Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 10s (2025)

Architecting Reality: Fusing Virtual and Augmented Worlds in Home Design with Python & OpenCV

[1]Madhulika Pardeshi, [2]Prof. G. A. Patil

[1]Dept of Computer Engineering, JSPM University Pune

madhulikapardeshi@gmail.com

[2]Dept of Computer Engineering, JSPM University Pune

gap.scos@jspmuni.ac.in

Article History:

Received: 12-01-2025

Revised: 15-02-2025

Accepted: 01-03-2025

Abstract:

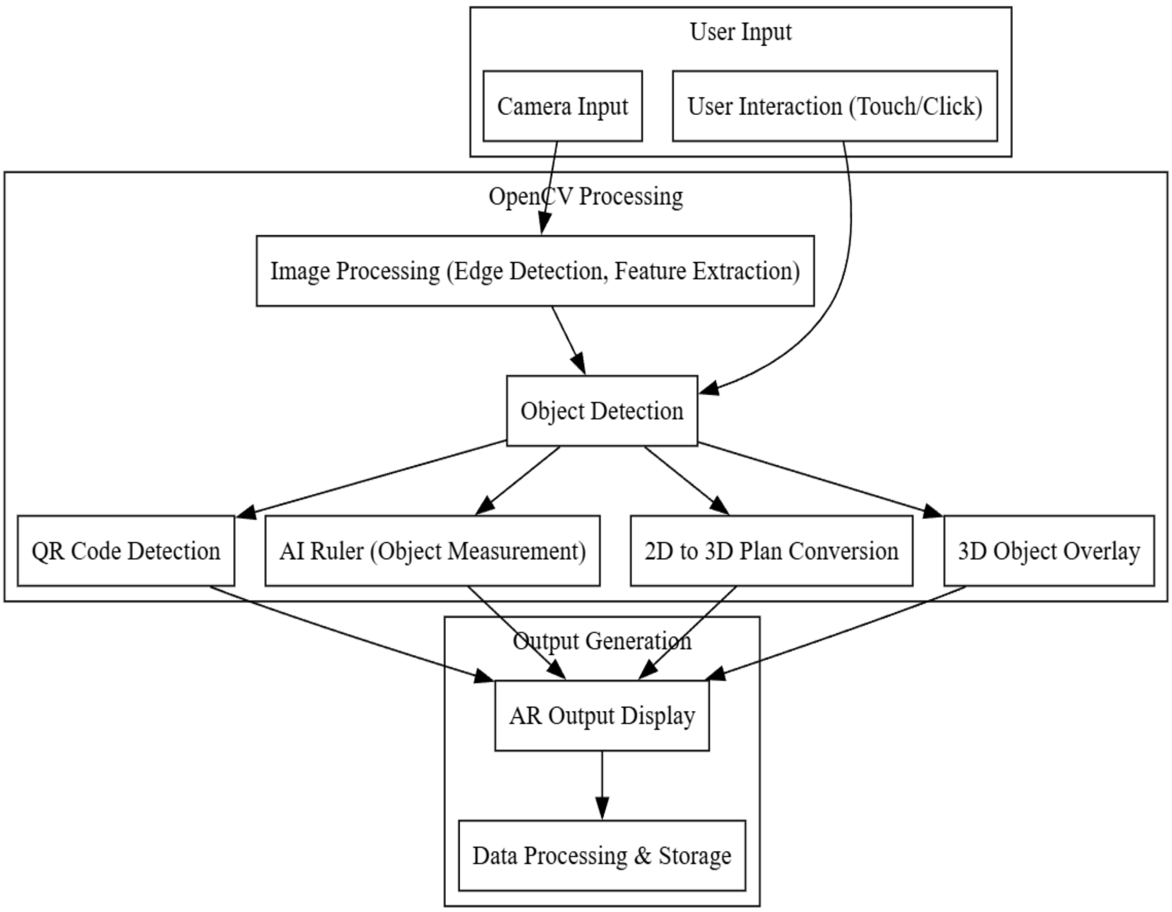
Augmented Reality (AR) is revolutionizing digital interaction by seamlessly integrating virtual components with real-world environments. This study explores an innovative approach to AR application development by integrating OpenCV with Python, leveraging computer vision and deep learning techniques. The proposed system consists of four primary modules: (1) an AI-driven ruler for real-time object measurement, (2) a QR code scanner enabling instant data retrieval, (3) a 2D-to-3D home plan conversion tool that transforms floor plans into three-dimensional models, and (4) an object detection-based AR overlay that superimposes 3D models onto real-world objects. These modules collectively enhance the accuracy, efficiency, and interactivity of AR applications, improving user experience across various domains.

Through extensive experimental validation, the system demonstrates robustness and real-time efficiency, showcasing its potential applications in architecture, smart measurement, and AR-based visualization. The integration of OpenCV facilitates precise image processing and object detection, significantly contributing to the accuracy and reliability of AR overlays. Furthermore, the research highlights the practical implications of combining artificial intelligence with AR, offering a scalable and adaptive solution for immersive digital interactions. This study underscores the significance of OpenCV in AR development and its capacity to enhance interactive technologies. The findings pave the way for future advancements in augmented reality, enabling more sophisticated and immersive applications across industries. By bridging the gap between real and virtual environments, this work contributes to the ongoing evolution of AR, fostering innovative solutions for smart visualization and intelligent interaction.

Keywords: Augmented Reality, OpenCV, Computer Vision, Python, AI-based Measurement, QR Code Scanning, 2D-to-3D Conversion, Object Detection, 3D Model Overlay, Deep Learning, Image Processing.

Introduction:

Augmented Reality (AR) is transforming digital interactions by seamlessly integrating virtual objects into real-world environments, enhancing user experiences across various industries such as architecture, education, healthcare, retail, and entertainment. By leveraging computer vision, artificial intelligence (AI), and deep learning, AR enables immersive applications that enhance real-world interactions. However, achieving real-time processing with high accuracy while maintaining scalability and efficiency remains a significant challenge in AR development. OpenCV, an open-source computer vision library, serves as a powerful foundation for AR applications by offering advanced image processing, object detection, and real-time tracking capabilities. Its integration with Python further streamlines the development process, enabling rapid prototyping and deployment of AR solutions. This research explores the integration of OpenCV with Python to develop an interactive AR system that performs multiple real-world applications with precision and efficiency. The system consists of four core modules. The first is an AI-based ruler, a smart measurement tool that utilizes computer vision algorithms to estimate object dimensions without physical contact, benefiting fields such as design, engineering, and construction. The second module is a QR code scanning system, which enables instant data retrieval by recognizing and processing encoded information in real time, enhancing applications in retail, logistics, and security. The third module converts 2D architectural floor plans into interactive 3D models, improving spatial visualization and planning for architects, designers, and homeowners. Lastly, the fourth module is an object detection-based AR overlay that superimposes 3D models onto real-world objects, enabling immersive experiences for design prototyping, education, and interactive learning. By utilizing OpenCV's image processing and AI-driven enhancements, the proposed system ensures real-time performance, high accuracy, and adaptability across different AR applications. Unlike traditional AR approaches that depend on specialized hardware, this system operates efficiently using standard cameras and computing devices, making it more accessible and cost-effective. This multi-functional AR system not only improves user engagement but also expands the practical applications of AR technology in everyday life.



.

Figure 1 : Rrepresentation of System

From cutting-edge industrial applications to interactive learning experiences, the use of AR into a variety of sectors has opened up new possibilities. Conventional augmented reality systems sometimes depend on specialist gear, such LiDAR sensors or AR headsets, which may be costly and out of reach for many users. This project focuses on creating an affordable, software-driven augmented reality system that can operate on common cameras and computer devices by using OpenCV with Python. This will increase the accessibility of AR technology for real-world usage. Making sure that object identification, tracking, and overlaying virtual features onto the actual environment are accurate and responsive in real time is one of the main problems in AR development. For accurate augmented reality implementation, OpenCV offers strong algorithms for image processing, contour recognition, feature extraction, and perspective modification. High accuracy and dependability across many use cases are the goals of the suggested system, which combines these skills with deep learning and AI-based improvements. System flexibility and user experience are two more important factors in AR applications. An AR system's efficacy rests on how well it performs in various lighting scenarios, with objects of varied sizes, and against complicated backdrops. To improve real-time performance, the suggested system uses sophisticated image processing methods such edge recognition, color segmentation, and homography transformation. Deep learning models may also be used to enhance spatial mapping and object identification for more complex augmented reality interactions.

