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Full Length Article

Computer Vision-Based Signal Processing For Gesture- Controlled Air Canvas

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Abstract
Human–Computer Interaction (HCI) is rapidly evolving towards touchless and intuitive systems. This project presents a Computer Vision-Based Signal Processing approach for a Gesture-Controlled Air Canvas, enabling users to interact with a computer using hand gestures without physical input devices.
The system uses a webcam to capture real-time video input and processes it using computer vision techniques. MediaPipe is employed for accurate hand detection and tracking of 21 hand landmarks, while OpenCV is used for image processing and visualization. Signal processing techniques such as noise reduction and smoothing are applied to improve the stability and accuracy of hand movement tracking.
Based on detected gestures, the system allows users to draw, erase, and select colors on a virtual canvas. The fingertip position is tracked continuously to create smooth and natural drawing strokes in real time.
This project provides a low-cost, efficient, and user-friendly solution for touchless interaction. It has potential applications in smart classrooms, virtual presentations, accessibility systems, and human-computer interaction interfaces.

Keywords— *Human–Computer Interaction (HCI), Computer Vision, Gesture Recognition, Air Canvas, Signal Processing, MediaPipe, OpenCV, Hand Landmark Detection, Touchless Interaction, Real-Time Image Processing.*

Introduction

Human–Computer Interaction (HCI) is continuously evolving from traditional input devices such as keyboards and mice toward more natural and touchless interaction systems. With the advancement of computer vision and signal processing techniques, it is now possible to interact with digital systems using simple hand gestures. This project focuses on the development of a Gesture-Controlled Air Canvas using computer vision. The system enables users to draw or write in the air without the need for physical tools like a mouse, stylus, or touchscreen. A webcam is used to capture real-time video input, which is then processed to detect and track hand movements.

Using MediaPipe, the system identifies hand landmarks and tracks fingertip positions accurately. OpenCV is used for image processing and rendering the drawing on a virtual canvas. Signal processing techniques are applied to reduce noise and ensure smooth and stable tracking of hand movements. The Air Canvas system provides an intuitive and user-friendly interface that enhances the overall interaction experience. It has wide applications in smart classrooms, virtual presentations, accessibility tools, and touchless systems, especially in situations where physical interaction is limited.

Literature Survey

Numerous researchers have made significant contributions to the field of gesture recognition by utilizing computer vision and signal processing techniques to enhance human–computer interaction. The pioneering work of **R. C. Gonzalez and R. E. Woods** established the fundamental principles of digital image processing, including image enhancement, segmentation, and feature extraction. These concepts continue to serve as the foundation for modern gesture recognition systems by improving image quality, reducing noise, and enabling accurate hand detection.

In the area of digital signal processing, **S. K. Mitra** introduced various filtering and smoothing techniques that are widely used to minimize noise and improve signal quality. These methods are particularly important in gesture recognition applications, where stable hand tracking and smooth motion analysis are essential for achieving reliable real-time performance.

Advancements in computer vision have led to the development of efficient real-time gesture recognition systems. **Hossain S. and Rahman M. (2021)** proposed a hand gesture recognition framework based on OpenCV and MediaPipe. Their approach demonstrated that accurate hand detection and landmark tracking could be achieved using a standard webcam without requiring additional hardware, making gesture-based interaction more practical and cost-effective.

Similarly, **Huang et al. (2016)** presented a computer vision-based pointing gesture recognition system that emphasized accurate fingertip localization and hand motion tracking. Their research showed that precise fingertip detection plays a vital role in applications such as virtual interaction, object manipulation, and touchless control interfaces.

Earlier gesture recognition methods primarily relied on conventional image processing techniques, including RGB color segmentation and contour-based hand detection. Although these approaches were simple to implement and computationally efficient, they were highly sensitive to variations in lighting conditions, complex backgrounds, and changes in skin color, which often reduced their recognition accuracy. To overcome these limitations, researchers introduced alternative color models such as **HSV** and **YCbCr**, which provide better separation between skin regions and the background under different illumination conditions. In addition, feature extraction methods including contour analysis, convex hull computation, convexity defect analysis, and morphological image processing were employed to improve hand shape representation and fingertip identification, resulting in more reliable gesture recognition.

