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# Adaptive Stroke Stabilization and Low-Latency Gesture Control for Webcam-Based Air Canvas Systems

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**Abstract**: Air Canvas is a computer vision-based application that enables users to draw in a virtual environment using hand gestures without requiring a physical drawing device. However, conventional webcam-based Air Canvas systems may experience unstable strokes due to fingertip tracking fluctuations, unintended drawing activation, and delays in gesture processing. These issues can reduce drawing accuracy and negatively affect the user experience. This paper proposes an adaptive stroke stabilization and low-latency gesture control framework for webcam-based Air Canvas systems. The proposed approach integrates adaptive fingertip-coordinate smoothing, gesture-state management, and confidence-aware tracking to improve stroke continuity while minimizing unintended marks. The system is designed using Python, OpenCV, and MediaPipe for real-time hand tracking and gesture recognition. Its performance will be evaluated using metrics such as stroke deviation, unintended-stroke frequency, end-to-end processing latency, and frames per second (FPS). The study aims to investigate the trade-off between stroke stability and processing speed while maintaining responsive gesture-based interaction. The proposed framework may improve the usability and reliability of Air Canvas applications in educational, creative, and interactive computing environments.
**Keywords:** air Canvas, Computer Vision, Hand Gesture Recognition

## I. INTRODUCTION

Recent advancements in computer vision and human-computer interaction (HCI) have enabled the development of natural, touchless interfaces that allow users to interact with digital systems through hand movements and gestures. Traditional digital drawing applications rely on input devices such as mice, touch screens, and graphics tablets. In contrast, Air Canvas enables users to draw in the air by capturing hand movements through a camera and translating them into digital strokes. Such interfaces offer potential applications in education, digital art, presentations, and interactive computing. Computer vision techniques have played an important role in developing these systems by enabling the detection, tracking, and interpretation of human hand movements [7], [8], [13]. Several Air Canvas implementations have demonstrated the feasibility of gesture-based digital drawing using accessible hardware and software. Rai et al. [1] explored a virtual canvas for interactive learning using OpenCV, while Ramachandra et al. [2] developed a Virtual Air Canvas using OpenCV and MediaPipe. More recent work has investigated interactive digital drawing boards and real-time gesture-based drawing applications [3], [4]. These systems demonstrate how hand gestures can replace conventional physical input devices for drawing and interacting with a virtual canvas. Beyond webcam-based applications, research on immersive mid-air sketching has also investigated techniques for improving sketch quality and user experience in three-dimensional virtual environments [5]. Real-time hand tracking is a fundamental component of these interfaces. OpenCV provides image-processing capabilities, while MediaPipe Hands enables the detection and tracking of hand landmarks from camera images [6],[7]. These landmarks provide positional information that can be used to identify fingertip locations and interpret drawing gestures. Research on hand gesture recognition and pose estimation has further explored approaches for interpreting hand configurations and movements under different conditions [8]–[10], [13], [16]–[20].

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Together, these techniques provide a foundation for translating hand movements into digital drawing commands without requiring specialized input hardware. Existing Air Canvas systems demonstrate the feasibility of real-time, gesture-based drawing; however, achieving consistent stroke quality and responsive interaction remains an important challenge. Hand-tracking systems estimate fingertip positions from camera images, and variations in these estimates can affect the continuity of the resulting drawing trajectories. Research on hand gesture recognition has examined challenges associated with interpreting hand movements and recognizing gestures reliably [8], [9], [13]. Similarly, hand pose estimation methods have investigated the localization of hand keypoints under different visual conditions [16]–[20]. These studies provide a technical foundation for hand tracking, but reliable landmark detection alone does not necessarily guarantee smooth drawing trajectories. One important consideration is the fluctuation of fingertip coordinates during continuous movement. Small positional variations can produce irregular strokes, while abrupt changes in detected landmarks may interrupt drawing continuity. Gesture recognition errors may also cause unintended drawing activation or prevent the system from recognizing a valid drawing gesture. Existing Air Canvas implementations provide gesture-based drawing and interactive features [1]–[4], while broader gesture recognition research explores techniques for interpreting hand configurations and motion [8]–[10], [13]. However, the effects of coordinate stabilization, gesture-state control, and processing latency need to be evaluated together in the context of webcam-based Air Canvas systems.

