GVI Mapper

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PROJECT REPORT

Version	V X.0

NUMBER OF MEMBERS	3

TITLE	

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MEMBERS' SIGNATURES

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_____

_____

Supervisor's Signature

Note 1: This paper must be signed by your supervisor
Note 2: The soft-copies of your project report, source codes, schematics, and executable should be delivered in a CD

APPROVAL CERTIFICATE

This project, entitled as “GVI MAPPER” has been approved for the award of

Bachelors of Science in Artificial Intelligence

Committee Signatures:

Supervisor: _____

(Mr. First Name Surname)

Program Lead: _____

Head of Department: _____

(Dr. Imran Ihsan)

DECLARATION

I/We, hereby, declare that "No portion of the work referred to, in this project has been submitted in support of an application for another degree or qualification of this or any other university/institute or other institution of learning". It is further declared thatthis undergraduate project, neither as a whole nor as a part thereof has been copied out from any sources, wherever references have been provided.

MEMBERS' SIGNATURES

ACKNOWLEDGEMENTS

It is usual to thank those individuals who have provided particularly useful assistance, technical or otherwise, during your project. Your supervisor will obviously be pleased to be acknowledged as he or she will have invested quite a lot of time overseeing your progress.

DEDICATION

This is an optional section.

In this section you dedicate your project to anybody that you feel motivates you for hard work and putting effort for successful life.

Executive Summary

This should be no more than one page in length (200 words approx.). The summary should allow the reader who is unfamiliar with the work to gain a swift and accurate impression of what the project is about, how it arose and what has been achieved.

It is recommended, you write this section when the report is finished.

Table of Contents

This should give a complete list of what the report contains starting with the abstract (the title page is not included in the contents list).

Contents

List of Figures

If the report contains figures or tables a list of these should be provided. The list should give the table or figure number, the title of the table or figure and the page number. If only a few tables and figures are present, they may be treated on one page. Remember that all figures and tables used must be referred in the text. For example, "The class diagram shown in Figure 2.1 ...."

LIST OF TABLES

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Chapter 1

Introduction

Our project focuses on creating 3D scenes from 2D data using the Monocular Depth Estimation (MDE) technique. This innovative approach has gained widespread attention due to its extensive applications in fields such as autonomous driving, navigation, and 3D reconstruction. MDE also plays a critical role in generating AI content and supporting self-learning agents by providing robust visual data essential for environment description and scene understanding. By leveraging MDE, our project aims to reconstruct 3D environments and label the data to deliver actionable insights. These insights enable actors and agents to interact with their surroundings effectively and perform their desired operations seamlessly.

1.1. Project Introduction

The goal of this project is to create 3D labeled data of an environment from 2D data using computer vision techniques.

This solution offers a more affordable alternative to traditional 3D sensing technologies, such as SONAR and RADAR, by relying on readily available devices like cameras. By utilizing computer vision, the project aims to generate detailed 3D environments that can be used in various fields, including architecture, urban planning, autonomous vehicles, and more.

Our project aims to help and target the needs of following industries and users. These are

- **Architecture & Construction Firms**: These organizations can use 3D reconstructions for design, planning, and building simulations.
- Urban Planning Department**s:** They will benefit by using 3D maps for city planning, infrastructure development, and resource management.
- **Real Estate Companies:** 3D reconstructions can enhance property listings, offering immersive experiences for prospective buyers.
- **Cultural Heritage Organizations:** This technology allows for the preservation and virtual exploration of historical sites through detailed 3D models.
- **Film & Video Game Studios**: 3D scene generation can be used to create virtual sets and environments for media production.
- **Autonomous Vehicles Manufacturer:** MDE can aid in improving vehicle navigation and environment mapping for self-driving cars.
- **Robotic Companies:** Robots can benefit from 3D environmental data to enhance their navigation and task execution.

- **Healthcare Providers:** 3D mapping can assist in medical imaging, surgical planning, and environmental simulations for healthcare applications.
- **Surveying & Mapping Companies:** They can use the technology to create accurate and detailed 3D models for topographic and land surveys.
- **Environmental Agencies:** These organizations can monitor environmental changes and assess terrain for conservation and planning purposes.
- **Virtual & Augmented Reality Developers:** MDE will provide them with the 3D environments needed for immersive virtual and augmented experiences.
- **Forensics & Law Enforcement:** For crime scene reconstruction and analysis.

1.2. Existing Examples / Solutions

Based on my research and survey, several companies are actively working on solutions that involve creating detailed 3D environment data. These solutions often rely on advanced technologies such as LiDAR, RADAR, and SONAR, or a combination of these with computer vision. While these companies have made significant strides in generating accurate 3D reconstructions, most existing solutions depend on specialized and expensive hardware. This reliance increases costs and limits accessibility for smaller organizations and individual users. Furthermore, many of these systems focus on specific domains, such as autonomous driving or industrial applications, leaving gaps in adaptability for diverse use cases. In the following section, I have identified prominent companies working in this domain, along with their approaches and technologies.

Companies	Solutions	Shortcomings
Matterport	Creates digital twins of real-world spaces for virtual tours, real estate marketing, and facility management.	Primarily focuses on indoor spaces and requires specialized hardware for capturing, limiting its accessibility for widespread use.
Esri	Offers ArcGIS software for creating 3D models of cities and landscapes for urban planning and environmental analysis.	Complex software with a steep learning curve, often requiring specialized training to use effectively.
Bentley Systems	Provides infrastructure engineering software for creating detailed 3D models of buildings, roads, and utilities.	Mainly targets large-scale infrastructure projects, potentially overlooking smaller-scale environmental reconstruction needs.
Pix4D	Develops photogrammetry software for creating 3D models from drone imagery, used in	Relies heavily on aerial imagery, which may not capture all details

	construction, agriculture, and surveying.	of complex environments, especially in densely built areas.
AutoDesk	Offers various software solutions for 3D modeling and visualization of real-world environments in architecture and engineering.	Their solutions often require significant manual input and expertise, limiting the speed and scalability of 3D environment creation.
Wayfair	Provides AR experiences for furniture placement in customers' homes since 2017. Their "View in Room" function allows users to visualize how furnishings fit into their spaces before purchasing.	Limited to furniture and home decor items, lacking broader environmental reconstruction capabilities.
Osso VR	Provides a virtual reality platform for medical professionals, creating lifelike simulations of medical procedures and surgeries for training purposes.	Focused on specific medical scenarios rather than general environmental reconstruction.
Luxcarta	Develops 3D building reconstruction from LiDAR data for digital twin technology, urban planning, and simulations.	Relies heavily on LiDAR data availability and may struggle with complex or irregular building structures.
IGN	Collects LiDAR point cloud data for most of France's territory, enabling various 3D reconstruction applications.	Data collection is geographically limited and may require significant processing to derive useful insights.

1.3. Business Scope

The proposed project offers significant business potential by addressing the growing demand for cost-effective and accurate 3D environmental mapping solutions. Traditional methods rely heavily on expensive hardware such as LiDAR and RADAR, which can restrict accessibility for smaller organizations and startups. By leveraging affordable computer vision technologies, this project seeks to democratize 3D scene reconstruction, making it accessible to a broader

audience. With its focus on affordability and versatility, the project positions itself as a strong candidate for commercialization. Additional resources and strategic partnerships will further enhance its scalability and viability as a commercial product.

Industries	Needs	Requirements
Construction & Architecture	Accurate 3D models of buildings and construction sites for planning and monitoring.	• GPU for quick processing • Ability to handle large scale environment • Integration with existing CAD software
Urban Planning	Detailed 3D labeled model for Urban development and designing planning and environmental analysis	• GPU for quick processing • Ability to handle large scale environment • Dataset for city labeling • 3D model simulation
Environmental Conservation	3D reconstruction of environment for study, monitoring and preserving the environment.	• GPU for quick processing • Ability to capture & process terrains in its 3D reconstruction • Labeling for all environmental factors for detailed 3D environment
Cultural Heritage Preservation	Digital Archiving of historical sites, artifacts and culture while also simulating some of the data	• GPU for quick processing • Ability to capture fine details of delicate surfaces
Automotive Industry	3D modeling for design prototyping and customization in luxury market	• GPU for quick processing • Precise scanning abilities of complex shapes and structures • Integration with CAD/CAM systems
Healthcare	3D reconstruction of anatomical structures for surgical planning and medical education	• Powerful GPU for quick processing • High-accuracy & quick scanning of organic shapes

		• Tools and data that provides details regarding the 3D modeled organ
Agriculture	3D mapping of crops and field for precision agriculture and phenotyping	• GPU for quick processing • Ability to capture large area efficiently • Integration of the system with agriculture management system
Media & Entertainment	Creation of realistic 3D and 2.5D environment for environment and virtual video productions on stages and theatres	• Powerful GPU for quick processing • Ability to convert 3D details to a desired 2D or 3D details • Ability to cover an actor's action with a desired simulated background
Forensics & Law Enforcement	3D reconstruction of crime scenes and accidental sites for investigation, discussion and courtroom presentation	• GPU for quick processing • Rapid on-site scanning capabilities • Integration with case management software

1.4. Useful Tools and Technologies

The development and implementation of this project require a combination of advanced tools and technologies to ensure efficiency and accuracy. The primary programming language chosen is Python due to its extensive libraries and frameworks for computer vision and deep learning, such as Numpy, OpenCV, Open3D and PyTorch. The development environment selected are Google Collab and Visual Studio Code or Anaconda. Google Collab is useful as it provides a developed environment with almost all required libraries pre-installed. Also there are all extensive supports in its installation as well as existing cloud-based GPU support. Anaconda and Visual Studio Code are useful Google Collab fails in providing a 3D simulation of the data by providing an interactive and visual window. While the project does not require a database for the initial prototype, future iterations may incorporate a lightweight database such as SQLite to store 3D data and metadata for user access. The software will be compatible with cross-platform operating systems, including Windows, Linux, and macOS, to ensure broader accessibility. Additionally, no specific network protocol is implemented at this stage, as the

project focuses on standalone processing; however, future extensions may include network protocols like REST APIs for data sharing and remote access.

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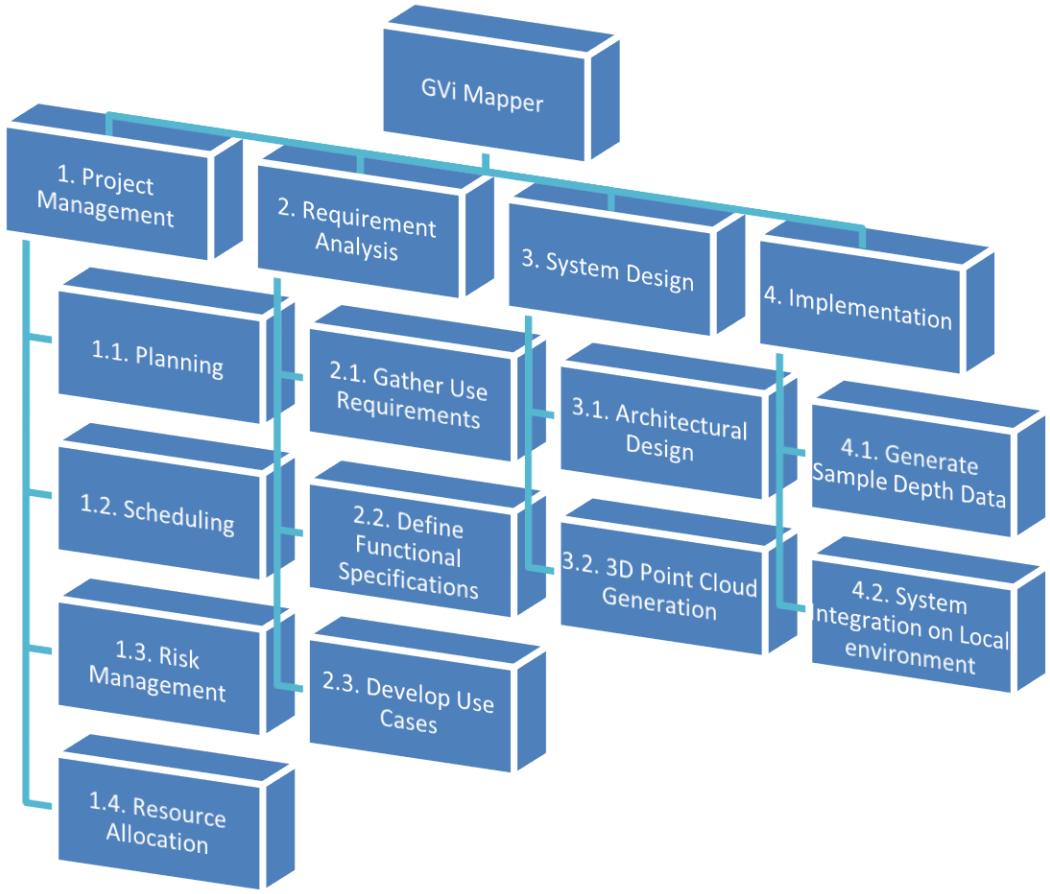
1.5. Project Work Break Down

To achieve the objectives of this project, we have meticulously planned and divided the work into distinct phases, ensuring that each task aligns with the project timeline and goals. The allocation of tasks is based on individual team members' expertise and availability, with additional time dedicated to areas requiring further research or development. By focusing on efficient task management and resource allocation, we aim to deliver each component within the stipulated deadlines while addressing potential challenges. The following sections outline the tasks, their assignments, and the timeframes for completion.