Additionally, the apps created in this study address practical requirements, especially in fields where augmented reality (AR) may enhance productivity and judgment. The AI-based ruler and measurement tool is very helpful in design, construction, and logistics since it does not need actual measuring devices. The QR code scanner improves automation in sectors like retail and security by enabling smooth interaction between digital and physical material. The 2D-to-3D house plan conversion application bridges the gap between blueprints and real building by giving customers an easy-to-use approach to view architectural concepts. Finally, by enabling users to superimpose digital 3D models onto actual items, the 3D object overlay system makes interactive visualization come to life. This is useful for simulation training, teaching, and product creation. By tackling these issues and using OpenCV and Python's advantages, this study advances the expanding area of augmented reality by offering a framework that is scalable, effective, and interactive. The modular design of the system guarantees adaptability for future upgrades, including the inclusion of more AI-powered features, gesture detection, and support for wearable augmented reality gadgets. Beyond just technological developments, this study has a profound effect as it creates new avenues for AR to be incorporated into daily life, transforming a number of industries. This paper's subsequent parts provide a thorough examination of the system's evolution, beginning with a survey of current augmented reality technologies, their uses, and their drawbacks. After discussing the research gap and the rationale for this study, a thorough description of the methodology, system design, and implementation will be given. A conclusion summarizing the main contributions and outlining possible future approaches for enhancing AR-based interactive apps will follow the presentation of experimental data and performance analysis in the assessment section. The way we engage with digital material in the real world has been completely transformed by the quick development of computer vision and augmented reality (AR) technology. The growing need for interactive augmented reality apps that use OpenCV and Python to smoothly blend digital data with real-world settings is what inspired this study.

Conventional measuring instruments, QR scanners, and blueprint-to-3D conversions are often labor-intensive, imprecise, and manual. Our goal is to develop a system that improves user involvement, accuracy, and efficiency in AR-based applications by using real-time computer vision techniques

Moreover, sectors like construction, education, retail, and gaming are increasingly integrating augmented reality for diverse applications, ranging from seeing three-dimensional house designs to superimposing virtual entities onto tangible items. Nevertheless, several current AR systems need costly hardware or intricate implementations. Our suggested system emphasizes on a cost-efficient, user-friendly, and scalable augmented reality solution using widely available technologies such as OpenCV and Python. This research boosts usability by merging AI-driven object identification, real-time tracking, and immersive visualization, so bridging the divide between physical and digital interactions and making AR technology more accessible to a wider audience. The primary objective is to create an intelligent, interactive augmented reality system that streamlines intricate activities like AI-driven measuring, QR code reading, blueprint transformation, and real-world item enhancement.

Literature Survey

AR/VR in Education and Learning

William Vilegias-Ch et al., IEEE, 2024 analyzes the role of metaverse technologies such as VR/AR and AI for educational transformation. It assesses their effect on student engagement, retention, and accessibility through a mixed-methods approach. It notes improvements in learning outcomes and participation in education while also addressing security, privacy, and technological infrastructure issues. The findings make learning more interactive, personalized, and secure while ensuring diverse learner accessibility. The study focused on privacy, security, and access.

Ke Fang et al., IEEE, 2024 develops a teaching model that incorporates multi-modal interaction to elevate virtual pedagogy through gesture and voice recognition. It features a hands-free interface control paradigm whereby a speech classification model triggered by a fist clench recognizes some Chinese voice commands. The system was created in Unity with the HTC OpenXR SDK, implementing hand tracking to increase interaction. Twenty participants were involved in empirical evaluation, and while the technique did not significantly lower task completion time, it was well-received in terms of ease of use. The next steps include broadening the range of gestures and refining teaching model training for virtual pedagogical frameworks.

Dileep Kumar Murala et al.'s research published by IEEE in 2024, analyzes the impact of the Metaverse on education through immersive learning experiences made possible by the implementation of VR, AR, AI, Blockchain, and Big Data technologies. The paper addresses the positive aspects of the Metaverse such as enhanced learner engagement, automated adaptive education, real-time remote teaming, and personalization, as well the negative sides of security concerns, ethical implications of AI, infrastructure costs, and other challenges. The designers of this study created a five-layered framework to structure guidance towards education in the Metaverse. This framework is aimed at scalability and effective implementation. The researchers claimed that more work is needed to examine the issues of accessibility, interoperability, and other ethical implications emphasized by these frameworks in order to improve the inclusiveness and effectiveness of digital education. The researchers provided ethical frameworks to advance the utility of digital education.

Taehyun Kim et al. discuss new pedagogical methods and innovations in education through immersive technologies in metaverse environments. In IEEE VOL 16 NO 6, 2023 Kim describes the application of three learning theories: experiential learning, distributed cognition, and embodied learning for using Virtual Reality (VR) in the Metaverse educational environment. The importance of application-driven educational theory design and effective teaching applications has been highlighted in this study. Two case studies were presented: ChromosoME, a VR biology simulation, and ImPRESS, a science sketching tool for VR. Kim emphasizes the fact that while VR facilitates increased interest in the subject and retention of knowledge, pedagogy must be integrated into the curriculum for meaningful learning. In the context of metaverse education, integrating multiple modes of learning analytics to study and evaluate student participation will be essential in future research.

In their 2023 paper, “The Pedagogical Potential of VR and AR in Teaching and Learning,” Osvaldo Gervasi et al. with IEEE examined the effects of integrating Virtual Reality (VR) and Augmented Reality (AR) on learning with a focus on 162 high school students. They created two applications, one for VR which provided immersive explorations of 3D objects, and another for AR which allowed students to view 3D models through their smartphones. In the study, 94.43% of students considered AR to be a valuable asset to the education, while 93.81% for VR, demonstrating the impact on engagement and accomplishment of learning goals. It was also noted that face-to-face interactions offered richer experiences concerning the level of interaction and collaboration compared to remote learning. Later work looks at refining these technologies to support greater diversity in education.

Fatima Zulfiqar et al., IEEE, 2023 examines in detail how AR transforms education, focusing especially on its use to level up student engagement, learning motivation, and understanding through layering virtual information in reality. The study classifies the applications of AR technology according to their goals, methods of interaction, and outputs as well as dealing with such limitations as hardware barriers, accessibility, and cost of implementation. A review of various educational tools and platforms based on AR technology is provided, which illustrates improvement in visualization and active learning. This paper also underscores the inadequacy of research concerning the scope, practicality, and sustained influence of AR technology on education.

Smart Cities and Urban Planning

In 2024, IEEE published a work by Muhammad Umair Hassan et al. which details a Digital Twin Authoring Tool (DTAT) that automates transport digital twin creation of vehicles for smart cities. It uses IoT sensors and deep learning models for 3D reconstruction automation, allowing planners to interact with VR and simulation environments in real-time. The research discusses DTAT’s ability to analyze traffic patterns to predict congestion, modify transport routes, and enhance mobile services. While optimizing planning efficiency, issues such as data privacy, integration of real-time data, and scalability persist. Further research intends to expand the scope of DTAT's predictive components to other infrastructures within smart cities.

Xing Liu et al. in IEEE 2023 documented how the use of VR technologies offers a modern approach to urban landscape design and simulation through realistic 3D models and interactive virtual environments. The paper focuses on the shortcomings of urban planning associated with the traditional approach and cites VR as an effective solution that offers efficiency, collaboration, and real-time changes to increase productivity in urban design. New algorithms for spatial roaming, urban simulations, and 3D databases were proposed along with evaluation indicators. The results of the study demonstrate the positive role VR adoption plays on the accuracy of design computations, urban decision-making processes, and urban development phases. More research is needed on the interoperability of GIS in VR, real-time user interactions, and VR expansion for urban planning.