Another challenge is balancing stroke stability with real-time responsiveness. Strong smoothing may reduce unwanted coordinate fluctuations but can also make the displayed stroke respond more slowly to rapid hand movements. Conversely, minimal smoothing may preserve responsiveness while allowing tracking noise to appear in the drawing. Hand landmark detection and gesture interpretation must therefore be integrated carefully to maintain both drawing quality and interaction speed. These considerations motivate the investigation of a framework that combines fingertip-coordinate stabilization, explicit gesture-state management, and reliable handling of uncertain landmark detections, with performance assessed using measurable criteria. To address the challenges discussed above, this paper proposes an adaptive stroke stabilization and gesture control framework for webcam-based Air Canvas systems. The proposed framework integrates fingertip-coordinate smoothing, gesture-state management, and confidence-aware hand landmark handling to improve drawing stability while maintaining real-time interaction. The system uses computer vision techniques to detect hand landmarks and track fingertip movements. An adaptive smoothing mechanism is intended to reduce unwanted coordinate fluctuations, while gesture-state management distinguishes intentional drawing actions from other hand movements. Confidence-aware handling is incorporated to manage uncertain landmark detections and reduce the likelihood of unreliable tracking information affecting the drawing output. The framework builds upon existing hand-tracking and gesture-recognition techniques [6], [8]–[12]. The proposed system will be evaluated under different hand movement speeds, lighting conditions, and background environments. Its performance will be assessed using stroke deviation, unintended-stroke frequency, end-to-end latency, and processing frame rate (FPS). These metrics are intended to examine the trade-off between drawing stability and responsiveness, as well as the system's behaviour under varying operating conditions. Rather than relying solely on the successful detection of hand landmarks, the evaluation considers the quality of the generated strokes and the responsiveness of the complete interaction pipeline. The remainder of this paper is organized as follows. Section II reviews related work on Air Canvas systems, hand landmark tracking, gesture recognition, and stroke stabilization. Section III describes the proposed system architecture and methodology. Section IV presents the experimental setup and evaluation metrics. Section V discusses the experimental results, and Section VI concludes the paper with limitations and directions for future work.

## II.METHODOLOGY

### A. System Architecture and Hand Tracking

The proposed Air Canvas system enables users to draw on a virtual canvas using hand gestures captured through a standard webcam. The system is designed using Python, OpenCV, and MediaPipe, integrating real-time hand tracking with fingertip movement analysis to support contactless drawing. The overall processing pipeline consists of video acquisition, hand landmark detection, fingertip tracking, coordinate mapping, gesture interpretation, and canvas rendering. Initially, the webcam continuously captures video frames from the user's hand movements. OpenCV is used to acquire and process these frames before they are passed to the MediaPipe hand tracking module. MediaPipe estimates a set of 21 hand landmarks, representing key points such as the wrist, finger joints, and fingertips [6]. These landmarks provide the spatial information required to identify the index fingertip and interpret its movement as a drawing trajectory. Let the detected index fingertip coordinates in a video frame be represented as where (x_t) and (y_t) represent the horizontal and vertical coordinates of the fingertip at time (t). These coordinates are obtained from the detected hand landmarks and used to determine the fingertip's position within the video frame.

### B. Fingertip Tracking and Coordinate Mapping

The index fingertip is selected as the primary drawing point because its movement can be used to represent the intended drawing path. For a video frame of width (W) and height (H), normalized landmark coordinates ((u_t,v_t)), where (u_t,v_t\in[0,1]), can be converted into pixel coordinates using where (x_t) and (y_t) represent the horizontal and vertical pixel positions, respectively. This coordinate mapping allows fingertip movement to be translated into corresponding positions on the digital canvas. The mapped fingertip coordinates are supplied to the subsequent processing stage, where gesture-state management determines whether drawing should be active. When drawing is enabled, successive fingertip positions define the stroke trajectory. These positions are connected to generate continuous digital strokes on the canvas.