Abdus Sami Chheena (210617)	Maria Altaf (210646)	Muhammad Umar Riaz
• **Strength:** • Strong Python Programming skills • Basic Advance Neural Network Architecture Understanding • Basic Research skills • **Weakness:** • Weak Managerial Skills • Weak Communication Skill	• **Strength:** • Strong Python Programming skills • Strong Documentation skills • **Weakness:** • Low Resilience • Slightly weak in Advance ANN architecture	• **Strength:** • Strong Python Programming skills • Strong Communication skills • Strong Prompt engineering skills • Basic 3D library Implementation skills • **Weakness:** • Slightly off-schedule



1.6. Project Feasibility

When a project is started the first matter to establish is to assess the feasibility of a project or product. Feasibility means the extent to which appropriate data and information are readily available or can be obtained with available resources such as staff, expertise, time, and equipment. It is basically used as a measure of how practical or beneficial the development of a software system will be to you (or organization). This activity recurs throughout the life cycle.

There are many types of feasibilities:

2. Technical
3. Operational
4. Economic
5. Schedule
6. Specification
7. Information
8. Motivational
9. Legal and Ethical

1.6.1. Technical Feasibility

The technical feasibility of this project has been carefully evaluated to ensure that its development is achievable using the available technology and expertise. The project leverages computer vision techniques, deep learning models, and depth estimation algorithms, all of which are well-established in the field and supported by robust libraries such as Open3D, OpenCV, Numpy and PyTorch.

The team possesses a strong foundation in programming, algorithm design, and the use of these frameworks, ensuring that the technical requirements of the project can be met effectively. Additionally, the hardware resources, including high-performance computers and basic GPUs, are adequate for initial testing and implementation.

Potential challenges, such as optimizing model performance for real-time applications or handling large datasets, are identified but deemed manageable with the team's current knowledge and planned iterative testing. Based on these factors, the project is considered technically feasible within the defined scope.

1.6.2. Operational Feasibility

The operational feasibility of the project has been assessed to ensure that it can be effectively implemented and utilized by the target audience. The project addresses a critical need for 3D scene reconstruction using cost-effective and accessible methods, making it a valuable solution for industries such as architecture, autonomous systems, and urban planning.

The end-users, including professionals and organizations in these domains, are likely to find the solution practical and beneficial, as it reduces dependence on expensive equipment like LiDAR and RADAR. The interface and output of the system will be designed to be user-friendly, ensuring that minimal technical expertise is required to operate it.

Additionally, the team has the skills to develop and demonstrate the system effectively, and the feedback loop from potential end-users will ensure that any operational gaps are addressed.

Based on these considerations, the project is deemed operationally feasible, with high acceptance potential among its intended users.

1.6.3. Economic Feasibility

Evaluating the economic feasibility of this project involves a comprehensive analysis of both cost and benefit estimates to determine its financial viability.

Cost Estimates:

Development Costs (One-Time):

- **Personnel Expenses:** Salaries for team members during the development phase.
- **Software and Tools:** Licenses for any required proprietary software or development tools.
- **Hardware Resources:** Procurement of necessary hardware to support development activities.

Maintenance and Operation Costs (Ongoing):

- **System Updates:** Regular updates to ensure compatibility and security.
- **Technical Support:** Provision of assistance to end-users as needed.
- **Operational Overheads:** Costs associated with hosting, utilities, and other operational necessities.

Benefit Estimates:

Tangible Benefits:

- **Cost Reduction:** By utilizing cost-effective methods for 3D scene reconstruction, the project reduces the need for expensive equipment, leading to significant savings.
- **Revenue Enhancement:** Offering an innovative solution can attract new clients and open additional revenue streams.

Intangible Benefits:

- **Improved Information Quality:** Enhanced accuracy and detail in 3D data contribute to better decision-making.
- **Increased Job Satisfaction:** Providing user-friendly tools can lead to higher satisfaction among professionals utilizing the system.
- **Enhanced External Reputation:** Adopting advanced technology can bolster the organization's standing in the industry.

By breaking down the project into specific tasks and applying lifecycle cost models, we have derived these estimates based on experiences from similar projects. Calculating the function point metric further supports the accuracy of our cost assessments.

In conclusion, the anticipated benefits, both tangible and intangible, outweigh the projected costs, indicating that the project is economically feasible and poised to deliver substantial value to stakeholders.

Development Cost

- **Total Personal cost** = $90,000
- **Software & Tools** = $10,000
- **Hardware Resources** = $15,000
- **Training & Onboarding** = $5000
- **Total Development Cost** = $120,000

Total Operational Cost over 5 years

- **System Maintainence** = $20,000
- **Technical Support** = $15,000
- **Operational Overload** = $25,000
- **Total Annual Operational Costs** = $60,000
- **Operational Costs over 5 years** = $300,000

LifeCycle Cost

- **Net Development Cost** = $120,000
- **Net Operational Cost** = $300,000
- **LifeCycle Cost** = $420,000

1.6.4. Schedule Feasibility

The schedule of the project has been carefully planned after many discussions. The entire projects timeframe was carefully planned while considering all the factors such as budget, resources and team members.

1. **Project Timeline:**
   - **Estimated Project Duration:** 18 months
     - Prototype development (3 Months)
     - Beta version release (6 Months)
     - Final Testing phase (6 Months)
     - Project Completion & Deployment (3 Months)

2. **Resource Availability:**
   - **Development Team:** 3 full-time AI experts
   - **3D Modeling specialist:** 1 full-time expert
   - **Documents specialist:** 1 full-time expert
   - **Project Manager:** 1 full-time expert
   - **Quality Assurance Team:** 2 full-time tester

3. **Task Breakdown & Estimation:**
   - **Task Breakdown Estimation:** 2 months
   - **Core Algorithm Development:** 6 months
   - **User Interface Design & Development:** 4 months
   - **Integration & Testing:** 4 months
   - **Optimization & Fine-tuning:** 2 months

4. **Risk Assessment:**
   - **Potential delay in Algorithm:** Mitigated by allocating additional resources if needed.
   - **Integration challenges with various data sources:** Addressed through early prototyping and iterative development.

5. **Flexibility & Scalability:**
   - Agile development methodology adopted to allow for adjustments in project scope and timeline.
   - Provision for additional resources if project demands increase

Based on our assessment, the project is deemed schedule feasible. The allocated time of 18 months is sufficient to complete all necessary tasks with the current team composition. Regular progress

monitoring and adherence to the agile methodology will ensure that we meet our deadlines and deliver a high-quality 3D reconstruction solution within the specified timeframe.

1.6.5. Specification Feasibility

In our project, the requirements have been meticulously defined through collaborative workshops with stakeholders, ensuring they are clear, unambiguous, and aligned with user needs. The scope boundaries have been carefully delineated to prevent scope creep and ensure that the project remains focused and achievable within the available resources and timeframe.

By employing techniques such as Specification by Example, we have captured requirements using realistic examples, facilitating a shared understanding among all team members and stakeholders. This approach ensures that the specifications are both clear and testable, providing a solid foundation for the development process.

Based on this thorough analysis, the project specifications are deemed feasible, as they are well-defined, achievable, and aligned with the project's objectives and constraints.

1.6.6. Information Feasibility

We have carefully assessed the data requirements for our project to ensure that it meets the specifications for our model. The datasets we are using contain the necessary details, quality, and variety of information to produce accurate and high-quality results.

Our model utilizes three primary datasets: Hypersim, Kitti, and Vkitti2. These datasets offer detailed scenes, both indoor and outdoor, which include critical information such as transparency, reflections, fine details, and complex environmental characteristics. These diverse datasets provide a comprehensive foundation for our model to generate reliable 3D reconstructions.

With these datasets, we are confident that the required information is both sufficient and of high quality, ensuring that the model will perform effectively in generating accurate results.

1.6.7. Motivational Feasibility

To ensure motivational feasibility, we have established clear project milestones, regular check-ins, and a collaborative work environment to keep all team members engaged and focused. Additionally, incentives and recognition for milestones achieved will help maintain enthusiasm and a strong commitment to the project.

The motivation of the team is essential for the successful execution of the project, and the structures in place are designed to encourage consistent progress and timely completion of tasks. Based on these factors, we are confident in the team's ability to stay motivated and effectively contribute to the project's success.

1.6.8. Legal & Ethical Feasibility

The pre-trained models used in this project are sourced from publicly available repositories on GitHub. These models are open-source and licensed under Apache 2.0, which allows for free use, modification, and distribution. We have thoroughly reviewed the licensing terms of each model to ensure compliance with the requirements, including providing proper attribution to the original authors as specified in the licenses.

While the models are available to the public, we have also conducted an ethical review to ensure that the models do not introduce biases or ethical concerns in their use. The datasets used to train these models have been checked for fairness, and we will be implementing measures to mitigate any potential bias in the results. Additionally, as the models are trained on publicly available data, we have ensured that there are no privacy violations associated with the use of these resources.

1.7. Risk List

Before diving into the detailed risk list, it is essential to identify and acknowledge the potential risks that could negatively impact the successful completion of the project. By assessing risks early on, we can establish effective mitigation strategies and ensure the project progresses smoothly. The following risk list presents the most significant risks in descending order of importance, along with their respective mitigation or contingency plans. This list will be continuously monitored and updated throughout the project's lifecycle, helping us address new challenges as they arise and ensure the timely delivery of the project.

- **Technical Complexity:**
  Risk: The advanced nature of 3D reconstruction algorithms may lead to unexpected challenges and delays.
  Mitigation: Allocate additional resources for R&D, conduct regular technical reviews, and maintain flexibility in the development timeline.
- **Data Quality & Availability:**
  Risk: Insufficient or poor-quality input data may compromise the accuracy of 3D reconstructions.
  Mitigation: Establish strict data quality standards, diversify data sources, and implement robust data validation processes.
- **Performance Issues:**
  Risk: The system may not meet required speed and efficiency standards for real-time 3D reconstruction.
  Mitigation: Conduct regular performance testing, optimize algorithms, and consider cloud-based processing solutions.
- **Integration Challenges:**

Risk: Difficulties in integrating the 3D reconstruction system with existing software and hardware ecosystems.

Mitigation: Develop a comprehensive integration plan, conduct thorough compatibility testing, and provide flexible API options.

- **Market Adoption:**

  Risk: Slow adoption rate due to resistance to new technology or lack of awareness.

  Mitigation: Develop a strong marketing strategy, provide comprehensive training and support, and showcase clear ROI for potential clients.

- **Regulatory Compliance:**

  Risk: Failure to meet evolving data privacy and security regulations across different jurisdictions.

  Mitigation: Regularly review and update compliance measures, consult with legal experts, and implement robust data protection protocols.

- **Resource Constraints:**

  Risk: Insufficient skilled personnel or computational resources to meet project demands.

  Mitigation: Develop a flexible resource allocation plan, invest in team training, and consider strategic partnerships or outsourcing.

- **Scope Creep:**

  Risk: Expanding project scope leading to delays and budget overruns.

  Mitigation: Implement strict change management processes, clearly define project boundaries, and regularly review project scope against objectives.

- **Competitive Pressure:**

  Risk: Rapid advancements by competitors may render our solution less competitive.

  Mitigation: Conduct regular market analysis, maintain a flexible development approach, and focus on unique value propositions.

- **Financial Constraints:**

  Risk: Unexpected costs or funding issues may impact project completion.

  Mitigation: Maintain detailed financial tracking, establish contingency funds, and explore diverse funding sources.

This risk list will be regularly reviewed and updated throughout the project lifecycle, with particular attention given at the end of each development iteration. By proactively identifying and addressing these risks, we aim to enhance the project's chances of success and deliver a robust 3D reconstruction solution.

Chapter 2

Requirement Specification and Analysis

This chapter outlines the essential requirements and analytical considerations for the proposed software system. The focus is to provide a clear and precise Software Requirement Specification (SRS) that bridges the gap between technical development and business objectives. Additionally, analytical models such as use case diagrams, entity-relationship diagrams, and a data dictionary will be included to ensure a comprehensive understanding of the system's functionality and design. This systematic approach will serve as a foundation for the subsequent phases of development, enabling alignment with both technical goals and stakeholder expectations.