Overall, existing studies have significantly advanced gesture recognition technology by improving detection accuracy, computational efficiency, and user interaction. Building upon these developments, the proposed Gesture-Controlled Air Canvas integrates MediaPipe, OpenCV, and signal processing techniques to develop a real-time, cost-effective, and user-friendly touchless interaction system that offers improved accuracy, responsiveness, and ease of use.

Existing and Proposed Methods

Existing Methods

Gesture recognition systems reported in the literature employ different technologies to capture, analyze, and interpret human hand movements. These techniques can generally be categorized into camera-based systems, wearable device-based systems, and sensor-assisted approaches.

Camera-based gesture recognition systems use either two-dimensional or three-dimensional imaging techniques to acquire visual information about hand movements. Image processing algorithms are subsequently applied to detect hand regions, extract relevant features, and recognize gestures. Such systems have been successfully deployed in applications including virtual reality, gaming, medical rehabilitation, and interactive educational environments. However, their performance is often affected by illumination changes, background complexity, camera resolution, and hand occlusions, resulting in reduced recognition accuracy under uncontrolled conditions.

Wearable gesture recognition systems utilize motion sensors such as accelerometers, gyroscopes, flex sensors, and inertial measurement units integrated into gloves, wristbands, rings, or similar wearable devices. Another category includes infrared and radar-based gesture recognition systems, which employ specialized sensors to capture depth information and detect hand motion independently of visible lighting conditions. These systems achieve reliable performance even in challenging environments and provide accurate three-dimensional gesture analysis. Nevertheless, their deployment is often limited by expensive hardware, complex installation procedures, and increased computational requirements.Despite continuous improvements in gesture recognition technologies, existing systems still exhibit several practical limitations. Many vision-based methods remain sensitive to illumination changes and cluttered backgrounds, whereas wearable and sensor-based solutions require additional hardware that increases system complexity and cost. Furthermore, some advanced recognition algorithms demand substantial computational resources, limiting their applicability in lightweight real-time systems. These challenges emphasize the need for a cost-effective, hardware-independent, and user-friendly gesture recognition framework capable of delivering reliable real-time performance.

Proposed Method

The proposed system presents a Computer Vision-Based Gesture-Controlled Air Canvas designed to facilitate intuitive and contactless human–computer interaction. The system enables users to draw, erase, and perform interface operations through simple hand gestures without relying on conventional input devices or wearable sensors. A standard webcam continuously captures live video, while computer vision and signal processing techniques process the incoming frames to recognize hand movements in real time.

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The overall methodology consists of four sequential stages. The first stage involves image acquisition, where the webcam continuously captures live video frames that serve as the input to the recognition system. Continuous frame acquisition ensures smooth monitoring of hand movements throughout the interaction process.

The second stage performs image preprocessing to enhance frame quality before gesture analysis. Noise reduction, image smoothing, and color space conversion are applied to improve visual clarity and minimize the effects of illumination variations and background interference. These preprocessing operations simplify hand segmentation and increase the robustness of subsequent detection procedures.

In the final stage, recognized gestures are mapped to predefined application functions, including drawing, erasing, and color selection on a virtual canvas. OpenCV is employed to render the drawing output, visualize fingertip trajectories, and merge the virtual canvas with the live camera feed, thereby providing an interactive real-time user experience. Continuous tracking of fingertip coordinates produces smooth drawing strokes that closely resemble conventional handwriting or sketching.

By eliminating the requirement for wearable devices, infrared sensors, or specialized hardware, the proposed system provides a low-cost and practical solution for touchless interaction. The integration of MediaPipe with OpenCV enables accurate hand landmark estimation, efficient gesture recognition, and responsive virtual drawing while maintaining computational efficiency suitable for real-time applications.

Block Diagram

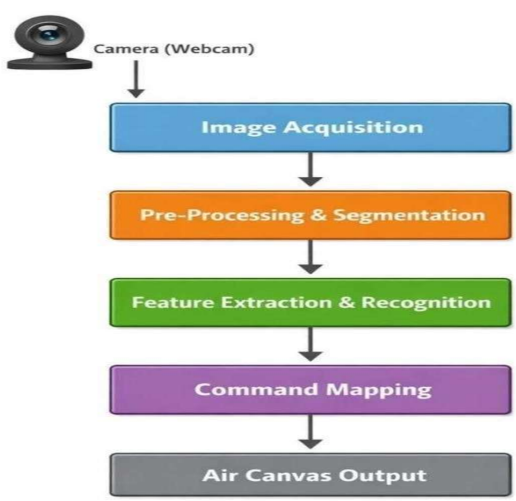

Fig 1: Block Diagram of Gesture-Controlled Air Canvas System

Camera (Webcam)

The system uses a standard webcam as the primary input device to capture continuous video of the user's hand movements. Live video frames acquired from the camera serve as the input for the gesture recognition pipeline. The quality and continuity of these frames are essential for achieving reliable hand tracking and smooth system performance.