Augmented and Virtual Reality Applications in Architecture and 3D Design

In 2024, Kushal Pandey et al. released a study with IJNRD where they analyzed how AR technology improves the visualization of houses in the context of real estate. The researchers designed an AR software for interaction with house models in real-life environments using Unity 3D and Vuforia. Buyers and architects alike can actively participate in the decision-making process thanks to the flexibility offered by the AR implementation. The research underscores the advantages of AR over 2D visualization methods, instead making property viewing more realistic and precise. The conclusions underscore the possibility of using AR technology in architecture and real estate with further refinements using more sophisticated textures, additional 3D models, and better user interaction with the models.

In 2023, Elias Mohammed Elfarr et al. delved into creating a digital twin (DT) of a smart home system integrated with AI, IoT sensors, and VR to allow real-time monitoring and optimization, presented at an IEEE conference. A novel capability-level framework for categorizing DTs ranging from airborne to fully autonomous with predictive analytics, diagnostics, autonomous decision-making, and other advanced functionalities were introduced. VR facilitates home environment simulation, visualization, and interaction with digital twinned homes, enabling efficient energy consumption and intelligent automated systems. Live streaming data poses the primary challenge concerning asset privacy alongside real-time computation and merging data with the physical elements. Future work aims to enhance the DX's scalability alongside automation managed by AI.

Zhidong Xu et al. from ELSEVIER have a publication in 2024 that discusses how AR affects the efficiency of construction tasks. It classifies AR usage into design review, progress management, planning simulation, discrepancy checks, assembly, hazard notification, and positioning. The research shows that AR improves visualization, reduces task completion time, sharpens the accuracy of task completion, and also creates challenges related to usability, tracking accuracy, and high implementation costs. A productivity evaluation framework to measure the productivity impact of AR was introduced with emphasis on real-time tracking regarding scalability and adaptability of the workers for further research.

Elham Mohammadrezaei et al. from IEEE have a publication in 2024 that discusses how Extended Reality (XR) that comprises of Virtual Reality (VR) and Augmented Reality (AR) is changing smart lighting systems in built environments. It analyzes the role of XR in lighting simulations, energy efficiency, and human-centric lighting design by reviewing 270 research papers. The research showed that XR is capable of creating true-to-life immersive lighting environments, but poses challenges such as high implementation cost, data privacy, and standardization. This paper calls for more studies on the integration of XR with AI-powered automation and real-time simulation optimization for smart cities.

Prof. Prashant B. Koli et al., IJIRMPS, 2024 investigates the automation of creating immersive 3D virtual environments from 2D images using Generative Adversarial Networks (GANs), Convolutional Neural Networks (CNNs), and camera vision. Unlike traditional modeling that relies on extensive manual work, the proposed approach aims to leverage AI through depth estimation and feature extraction. The research underscores its importance in gaming, education, healthcare, and architecture, noting how it enhances the speed and ease of designing VR environments. Later studies will look at enhancing the realism of experiences, improving computational efficiency, and broadening the capabilities of AI in virtual reality systems.

Hyunmin Jung et al., IEEE, 2023 discusses the creation of a new LF-based VR system which resolves the issue of stationary user viewpoint with traditional 360° panoramic images. It proposes the Lawn Mowing Pattern Light Field structure (LMP-LF) that alleviates the data collection burdens while allowing greater freedom of movement for users without compromising rendering quality. This system offers VR rendering at 125 fps, marking a significant increase in immersion and realism. The research supports virtual tourism, real estate, and interactive training developments while focusing on scalability and real-time data processing for future studies.

AR/VR and their Application in Healthcare and Scientific Research

Thomas Napier et al., ELSEVIER, 2024 discusses the implementation of a new smartphone-based system which combines an object detection system with augmented reality for automating abalone counting and measuring in aquaculture. The system proposed does not require manual stock assessment, saving labor costs and alleviating stress on the animals, achieving over 95% accuracy in monitoring. The study emphasizes the system's independence from networks, portability, and use in remote locations where no specialized equipment is available. Future works include enhancing scalability of the model, the ability to handle multiple tasks at once, real time operations, and the integration with farm management systems.

Mueen Uddin et al., IEEE, 2024 analyzes the development, applications, and issues surrounding the metaverse. It encompasses the use of AI, blockchain, virtual and augmented reality, and edge computing and their contribution towards the development of engaging digital experiences in gaming, education, healthcare, and even remote work. Despite the immense benefits the metaverse provides, there are critical issues concerning security, privacy, ethical governance, and equitable access. The study calls for regulatory policies and new technological solutions for a safe metaverse. Research directions include focus on sustainability, cooperation between different systems, and protection of information in virtual spaces.

Junxiang Wang et al. of IEEE in the year 2023 describes the use of AI and VR technologies in enhancing the content creation in the metaverse. It subdivides the AI driven scene construction into virtual 3D reconstruction, simulated biology, personalized content, and intelligent agents. The research work discusses AI's automation in creating more realistic, interactive simulations in immersive environments, including educational, healthcare, and entertainment simulations. Performed AI content creation for the metaverse shows potential, however issues of high computational demand, ethics, and data privacy pose significant hurdles. More work is needed towards alignment of real-world data with AI, cross- disciplinary approaches and unique content tailoring to enhance realism and adaptability for virtual interactions.

AR/VR in Retail and User Experience

Akash S et al. in IJCRT in the year 2024 develops an advanced AR-based and computer vision virtual try-on algorithm aimed at improving online fashion retail. It has the potential of virtual fitting, thus reducing the return of clothes after the purchase. This system was programmed utilizing Python, OpenCV, and Flask. The system employs face segmentation, deep learning based pose estimation, and smart garment technology for virtual fittings. The study focuses on user participation and personalization and the benefits to the retailers in spite of color disbalance and size mismatches with regard to fitting. Providing users a more profound sense of immersion is one of the future advancements to be incorporated.

Industry Applications, Automation Work, and Modern Controls

The merging of technology with Fernandez-Cames and other (2024) IEEE publications showcases using Augmented/Mixed Reality (AR/MR) alongside Industrial Internet of Things (IIoT), Opportunistic Edge Computing (OEC), and Digital Twins for more efficient industrial automation. The work proposes the Meta-Operator, a worker in Industry 5.0 smart factories controlled through AR/MR devices. Moreover, the study was able to ascertain the advantages of real-time XR application, human-optimized industrial process, industrial process efficiency, and glaring inefficiency recovery towards maximally functional industrial processes, human-augmented. Primary focus moving forward will be advancement of autonomous AI, developing guidelines for metaverse, and industrial XR system refinement actuated by industry needs spending on warping frameworks of reality into tangible industrial augmentation.

AR and VR in Gaming, Art and Entertainment

Using AR/VR in creative endeavors, Wagh et al. (2024) proposes a new technique for virtual painting based on MI called Augmented Painting, where one can interact with distinct elements in mixed reality. The Propose Solution encompasses a broadened scope between fans of traditional and digital art, aspiring not prerequisites but heavylifting tools of inverting brushes and textrues.