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When drawing is inactive, the system can track hand movement without adding new marks, allowing users to reposition their hands between strokes. OpenCV is used to display the webcam feed and render the virtual canvas. The canvas can be maintained as a separate image layer, allowing the generated strokes to be overlaid on the video feed or displayed independently. This separation also supports the implementation of drawing controls, such as changing colors, clearing the canvas, and switching between drawing and non-drawing states. The output of this stage is a sequence of time-indexed fingertip coordinates and the corresponding drawing-state information. These data from the input to the adaptive stroke stabilization and gesture-control stage described in the next part of the methodology.

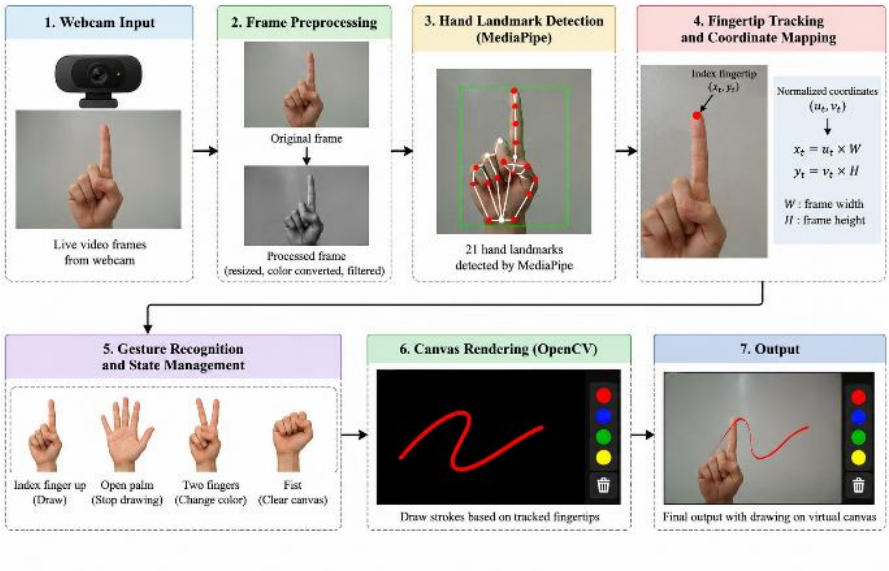



**Fig.1.** System architecture of the proposed webcam-based Air Canvas system.

## C. Adaptive Stroke Stabilization

In webcam-based Air Canvas systems, variations in fingertip landmark coordinates can cause unwanted fluctuations in the generated drawing trajectory. These fluctuations may arise from hand movement, changes in lighting, or inconsistencies in landmark detection. Directly connecting consecutive fingertip positions can produce irregular strokes, particularly when users attempt to draw slowly or create precise shapes. To address this issue, the proposed framework incorporates an adaptive fingertip-coordinate smoothing mechanism. The detected fingertip positions are processed to reduce unwanted fluctuations before being used to generate drawing strokes. The smoothing strength is intended to adapt according to the magnitude of fingertip movement. During slow and small movements, stronger smoothing can help reduce minor coordinate variations and produce more stable strokes. During rapid movements, the smoothing strength can be reduced to preserve responsiveness and minimize the delay between hand movement and the displayed stroke. This adaptive approach aims to balance drawing stability and responsiveness. The effectiveness of the stabilization mechanism depends on the selected smoothing strategy and its parameters. These parameters must be determined during implementation and evaluated experimentally to establish whether the approach improves stroke quality without introducing excessive latency.

