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Air Writing Detection and Recognition

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Abstract*: Air Writing, a groundbreaking concept, revolutionizes the act of writing by allowing users to create characters or words in free space through hand or finger movements and coloured light. Unlike traditional pen-and-paper methods, this approach replaces pen-up and pen-down motions with colour shifts or light toggling to indicate the beginning and end of characters or words. The Air Handwriting Recognition project combines computer vision object tracking with handwriting recognition using machine learning techniques. Using a computer's webcam, the system tracks the characters users write in the air, following a user-selected colour with the aid of a mask. These tracked movements are then transcribed onto a virtual canvas, mimicking a plain whiteboard. The resulting canvas image serves as input for the recognition model, employing machine learning to interpret air-written words and characters. The integration of colour-based tracking and advanced recognition algorithms ensures the avoidance of plagiarism, making Air Handwriting Recognition a cutting-edge solution for hands-free writing in the digital realm.. A brief history of CNN and other approaches to characters detection and recognition are discussed in this paper*

Keywords: Air Writing, Handwriting Recognition, Machine Learning Techniques, Computer Vision Object Tracking, Convolutional Neural Network (CNN)

I. INTRODUCTION

Several methods have been proposed for character recognition, encountering notable challenges stemming from unanticipated difficulties. This review paper delineates the historical evolution of character recognition systems across three distinct epochs, denoted by the cited time periods [3]

Air writing is a valuable technique for user interfaces that lack keyboard input or touchpad/touch screen writing capabilities. It provides an alternative method for text input, especially beneficial for controlling intelligent systems [1]. It holds significant value for individuals who prefer not to use traditional keyboard or touchscreen input methods. This innovative approach finds applications in smart device control and various contexts, such as medical and engineering fields. Medical disciplines like neurology and physical therapy, as well as engineering sectors like IoT and smart home technology, benefit from air writing's unique capabilities [2]. It is driven by the ambition to address specific needs, propelling a visualization-based approach. The concept revolves around air writing, where individuals engage in writing within an unseen, three-dimensional space. Recognizing the limitations of cameras capturing only two dimensions, the project confines its focus to a two-dimensional canvas. As an object manoeuvres through space, forming "invisible" writing, the computer translates these motions onto a virtual canvas using the camera's tracking data. The object's location is systematically recorded in an array, resulting in the creation of lines on the canvas. This innovative technique not only enhances convenience but also holds the potential to overcome barriers and broaden communication horizons.Air writing can manifest in three distinct styles: isolated, connected, and overlapped air writing. Isolated writing involves the creation of letters within an imaginary box, characterized by a fixed height and width within the image's field of view. The letters are generated one at a time in this manner. Connected writing, on the other hand, entails the composition of multiple letters from left to right, resembling the conventional process of writing on paper. In the overlapped style, individuals write multiple letters arranged in a stacked fashion, one over another, within the same imaginary box. This paper focuses on the study of the isolated writing style[4].

II. LITERATURE SURVEY

[4] Hsieh CH and et al (2021)in his research has introduces a pioneering methodology for recognizing air-writing patterns by leveraging six-degree-of-freedom (6-DOF) motion data. Air-writing, defined as the act of forming letters or words in the air using hand or finger movements without relying on visual or haptic feedback, is investigated at two distinct levels: motion characters and motion words. Motion characters involve the creation of isolated letters in a single stroke, while motion words are composed by connecting these characters with ligature motions. The proposed approach integrates a hybrid motion tracking system, merging optical and inertial sensors to comprehensively capture the position, orientation, acceleration, and angular speed during the writing motion.

To effectively model and recognize air-writing patterns, the methodology employs crucial techniques such as feature normalization, hidden Markov models (HMMs), and ligature modelling. The evaluation of recognition performance involves assessing various combinations of features and modelling methods using an extensive air-writing dataset collected from 22 subjects. Furthermore, a usability study is conducted to compare air-writing with a virtual keyboard for text input on a motion-based user interface. This comprehensive approach contributes valuable insights to the evolving field of gesture-based input systems.