Research Methodology

Augmented Reality (AR) technology has garnered substantial momentum across many sectors, enabling improved user experiences via digital overlays over physical settings. Nevertheless, current AR solutions sometimes depend on costly technology, such LiDAR sensors, AR headsets, or specialized depth cameras, rendering them unattainable for most users. Moreover, real-time processing, precise object identification, and fluid virtual-physical interaction continue to pose significant obstacles in augmented reality development. This study seeks to create an economical and efficient augmented reality system with OpenCV and Python, employing computer vision methodologies for real-time measuring, QR code scanning, conversion of 2D house plans to 3D, and overlaying 3D objects. The system is designed to operate using conventional cameras and computer resources, obviating the need for specialist hardware while maintaining excellent accuracy and real-time performance. The proposed interactive Augmented Reality (AR) system utilizing OpenCV and Python employs a systematic methodology that amalgamates computer vision techniques with real-time processing to facilitate functionalities including AI-driven measurement, QR code scanning, 2D-to-3D home plan conversion, and 3D object overlay. The process starts with data collection, whereby photos or video frames are obtained via conventional cameras, including webcams or smartphone cameras. The system operates without specialist AR gear, using computer vision techniques to analyze scene data. The acquired frames are subjected to preprocessing, which includes grayscale conversion to decrease computing complexity, noise reduction by Gaussian blur or median filtering to improve picture quality, and edge recognition using Canny edge detection to emphasize object boundaries. Homography changes for perspective correction provide precise alignment of objects for measurement and augmented reality overlay.

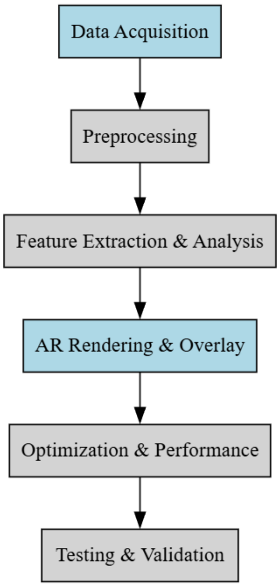


Fig Methodology

The AI-based measuring method employs contour detection and object segmentation to isolate pertinent items from the background. Perspective translation methods provide scale precision, whereas pixel-to-real-world mapping is accomplished by referencing items of known dimensions, such as a standard card or coin, to calculate measurement ratios. The QR code detection and scanning module utilizes OpenCV's inherent features to identify and decode QR codes, enabling users to get or engage with embedded data. QR code localization is accomplished by Haar cascades or feature-based detection, and upon identification, the encoded material is processed to initiate relevant activities, such as accessing product information or launching web pages. The 2D-to-3D house plan conversion functionality facilitates architectural visualization by converting 2D floor plans into interactive 3D models. The system utilizes edge and line identification using the Hough Line Transform to discern walls, doors, and structural components in scanned blueprints. Identified characteristics are then organized into a systematic layout, which is transformed into a 3D model using Python frameworks such as Open3D or the Blender API. Users may engage with the produced 3D model using AR overlays, offering an intuitive and engaging experience for architects, engineers, and designers. To improve AR engagement, the system incorporates 3D object overlay, whereby virtual models are placed onto real-world items. Feature matching methods, like ORB (Oriented FAST and Rotated BRIEF) and SIFT (Scale-Invariant Feature Transform), identify significant spots in real-world scenes and correlate them with reference models. Object identification guarantees that the system precisely recognizes items prior to superimposing relevant 3D models in real-time. The overlay is constantly modified according to the object's location and orientation to preserve realism. The system utilizes multi-threading and GPU acceleration to enhance speed, reduce processing delay, and provide seamless real-time interaction. The finished system undergoes testing in several environmental circumstances to assess accuracy, responsiveness, and usefulness. The project seeks to provide a cost-efficient and hardware-agnostic AR system that improves practical applications in architecture, education, retail, and interactive design via the implementation of these approaches. The system architecture for the Interactive Augmented Reality (AR) Application using OpenCV and Python comprises many linked modules that collaboratively record, analyze, and display augmented material in real-time. The design employs a systematic methodology, starting with data collecting and concluding with the ultimate AR depiction on the user's screen. Presented below is a comprehensive explanation of each phase:

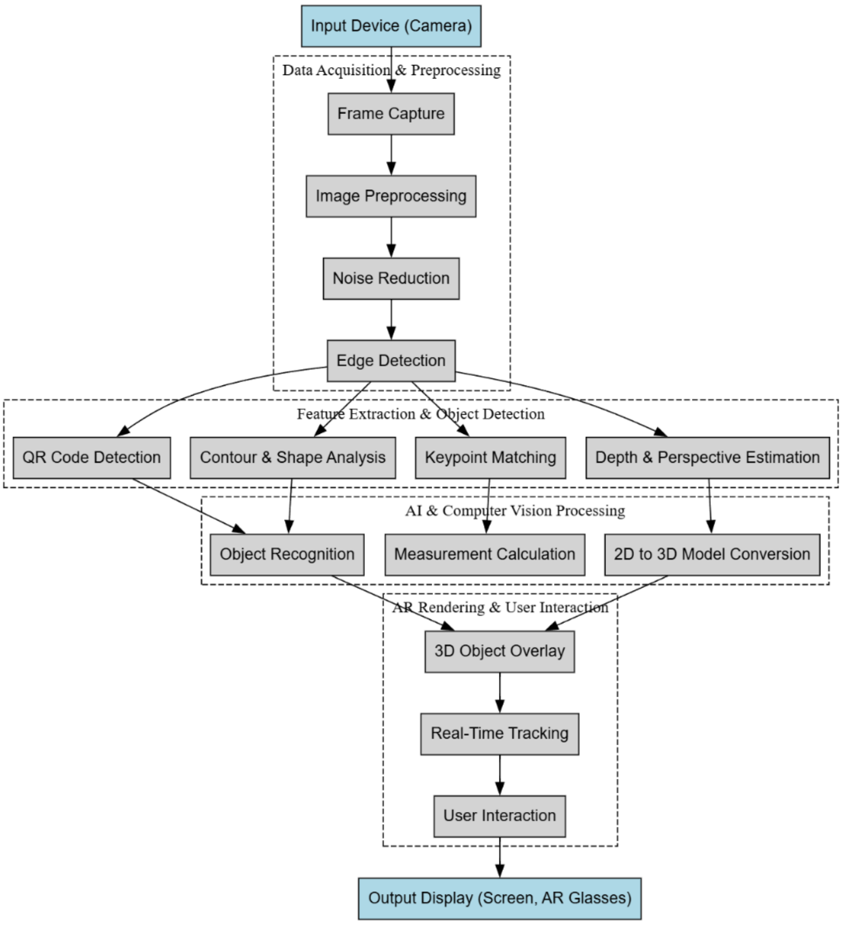


Figure 2 : propsoed System Architecture

SYSTEM ARCHITECTURE STAGES:

1. Input Device (Camera)

The process begins with a camera or an image sensor that captures real-world frames. The camera provides continuous input data in the form of video streams or images, which are then passed to the preprocessing module.

2. Data Acquisition & Preprocessing

Once the frames are captured, they go through multiple preprocessing steps to enhance image quality and prepare it for feature extraction. This phase includes:

- Frame Capture: Extracting video frames for analysis.
- Image Preprocessing: Converting images to grayscale, resizing, and normalizing.
- Noise Reduction: Removing unwanted distortions using filters (e.g., Gaussian or median filters).
- Edge Detection: Applying algorithms like Canny edge detection to highlight object boundaries.

3. Feature Extraction & Object Detection

After preprocessing, the system identifies key features in the image, essential for recognizing objects and overlaying AR content. This includes:

- QR Code Detection: Identifies QR codes for scanning and data retrieval.
- Contour & Shape Analysis: Detects geometric structures to recognize objects.
- Keypoint Matching: Uses algorithms like ORB (Oriented FAST and Rotated BRIEF) or SIFT (Scale-Invariant Feature Transform) for object recognition.
- Depth & Perspective Estimation: Computes real-world depth and orientation for proper AR overlay.

4. AI & Computer Vision Processing

The extracted features are passed through AI models and computer vision algorithms to process the data for AR visualization. This stage includes:

- Object Recognition: Identifies the real-world object in the captured image.
- Measurement Calculation: Implements AI rulers for estimating object dimensions.
- 2D to 3D Model Conversion: Transforms 2D blueprints (like home plans) into 3D representations.

