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Real Time Hand Gesture Detection For Mathematical Calculation

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ABSTRACT In recent years, the demand for natural and contactless modes of human-computer interaction has grown significantly, particularly in response to advancements in computer vision and gesture recognition. Air-writing - an approach that involves writing characters or symbols in free space using finger movements- offers a novel, hygienic, and intuitive method of user input without the need for physical devices. This paper introduces an air-writing calculator that allows users to perform basic mathematical operations by simply drawing expressions in the air. Utilizing real-time hand tracking and fingertip detection, the system accurately captures the trajectory of the index finger to form digits and operators. Once the input gesture is completed, the trajectory is rendered into an image and classified using a Convolutional Neural Network (CNN) trained on handwritten numerical and symbolic data. The model achieved a classification accuracy of 99.8%, ensuring high reliability in recognizing air-drawn inputs. The recognized mathematical expression is then parsed, validated, evaluated, and displayed on the screen, delivering a seamless and interactive calculation experience.

INDEX TERMS Air-writing, hand gesture recognition, computer vision, mathematical expression recognition, AI calculator.

1. INTRODUCTION

As digital technologies continue to permeate everyday life, the interaction paradigms between humans and machines must evolve to address new challenges and requirements. Traditional input devices like keyboards and touchscreens, while effective for general tasks, reveal significant limitations when applied to specialized domains, such as mathematical computations. These input devices often struggle to provide seamless access to complex mathematical symbols and operators, especially in mobile or compact environments where space is constrained. This creates a barrier for users in fields such as education, engineering, and scientific research, where the efficient and accurate input of mathematical expressions is essential. As a result, there is an increasing demand for more versatile, intuitive, and expressive modes of input that empower users to quickly and accurately construct complex mathematical formulas.

Air-writing—a technique where users write characters or symbols in mid-air using hand movements—offers a

compelling solution to this challenge. By leveraging hand gesture recognition, air-writing allows users to freely draw numerical digits and mathematical symbols without the need for physical devices, thereby facilitating a more natural, hygienic, and fluid mode of interaction. This contactless input not only enhances user experience but also breaks free from the constraints of traditional input methods, offering greater flexibility in expressing mathematical ideas.

The rapid advancements in computer vision and deep learning technologies have made real-time hand gesture recognition more feasible and accurate than ever before. Cutting-edge frameworks, such as MediaPipe, have demonstrated exceptional hand landmark tracking with minimal latency, enabling high-precision gesture detection. Simultaneously, Convolutional Neural Networks (CNNs) have emerged as the gold standard for classifying complex visual data, including handwritten digits and symbols. The combination of these technologies creates an ideal foundation for interpreting dynamic hand movements as meaningful mathematical inputs.

In this paper, we introduce a novel air-writing calculator that allows users to perform mathematical calculations through hand gestures. The system captures real-time hand motion using a webcam, employs computer vision algorithms to extract gesture trajectories, and applies a CNN classifier to recognize the drawn digits and mathematical operators. Once the system classifies the symbols, they are parsed into a syntactically valid mathematical expression, which is then evaluated to produce the final result. This system offers a touchless, efficient, and intuitive alternative to traditional input devices, particularly in environments where conventional methods may be impractical, such as mobile devices, classrooms, and scientific research settings.

1. MOTIVATION

Despite the widespread adoption of digital devices for computational tasks, traditional input systems like keyboards and touchscreens still face significant limitations, particularly when it comes to mathematical computations. One of the most glaring challenges is the restricted range of mathematical operators and symbols available on these devices. This issue becomes especially evident in mobile and compact hardware environments, where space constraints limit the availability of keys for specialized mathematical expressions. Users—such as students, scientists, and engineers—who frequently perform mathematical calculations are often forced to switch between different input modes, navigate through cumbersome symbol menus, or rely on external software to access basic operations. These interruptions not only hinder efficiency but also disrupt the natural flow of problem-solving, forcing users to pause their cognitive processes and adapt to the constraints of the interface.

To overcome these limitations, we propose a revolutionary approach that eliminates the need for conventional key-based interfaces: air-writing. This method allows users to write numerals and mathematical operators in mid-air using natural hand gestures, offering a flexible, free-form, and contactless mode of input. By leveraging real-time gesture recognition, users can easily and intuitively input complex mathematical expressions, thus bypassing the limitations of traditional input devices. While benefits such as improved hygiene and enhanced accessibility are valuable secondary advantages, the core motivation behind this work is to greatly expand the expressive capacity of mathematical input systems through the power of gesture-based interaction.

Recent breakthroughs in computer vision and machine learning have made real-time hand gesture recognition more accurate and feasible than ever before. Frameworks like MediaPipe, with their robust hand tracking capabilities, and Convolutional Neural Networks (CNNs), renowned for their ability to classify images with high precision, enable the development of a system capable of interpreting hand movements as meaningful mathematical input. This integration of technologies paves the way for a more inclusive, versatile, and intuitive interaction model, aligning perfectly with the goals of modern human-computer interaction: efficiency, accessibility, and a seamless user experience.

1. CONTRIBUTIONS

This research introduces a comprehensive system designed for the real-time recognition and interpretation of air-written mathematical expressions using hand gestures. The primary contribution of this work lies in the development of an innovative computer vision pipeline that captures dynamic hand movements through webcam input, detects key hand landmarks using the MediaPipe framework, and preprocesses the trajectory of gestures for further analysis.