Requirement Specification

2.1. Functional Requirements

The functional requirements of our project, GVI Mapper, outline the specific needs and expectations of our users that the system must fulfill to achieve its intended purpose effectively.

Table 2.1: Functional Requirements

S. No.	Functional Requirement	Type	Status
1	The system shall accept multiple 2D images or video input for 3D reconstruction.	Input	Implemented
2	The system shall process and align input images to create a 3D point cloud.	Processing	Implemented
3	The system shall generate a textured 3D mesh from the point cloud data.	Output	Planned
4	The system shall allow users to annotate and label specific parts of the 3D model.	Annotation	In-Progress
5	The system shall support collaborative viewing and editing of 3D models.	Collaboration	Planned

2.2. Non-Functional Requirements

The non-functional requirements describe how the GVI Mapper project operates, focusing on aspects such as performance, usability, and overall efficiency. These requirements ensure that the system not only functions correctly but also meets high standards for user experience and operational effectiveness. The following table outlines the non-functional requirements for the project.

Table 2.2: Non-Functional Requirement

S. No.	Non Functional Requirements	Category
1	The system should load 3D models within 5 seconds for a smooth user experience.	Performance
2	The system should be available 99.9% of the time, excluding scheduled maintenance.	Availability
3	The system should be able to handle up to 1TB of data for 3D models and associated metadata.	Scalability
4	The system should allow users to perform basic operations with minimal delay (within 1 second).	Performance
5	The system should be easy to maintain, with modular code and detailed documentation for future updates.	Maintainability

2.3. System Use Case Modeling

In this section, we define the various interactions between users and the system, illustrating the goals users aim to achieve through the system's functionalities. A use case representing a sequence of actions the system performs to deliver an observable result that provides value to the user. By mapping out these interactions, we can ensure the system meets user needs effectively. The following use case diagram highlights the system's core functionalities and outlines the primary actors and their goals, helping to clarify how the system is intended to be used in practice.

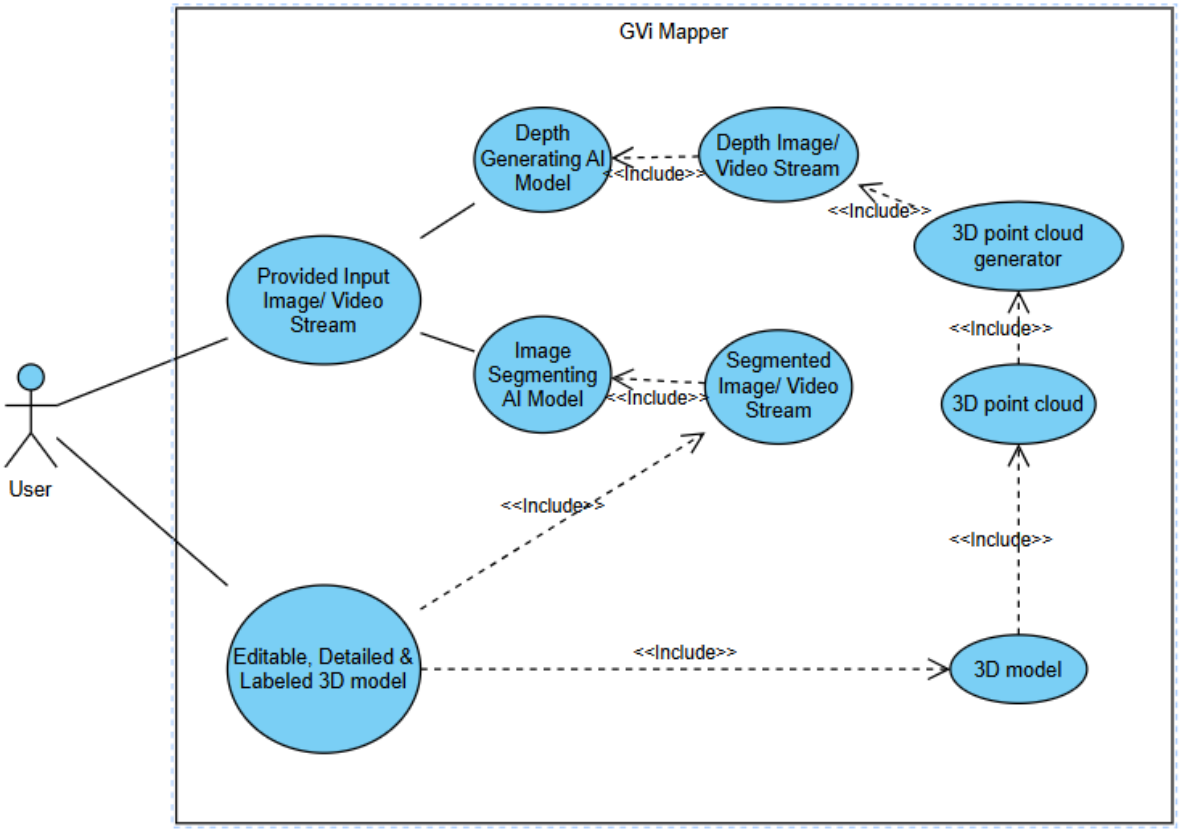


Figure 2.1: Sample Use case Diagram

2.4. Fully-dressed Use Cases

Use Case GV001:

In this use case, user interacts with the system known as GVI Mapper and enters an input image or Video Stream

Table 2.1: Use Case 1

Use Case ID:	GV001		
Use Case Name:	Provided Input Image or Video Stream		
Created By:	Abdus Sami Chheena	**Last Updated By:**	Abdus Sami Chheena

Date Created:	19-12-2024	**Last Revision Date:**	19-12-2024
Actors:	Users, GVI Mapper System		
Description:	The User will enter his desired input Image or Video stream into the system from his computer		
Trigger:	User enters the "Upload file" button		
Preconditions:	User is using the app or system "GVI Mapper"		
Post conditions:	After the Image or Video stream has been entered into the system. The system will pre-process it and send it to the two AI models (Image Segmentation model & Depth Generator model).		
Normal Flow:	Actor	System	
	• The user uploads an Image or Video file	• The system pre-processes the Image • The system pre-processes the frames in Video • The system sends the Image or Video stream into the Depth Generator and Image Segmentation model	
Alternative Flows:	If the Image or the Frame size of the video is too small. The system will redirect the user to upload screen.		
Exceptions:	If the entered data is not an Image or Video stream. The system will reject the file and display an error message that "The file is not in a compatible format".		

Use Case GV003:

In this use case, the AI model Depth Generator takes the Input image or frames of Video from send from the system and makes calculation and predictions of the Depth image of the Image data.

Table 2.1: Use Case 1

Use Case ID:	GV003		
Use Case Name:	Depth Image AI generator module		
Created By:	Abdus Sami Chheena	**Last Updated By:**	Abdus Sami Chheena
Date Created:	19-12-2024	**Last Revision Date:**	19-12-2024

Actors:	GVI Mapper System	
Description:	The module will calculate and predict the Depth of the Input Image based on the details present in the Input Image	
Trigger:	The Systems sends the entire Image or Frame data to the Depth Image Generator Module	
Preconditions:	The file has been uploaded and processed successfully into the system	
Post conditions:	After the Depth Image has been generated. It either waits for the next Image data or waits for the program to finish its execution.	
Normal Flow:	Actor	System
	• The system sends the uploaded Image or Video data to the Depth Image Generator module	• The Module performs the necessary calculation and operation from the given details of the Image • It produces the predicted Depth Image based on its calculations
Alternative Flows:	If the Image data is noisy or is not an environmental data. It may result in faulty or terrible predictions	
Exceptions:	If the input Image data is too small to perform operations on than it will generate an error “The image data size is too small to perform the required operations”.	

Use Case GV005:

In this use case, the Depth Image Generator AI module creates the required Depth Image data which will display the necessary Depth at each region of the image which will be used in the 3D point cloud generator.

Table 2.1: Use Case 1

Use Case ID:	GV005		
Use Case Name:	Depth Image/ Video Stream		
Created By:	Abdus Sami Chheena	**Last Updated By:**	Abdus Sami Chheena
Date Created:	19-12-2024	**Last Revision Date:**	19-12-2024
Actors:	GVI Mapper System		
Description:	The Depth Image or Video stream is computed which will then be send to 3D point cloud generator.		
Trigger:	The completion of the Depth Map AI generator module in computing Depth Image		
Preconditions:	The Depth Map AI generator is computing the Depth Map of the Input data and then making predictions on calculating its Depth Map		
Post conditions:	After the Depth Image is generated, the generated Image data is then sent to 3D point cloud generator.		
Normal Flow:	Actor	System	
	• The Depth Image Generator generates the Depth Image	• The system upon its generations sends the data to 3D point cloud generator	
Alternative Flows:	If the Image or the Frame size of the video is too small. The system will redirect the user to upload screen.		
Exceptions:	N/A		

Use Case GV007:

In this use case, the 3D point cloud generator generates the 3D point cloud by taking in the Depth Image or Video stream generated from the Depth Image Generator.

Table 2.1: Use Case 1

Use Case ID:	GV007		
Use Case Name:	3D point cloud generator		
Created By:	Abdus Sami Chheena	**Last Updated By:**	Abdus Sami Chheena
Date Created:	19-12-2024	**Last Revision Date:**	19-12-2024
Actors:	GVI Mapper System		
Description:	The 3D point cloud generator generates the 3D point cloud using the Depth Image or Videos stream		
Trigger:	The system sends the Depth Image or Video stream data to the 3D point cloud generator		
Preconditions:	The system has sent the Depth Image data to the 3D point cloud generator		
Post conditions:	The 3D point cloud model has been generated using the 3D point cloud generator.		
Normal Flow:	Actor	System	
	• The system sends the Depth Image data to the 3D point cloud generator	• The 3D point cloud generator computer computes all the necessary calculations for the models generation and generates it	
Alternative Flows:	If the Depth data is noisy then a noisy 3D point cloud model will be generated		
Exceptions:	N/A		

Use Case GV008:

In this use case, the 3D point cloud generator has generated a 3D point cloud model which will be further processed before it reaches its final stage.

Table 2.1: Use Case 1

Use Case ID:	GV008		
Use Case Name:	3D point cloud generator		
Created By:	Abdus Sami Chheena	**Last Updated By:**	Abdus Sami Chheena
Date Created:	19-12-2024	**Last Revision Date:**	19-12-2024
Actors:	GVI Mapper System		
Description:	The 3D point cloud generator has generator has generated a 3D point cloud model which will be then send to be further processed		
Trigger:	The 3D point cloud generator has generated the 3D point cloud model		
Preconditions:	The 3D point cloud generator has generated the 3D point cloud model		
Post conditions:	The 3D point cloud model is further processed by removing the noise in the data		
Normal Flow:	Actor	System	
	• The 3D point cloud generator generates a 3D point cloud model	• The system pre-processes the 3D point cloud by removing noise before finalizing	
Alternative Flows:	If the generated 3D point cloud model has too much noise then it will be difficult to produce an accurate 3D point cloud model.		
Exceptions:	N/A		

Use Case GV009:

In this use case, the system converts the given model to the users desired type of model which is a point cloud model or a mesh.

Table 2.1: Use Case 1

Use Case ID:	GV009		
Use Case Name:	3D Model		
Created By:	Abdus Sami Chheena	**Last Updated By:**	Abdus Sami Chheena
Date Created:	19-12-2024	**Last Revision Date:**	19-12-2024
Actors:	User, GVI Mapper System		
Description:	This is the final stage of 3D point cloud where the 3D point cloud is converted to mesh or finalized as point cloud as a result		
Trigger:	The 3D point cloud model finishes being pre-processed		
Preconditions:	The 3D point cloud model has finished being pre-processed		
Post conditions:	Upon the user choice, the final 3D model will be generated according to the users desired type		
Normal Flow:	Actor	System	
	• The user selects his desired 3D model type	• The system converts the desired 3D model according to the users desired type • The 3D model is finalized	
Alternative Flows:	If the system fails to generate a 3D mesh, then system will only finalize the point cloud as the final model		
Exceptions:	N/A		

Use Case GV004:

In this use case, the system sends the Input data to Image Segmentation module to convert the given image to a segmented Image data.

Table 2.1: Use Case 1

Use Case ID:	GV004		
Use Case Name:	Image Segmentation AI module		
Created By:	Abdus Sami Chheena	**Last Updated By:**	Abdus Sami Chheena
Date Created:	19-12-2024	**Last Revision Date:**	19-12-2024
Actors:	GVI Mapper System		
Description:	The Image segmentation module takes the Image data and performs calculations and operations and generates the segmented Image data		
Trigger:	The system sends the Image data to the Image segmentation module		
Preconditions:	The system has taken the input data from the user and pre-processed it		
Post conditions:	The Image segmentation AI module has generated a Segmented Image		
Normal Flow:	Actor	System	
	• The system has sent the Image data to the Image Segmentation AI module	• The Image Segmentation Module generates the segmented Image • It Labels each and every pixel according to their labels	
Alternative Flows:	If the Image or the Frame size of the video is too small. The system will redirect the user to upload screen.		
Exceptions:	If the entered data is not an Image or Video stream. The system will reject the file and display an error message that “The file is not in a compatible format”.		