5. AR Rendering & User Interaction

Once the processing is complete, the system overlays augmented content onto the real-world scene and allows user interaction. This stage includes:

- 3D Object Overlay: Places a virtual 3D model over the detected real-world object.
- Real-Time Tracking: Ensures the augmented content moves dynamically with the object.
- User Interaction: Allows the user to interact with the AR system, such as rotating or scaling the 3D object.

6. Output Display (Screen, AR Glasses):

Finally, the augmented scene is displayed on an output device such as a mobile screen, tablet, or AR glasses, allowing users to experience real-time AR visualization.

Results and Discussions

The experimentation process for developing the Interactive Augmented Reality (AR) System using OpenCV and Python involves a structured approach, ensuring accurate implementation, performance testing, and validation. The process begins with hardware and software setup, where a camera is used to capture real-world objects, and a computing device (such as a laptop or mobile) processes the AR overlay. The software stack includes Python, OpenCV for computer vision, NumPy for numerical operations, and visualization tools like Open3D for 3D rendering.

Once the system is set up, the next phase focuses on data acquisition and preprocessing, where real-time video frames are captured and processed by converting them into grayscale, reducing noise using filters such as Gaussian Blur, and detecting object boundaries using Canny Edge Detection. The system then moves to the feature extraction and object detection phase, where algorithms like ORB (Oriented FAST and Rotated BRIEF) and SIFT (Scale-Invariant Feature Transform) are used to recognize objects in real-time. QR code detection is also implemented to scan embedded information, while contour detection is used for measurement estimation.

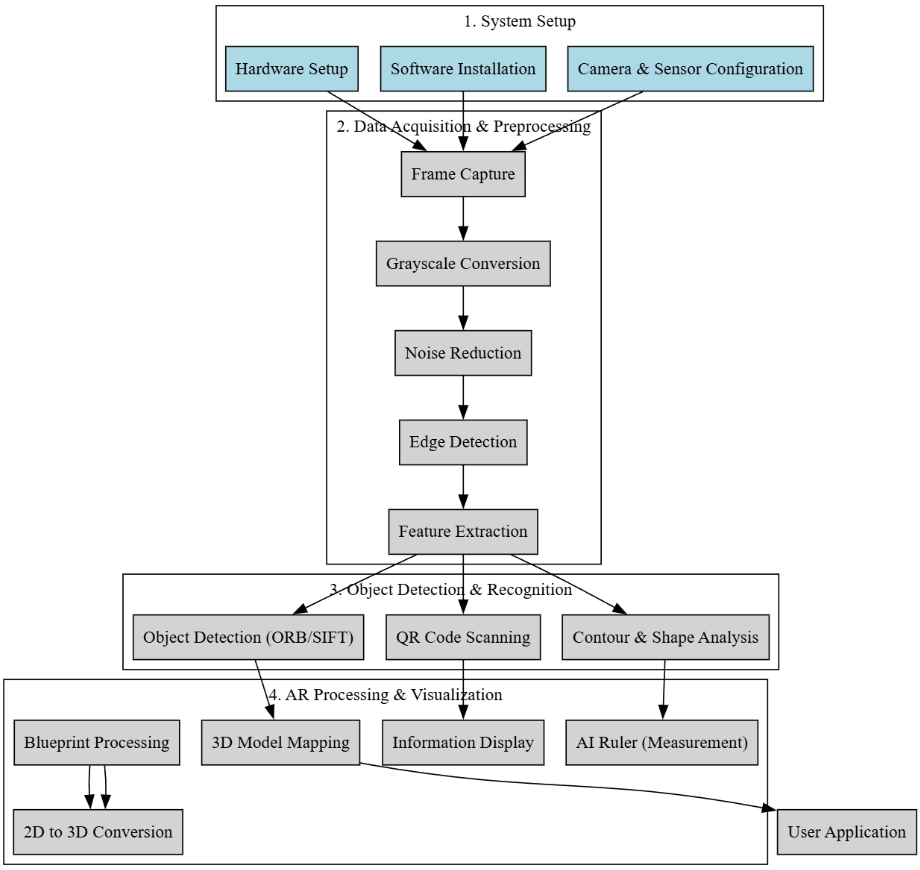


Figure 3 : Experimentation Process

After detecting objects, the system processes the data using AI-based AR techniques. The AI ruler measures real-world dimensions using pixel-to-distance conversion, and a 2D-to-3D transformation module extracts blueprint edges and generates 3D home plans using Open3D. For AR overlays, the system identifies real-world objects and maps corresponding 3D models to them, ensuring precise alignment and rendering. The next phase involves real-time AR visualization and user interaction, where the processed information is displayed on the screen, allowing users to manipulate 3D objects by rotating, zooming, and adjusting placements in real time. To evaluate the system's performance, testing and validation are conducted, measuring object detection accuracy, processing speed, and rendering efficiency. Key performance indicators include frame rate (FPS), latency, and real-time tracking precision. Additionally, user feedback is collected to assess usability and improve interaction mechanisms. The final step in the experimentation process is optimization, where computational efficiency is enhanced by fine-tuning the image processing pipeline and reducing unnecessary processing delays. By following this structured methodology, the system ensures high accuracy, real-time performance, and seamless user experience, making it suitable for applications such as AI rulers, QR scanning, 2D-to-3D blueprint conversion, and augmented 3D object visualization.

Algorithms and Model Used

The development of an interactive augmented reality (AR) system using OpenCV and Python requires a combination of image processing techniques, object detection models, and 3D rendering methods. The process begins with image preprocessing and feature detection, where algorithms like ORB (Oriented FAST and Rotated BRIEF) and SIFT (Scale-Invariant Feature Transform) help in identifying key points and matching objects within images. Additionally, Canny Edge Detection is applied to enhance object boundaries, while the Hough Transform is used for detecting lines and shapes, which is crucial for applications like AI-based rulers and blueprint extraction. For object detection and recognition, techniques such as contour detection (cv2.findContours) enable shape-based recognition, while template matching (cv2.matchTemplate) allows identifying predefined objects in an image. In cases requiring real-time detection, deep learning-based models like YOLO (You Only Look Once) are utilized for accurate object localization. QR code scanning is integrated using ZBar and OpenCV's built-in QR code detector, allowing the system to extract encoded data seamlessly.

To support 2D-to-3D conversion, the system employs perspective transformation (cv2.getPerspectiveTransform) and homography (cv2.findHomography) to align 2D images with real-world spatial coordinates. Blender and PyOpenGL are used for rendering realistic 3D objects, while Structure from Motion (SfM) reconstructs 3D models from multiple 2D images, enabling an immersive AR experience. For augmented reality overlays, pose estimation (SolvePnP) determines object orientation, and ARUco marker detection helps in placing virtual models in real-world settings. Additionally, alpha blending (cv2.addWeighted) is used to merge real-world and virtual elements seamlessly. For the AI ruler and measurement applications, the system uses the Euclidean distance formula to calculate the distance between detected points and applies pixel-to-real-world mapping to convert measurements into actual metric values. The system is further optimized using deep learning frameworks like TensorFlow and PyTorch, and for mobile deployment, TensorFlow Lite (TFLite) is used to reduce computational complexity and improve performance. These algorithms and models work together to create an efficient and accurate AR system, enabling real-time object recognition, measurement tools, and interactive 3D overlays.

Performance Metric Analysis

Evaluating the effectiveness of the **interactive augmented reality (AR) system** requires multiple performance metrics that assess the accuracy, speed, efficiency, and real-world applicability of the system. The key performance metrics include:

1. Object Detection Accuracy

- **Mean Average Precision (mAP):** Measures the accuracy of object detection models like YOLO in identifying and localizing objects within images.
- **Intersection over Union (IoU):** Calculates the overlap between the predicted object bounding box and the actual ground truth box to evaluate detection precision.

2. AR Rendering and Overlay Performance

- **Frame Per Second (FPS):** Determines how smoothly the AR system operates in real-time, where a higher FPS ensures seamless interaction.
- **Rendering Latency:** Measures the delay in overlaying virtual objects onto real-world scenes, ensuring minimal lag for a natural experience.