To facilitate accurate recognition, a Convolutional Neural Network (CNN)-based classifier is employed to identify numerical digits and basic arithmetic operators from the processed image sequences. The recognized symbols are then parsed into a syntactically valid mathematical expression, which is evaluated to provide the final result. The system's high real-time responsiveness and accuracy under various user conditions underscore its potential for practical deployment in diverse environments, including education, assistive technology, and mobile computing.

In addition to the design and implementation of this air-writing calculator, this research also lays the groundwork for future explorations into gesture-based mathematical input systems. The contributions of this work provide a foundation for the integration of more advanced mathematical operations, support for multilingual numeral systems, and the extension of gesture recognition capabilities to accommodate a broader range of hand movements and symbols. These future enhancements would significantly expand the system's versatility and usability, offering a highly adaptable tool for a wide range of practical applications in fields ranging from education to scientific research.

RELATED WORK

METHODOLOGY

1. PROPOSED FRAMEWORK

This framework enables real-time interpretation of air-written mathematical expressions using hand gestures. The system uses a webcam to capture hand movements and MediaPipe-based hand tracking via the cvzone library to detect the index fingertip as a virtual pen.

The tracked finger trajectory is processed to segment digits and mathematical symbols. These gestures are resized and input into a custom-trained CNN, which recognizes 23 classes: digits (0–9) and symbols (+, −, \*, /, !, (, ), [, ], {, }, pi, sqrt).

The recognized symbols are combined into a valid mathematical expression, which is evaluated and displayed in real-time. This hands-free system demonstrates the effectiveness of gesture-based computation without physical input devices.

1. RECOGNITION AND EXTRACTION OF EXPRESSION

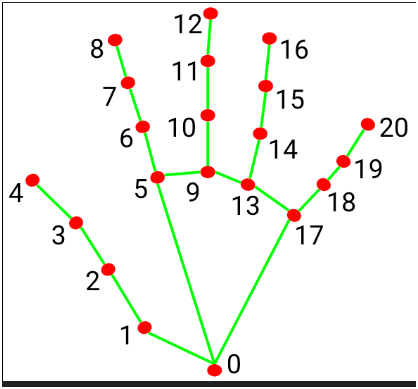
The system follows a modular pipeline designed for real-time hand gesture recognition and mathematical evaluation. The framework consists of the following stages:

1. Hand Detection - The system uses a webcam to continuously capture frames. cvzone, a high-level computer vision library built on top of OpenCV and MediaPipe, is used for detecting the user's hand. Specifically, the HandDetector class detects one or more hands and identifies key landmarks such as finger tips, which are used for gesture tracking.
2. Fingertip Tracking and Gesture Recording - Once a hand is detected, the system isolates the tip of the index finger and tracks its (x, y) coordinates across frames. These coordinates are stored and plotted as a sequence of points, effectively creating an "air-written" symbol.
3. Symbol Extraction and Preprocessing - The fingertip trajectory is tracked only when a specific gesture is detected. The system uses a 5-bit binary list representing the state of each finger: [Thumb, Index, Middle, Ring, Pinky]. Depending on the combination, the system determines what action to take. The index finger is primarily used for drawing:

* Draw Mode [0, 1, 0, 0, 0]: The user is actively drawing a symbol using only the index finger. The fingertip coordinates are recorded frame-by-frame to form the symbol's trajectory.
* Pause Drawing [0, 1, 1, 0, 0]: The system temporarily pauses tracking, allowing users to reposition without adding new points to the trajectory.
* Predict Symbol [0, 1, 0, 0, 1]: The current drawing is finalized. The trajectory is converted into a binary image, resized to 28×28 pixels, normalized, and passed into the CNN model for classification.

1. Classification using CNN - The preprocessed image is passed into a trained CNN model, which classifies it into one of 23 categories (digits 0–9 and 13 mathematical symbols). The predicted symbol is appended to the current expression.
2. Expression Construction and Evaluation – Once a symbol is predicted, it is added to the current expression. The system interprets additional gestures to manage the expression:
3. Remove Last Symbol [0, 0, 0, 0, 1]: Deletes the most recently added symbol from the expression.

* Evaluate Expression [0, 1, 1, 1, 1]: Signals that the user has completed the full expression. The string is safely parsed and evaluated, and the result is displayed.
* Clear Expression [1, 1, 1, 1, 1]: Resets the current expression to an empty state



This structured use of multi-finger gestures ensures precise control over drawing, editing, and evaluating expressions using only hand movements, improving usability and minimizing recognition errors.

1. DESIGN OF PROPOSED CNN MODEL

The proposed system utilizes a shallow CNN architecture designed for real-time recognition of air-written mathematical expressions. The system processes the input image through a series of convolutional, pooling, and fully connected layers to classify hand-drawn symbols efficiently. Below is the breakdown of the design for the shallow CNN model used in this air-writing calculator.

1. DATASETS
2. EXPERIMENTAL RESULT AND ANALYSIS

CONCLUSION

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

APPENDIX A

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APPENDIX E

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Dr. Author was a recipient of the International Association of Geomagnetism and Aeronomy Young Scientist Award for Excellence in 2008, and the IEEE Electromagnetic Compatibility Society Best Symposium Paper Award in 2011.

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Mr. Author’s awards and honors include the Frew Fellowship (Australian Academy of Science), the I. I. Rabi Prize (APS), the European Frequency and Time Forum Award, the Carl Zeiss Research Award, the William F. Meggers Award and the Adolph Lomb Medal (OSA).

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