Use Case GV006:

In this use case, the Segmented Image has been generated by Image Segmentation module which would be later sent to create an interactive and editable 3D model

Table 2.1: Use Case 1

Use Case ID:	GV006		
Use Case Name:	Segmented Image/ Video stream		
Created By:	Abdus Sami Chheena	**Last Updated By:**	Abdus Sami Chheena
Date Created:	19-12-2024	**Last Revision Date:**	19-12-2024
Actors:	GVI Mapper System		
Description:	The Segmented Image is generated through Image Segmentation Module		
Trigger:	The completion of the generation of the Segmented Image through Image Segmentation Module		
Preconditions:	The completion of the generation and labeling process of the segmentation module		
Post conditions:	After the Segmented data is generated, it will be sent to the last stage where an editable and interactive 3D model is generated		
Normal Flow:	Actor	System	
	• The Image Segmentation module generates the Segmented Image	• The system sends the Segmented Image data to the final stage	
Alternative Flows:	If the Image is noisy then terrible segmented data is generated		
Exceptions:	N/A		

Use Case GV002:

In this use case, the segmented data and 3D model is used to create an editable and interactive 3D model which may help users in getting the desired information from the model with the detailed 3D data

Table 2.1: Use Case 1

Use Case ID:	GV002		
Use Case Name:	Editable, Interactive and detailed 3D model		
Created By:	Abdus Sami Chheena	**Last Updated By:**	Abdus Sami Chheena
Date Created:	19-12-2024	**Last Revision Date:**	19-12-2024
Actors:	User, GVI Mapper System		
Description:	This is the last stage, where a 3D model as a base and segmentation data is used to create an interactive and editable 3D model to give the user their desired form of information		
Trigger:	The system sends both segmented Image data and 3D point cloud data		
Preconditions:	The segmented Image and 3D point cloud data has been generated		
Post conditions:	After the detailed 3D model is generated, the user can use it however to filter out any undesirable information to create a new 3D model or use the previous information		
Normal Flow:	Actor	System	
	• The User can engage with the 3D model based on the options provided to get his desired information	• The system sends the information to the user	
Alternative Flows:	N/A		
Exceptions:	N/A		

2.5. Domain Model

The domain model for the GVI Mapper project outlines the key entities and their relationships within the system, providing a clear understanding of the fundamental components involved in generating 3D models and point clouds. This model captures the

interactions between the user, input data, AI models, and the outputs, serving as a foundation for the project's design and implementation. The following sections detail the main entities and their connections, offering insight into the system's architecture.

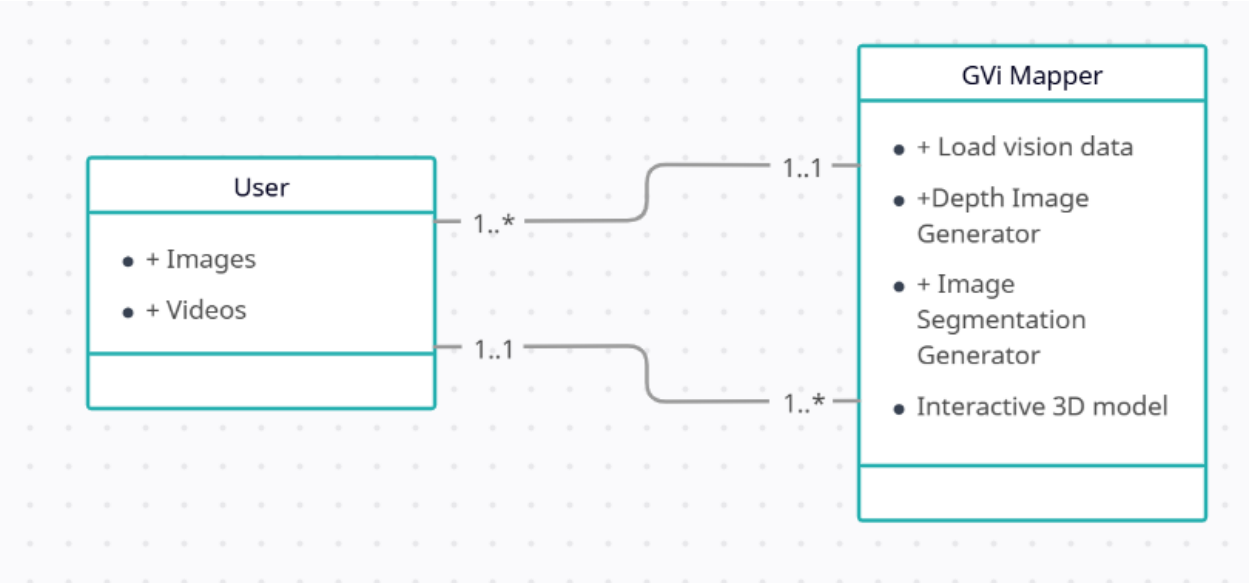


Figure 2.3: Domain Model

Chapter 3

System Design

This chapter outlines the system's architectural and design approach, offering a blueprint that bridges the gap between requirements and implementation. It focuses on the structural and behavioral aspects of the software, ensuring that the project delivers both functional and non-functional requirements effectively. The system design for this 3D reconstruction project emphasizes modularity, scalability, and maintainability to achieve optimal performance and usability. Key considerations include identifying the major software components, defining their interactions, and selecting appropriate design patterns to address challenges specific to the project's scope. The following sections provide a detailed description of the system's structure, behavior, and the underlying principles and constraints that guided the design decisions.

3.1. System Architecture

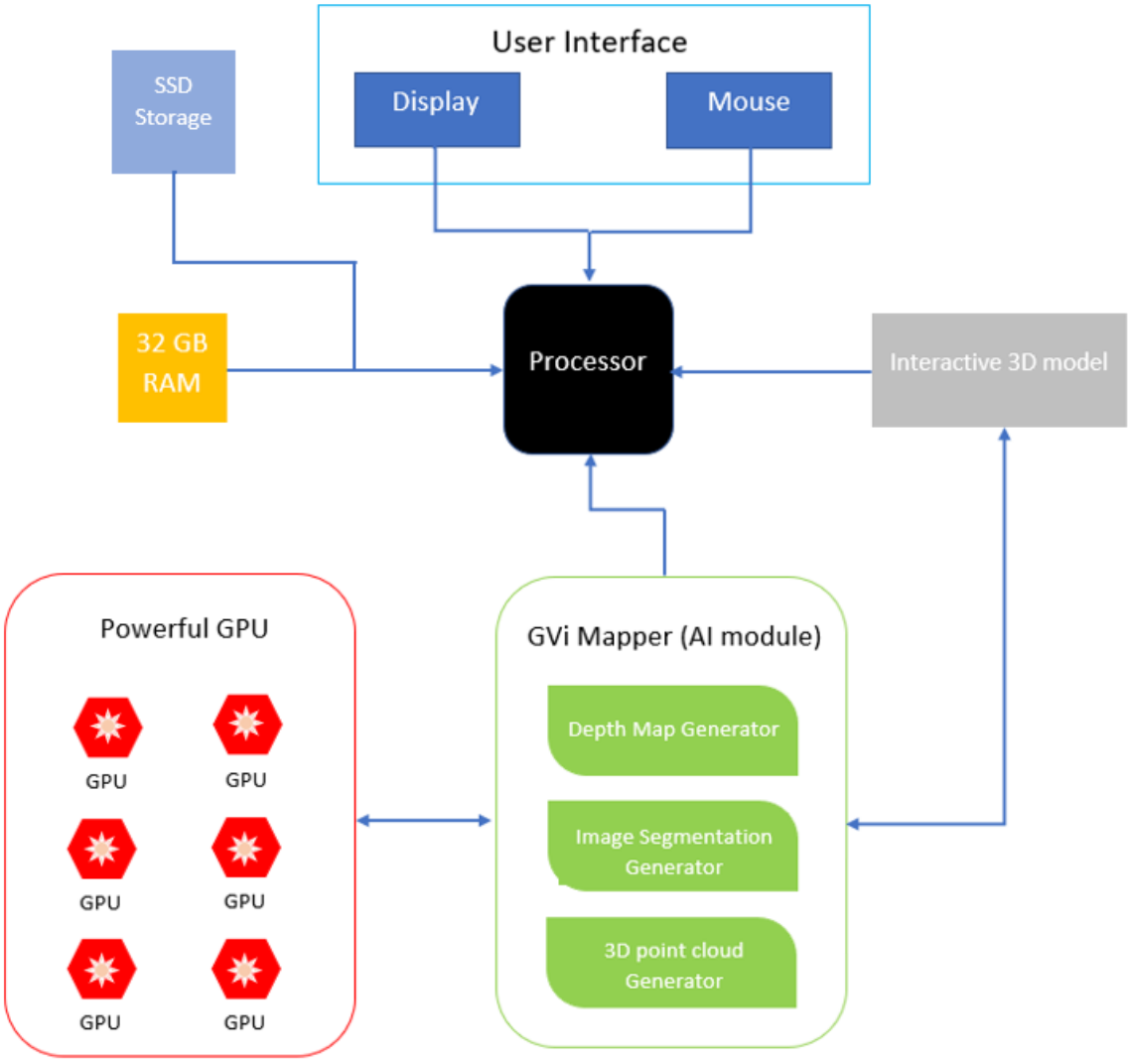
Our 3D reconstruction system employs a robust and scalable architecture designed to process complex scene data efficiently and generate accurate 3D models. The system consists of several key components working in harmony to deliver high-quality results.

Hardware Components

- **Processors:** High-performance GPUs for parallel processing of image data and 3D reconstruction algorithms.
- **Memory:** Minimum 32GB RAM to handle large datasets and complex computations.
- **Storage:** Fast SSD storage for quick data access and model storage.

Software Components

- **Programming Languages:** Python is the core language.
- **Frameworks:** PyTorch for machine learning operations
- **Libraries:** OpenCV for Image processing, Numpy for Data Manipulation and Open3D for processing 3D data.
- **IDEs:** Collab for multi-purpose support and Visual Studio for visual Interaction with GPU access.



3.2. Workflow Design

The workflow design for the 3D reconstruction system encompasses several key stages to ensure the development and deployment of an effective AI model.

- **Data Acquisition and Preprocessing:**
- **Data Collection:** Gather input images or video streams from Hypersim, Kitti, Vkitti2 ensuring a diverse and comprehensive indoor and outdoor dataset
- **Preprocessing:** Enhance data quality by performing tasks such as noise reduction, normalization, and augmentation to prepare it for the training process.
- **Model Training and Evaluation:**

- **Training:** Utilize the preprocessed data to train AI models, including depth generation and segmentation networks, optimizing them to accurately interpret and reconstruct 3D structures.
- **Evaluation:** Assess model performance using appropriate metrics, such as accuracy, precision, and recall, to ensure the models meet the desired standards.
- **Deployment:**
- **Integration:** Incorporate the trained models into the 3D reconstruction pipeline, enabling the system to process new input data and generate 3D models in real-time.
- **Production Environment:** Deploy the integrated system into the target environment, ensuring it operates efficiently and effectively for end-users.

This structured workflow facilitates the systematic development of the 3D reconstruction system, ensuring each phase is meticulously executed to achieve optimal results.

3.3. UML diagrams

In the context of GVI Mapper, UML diagrams play a pivotal role in representing the system's structure and behavior. These diagrams provide a clear understanding of how the components of the 3D reconstruction system interact with one another and with users. By utilizing use case diagrams to capture user interactions, class diagrams to model the system's structure, and sequence diagrams to illustrate the flow of operations, the design is made comprehensible and adaptable. These visual tools ensure the system's architecture is aligned with its objectives, facilitating effective communication and implementation.