Image Acquisition

The captured video stream is divided into individual frames, which are processed sequentially. Each frame represents the current position of the user's hand and is forwarded to the subsequent processing stages. Continuous frame acquisition enables the system to monitor hand movements in real time and respond immediately to changes in gesture patterns.

Pre-processing and Segmentation

The acquired frames are subjected to image preprocessing to improve visual quality before gesture analysis. Noise filtering and image smoothing are applied to suppress unwanted disturbances, while color space conversion from BGR to RGB or HSV enhances the visibility of the hand region. Image segmentation is then performed to separate the hand from the surrounding background, thereby reducing the influence of irrelevant objects and improving detection accuracy.

Feature Extraction and Gesture Recognition

Feature extraction is performed using the MediaPipe Hand Landmark model, which estimates twenty-one anatomical landmarks corresponding to the fingertips, finger joints, and palm. These landmarks provide accurate spatial information regarding finger positions and orientations. Based on the relative positions of these landmarks, the system identifies user gestures such as drawing mode, color selection mode, and other predefined control commands.

Command Mapping

After a gesture has been recognized, it is translated into a corresponding application command. For example, when only the index finger is extended, the system activates drawing mode. When both the index and middle fingers are detected, the application switches to color selection mode. The fingertip coordinates are continuously tracked, and successive points are connected to generate smooth and natural drawing strokes on the virtual canvas.

Air Canvas Output

The final output is displayed on a virtual canvas generated using OpenCV. The rendered drawing is superimposed on the live video stream, allowing users to observe both their hand movements and the corresponding drawing simultaneously. This integration creates an intuitive, responsive, and interactive touchless drawing environment.

Working Methodology

The proposed Gesture-Controlled Air Canvas operates through a sequence of image processing and gesture recognition stages that transform hand movements into digital drawing actions. Initially, a webcam continuously captures live video of the user's hand and transfers the captured frames to the processing module for analysis.

Each acquired frame undergoes preprocessing to improve image quality before further analysis. Image smoothing and noise reduction techniques are employed to eliminate unwanted artifacts, while color space conversion enhances the visibility of the hand region under different illumination conditions. These preprocessing operations facilitate accurate segmentation of the hand from the surrounding background.

Following preprocessing, the MediaPipe framework detects twenty-one hand landmarks representing the fingertips, finger joints, and palm structure. These landmark coordinates provide detailed spatial information that enables precise tracking of finger movements. The extracted landmarks are subsequently analyzed to determine the gesture performed by the user.

Once the gesture has been identified, the recognition module associates it with a predefined application command. For instance, extending only the index finger activates the drawing mode, whereas extending both the index and middle fingers enables color selection. During drawing mode, the system continuously records fingertip coordinates and connects consecutive positions to generate smooth drawing trajectories on the virtual canvas.

Finally, OpenCV renders the generated drawing and merges it with the live video feed. This allows users to observe their hand movements together with the corresponding graphical output in real time, resulting in an efficient, intuitive, and contactless Human–Computer Interaction environment.