[5]Ahmed Sanmd et al (2022)has proposed the approach for in-air digits recognition using a frequency-modulated continuous-wave (FMCW) radar, specifically designed for human-computer interaction (HCI). Hand gestures, as a natural and convenient form of communication, have garnered significant attention, with mid-air writing detection emerging as a promising application. The proposed method employs a multistream convolutional neural network (MS-CNN) architecture, utilizing a single FMCW radar with two receiving channels. The three independent input streams, representing range-time, Doppler-time, and angle-time spectrograms, enable the creation of a multidimensional deep-learning model tailored for FMCW radars. This innovative approach demonstrated a remarkable accuracy of 95% in recognizing in-air digits during experiments conducted with twelve human volunteers in both home and lab environments.

In the realm of gesture recognition systems, the study highlights the advantages of wireless sensors, particularly FMCW radar, over wearable counterparts. Unlike wearable sensors, FMCW radar provides a natural and non-contact solution for mid-air writing, avoiding discomfort for users. Comparative analysis with 45 different CNN variants indicates that the proposed MS-CNN system outperforms traditional CNN architectures, showcasing its potential for HCI applications. The radar data collected during the experiments have been made available to the research community, encouraging further exploration and development in the field of gesture-based interaction systems.

[6]Wang C and et al(2018)This paper introduces RF-finger, a device-free system utilizing commercial off-the-shelf (COTS) RFID technology to track intricate finger movements and recognize multi-touch gestures. The RF-finger system employs a tag array affixed to a letter-size paper to capture finger movements in its vicinity. Through the development of a theoretical model for extracting reflection features from raw RF signals, RF-finger accurately determines finger positions and creates reflection images of multi-touch gestures. Subsequently, a KNN-based algorithm is applied for precise finger trace tracking, while a CNN-based algorithm classifies the recognized multi-touch gestures. Through extensive experiments, RF-finger demonstrates impressive performance with up to 88% accuracy for finger tracking and 92% accuracy for multi-touch gesture recognition. This system underscores the potential of RFID technology in facilitating natural and intuitive human-computer interaction.

[7] Anjaneyulu P et al (2017)The central focus of this paper is to assess the performance of an embedded system's operating system, particularly in the context of utilizing the Linux operating system within embedded systems. Before delving into the implementation details, a comprehensive introduction to the pertinent components is essential. The study centers around embedded systems and their integration with the Linux OS, with a specific emphasis on exploring the capabilities of an accelerometer-equipped digital pen for gesture recognition. This digital pen encompasses a tri-axial accelerometer, a microcontroller, and an RF transmission module. Through the analysis of acceleration signals in both time and frequency domains, the system adeptly tracks finger movements and transmits the acquired data through an RF transmitter. On the receiving end, RF signals are captured by an RF receiver and processed by the microcontroller, with the final outcomes conveniently displayed on a Graphical LCD.

The proposed system extends its functionality by incorporating a webcam, an ARM microcontroller, and a display unit. By leveraging hand gestures while drawing in front of the camera, the corresponding output is dynamically showcased

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on the display unit. This integrated approach showcases the synergy between hardware components, gesture recognition algorithms, and the Linux operating system in the realm of embedded systems, offering a comprehensive evaluation of system performance.

[8] Kumar P and et al (2017)Sign languages are complex communication systems characterized by three primary components: manual signs, involving gestures made by hand or finger movements; non-manual signs, which encompass facial expressions or body postures; and finger-spelling, a method where words are spelled out through specific gestures. Despite existing research primarily concentrating on the isolated analysis of these components, the comprehensive exploration of their combined utilization remains relatively uncharted. In our paper, we present a novel framework designed to recognize both manual signs and finger spellings through the utilization of a Leap Motion sensor.

Our approach addresses the holistic nature of sign languages by incorporating a unified framework that embraces manual signs and finger-spelling concurrently. The integration of a Leap Motion sensor facilitates the recognition process, capturing the intricate hand and finger movements crucial for interpreting sign language gestures. By examining these components collectively, our framework aims to contribute to a more nuanced understanding of sign language communication, fostering advancements in gesture recognition technology.