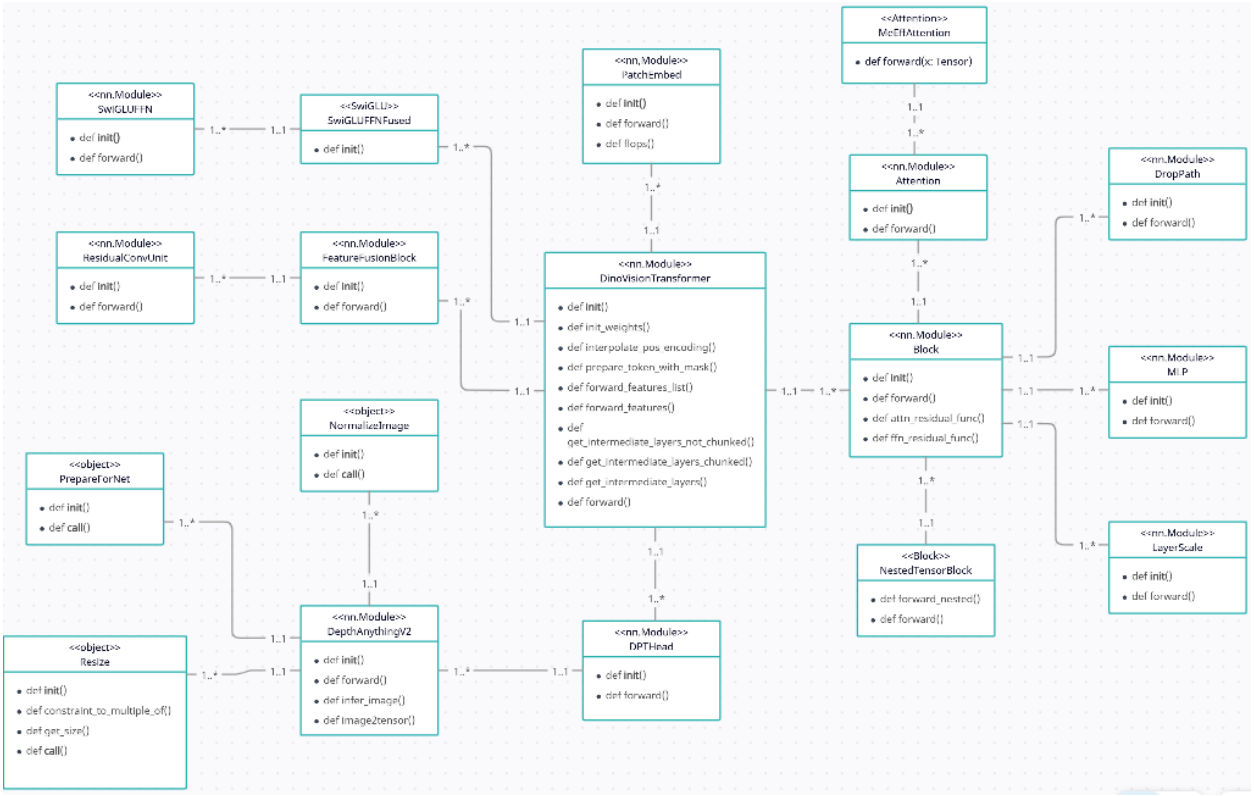


Figure 3.1: Class Diagram

Sequence diagrams, when used alongside class diagrams, provide a comprehensive understanding of the system's behavior by demonstrating how various objects interact during specific processes. In the context of the 3D reconstruction system, sequence diagrams, as depicted in Figure below, illustrate the communication between system components such as the user interface, processing modules, and the AI model during tasks like 3D model generation or export. These diagrams effectively depict the sequence of operations and the flow of data, complementing the relationships and dependencies outlined in the class diagram. Together, these diagrams offer a clear and detailed view of the system's structure and dynamic interactions.

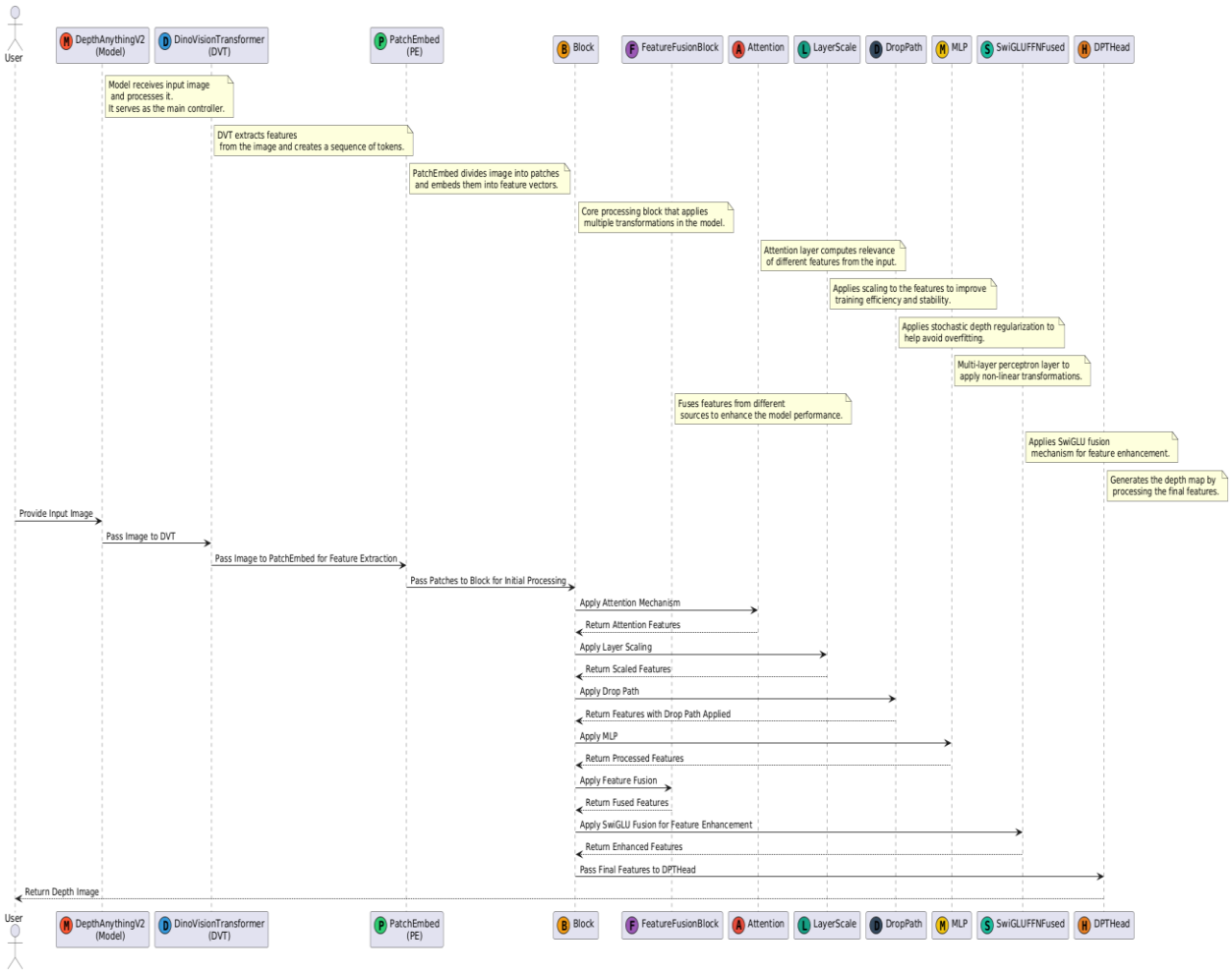


Figure 3.3: Sequence Diagram

3.4. Dataflow and preprocessing pipelines

Our 3D reconstruction project employs a comprehensive dataflow and preprocessing pipeline to ensure high-quality input for the reconstruction algorithms. The pipeline consists of several key stages:

1. **Data Acquisition**

   - For Indoor scenes, we have used Hypersim dataset for their Indoor scenes
   - For Outdoor scenes, we have used Kitti and Vkitti2 dataset for their Outdoor scenes

2. **Data Ingestion**

   - The Hypersim Dataset will be loaded through GitHub

- The Kitti and Vkitti2 dataset will be loaded through their official site

3. **Preprocessing**

- Normalize and standardize input data
- Apply image enhancement techniques (e.g., contrast adjustment, denoising)
- Dividing the images into Patches and embedding them to extract features

4. **Data Visualization**

- Use 3D point cloud to for modifying and visualizing 3D data

3.5. Activity Diagram

Activity diagrams visually represent the workflow or sequence of actions involved in completing a particular use case. They provide a high-level overview of how different components and actors interact to achieve specific objectives within the system. For the 3D reconstruction project, activity diagrams outline the step-by-step process for tasks such as image acquisition, 3D model generation, and exporting models, ensuring a clear understanding of the operational flow. These diagrams help identify potential bottlenecks and enhance the efficiency of the system's design and implementation.

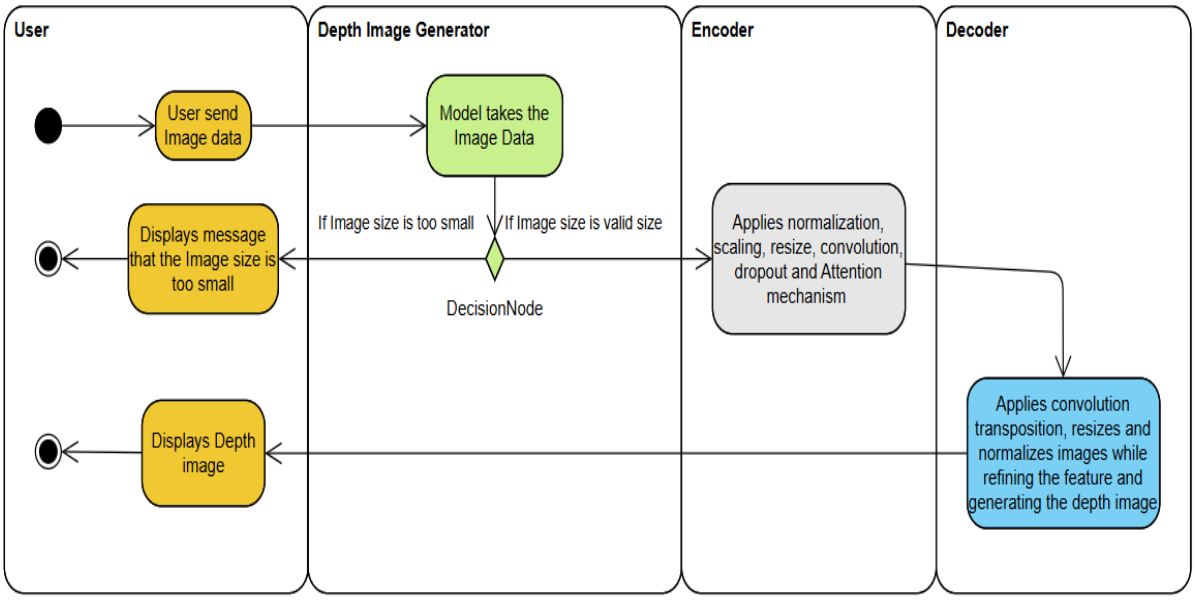


Figure 3.2: Activity Diagram

3.6. Algorithms and model design

The algorithms and model design section forms the foundation of the AI system, detailing the processes and structures that drive its functionality. For the GVi Mapper project, this involves selecting a suitable model architecture tailored to the problem domain, defining its layers and components, and outlining the training methodology. This section explains the rationale behind the chosen algorithms, the optimization strategies employed, and how the model architecture aligns with the project objectives. By providing a comprehensive overview, this section highlights the systematic approach taken to ensure the system's accuracy and efficiency.

For our project, we have chosen Depth Anything V2 architecture which comprises of following key components.

Model Architecture

1. **Input Layer**:
    - **Function**: Processes input images by resizing and cropping to standardize dimensions, ensuring uniformity across the dataset.
    - **Configuration**: Images are resized so their shortest side is 518 pixels, followed by a random 518×518 crop.

2. **DINOv2 Backbone**:
    - **Function**: Serves as the feature extractor, capturing high-level representations from input images.
    - **Configuration**: Utilizes the DINOv2-G (giant) encoder for the teacher model, and DINOv2 small, base, or large encoders for student models.

3. **DPT Decoder**:
    - **Function**: Interprets features from the backbone to predict depth information, enabling dense depth estimation.
    - **Configuration**: Incorporates transformer-based mechanisms to handle complex spatial relationships.

4. **Output Layer**:
    - **Function**: Generates the final depth map, providing pixel-wise depth predictions for the input image.
    - **Configuration**: Outputs a depth map corresponding to the input image dimensions.

Training Process

The training methodology is structured into distinct phases:

1. **Teacher Model Training**:
    - **Data**: Approximately 595,000 synthetic labeled images are utilized to train the teacher model, ensuring high-quality depth supervision.
    - **Optimization**: The Adam optimizer is employed with a learning rate of 5e-6 for the encoder and 5e-5 for the decoder.
    - **Iterations**: Training is conducted over 160,000 iterations with a batch size of 64.

2. **Pseudo-Label Generation**:
    - **Process**: The trained teacher model generates pseudo-depth labels for over 62 million real unlabeled images, bridging the gap between synthetic and real-world data.