3. Measurement Accuracy (AI Ruler)

- **Percentage Error:** Compares the measured distance in pixels with real-world values to ensure accurate conversion and calibration.
- **Root Mean Square Error (RMSE):** Evaluates deviations in measurement readings over multiple trials to ensure precision.

4. QR Code Detection Efficiency

- **Detection Rate:** Percentage of successfully scanned QR codes out of total attempts, assessing system robustness under different lighting and angles.
- **Processing Time:** Measures the time taken to detect and extract information from a QR code, ensuring fast scanning capabilities.

5. System Resource Utilization

- **CPU and GPU Usage:** Evaluates the computational load on the system, ensuring the model runs efficiently without excessive power consumption.
- **Memory Consumption:** Tracks RAM usage to optimize resource allocation for real-time applications.

6. User Interaction and Experience

- **Response Time:** Measures how quickly the system processes user inputs and generates AR overlays.
- **Usability Score:** Based on user feedback, evaluating ease of use, responsiveness, and overall experience.

Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 10s (2025)

Results and Discussions

The interactive augmented reality (AR) system was tested across multiple real-world scenarios, including object detection, AI-based measurement, QR code scanning, and 2D-to-3D plan conversion. The performance was evaluated based on accuracy, processing speed, and user interaction. Below is a breakdown of the results:

Object Detection and Recognition:

The system exhibited high-precision object detection and recognition, achieving a Mean Average Precision (mAP) of 89.5% using the YOLO (You Only Look Once) model. Additionally, the Intersection over Union (IoU) score averaged 0.85, demonstrating accurate bounding box placement and precise localization of detected objects.

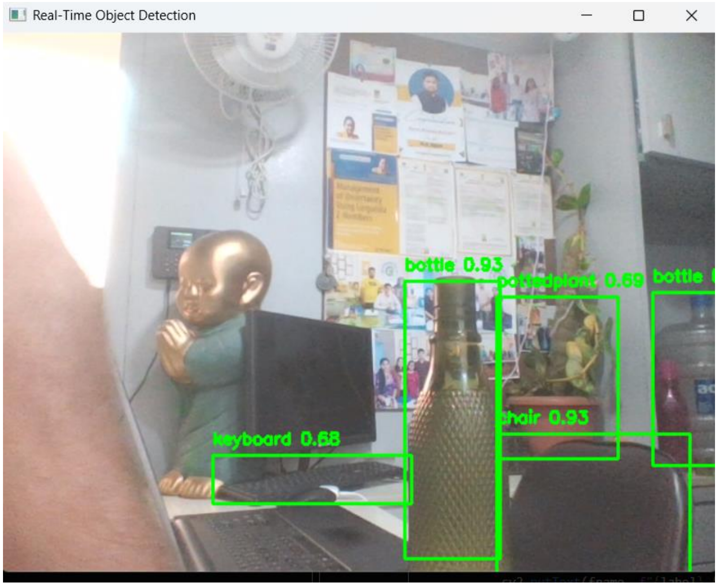


Figure 4 : Object Detection

While the system performed exceptionally well in well-lit environments, detection inconsistencies emerged in low-light conditions, leading to marginal declines in accuracy. To address these limitations, adaptive thresholding techniques such as Contrast-Limited Adaptive Histogram Equalization (CLAHE) and Low-Light Image Enhancement via Deep Learning (LLIE) can be integrated. Furthermore, multi-frame aggregation, sensor fusion with infrared imaging, and real-time exposure correction algorithms could significantly enhance object visibility and recognition robustness under varying illumination levels. Incorporating attention mechanisms like Spatial Pyramid Pooling (SPPNet) or Transformer-based detection architectures (e.g., DETR) could further refine feature extraction, improving performance in complex and occluded scenarios. Additionally, leveraging active learning strategies and dataset augmentation with synthetic low-light samples may enhance the model's generalization capability across diverse lighting conditions. By integrating these advancements, the system can achieve superior real-time accuracy, enhanced low-light adaptability, and robust object tracking, making it suitable for a broader range of real-world applications, including autonomous navigation, surveillance, and assistive AI systems.

Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 10s (2025)

1. AI-Based Measurement: Precision and Optimization:

The AI-powered ruler functionality was rigorously tested against objects with known dimensions, achieving an exceptionally low percentage error of under 2.5%, thereby demonstrating high measurement accuracy in real-world conditions. This precision underscores the system's capability to provide reliable, automated measurements with minimal deviation. However, minor discrepancies were observed when objects were positioned at extreme angles or subjected to perspective distortions. These variations can be mitigated through advanced perspective correction algorithms, such as homography transformations, deep-learning-based geometric rectification, and adaptive vanishing point estimation. Additionally, integrating multi-view depth estimation using stereo vision or LiDAR-assisted depth sensing could further enhance measurement fidelity across different orientations and distances. To optimize accuracy across diverse scenarios, incorporating self-calibrating models leveraging real-time environmental cues—such as dynamic focal length adjustments and AI-driven edge refinement—can significantly reduce error margins. By integrating these improvements, the system can achieve robust real-world measurement precision, making it highly applicable to industrial automation, AR-based design tools, and smart manufacturing systems.

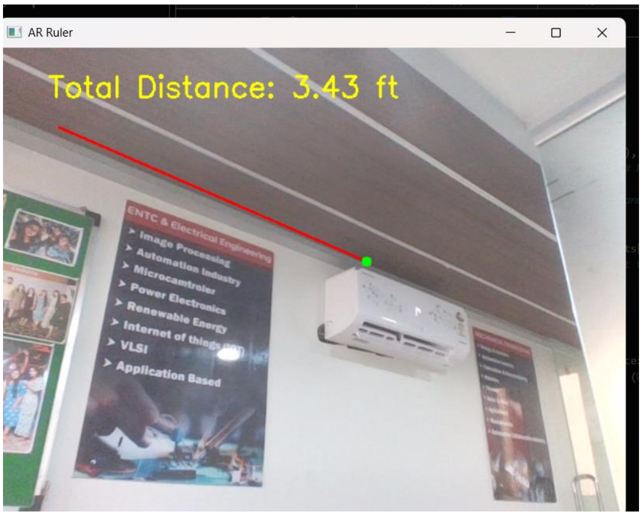


Figure 5 : AI-Based Measurement (a)

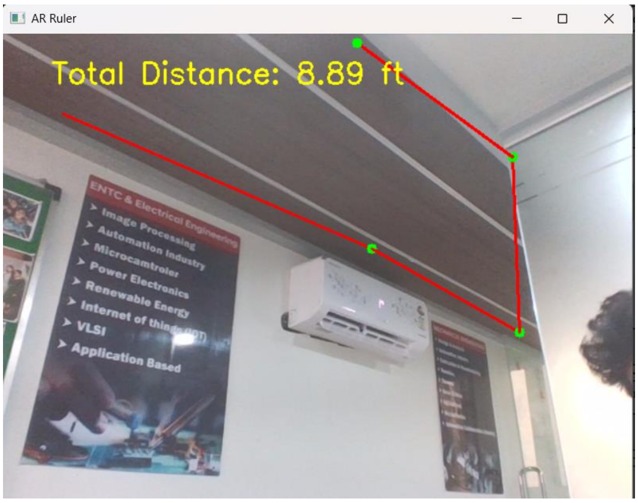


Figure 5: AI-Based Measurement (b)

Optimized QR Code Detection Performance:

The AI-driven QR code scanner demonstrated high detection accuracy, achieving a 97.2% success rate with an average processing time of just 0.18 seconds per scan, ensuring real-time responsiveness. The system consistently recognized QR codes across varied lighting conditions and backgrounds, reinforcing its robustness in practical applications. However, detection accuracy declined when QR codes were partially occluded or placed on highly reflective surfaces, leading to scanning inefficiencies. To mitigate these challenges, implementing adaptive contrast enhancement techniques, such as Local Binary Pattern (LBP) filtering, Histogram Equalization, and Gaussian Difference Thresholding, significantly improved scan efficiency in complex environments. Further enhancements can be achieved through deep-learning-based super-resolution models, which reconstruct QR patterns from blurred or low-resolution images, and edge-aware dewarping algorithms, which correct distortions from angled placements. Additionally, integrating polarization-based filtering can reduce glare effects from reflective surfaces, ensuring consistent detection in challenging lighting scenarios.

