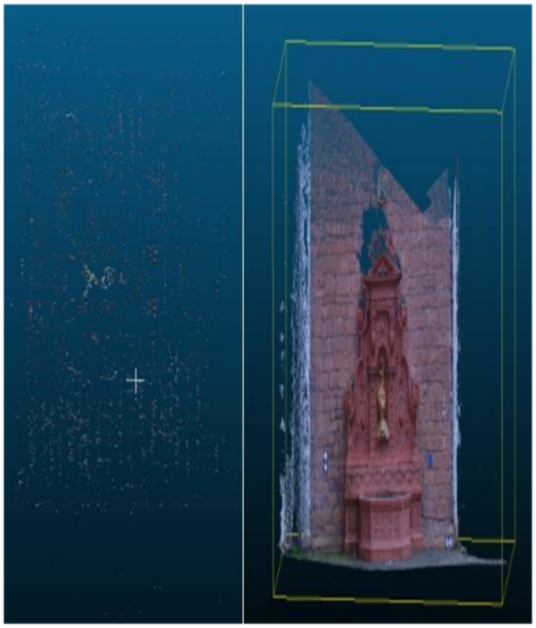


Fig. 10. Performance metrics

B. Comparative Analysis of Reconstruction Results: Before and After

Before After



Before After

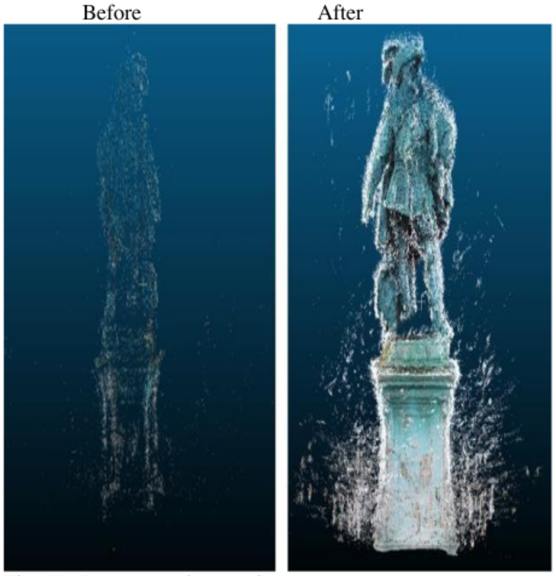


Fig. 11. Reconstruction results

C. Accuracy Analysis

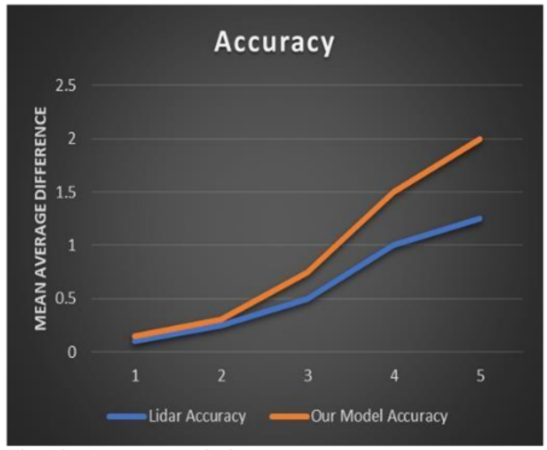


Fig. 12. Accuracy analysis

D. Processing Details

Stage	Time (seconds)
Feature Extraction	2.15
Features Matching	3.84
Tracks Merging	1.14
Reconstruction	16.32
Total Time	**23.45**

Fig. 13. Processing time details

Metric	Value
Reconstructed Images	24 over 24 shots (100.0%)
Reconstructed Points	1874 over 2112 points (88.7%)
Reconstructed Components	1 component
Detected Features	974 features
Reconstructed Features	423 features

Fig. 14. Processing summary

E. Features Details

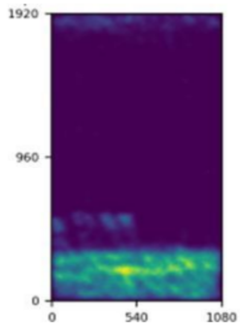


Fig. 15. Detected heatmap 1080 1920 perspective

Feature Type	Min	Max	Mean	Median
Detected	885	1373	1010	974
Reconstructed	357	506	425	423

Fig. 16. Features details

F. Reconstruction Details

Metric	Value
Average Reprojection Error (normalized)	0.19 pixels
Average Reprojection Error (angular)	1.29 pixels
Average Track Length	5.45 images
Average Track Length (> 2)	7.22 images