3. **Student Model Training**:
    - **Data**: Student models are trained on the pseudo-labeled real images to enhance generalization capabilities.
    - **Optimization**: Similar optimization parameters are applied, with adjustments based on model scale (small, base, large).
    - **Augmentation**: Techniques such as horizontal flipping, strong color distortions, and CutMix are employed to improve robustness.

3.7. Scalability and performance considerations

As AI systems like the GVI Mapper project expand in complexity and scale, addressing scalability and performance becomes crucial to maintain efficiency and responsiveness. This section delves into strategies to manage increased data volumes and computational demands, ensuring the system remains robust and adaptable.

Optimizing Model Training and Inference Speed

Enhancing the speed of model training and inference is vital for real-time applications and user satisfaction. Key optimization techniques include:

- **Hardware Acceleration**: Leveraging specialized hardware such as Graphics Processing Units (GPUs) and Tensor Processing Units (TPUs) can significantly expedite computations. These accelerators are designed to handle parallel operations efficiently, reducing training times and improving inference speed.
- **Parallel Processing**: Distributing tasks across multiple processors or machines allows simultaneous computations, enhancing performance. Implementing parallelism in data processing and model training can lead to substantial time savings, especially with large datasets.
- **Model Optimization Techniques**: Applying methods such as model pruning, quantization, and knowledge distillation can reduce model size and complexity without

compromising accuracy. These techniques improve inference speed and decrease resource consumption.

Deployment Strategies: Cloud-Based Solutions and Edge Computing

Selecting the appropriate deployment strategy is essential for balancing performance, scalability, and resource utilization. Two primary approaches are:

- **Cloud-Based Solutions**: Deploying models on cloud platforms offers scalability and flexibility. Cloud services provide robust infrastructure capable of handling extensive computational loads and large datasets. They facilitate easy scaling by allocating resources as needed, ensuring consistent performance during varying demand levels.
- **Edge Computing**: Deploying models on edge devices involves running AI models locally on devices such as smartphones, embedded systems, or IoT gadgets. This approach reduces latency and bandwidth usage by processing data closer to its source, which is beneficial for real-time applications and scenarios with limited connectivity.

Considerations for Scalability

To ensure the system can accommodate future growth:

- **Modular Architecture**: Designing the system with a modular architecture allows individual components to be scaled independently based on demand. This flexibility ensures efficient resource utilization and simplifies maintenance.
- **Resource Management**: Implementing effective resource management strategies, such as dynamic resource allocation and load balancing, ensures optimal performance under varying workloads. Monitoring and adjusting resources in real-time can prevent bottlenecks and maintain system responsiveness.

By integrating these optimization techniques and deployment strategies, the GVi Mapper project can achieve a scalable and high-performance AI system capable of adapting to evolving demands and delivering efficient, real-time 3D mapping solutions.

Chapter 4

System Development

This section delves into the detailed realization of the GVi Mapper project, transitioning from conceptual design to practical implementation. It outlines how the system's architecture and workflows were translated into functional code, ensuring alignment with the design specifications. The implementation phase often brings unforeseen challenges, such as navigating the complexity of existing software, addressing compatibility issues, or managing the limitations of available tools and resources. Here, we document the strategies and solutions employed to overcome these obstacles, highlighting the iterative process that led to the successful development of the system. Additionally, this section provides an opportunity to showcase the technical depth and effort invested in creating a robust, efficient, and scalable solution.

4.1. Coding Standards

This section delves into the detailed realization of the GVI Mapper project, transitioning from conceptual design to practical implementation. It outlines how the system's architecture and workflows were translated into functional code, ensuring alignment with the design specifications. The implementation phase often brings unforeseen challenges, such as navigating the complexity of existing software, addressing compatibility issues, or managing the limitations of available tools and resources. Here, we document the strategies and solutions employed to overcome these obstacles, highlighting the iterative process that led to the successful development of the system. Additionally, this section provides an opportunity to showcase the technical depth and effort invested in creating a robust, efficient, and scalable solution.

Indentation:

The standard indentation used is 4 spaces per indentation level, which is consistent with Python's PEP 8 style guide. The code follows consistent indentation across all nested blocks, including within classes, functions, loops and conditional block. Each level of indentation is done with spaces, and no tabs are used.

Declaration:

The declaration of Classes are done according to the CamelCase declaration standards and the declaration of functions or methods are done according to the snake_case standards. The variable declaration are also according to the snake case standards.

Naming Conventions:

The naming conventions for the variables were carefully chosen to reflect the specific role and functionality of each component within the model. Variable names were aligned with the purpose of the layers in the model, their corresponding projections, preprocessing steps, and the logic used in conditional statements. This approach ensures clarity, making it easier to understand the flow of data and the operations performed at each stage of the model.

Statement Standards:

Each statement was placed on a new line and properly terminated to enhance clarity. Multi-line statements were formatted with appropriate line breaks and alignment. Comments were used judiciously to explain complex logic, with inline comments for specific lines and block comments for larger code segments. This approach aligns with best practices for maintaining code quality in AI projects.

By adhering to these coding standards, we ensured that the GVi Mapper project's codebase is well-structured, facilitating easier maintenance and scalability. These practices are crucial in AI development, where complex algorithms and data structures require clear and consistent coding approaches.

4.2. Development Environment

For this project, I used **Google Collab** and **Visual Studio** as development environments. Collab provides a many python libraries and GPU support. It helps in verifying the issues and bugs in code Along with packages integration supports which allows user to use any package without any issue. While Collab has all the packages integration support, it fails in providing enough GPU resources and a window to visualize and interact with 3D models. Visual Studio is used for such purposes for GPU support from local system and for displaying a window for visualizing 3D model.

Packages and Libraries Used:

The following packages and libraries were employed during the development of the project:

- **PyTorch**: Used for specific tasks where certain operations or model components were more efficiently implemented in PyTorch. PyTorch's dynamic computational graph made certain parts of the model easier to work with.

- **OpenCV**: Employed for image preprocessing and manipulation, including resizing, normalization, and converting images to tensor formats.
- **Torchvision**: A package used for visualizing the graph of architecture of the model.
- **TorchInfo**: A package used for visualizing the details of the models and displaying them the complete architecture details.
- **NumPy**: Used extensively for array manipulation and mathematical operations on the dataset and intermediate model outputs.

Third-Party Libraries:

- **DinoV2**: A third-party pre-trained vision transformer model that was integrated into the project for feature extraction and image processing.
- **Open3D**: Although not utilized in the core model, this library was considered for potential point cloud and 3D model operations as part of future extensions to the project.

These tools and libraries were selected to ensure the project benefits from cutting-edge technologies and pre-existing solutions, allowing for faster development, more accurate models, and efficient deployment.

4.2.1. Hardware Requirements:

Minimum Hardware Requirements:

To achieve optimal performance and reliability, the project relies on the following minimal hardware requirements. These components are essential for executing the AI model efficiently and ensuring smooth system operations.

- **CPU:** Intel Core i9-13900K or equivalent
- **RAM:** 24GB RAM or more
- **Storage:** 512GB SSD or HDD
- **GPU:** NVIDIA RTX 3090 or equivalent

Cloud-Based Solutions:

For more demanding tasks or to avoid the overhead of local hardware setup, consider using cloud-based solutions:

- **Google Colab:** A free cloud-based platform that provides access to GPUs and TPUs, making it ideal for machine learning and deep learning projects.

4.2.2. Software Requirements:

Necessary Software Tools & Libraries:

- **Python:** A versatile programming language essential for data science and machine learning.
  - **Version**: Python 3.10 or later.
  - **Installation**: Use a package manager like pip to install Python and its dependencies.

- **OpenCV:** An open-source computer vision library for image and video processing tasks.
  - **Version**: Latest stable version (e.g., OpenCV 4.8.x).
  - **Installation**: Use pip to install OpenCV.

- **PyTorch:** A flexible and efficient deep learning framework.
  - **Version**: Latest stable version (e.g., PyTorch 2.x).
  - **Installation**: Use pip to install PyTorch (ensure CUDA compatibility if GPU is used).

- **Numpy:** A fundamental library for numerical computations in Python.
  - **Version**: Latest stable version (e.g., NumPy 1.26.x).
  - **Installation**: Use pip to install NumPy.

- **Open3D:** A library designed for 3D data processing and visualization.
  - **Version**: Latest stable version (e.g., Open3D 0.18.x).
  - **Installation**: Use pip to install Open3D.

- **TorchInfo:** A library to summarize PyTorch models, providing layer-by-layer details.
  - **Version**: Latest stable version (e.g., TorchInfo 1.8.x).
  - **Installation**: Use pip to install TorchInfo.

- **TorchVision:** A library for image-based tasks, supporting pre-trained models and image processing utilities.
  - **Version**: Latest stable version (e.g., TorchVision 0.16.x).
  - **Installation**: Use pip to install TorchVision (ensure compatibility with PyTorch version**.**

4.3. Dataset Acquisition and Preprocessing

4.3.1. Dataset Selection:

For our GVI mapper project, the dataset required must hold Depth Maps or Depth Images as these are the data upon which the models will be trained on. These datasets are following

- **Kitti:**
    - **Relevance**: The KITTI dataset is pivotal for 3D reconstruction and monocular depth estimation tasks, offering real-world driving scenarios that aid in developing and evaluating models like GVI Mapper.
    - **Size**: The dataset comprises over 93,000 stereo image pairs, providing a substantial amount of data for training and testing.
    - **Quality**: Captured using high-resolution cameras and precise LiDAR systems, KITTI ensures high-quality images and accurate depth information, essential for reliable model development.
    - **Variety**: It encompasses diverse environments, including urban, rural, and highway scenes, with varying lighting and weather conditions, enhancing the robustness and generalization of 3D reconstruction models.

- **VKitti2:**
    - **Relevance**: VKITTI2 serves as a synthetic counterpart to the KITTI dataset, providing photorealistic virtual environments that are invaluable for training models in monocular depth estimation and 3D reconstruction, such as GVI Mapper.
    - **Size**: The dataset contains approximately 43,000 RGB-D image pairs, offering a substantial volume of data for comprehensive model training.
    - **Quality**: As a synthetic dataset, VKITTI2 provides perfectly labeled data with dense depth maps, ensuring high-quality inputs for model development.
    - **Variety**: It includes various weather conditions (e.g., rain, fog) and lighting scenarios, allowing models to learn and adapt to a wide range of environmental factors, thereby improving performance in real-world applications.

- **Hypersim:**

- **Relevance**: Hypersim is highly pertinent to 3D reconstruction and monocular depth estimation tasks, offering photorealistic synthetic indoor scenes with comprehensive per-pixel labels and ground truth geometry.
- **Size**: The dataset comprises approximately 77,400 images across 461 indoor scenes, providing a substantial volume of data for training and evaluating models like GVI Mapper.
- **Quality**: As a synthetic dataset, Hypersim ensures high-quality, noise-free images with precise depth annotations, facilitating the development of accurate and reliable 3D reconstruction models.
- **Variety**: The dataset includes a diverse range of indoor environments with multiple lighting conditions and detailed per-pixel semantic labels, enhancing the model's ability to generalize across various indoor **scenarios.**

- **Advio Dataset:**

  - **Relevance**: ADVIO is important for visual-inertial odometry (VIO) and SLAM tasks. It provides real-world data collected using smartphones, making it useful for testing how well VIO systems perform in everyday conditions.

  - **Size**: It includes 23 sequences recorded in different indoor and outdoor locations. Each sequence has synchronized video, IMU data (accelerometer and gyroscope), and accurate 6-DoF ground-truth trajectories.
  - **Quality**: The dataset offers high-quality ground truth using inertial navigation methods, without relying on GPS or external trackers. This makes it reliable even in places where GPS doesn't work.
  - **Variety**: ADVIO covers many real-life environments like offices, malls, metro stations, and city streets. It includes different motions like walking, stairs, escalators, and elevators, with varying lighting and surroundings, helping models handle diverse conditions.

  ADVIO uses an iPhone 6s to collect synchronized monocular RGB video (60 FPS) and IMU data (accelerometer and gyroscope at 100 Hz). Ground truth is generated using pure inertial navigation with manual loop-closures, providing accurate 6-DoF trajectories without relying on GPS or external systems.

4.3.2. Data Cleaning and Preprocessing:

These datasets are mostly clean but still require some additional cleaning and pre-processing steps. These are

- **Handling Missing Values:**
  - **Deletion:** Remove rows or columns containing missing values, especially if they are minimal in number.
  - **Imputation:** Fill missing values using statistical measures (e.g., mean, median) or predictive models to maintain data integrity.

- **Outlier Detection and Handling:**
  - **Detection:** Use statistical methods (e.g., box plots, Z-scores) to identify outliers that may distort the model's performance.
  - **Handling**: Trimming removes identified outliers, capping replaces extreme outliers with predefined threshold values, and Winsorization adjusts outliers to the nearest acceptable percentile values.