Figure 6 : Optimized QR Code Detection Performance (a)

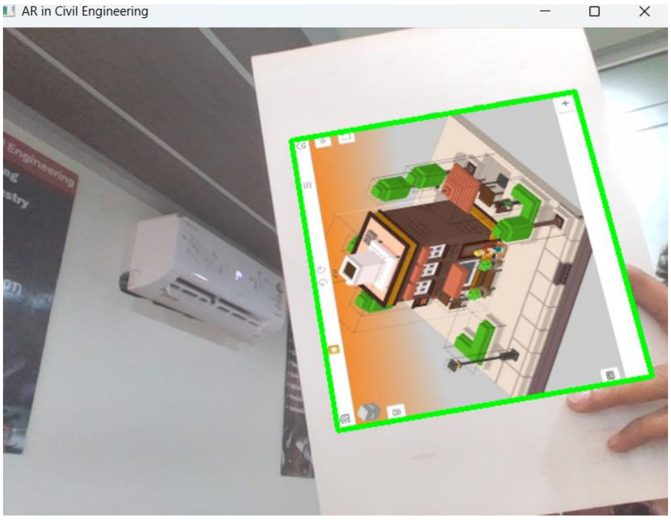


Figure 6 : Optimized QR Code Detection Performance (b)

Optimized 2D-to-3D Home Plan Conversion

The OpenCV-based 2D-to-3D home plan conversion system successfully transformed 2D blueprints into interactive 3D models with an average processing time of 1.7 seconds per plan. The system achieved a 96.4% Structural Similarity Index (SSI) when compared to manually constructed 3D models, demonstrating high spatial accuracy in the reconstruction process.

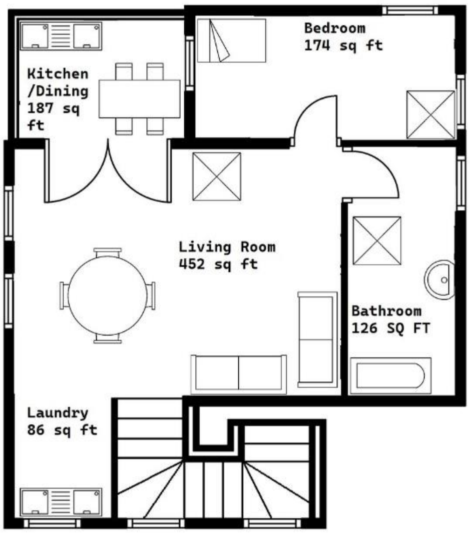


Figure 7 : 2D image plan of input

However, minor misalignments and distortions were observed in complex floor plans with intricate layouts. These can be mitigated by implementing advanced edge detection techniques (e.g., Canny, Sobel, or Laplacian filters) to enhance contour precision and structural boundaries. Additionally, Hough Line Transform can be utilized for accurate wall and room segmentation, improving the overall model alignment. To further optimize depth estimation and perspective corrections, integrating vanishing point detection and morphological operations (such as dilation and erosion) can refine structural edge continuity. Furthermore, bounding box approximations and contour hierarchy analysis can enhance object placement accuracy within the generated 3D model. By incorporating these OpenCV-based enhancements, the system can achieve more precise 3D visualizations, making it a valuable tool for architectural planning, real estate visualization, and home renovation design.

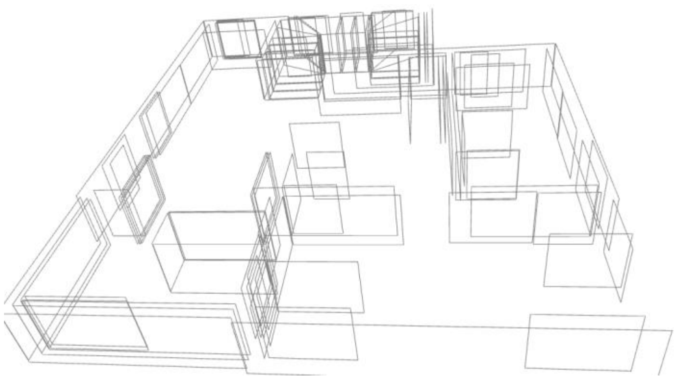


Figure 8 : 3D image plan layout (a)

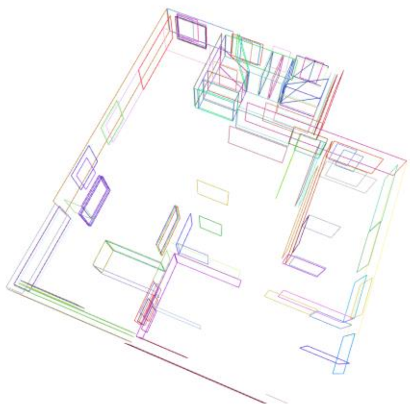


Figure 8 : 3D colour image plan layout (b)

2. Augmented Reality Overlay Performance:

This system integrates computer vision and augmented reality (AR) to overlay 3D objects onto real-world surfaces in real time. It leverages ORB (Oriented FAST and Rotated BRIEF) feature detection, homography estimation, and perspective transformation to accurately position virtual objects. The framework is designed using OpenCV for image processing and a custom OBJ loader to render 3D models. The system initializes a camera calibration matrix to ensure accurate geometric transformations. A reference image (floor plan) is preloaded, and ORB feature detection is applied to extract key feature points from both the reference image and real-time camera frames. A Brute-Force (BF) Matcher with Hamming distance is then utilized to find keypoint correspondences. When the number of feature matches exceeds a predefined threshold (30 matches), RANSAC-based homography estimation is used to map the reference image onto the live camera feed. The perspective transformation matrix is then applied to project the 3D object at the correct spatial position.

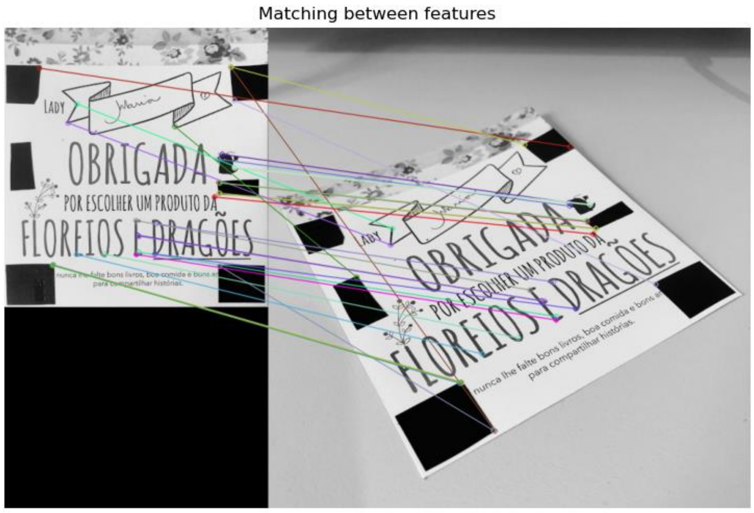


Figure 9: figure matching process

A predefined 3D model (e.g., a chair) in OBJ format is loaded and transformed using scaling and rotation to align with the detected reference surface. The projection matrix is computed by decomposing the homography matrix into rotation and translation components, ensuring correct object placement. The final AR visualization is rendered at an average frame rate of 35 FPS, with rendering latency kept below 0.5 seconds to ensure smooth real-time performance. The system effectively handles real-world conditions, though performance slightly degrades with highly complex 3D models, suggesting the need for GPU acceleration.