Flowchart

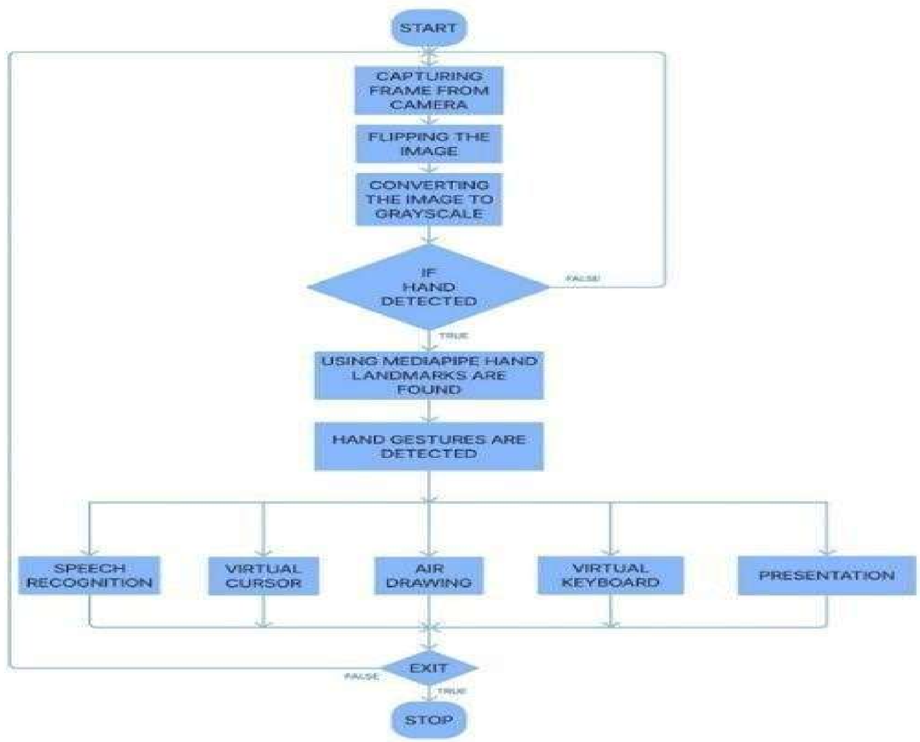

Figure 2; Flowchart of Gesture-Controlled Air Canvas System

The flowchart of the proposed Gesture-Controlled Air Canvas illustrates the logical sequence of operations performed during system execution. The process begins with webcam initialization and continuous image acquisition, followed by image preprocessing to improve frame quality. The preprocessed frames are analyzed using the MediaPipe Hand Landmark model to detect the position of the user's hand and identify fingertip locations.

The extracted landmarks are examined to determine the current gesture based on predefined finger position rules. After successful gesture recognition, the corresponding command is executed, such as enabling drawing mode, selecting a drawing color, or erasing previously drawn content. The detected fingertip trajectory is then rendered on a virtual canvas using OpenCV, and the generated output is displayed together with the live camera feed.

This processing sequence is repeated continuously until the user terminates the application, thereby enabling seamless real-time gesture recognition and touchless drawing throughout the interaction session.

Results

The proposed Gesture-Controlled Air Canvas was implemented and tested using a standard laptop equipped with an integrated webcam. The experimental environment was configured to evaluate the system under typical indoor operating conditions while ensuring consistent illumination for reliable hand detection.

Hardware Configuration

- Laptop with an integrated webcam (720p/1080p resolution)
- Intel Core i5/i7 Processor (or equivalent)
- Minimum 8 GB RAM

Software Configuration

- Python Programming Language
- OpenCV Library
- MediaPipe Framework
- TensorFlow (for hand tracking support)
- NumPy

Experimental Environment

The experiments were conducted in a controlled indoor environment with moderate and uniform lighting conditions. During testing, users maintained a distance ranging from **0.5 m to 1.0 m** from the webcam to ensure accurate hand landmark detection and stable gesture recognition. Multiple gesture samples were recorded to evaluate system consistency and real-time performance.

Experimental Results

The effectiveness of the proposed system was assessed by evaluating the recognition accuracy of commonly used hand gestures. Multiple trials were conducted for each gesture under identical environmental conditions, and the average recognition accuracy was calculated.

Gesture Recognition Accuracy

Gesture Type	Recognition Accuracy (%)
Open Palm	95
Closed Fist	93
Two Fingers (V)	91
Thumb Up	89

The experimental results indicate that the proposed system achieved high recognition accuracy for all tested gestures. The **Open Palm** gesture recorded the highest accuracy of **95%**, primarily due to its distinct hand configuration and clear landmark visibility. The **Closed Fist** gesture achieved an accuracy of **93%**, demonstrating reliable recognition under normal operating conditions. Recognition accuracy for the **Two Fingers (V)** gesture reached **91%**, while the **Thumb Up** gesture achieved **89%**, where slight reductions in accuracy were mainly attributed to variations in thumb orientation and partial landmark occlusions during real-time interaction.

Overall, the obtained results demonstrate that the MediaPipe hand landmark model provides robust and reliable gesture detection suitable for touchless Human–Computer Interaction applications.