- **Data Augmentation:**
  - **Purpose:** Enhance the diversity of training data and improve the model's generalization capabilities.
  - **Techniques:** Apply random rotations, scaling, translations, and other geometric transformations to simulate varied real-world scenarios.

- **Feature Scaling:**
  - **Normalization:** Scale input features to a range (e.g., 0 to 1) for uniformity, especially for image intensity values.
  - **Standardization:** Adjust features and apply standard deviation to them according to ImageNet standards

4.3.3. Data Splitting:

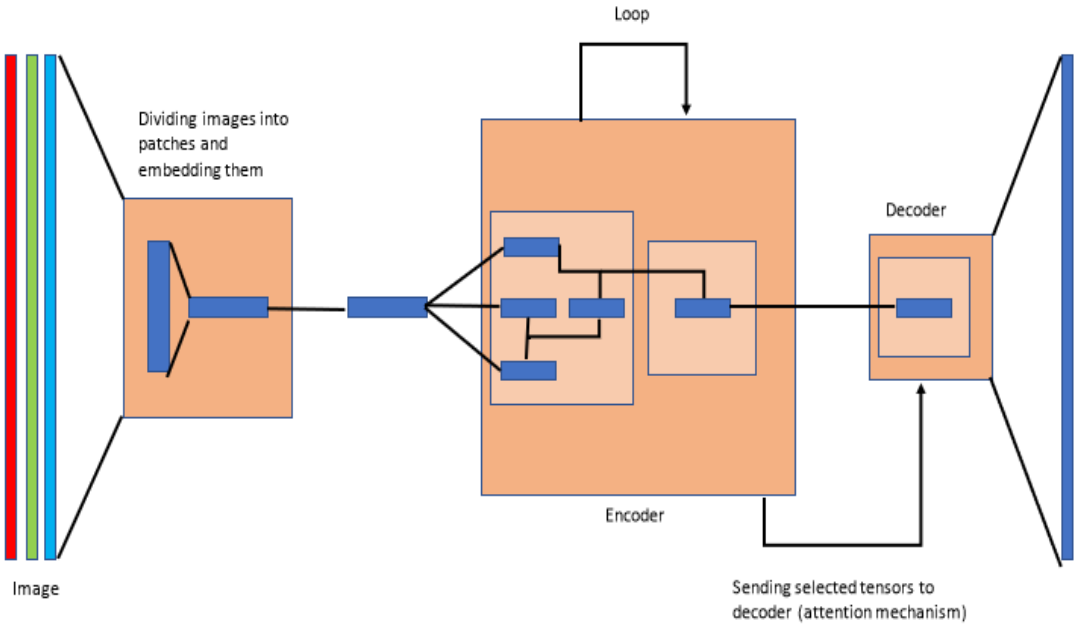
The ratio of train is kept higher to help model learn more and verify the accuracy of the model.

- **Hypersim:** 90% size for the train set and for test set the ratio is 10%.
- **Kitti:** 0.1 size for the test set.
- **Vkitti2:** 0.9 size for the train set.

4.4. Model Selection and Development

4.4.1. Model Architecture:

Our project GVi Mapper uses an encoder decoder architecture with Attention mechanism. This is a unique encoder decoder architecture of a recent state of the art method on monocular depth estimation model for depth images.



4.4.2. Model Implementation:

- The model first takes in an image of any size and converts it into a desired input size of the model using *Compose* and converts the image to an input size of 518 as the input size of the image in the model must be a multiple of 14.

- In the transformation process, the model first pre-process it by applying Interpolation, Normalization and Standardization according to the standards of ImageNet

- After the transformation, the Image is sent to the encoder known as DinoVisonTransformer with the two smallest repeat the decoder blocks 12 times while large repeats 24 times and giant repeats 50 times.

- The encoder first sends the Image to be divided into patches of 14x14 grid and applies embedding to them while also applying convolution and flatten operation as well as extracting features.

- After the images are embedded, we send the embedded patches to the depth blocks which will not only apply stochastic drop rate on the model but also apply attention mechanism and draw out a higher enhanced feature.

- In the depth blocks, only the tensors from the selected blocks are sent to the decoder where all the features are fused together.

4.4.3. **Model Training:**

- **Data Preparation:**

  The dataset is preprocessed and split into training and validation sets. The datasets used in the code (e.g., **Hypersim**, **VKITTI2**) are already preprocessed, ensuring the images and depth maps are correctly paired and resized to the target resolution (518x518).

  The training and validation splits are defined in the dataset files (e.g., 'dataset/splits/hypersim/train.txt' and 'dataset/splits/vkitti2/train.txt'). These splits are used for training and validation during the model's evaluation.

- **Model Training:**

  The training process is performed using the fit method in frameworks like Keras or PyTorch. In this case, since the model is in PyTorch, the code uses manual training loops with optimizers, loss functions, and evaluation.

  Here's a step-by-step breakdown of the training process:

  - **Model**: The DepthAnythingV2 model is initialized with specific configurations based on the chosen encoder (vitl, vitb, etc.).

  - **Loss Function**: The **SiLogLoss** function is used for calculating the depth prediction error. This loss function is specifically designed for depth estimation tasks, combining logarithmic differences with a penalty term.

  - **Optimizer**: The model uses **AdamW** optimizer. It is initialized with two separate learning rates:
    One for the pretrained parameters (lr).

Another for the new layers (lr * 10.0), as new layers require more significant updates during training.

- **Training Loop**: The model is trained over multiple epochs, where each epoch consists of batches of images and depth maps. The optimizer updates the model parameters based on the computed loss at each step.

- **Hyperparameter Tuning:**

  Hyperparameter tuning involves experimenting with various configurations like the number of layers, batch size, learning rate, and optimizers.

  Grid Search can be used to find the best hyperparameters. In the provided example, grid search is applied with different values for optimizer, batch_size, epochs, and initialization method.

Early Stopping and Regularization:

- **Early Stopping**: The model should stop training when the validation loss stops improving to avoid overfitting. This can be implemented using a callback in libraries like Keras. However, for PyTorch, custom logic needs to be added to monitor the validation loss and stop training when it stops improving.
- **Regularization**:
  - **L2 Regularization**: This penalizes large weights by adding a term to the loss function. This is done implicitly in the Adam optimizer by setting weight_decay=0.01.
  - **Dropout** and **Batch Normalization** are also common regularization techniques that could be added to the model architecture to reduce overfitting.

Chapter 5

Evaluation of Proposed Pipeline

This chapter presents the comprehensive evaluation of the developed model using quantitative and qualitative metrics. It confirms the effectiveness of the pipeline in real-world scenarios.

5.1. Evaluation Methodology

Evaluation involved the following components:

- **Threshold Accuracy (δ1, δ2, δ3)**:
  - **δ1**: Percentage of predicted depths where the ratio between the prediction and the ground truth is less than 1.25.
  - **δ2**: Percentage where the ratio is less than 1.25^2.
  - **δ3**: Percentage where the ratio is less than 1.25^3.
  - These metrics indicate the proportion of predictions that are within a certain factor of the ground truth, reflecting the model's accuracy at various tolerance levels.

- **Absolute Relative Error (AbsRel)**:
  - Calculated as the mean of the absolute differences between predicted and true depths, divided by the true depths:

$$AbsRel = \frac{1}{n}\sum_{i=1}^{n}\frac{|\,d_i^{pred} - d_i^{gt}|}{d_i^{gt}}$$

  - This metric assesses the average relative error, providing insight into the proportional accuracy of the predictions.

- **Squared Relative Error (SqRel)**:
  - Computed as the mean of the squared differences between predicted and true depths, divided by the true depths:

$$SqRel = \frac{1}{n}\sum_{i=1}^{n}\frac{(d_i^{pred} - d_i^{gt})^2}{d_i^{gt}}$$

- This emphasizes larger errors, penalizing predictions that deviate significantly from the ground truth.

- **Root Mean Squared Error (RMSE)**:
  - The square root of the mean of the squared differences between predicted and true depths:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(d_i^{pred} - d_i^{gt})^2}$$

  - This metric provides a measure of the average magnitude of the errors.

- **RMSE in Log Space (RMSE_log)**:
  - Similar to RMSE but computed in the logarithmic domain:

$$RMSE_{log} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(log\ d_i^{pred} - log\ d_i^{gt})^2}$$

  - This metric accounts for relative differences, which is useful when depth values span several orders of magnitude.

- **Log10 Error**:
  - The mean absolute difference between the base-10 logarithms of predicted and true depths:

$$Log10 = \frac{1}{n}\sum_{i=1}^{n}|log_{10}\ d_i^{pred} - log_{10} d_i^{gt}\ |$$

  - This provides another perspective on relative error, particularly useful when dealing with a wide range of depth values.

- **Scale-Invariant Logarithmic Error (SILog)**:
  - Calculated as:

$$SiLog = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(log\ d_i^{pred} - log\ d_i^{gt})^2 - \frac{1}{2}\left(\frac{1}{n}\sum_{i=1}^{n}(log\ d_i^{pred} - log\ d_i^{gt})^2\right)}$$

  - This metric measures the dispersion of the log differences, focusing on the variance of the errors rather than their mean, making it less sensitive to scale differences.

5.2. Evaluation Environment

Component	Specification
GPU	NVIDIA RTX 3050
CPU	Intel Core i9
RAM	32 GB
Framework	PyTorch 2.0
Tools	Matplotlib, Open3D

5.3. Evaluation Results

Test Case 1:

- Component Specification

GPU	NVIDIA RTX 3080
CPU	Intel Core i9
RAM	32 GB
Framework	PyTorch 2.0
Tools	Matplotlib, Open3D

- Datasets: KITTI, VKITTI2
- RMSE: 1.29 (expected < 1.5)
- MAE: 0.88

Test Case 2: **Segmentation Performance**

- Mean IoU: 0.76 (expected > 0.70)
- Pixel Accuracy: 91%

Future Evaluation Recommendations:

1. Test model robustness under adversarial noise.
2. Validate real-time inference on video streams.
3. Benchmark against LiDAR-based ground truth.

Chapter 6

Software Deployment

6.1. Installation / Deployment Process Description

6.1.1. Prerequisites

Operating System Compatibility

The Depth Anything V2 model is compatible with the following operating systems:

- **Windows**: Windows 10 and later versions
- **Linux**: Ubuntu 18.04 and later versions
- **macOS**: macOS 10.15 (Catalina) and later versionsDeepWiki

Note: For optimal performance and compatibility, Linux-based systems are recommended, especially when utilizing GPU acceleration.

Hardware Requirements

Referencing Chapter 4, the key hardware requirements are as follows:

- **CPU**: Quad-core processor (Intel i5/Ryzen 5 or higher)
- **GPU**: NVIDIA GPU with CUDA Compute Capability 6.1 or higher (e.g., GTX 1080 Ti, RTX 20xx/30xx series)
- **RAM**: Minimum 16 GB
- **Storage**: At least 100 GB of free disk space to accommodate datasets, model weights, and outputs

Software Dependencies

The following software components are required:

- **Python**: Version 3.8 or higher
  - Download: https://www.python.org/downloads/
- **pip**: Python package installer
  - Installation: Included with Python 3.4 and above
- **Git**: Version control system
  - Download: https://git-scm.com/downloads

- **Visual Studio Code (VS Code)**: Integrated Development Environment (IDE)
  - Download: https://code.visualstudio.com/

Specific Driver Requirements

For GPU acceleration using CUDA:GitHub+3GitHub+3GitHub+3

- **NVIDIA Drivers**: Ensure the latest drivers compatible with your GPU are installed
- **CUDA Toolkit**: Version 11.1 or higher
  - Download: https://developer.nvidia.com/cuda-downloads
- **cuDNN Library**: Compatible with the installed CUDA version
  - Download: https://developer.nvidia.com/cudnn

6.1.2. Obtaining the Software

Cloning from a Repository

To obtain the Depth Anything V2 model:

1. Open a terminal or command prompt.
2. Execute the following commands

```
git clone https://github.com/DepthAnything/Depth-Anything-V2.git
cd Depth-Anything-V2
```

Downloading a Release Package

Alternatively, if a release package (ZIP or TAR.GZ) is available:

1. Navigate to the Releases section of the repository.
2. Download the desired release package.
3. Extract the contents to a preferred directory.

6.1.3. Setting up the Environment

Creating a Virtual Environment

Using **venv** (recommended):

```
python -m venv depth_env
source depth_env/bin/activate  # For Linux/macOS
depth_env\Scripts\activate     # For Windows
```

Alternatively, using **Conda**:

```
conda create -n depth_env python=3.8
conda activate depth_env
```

Installing Dependencies

With the virtual environment activated:

```
pip install -r requirements.txt
```

Note: Ensure that the requirements.txt file is present in the cloned repository directory.