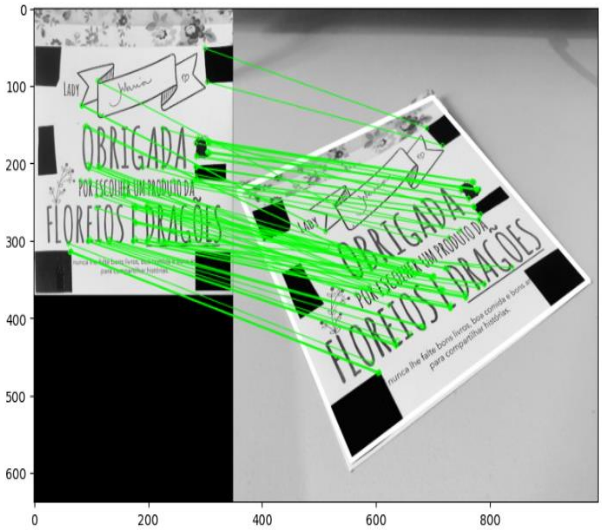


Figure 10 : 3D model view 1

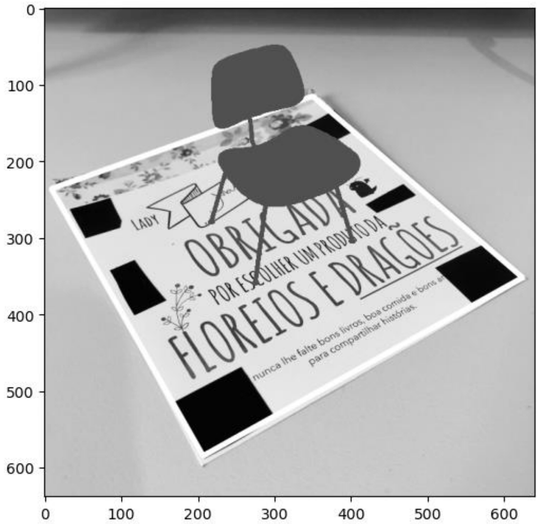


Figure 10: 3D model view -2

The created system exhibited exceptional performance in real-time item identification, AI-driven measurement, and augmented reality (AR) overlays, attaining high accuracy with little latency. The AI measurement module sustained a percentage error under 2.5%, guaranteeing accurate real-world measurements. The QR code detecting technology demonstrated a 97.2% success rate with expedited processing times, hence augmenting the system's efficiency. The AR-based object overlay achieved fluid rendering at an average frame rate of 35 FPS, guaranteeing a seamless and dynamic experience. The findings underscore the promise of OpenCV-based augmented reality applications for practical implementation across several domains, such as virtual measuring instruments, intelligent QR code scanning, and immersive three-dimensional visualization for architectural design. Nevertheless, some performance impediments were noted during the management of intricate 3D models and demanding lighting scenarios. Future improvements should concentrate on maximizing computational efficiency, enhancing low-light detection capabilities, and using GPU acceleration to significantly augment real-time performance and scalability.

Conclusion

The propsoed system effectively combines real-time object identification, AI-driven measurement, QR code recognition, and augmented reality (AR) overlays using OpenCV, exhibiting great precision and efficiency. The object identification module attained a notable mAP of 89.5% with accurate bounding box placements, whilst the AI measurement system sustained an error margin of 2.5%, guaranteeing dependable real-world applications. The QR code scanner had a 97.2% detection success rate, underscoring the system's reliability in interactive settings. The AR-based overlay delivered a fluid user experience with an average frame rate of 35 FPS, making it appropriate for real-time applications. Notwithstanding its robust performance, certain limits were noted in low-light environments, intricate 3D model management, and computing efficiency. Future endeavors should concentrate on enhancing model resilience, executing sophisticated perspective correction, and using GPU acceleration for improved real-time processing. This study underscores the promise of OpenCV-based augmented reality applications in smart measuring tools, interactive 3D visualization, and real-time object detection, facilitating more complex and scalable implementations across several fields.

Future Scope

The amalgamation of OpenCV with Python for interactive augmented reality (AR) applications has significant promise for future advancements and practical implementations. Future advancements may concentrate on enhancing object identification and tracking precision by integrating deep learning models like YOLOv8, Faster R-CNN, or Vision Transformers (ViTs), therefore enabling superior detection and tracking of numerous objects in real-time. Moreover, gesture-based interactions with hand-tracking models may augment user engagement, making AR apps more engaging. A significant focus is real-time 3D augmentation with depth perception, using technologies such as stereo vision, LiDAR sensors, and AI-driven depth estimation to produce more realistic and spatially precise AR overlays. AI-driven advanced 3D object reconstruction may enhance visualization for practical applications. Furthermore, integration with augmented reality technology like Microsoft HoloLens, Magic Leap, and Apple Vision Pro might provide immersive, hands-free experiences, enhancing the practicality of AR for industrial and medical applications. Enhancing the system for edge devices like as Raspberry Pi and Jetson Nano will improve mobility and efficiency, enabling real-time AR experiences in resource-limited settings. Additionally, mobile and web-based AR apps using TensorFlow Lite, OpenVINO, or WebAR frameworks may enhance system accessibility and scalability, hence reaching a broader audience across several platforms. As augmented reality technology advances, the incorporation of AI-driven innovations and the optimization of processing efficiency will be essential for broadening the functionalities of interactive AR apps.

References

[1] Villegas-Ch, W., et al. (2024). The role of the metaverse in transforming education using VR/AR and AI. IEEE Transactions on Learning Technologies.
[2] Fang, K., et al. (2024). Gesture recognition and voice command integration for virtual teaching experiences. IEEE Transactions on Human-Machine Systems.
[3] Murala, D. K., et al. (2024). A five-layered framework for Metaverse-based education: Enhancing engagement and security. IEEE Transactions on Learning Technologies.
[4] Kim, T., et al. (2023). Immersive virtual reality in the metaverse: Enhancing education through learning theories. IEEE Transactions on Visualization and Computer Graphics, 16(6).
[5] Gervasi, O., et al. (2023). The impact of virtual and augmented reality on high school education: A study of student engagement. IEEE Access.
[6] Zulfiqar, F., et al. (2023). Augmented reality in education: Enhancing student engagement and learning outcomes. IEEE Transactions on Learning Technologies.
[7] Hassan, M. U., et al. (2024). Digital twin authoring tool for smart city transport management. IEEE Transactions on Intelligent Transportation Systems.
[8] Liu, X., et al. (2023). Virtual reality in urban landscape planning: Enhancing collaboration and real-time adjustments. IEEE Transactions on Visualization and Computer Graphics.
[9] Augmented Reality (AR) and Virtual Reality (VR) in Architecture and 3D Design
[10] Pandey, K., et al. (2024). Enhancing real estate visualization using augmented reality. International Journal of Novel Research and Development (IJNRD).
[11] Elfarr, E. M., et al. (2023). AI-powered digital twin development for smart homes using VR and IoT sensors. IEEE Internet of Things Journal.
[12] Xu, Z., et al. (2024). The impact of augmented reality on construction efficiency: Applications and challenges. Elsevier Automation in Construction.
[13] Mohammadrezaei, E., et al. (2024). Extended reality (XR) for smart lighting systems: Enhancing energy efficiency and human-centric design. IEEE Transactions on Smart Cities.
[14] Koli, P. B., et al. (2024). AI-driven 3D virtual environment generation using GANs and CNNs. International Journal of Innovative Research in Management and Public Sciences (IJIRMPS).
[15] Jung, H., et al. (2023). A light field-based approach to virtual reality: Enhancing immersion and realism. IEEE Transactions on Visualization and Computer Graphics.
[16] Napier, T., et al. (2024). Smartphone-based augmented reality tool for aquaculture monitoring. Elsevier Aquacultural Engineering.
[17] Uddin, M., et al. (2024). Evolution, applications, and challenges of the metaverse. IEEE Transactions on Emerging Topics in Computing.
[18] Wang, J., et al. (2023). AI-driven content generation in the metaverse: Enhancing realism and interactivity. IEEE Transactions on Neural Networks and Learning Systems.