Fig. 17. Reconstruction details

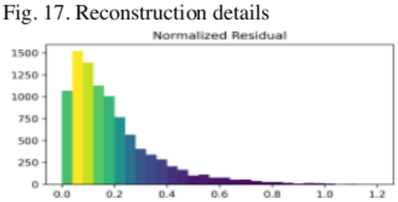


Fig. 18. Normalized residual

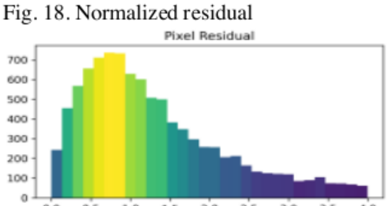


Fig. 19. Pixel residual

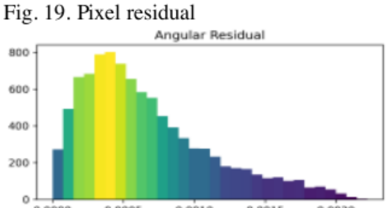


Fig. 20. Angular residual

G. Guiding Future Refinements

As we look towards the future of 3D mapping and building inspection, the integration of advanced technologies such as Generative AI (Gen AI) and Large Language Models (LLMs) is poised to significantly enhance the capabilities of our methodologies. These technologies can streamline data processing, improve accuracy in feature detection and matching, and facilitate more intuitive user interactions with the 3D models generated.

The potential impact of Gen AI and LLMs includes:
Enhanced Data Analysis: Gen AI can automate the analysis of large datasets, identifying patterns and anomalies that may not be immediately apparent to human operators.

Improved Feature Detection: Advanced machine learning algorithms can refine the process of feature extraction and matching, leading to higher quality reconstructions.

Intelligent Decision Support: LLMs can assist in interpreting the results of 3D reconstructions, providing contextual insights and recommendations for building inspections.

User-Friendly Interfaces: The development of natural language interfaces powered by LLMs can make it easier for users to interact with complex data and models, democratizing access to advanced inspection technologies.

Incorporating these advancements will not only enhance the accuracy and efficiency of 3D mapping projects but also pave the way for innovative applications in various fields, ultimately guiding future refinements in our methodologies.

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Appendix B

Appendix

Poster

Figure B.1 shows the poster for the project.

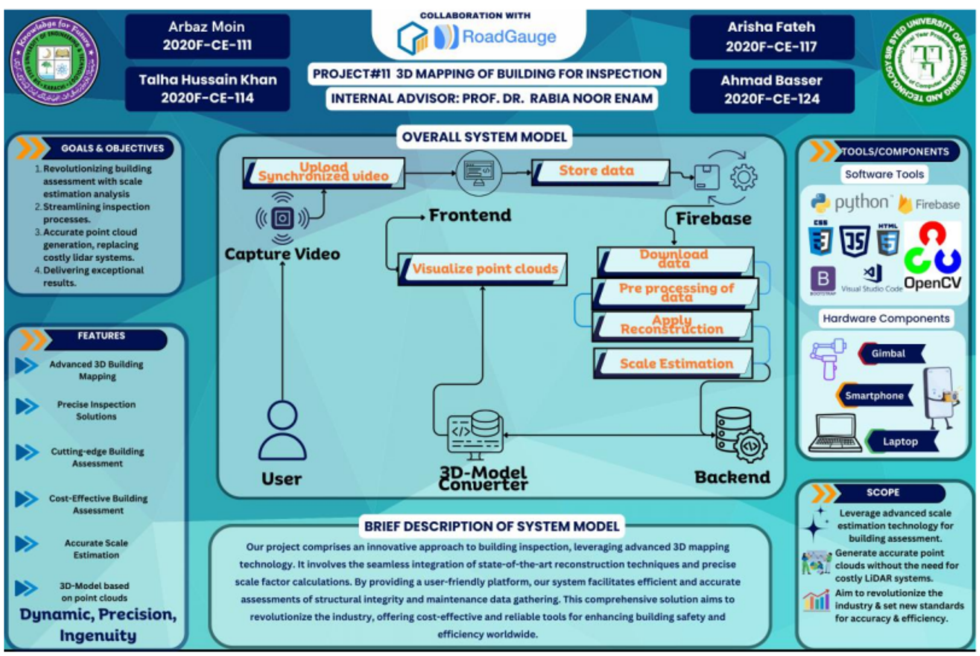

Figure B.1: Poster

Standee

Figure B.2 shows the standee for the project.