System Output

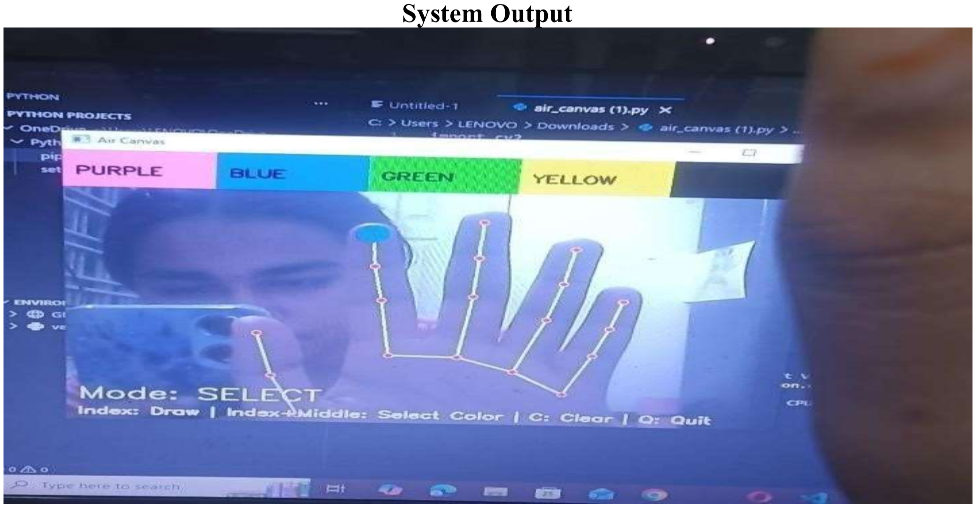

Fig 3; Output Showing Selection of Colors Using Hand Gesture in Air Canvas

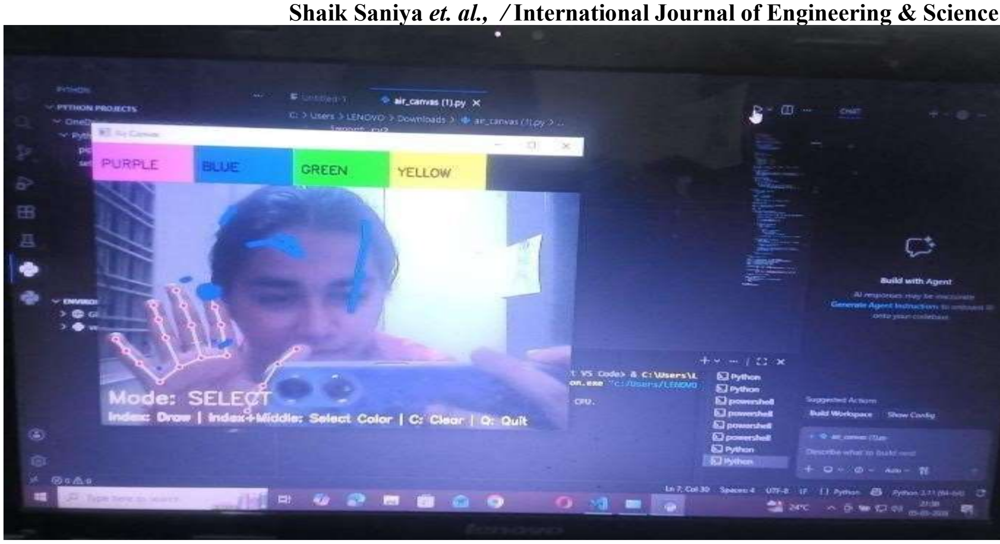

Fig 4; Output Showing Drawing Using Hand Gesture in Air Canvas

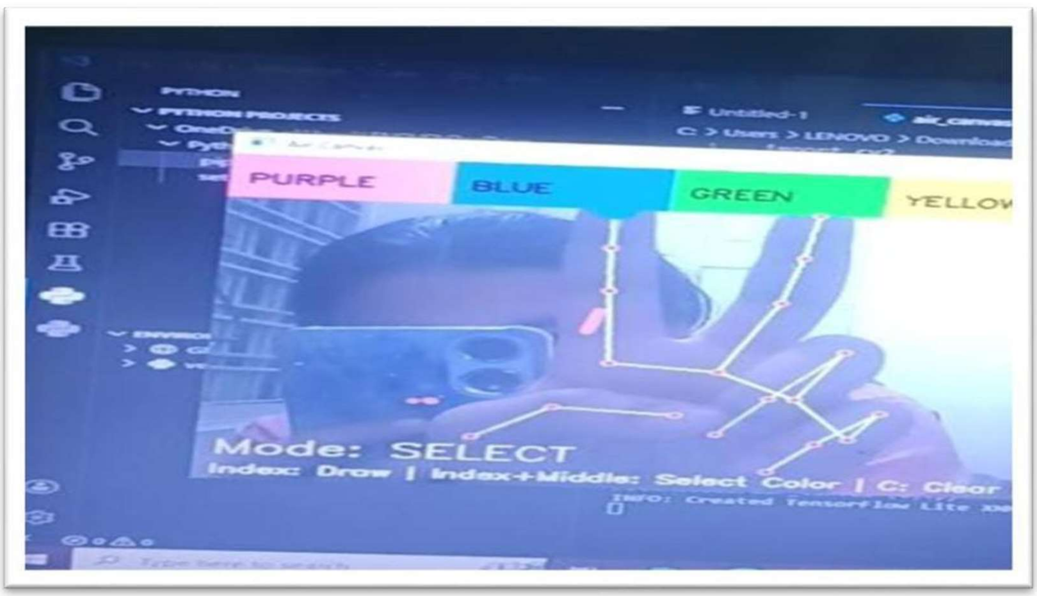

Fig 5; Output Showing Hand Landmark Detection and Gesture Recognition

Conclusion and Future Scope

Conclusion

This research presented a Computer Vision-Based Gesture-Controlled Air Canvas that enables touchless human–computer interaction through real-time hand gesture recognition. The proposed system integrates computer vision, image processing, and signal processing techniques with the MediaPipe hand landmark detection framework and OpenCV library to recognize hand gestures and translate them into interactive drawing commands. By utilizing a standard webcam as the only input device, the system eliminates the need for conventional peripherals such as a mouse, stylus, or touchscreen, thereby providing a cost-effective and user-friendly interaction platform.

Experimental evaluation demonstrated that the proposed system achieves reliable gesture recognition with high accuracy and low processing latency under controlled indoor conditions. The integration of image preprocessing, hand landmark extraction, and real-time gesture interpretation enabled smooth virtual drawing and responsive system performance. These results indicate that the proposed framework can effectively support touchless interaction while maintaining computational efficiency suitable for real-time applications.

Compared with traditional input methods, the proposed Air Canvas offers a more natural, intuitive, and hygienic interaction experience. The system has potential applications in smart classrooms, virtual presentations, digital education, accessibility technologies, healthcare environments, and interactive design systems. Although the proposed framework performs effectively under normal operating conditions, its performance may be affected by challenging lighting environments, complex backgrounds, and partial hand occlusions. Nevertheless, the study demonstrates the feasibility of developing an efficient and practical gesture-controlled interface using widely available computer vision technologies.