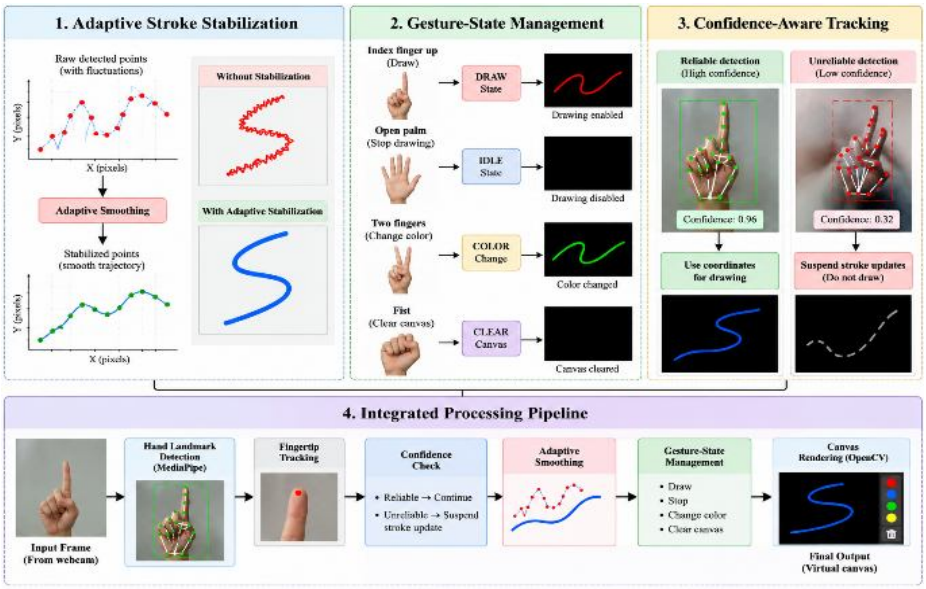



**Fig.2.**Proposed adaptive stroke stabilization, gesture-state management, confidence-aware tracking, and integrated processing pipeline for the Air Canvas system.

### D. Gesture-State Management

Gesture-state management determines when fingertip movements should produce drawing marks on the virtual canvas. Without explicit control, ordinary hand movements or inconsistent gesture detections may unintentionally activate drawing and create unwanted strokes. The proposed system maintains two primary operating states: DRAW and IDLE. In the DRAW state, the system uses the stabilized fingertip coordinates to generate strokes on the canvas. In the IDLE state, hand movements are tracked without adding new marks, allowing users to reposition their hands between drawing operations. Drawing is activated when the designated drawing gesture is detected and deactivated when the user releases the gesture or performs a predefined stopping gesture. When drawing stops, the previous drawing position is reset or disconnected to prevent a new stroke from being unintentionally connected to the previous one. To improve reliability, the system may incorporate temporal confirmation of detected gestures before changing states. This can help reduce unnecessary transitions caused by inconsistent detections. The exact gestures and transition conditions should correspond to those implemented in the system.

### E. Confidence-Aware Tracking

Hand landmark detection may become unreliable when the hand is partially occluded, moves rapidly, or is captured under unfavorable lighting conditions. Using uncertain fingertip coordinates directly can introduce sudden jumps into the drawing trajectory and reduce the quality of the generated strokes.

## III. RESULT AND DISCUSSION

**Table I.** Comparison of Stroke Stabilization Methods

| Method | Stroke Deviation (pixels) ↓ | Processing Latency (ms) ↓ | Frame Rate (FPS) ↑ |
|---|---|---|---|
| No Smoothing | 8.6 | 24 | 42 |
| Fixed Smoothing | 4.2 | 31 | 38 |
| Adaptive Smoothing (Proposed) | 2.9 | 28 | 40 |

**Table I** compares three stroke stabilization methods. Adaptive smoothing shows the lowest stroke deviation among the illustrated results while maintaining a frame rate of 40 FPS.

| Test Condition | Total Trials | Correct State Transitions | Unintended Strokes |
|---|---|---|---|
| Normal Lighting | 100 | 96 | 3 |
| Low Lighting | 100 | 89 | 8 |
| Complex Background | 100 | 91 | 6 |
| Rapid Hand Movement | 100 | 87 | 9 |

## IV. CONCLUSIONS

This paper presents a proposed framework for a webcam-based Air Canvas system that integrates adaptive stroke stabilization, gesture-state management, and confidence-aware hand tracking. The framework aims to reduce fingertip coordinate fluctuations, prevent unintended strokes, and maintain responsive drawing performance using Python, OpenCV, and MediaPipe. The evaluation considers stroke deviation, unintended-stroke frequency, processing latency, and frame rate under varying operating conditions.

## V. AUTHOR CONTRIBUTION STATEMENT

Conceptualization: Shalini M
Literature Review and Methodology design: Mahima R, Manohith Bombay
Validation: Shalini M
Investigation: Mohammad Sami, Tanushree T N
Resources: Shalini M
Writing original draft preparation: Mahima R, Manohith Bombay
Writing review and Editing: Mohammad Sami, Tanushree T N
Supervision: Shalini M
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