Figure B.2: Standee

Brochure

1. Brochure-Front

Here is the Broucher-Front for the project "3D Mapping of Building for Inspection".

Figure B.3: broucher-front

1. Brochure-Back

Here is the Broucher-Back for the project "3D Mapping of Building for Inspection".

Figure B.4: broucher-back

Appendix C

Appendix - Proposal Form (One Pager)

Department of Computer Engineering

Sir Syed University of Engineering & Technology, Karachi-Pakistan

Proposal Form for Final Year Design Project – Batch 2020F

Project Title	3D mapping of buildings for inspection
Project Number	11
Internal Advisor Name	Dr. Rabia Noor Enam
External Advisor (if any)	Sir Santhan Mathavan (Founder & CEO, Strada Imaging Ltd.)
Group Members Roll No	2020F-CE-111, 2020F-CE-114, 2020F-CE-117, 2020F-CE-124
Group Leader Contact Info	Ahmed Baseer, +92 316 3670504, ahmedbaseer871@gmail.com

1. Project/Product Description:

The 3D mapping of buildings for inspection is capable of utilizing 3D reconstruction techniques to map and visualize buildings. The project focuses on utilizing 3D reconstruction techniques to automate and streamline building assessment, aiming to replace labor-intensive and costly manual methods. Key features include algorithms for 3D reconstruction, optimal data hierarchy, and a user-friendly web application. The primary value lies in automating condition evaluation of building surfaces, leading to timely decision-making and cost-effective maintenance. The hypothesis is that using 3D reconstruction techniques can enhance efficiency. The methodology involves exploring reconstruction strategies, designing algorithms, and implementing optimal data hierarchy. The commercial applications include construction and infrastructure maintenance, benefiting construction companies and building maintenance firms. The software has the potential to be a valuable asset for both commercial and non-commercial users, contributing to more efficient building assessment processes.

2. Objectives/Functionalities of the Project:

S. No	Project Objective*	Completion Dates
1	Research on UI of the software which can support the data and on algorithms.	30-Nov-23
2	Designing the frontend for uploading the data set	7-Dec-23
3	Getting data ready for 3D reconstruction	onwards
	Mid-Year Evaluation	
4	Getting key points	
5	Implementation on IMU Data & interpolation points	15-March-2024
6	Implementing 3D reconstruction algorithms and Get point clouds	Onwards
7	Documentation	

3. Methodology

	Software	Hardware
Programming Languages	python, JavaScript, OpenCV, Colab Visual Studio openSFM/open3D, Html,Css	C,C++
Hardware	Camera/ Phone camera	Tripod/gimbal /drone
Operating Systems (desktop/mobile)	Windows / Linux/ Android 10	N/A
Databases	Firebase	N/A
Others (Any cloud-based service, domain, ML/AI algorithms, etc.)	3d reconstruction algorithms , Multi View Stereo algorithms OpenCamera Sensors, Virtual machines for cloud functions (if required)	N/A

4. List of Purchased and Designed Components:

Purchased Components	Designed Components
Tripod/gimbal /drone	A circuit for 360 rotation

5. Sustainable Development Goals (SDGs) aligned with your project.
GOAL 9: Industry, Innovation and Infrastructure
GOAL 11: Sustainable Cities and Communities

6. What will be the output of your final product:
The final product is a minimal software for 3D reconstruction of building interiors, generating point clouds with scale information. The output aids in automated condition evaluation, providing a user-friendly tool for efficient and cost-effective building assessment in construction and infrastructure maintenance.

7. What market/industry you are targeting?
Civil infrastructure, Construction and Infrastructure Inspection Industry

8. Who will be your potential customers/clients?
Construction Inspectors, Real Estate Developers, Construction Companies, Building Maintenance Firms, Surveyors.

9. Is your project affiliated with an industry?
Yes, Strada Imaging. Software company in Wooler, England

10. Is your project funded?
No

Note: Hand-filled documents will not be acceptable.

Department of Computer Engineering

Sir Syed University of Engineering & Technology, Karachi-Pakistan

11.

Estimated Cost?

30,000 - 80,000 PKR (approx).

Dr. Rabia Noor Enam

Rabia Enam

Name and Dated Signature of Internal Advisor

Ahmed Baseer

Ahmad

Name and Dated Signature of Group Leader

In charge FYPC: ☐ Approved ☐ Not Approved

Saba Ahsan

Name and Dated Signature of FYP-Head

Dr Rukaiya

2/4/24

Name Dated Signature of In-charge, FYP-Industry Linkages

Note: Hand-filled documents will not be acceptable.

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