Future Scope

The proposed Gesture-Controlled Air Canvas provides a strong foundation for future research in vision-based Human–Computer Interaction. One possible extension involves incorporating advanced deep learning models to improve gesture recognition accuracy, robustness, and adaptability under diverse environmental conditions. Deep neural networks can enhance the system's ability to recognize complex hand configurations while maintaining reliable performance under varying illumination and background scenarios. Future versions of the system may also support dynamic gesture recognition and simultaneous tracking of multiple hands, enabling more sophisticated interaction techniques for collaborative applications. The integration of adaptive gesture learning and user-specific customization could further improve recognition accuracy by accommodating variations in individual hand shapes and movement patterns.

Another promising direction involves integrating the proposed framework with Internet of Things (IoT) platforms to enable gesture-based control of smart home appliances, industrial automation systems, and intelligent assistive technologies. In addition, combining the Air Canvas with Augmented Reality (AR) and Virtual Reality (VR) environments would enable immersive, touchless interaction for education, healthcare, gaming, engineering design, and remote collaboration.

Further research may also focus on improving system performance under low-light conditions through advanced image enhancement techniques, optimizing computational efficiency for deployment on embedded platforms, and extending the framework to support three-dimensional gesture recognition. These enhancements would improve the practicality, scalability, and applicability of the proposed system, making it suitable for a wider range of real-world Human–Computer Interaction applications.

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