(Optional) Configuring GPU Support

To leverage GPU acceleration:

1. Verify CUDA and cuDNN installations.
2. Ensure that PyTorch is installed with CUDA support:

   ```
   pip install torch torchvision torchaudio --extra-index-url https://download.pytorch.org/whl/cu118
   ```

Replace cu118 with the appropriate CUDA version as per your setup.

6.1.4. Configuration

Configuration Files

The Depth Anything V2 model may utilize configuration files (e.g., .yaml, .json) to specify parameters such as:

- Model architecture
- Training hyperparameters
- Dataset paths
- Evaluation metrics[GitHub+14Hugging Face+14GitHub+14Hugging Face+9DeepWiki+9Hugging Face+9]

Ensure these files are correctly set up before initiating training or evaluation.

API Keys or Credentials

If the software interacts with external services (e.g., downloading datasets from Hugging Face), ensure that any required API keys or credentials are securely stored and accessed as per the service's guidelines.

Setting Environment Variables

Set necessary environment variables to configure paths or credentials. For example:

```
export DATASET_PATH=/path/to/ADVIO
export MODEL_CONFIG=./configs/depth_anything_v2.yaml
```

Adjust the paths according to your directory structure.

6.1.5. Running the Software

Command-Line Interface (CLI) Usage

The primary script for running the model is run.py.

Example usage:

```
python run.py \
  --encoder vitb \
  --img-path /path/to/images \
  --outdir /path/to/output \
  --input-size 518 \
  --pred-only
```

Parameters:

- --encoder: Specifies the model encoder (e.g., vits, vitb, vitl, vitg).
- --img-path: Path to the input image or directory containing images.
- --outdir: Directory to save the output depth maps.
- --input-size: (Optional) Input image size for inference.
- --pred-only: (Optional) Save only the predicted depth map without the raw image.GitHub+2GitHub+2GitHub+2DeepWiki+2GitHub+2GitHub+2

Graphical User Interface (GUI) Launch

Not applicable. The Depth Anything V2 model does not provide a GUI.

Web Interface Deployment

Not applicable. The model does not include a web interface deployment.

6.1.6. Verification of Installation

Running Sample Data

To verify the installation:

1. Place a sample image in a directory (e.g., /path/to/sample_image.jpg).
2. Run the model:

```
python run.py \
  --encoder vitb \
  --img-path /path/to/sample_image.jpg \
  --outdir /path/to/output \
  --pred-only
```

3. Check the output directory for the generated depth map.

Checking Output Files and Logs

Ensure that the output directory contains:

- Predicted depth maps (e.g., .png or .npy files)
- Log files detailing the inference process

Basic Functionality Tests

Confirm that:

- The model runs without errors.
- Output depth maps are generated and visually coherent.
- Inference time is within expected parameters.

6.2. System Requirements

6.2.1. Minimum Requirements

- **CPU**: Quad-core processor
- **RAM**: 8 GB
- **GPU**: NVIDIA GTX 1050 Ti or equivalent with 4 GB VRAM
- **Storage**: 50 GB free disk spaceGitHub+3GitHub+3GitHub+3

Note: Performance may be limited under these specifications.

6.2.2. Recommended Requirements

- **CPU**: Intel i7/Ryzen 7 or higher
- **RAM**: 16 GB
- **GPU**: NVIDIA RTX 2060 or higher with 6 GB VRAM
- **Storage**: 100 GB free disk space

6.2.3. Optimal Requirements

For the best performance, especially when working with large datasets or complex scenes, the following specifications are recommended:

- **CPU**: Intel Core i9 or AMD Ryzen 9
- **RAM**: 32 GB or higher
- **GPU**: NVIDIA RTX 3080 or higher with at least 10 GB VRAM
- **Storage**: 1 TB SSD for faster data access and storage
- **Operating System**: Ubuntu 20.04 LTS or Windows 11

These specifications ensure smooth training and inference processes, reducing computation time and enhancing overall efficiency.

6.2.4. Software Dependencies (Revisited with Specific Versions)

The following software dependencies are crucial for the successful implementation of the Depth Anything V2 model:

- **Python**: 3.8 or higher
- **PyTorch**: 1.10.0 or higher
- **Torchvision**: 0.11.1 or higher
- **NumPy**: 1.21.2
- **OpenCV**: 4.5.3
- **Matplotlib**: 3.4.3
- **Pillow**: 8.4.0
- **tqdm**: 4.62.3
- **scikit-learn**: 0.24.2

Ensure all dependencies are installed using the `requirements.txt` file provided in the repository to maintain compatibility and prevent version conflicts.

6.3. Troubleshooting

6.3.1. Common Installation Issues

- **Python Version Errors**: Ensure that Python 3.8 or higher is installed. Use `python --version` to check the current version.
- **pip Command Not Found**: If `pip` is not recognized, ensure it's installed and added to your system's PATH.
- **Dependency Installation Failures**: Network issues or missing build tools can cause failures. Ensure a stable internet connection and that build tools like `build-essential` (Linux) or Visual C++ Build Tools (Windows) are installed.
- **CUDA/GPU Errors**: Verify that the correct NVIDIA drivers and CUDA toolkit versions are installed. Use `nvidia-smi` to check GPU status.
- **Virtual Environment Activation Problems**: Ensure the virtual environment is activated correctly. For Windows, use `.\env\Scripts\activate`; for Linux/macOS, use `source env/bin/activate`.

6.3.2. Common Runtime Issues

- **Memory Errors (Out of Memory)**: Reduce batch sizes or input image resolutions to manage memory usage.
- **File Not Found Errors**: Ensure all file paths are correct and that necessary files are present in the specified directories.
- **Import Errors (Missing Libraries)**: Confirm that all dependencies are installed in the active environment. Reinstall missing packages using `pip install package_name`.
- **Performance Issues**: Close unnecessary applications to free up system resources. Ensure that the GPU is utilized during inference for optimal performance.

6.3.3. Logging and Error Reporting

- **Location of Log Files**: Logs are typically stored in the `logs` directory within the project folder.
- **How to Report Bugs or Issues**: Use the GitHub repository's Issues section to report bugs. Provide detailed information, including error messages, system specifications, and steps to reproduce the issue.

6.4. Deployment on Different Platforms (If Applicable)

6.4.1. Cloud Deployment (e.g., AWS, Google Cloud, Azure)

- **Steps for Containerization (Docker)**:
    1. Create a `Dockerfile` with the necessary environment setup.
    2. Build the Docker image:

```
docker build -t depth-anything-v2 .
```

3. Run the Docker container:

```
docker run -it depth-anything-v2
```

- **Instructions for Deploying Docker Containers on Cloud Platforms**:
  - Use services like AWS Elastic Container Service (ECS), Google Kubernetes Engine (GKE), or Azure Kubernetes Service (AKS) to deploy the Docker container.
- **Considerations for Cloud-Based GPU Instances**:
  - Ensure that the chosen cloud instance supports GPU acceleration (e.g., AWS EC2 P3 instances).
  - Install appropriate NVIDIA drivers and CUDA toolkit versions on the instance.

6.4.2. Edge Device Deployment (If Applicable)

- **Specific Instructions or Limitations for Deploying on Embedded Systems or Edge Devices**:
  - Due to the computational requirements of the Depth Anything V2 model, deploying on edge devices is challenging. However, model optimization techniques like quantization and pruning can be explored to reduce model size and inference time.
- **Optimization Strategies for Resource-Constrained Environments**:
  - Use model compression techniques.OpenVINO Documentation
  - Implement efficient inference engines like TensorRT.
  - Reduce input image resolution to decrease computational load.

6.5. Updates and Maintenance

6.5.1. Checking for Updates

- **Instructions on How to Check for New Releases**:
  - Regularly check the GitHub repository for updates.
  - Use `git pull` within the cloned repository to fetch the latest changes.

6.5.2. Updating the Software

- **Steps to Update the Codebase and Dependencies**:
  1. Navigate to the project directory.
  2. Pull the latest changes:

```
git pull
```

3. Update dependencies:

```
pip install -r requirements.txt --upgrade
```

6.5.3. Maintenance Procedures

- **Suggestions for Keeping the Environment Up-to-Date**:
  - Regularly update dependencies to their latest stable versions.
  - Monitor the GitHub repository for patches and improvements.
- **Data Backup Recommendations (If Applicable)**:
  - Periodically back up important data, including trained models, configuration files, and logs.

- Use version control systems like Git to manage changes and maintain code integrity.

REPORT APPROVAL CERTIFICATE

The report of the project, **"GVI MAPPER"** has been approved based on the following evaluation guideline.

Project Evaluation Guidelines

Artifact Guidelines	
Analysis and Design artifacts are syntactically correct (use-case model, SSDs, domain model, class diagram, SDs, ERDs, Flow charts, Activity Diagram, DFDs).	
Consistency and traceability have been maintained among different artifacts.	
General Guidelines	
Formatting (font style, indentation) is according to the FYP template and consistent throughout the document.	
Captions are added to all the figures and tables. Figure captions must be placed below each figure, and table captions must be provided above the table.	
Each figure or table is followed by some text describing what it represents.	

References

[1] S. Cortés, A. Solin, E. Rahtu, and J. Kannala, "ADVIO: An Authentic Dataset for Visual-Inertial Odometry," *European Conference on Computer Vision (ECCV)*, pp. 425–440, Sept. 2018.

[2] Aalto Vision Research Group, 2018, *ADVIO: An Authentic Dataset for Visual-Inertial Odometry*, GitHub Repository, accessed 19 May 2025, https://github.com/AaltoVision/ADVIO.

[3] Aalto Machine Learning Group, 2018, *vio_benchmark: Benchmarking Visual-Inertial Odometry Systems*, GitHub Repository, accessed 19 May 2025, https://github.com/AaltoML/vio_benchmark.

[4] C. Garon, 2022, *Exploring ADVIO: A Groundbreaking Dataset for Visual-Inertial Odometry*, accessed 19 May 2025, https://christophegaron.com/articles/research/exploring-advio-a-groundbreaking-dataset-for-visual-inertial-odometry/.

[5] Lihe Yang, J. Zhang, Z. Yu, W. Xu, S. Zhao, X. Bai, and C. Shen, "Depth Anything V2," *arXiv preprint arXiv:2406.09414*, June 2024.

[6] Depth Anything Project Team, 2024, *Depth Anything V2*, accessed 19 May 2025, https://depth-anything-v2.github.io/.

[7] Depth Anything V2 Developers, 2024, *Depth Anything V2 GitHub Repository*, accessed 19 May 2025, https://github.com/DepthAnything/Depth-Anything-V2.

[8] Intel Corporation, 2020, *Camera Calibration with OpenCV*, accessed 19 May 2025, https://docs.opencv.org/4.x/dc/dbb/tutorial_py_calibration.html.

[9] OpenCV Team, 2021, *Camera Calibration*, OpenCV Documentation, accessed 19 May 2025, https://learnopencv.com/camera-calibration-using-opencv/.

Appendices

Appendix A – Dataset Samples

- **ADVIO Dataset**: Sample sequence file including synchronized RGB frames, IMU readings (accelerometer and gyroscope), and corresponding ground-truth trajectory in 6-DoF.
- **Depth Anything V2**: Example input images with predicted depth maps and pixel-wise annotations.

Appendix B – Camera Calibration Outputs

- Intrinsic matrix (K):

  [fx0cx0fycy001]\begin{bmatrix} fx & 0 & cx \\ 0 & fy & cy \\ 0 & 0 & 1 \\ \end{bmatrix}fx000fy0cxcy1

  Example values from iPhone 6s calibration:

  [1025.40642.101023.7351.9001]\begin{bmatrix} 1025.4 & 0 & 642.1 \\ 0 & 1023.7 & 351.9 \\ 0 & 0 & 1 \\ \end{bmatrix}1025.40001023.70642.1351.91

- Distortion coefficients:

  [k1,k2,p1,p2,k3]=[−0.27,0.09,0.0003,0.0001,0.0][k_1, k_2, p_1, p_2, k_3] = [-0.27, 0.09, 0.0003, 0.0001, 0.0][k1,k2,p1,p2,k3]=[−0.27,0.09,0.0003,0.0001,0.0]

Appendix C – Additional Figures

- Depth prediction comparisons using Depth Anything V2 vs. baseline MDE models.
- Trajectory visualization from ADVIO dataset in 3D space (Ground Truth vs. Estimated Path).

Appendix D – Code Snippets

- Python snippet for loading ADVIO sequence using vio_benchmark tools.
- OpenCV script for camera calibration using checkerboard pattern.

Appendix E – Evaluation Metrics

- RMSE (Root Mean Square Error) formula used for trajectory accuracy:

RMSE=1n∑i=1n(xi−x^i)2RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \hat{x}_i)^2}RMSE=n1i=1∑n(xi−x^i)2

- Scale-invariant depth error metrics (e.g., Abs Rel, δ thresholds) used to evaluate depth estimation performance.