[9]Tsai TH and et al This paper introduces a pioneering real-time recognition system designed for the identification of air-written characters without the reliance on pen-starting-lift information, a common feature in many air-writing recognition systems. The traditional use of a pen-starting-lift sign in these systems simplifies trajectory matching but often proves inconvenient for users. To address this issue, the paper proposes a unique reverse time ordered stroke context that represents an air-written trajectory in a backward manner, effectively eliminating the need for redundant starting-lift data. By framing the air-writing recognition problem as a pathfinding challenge, solved through a stroke weighting scheme, the proposed system ensures improved user convenience without compromising recognition accuracy. Additionally, the paper addresses the multiplicity and confusion problems inherent in air-writing recognition systems. The multiplicity problem arises when a character is written differently among users, while the confusion problem occurs when different characters share similar writing trajectories (e.g., 'b,' 'p,' 'D'). These challenges are effectively mitigated through the introduction of a hierarchical classification scheme, incorporating a three-layer structure with different sampling rates to represent air-written characters. The system successfully recognizes all alphabets, including lowercase, capital, and digital letters, in real-time, achieving a high recognition accuracy of over 94.7%, even without requiring a starting gesture.

The proposed real-time recognition system not only addresses the inconvenience associated with pen-starting-lift information but also successfully tackles the multiplicity and confusion problems prevalent in air-writing recognition. The utilization of a reverse time ordered stroke context and a hierarchical classification scheme demonstrates the system's efficiency and accuracy, making it a promising advancement in the field of air-writing recognition technology.

[10] Tan X and et al(2023)-The task of air-writing recognition involves the computer's ability to directly interpret user input generated by finger movements in the air, providing a natural, cost-effective, and immersive interaction in the field of human-computer interaction (HCI). While traditional air-writing recognition has predominantly focused on recognizing individual characters, a recent advancement in 2022 introduced the concept of writing in the air (WiTA) to tackle continuous air-writing tasks. This paper posits that a Transformer-based approach can significantly enhance performance for the WiTA task. To address this, the study introduces TR-AWR, an end-to-end air-writing recognition method leveraging the Transformer model. Adopting a holistic approach, TR-AWR utilizes video frame sequences as input and generates letter sequences as outputs. To boost WiTA task performance, the method combines the vision transformer model with the traditional transformer model, introducing novel data augmentation techniques. Achieving a character error rate (CER) of 29.86% and a decoding frames per second (D-fps) value of 194.67 fps, the method surpasses baseline models in recognition accuracy while maintaining real-time performance. The contributions of this study include the incorporation of the Transformer method into continuous air-writing recognition, an end-to-end recognition approach, and tailored data augmentation guidelines for the WiTA task, presenting a promising direction for advancements in this domain.

In summary, this paper introduces a transformative approach to effectively address the continuous air-writing recognition task (WiTA). Through the integration of the Transformer model, the proposed TR-AWR method not only streamlines the recognition process but also achieves improved results, showcasing the potential for further advancements in this evolving domain.

[11]Zhang H and et al(2022)This study introduces an innovative real-time wearable system designed for finger air-writing recognition in three-dimensional (3D) space, utilizing the Arduino Nano 33 BLE Sense as a powerful edge device capable of running TensorFlow Lite for on-device recognition and classification. The system enables users to seamlessly write characters, including 10 digits and 26 English lower-case letters, in free space by moving their fingers. Leveraging deep learning algorithms, the system processes motion data captured by inertial measurement units (IMUs) and a microcontroller embedded in the Arduino Nano 33 BLE Sense, achieving a remarkable recognition accuracy of 97.95%. The proposed approach eliminates the need for additional dedicated devices, allowing users to wear the Arduino Nano 33 BLE Sense on their index finger and conduct air-writing recognition in real-time, addressing the challenges of conventional input methods in various HCI environments.

Living in the digital world, almost every aspect of our lives involves HCI, sometimes even without our noticing. For the output of HCI, the most advanced technology would refer to virtual and augmented reality, enabling users to see the results with dedicated glasses, rather than displays or screens, which are portable and more convenient. However, as for input, breakthroughs are still being explored. Traditional keyboards and touchscreens, although accurate, face limitations in certain situations, such as low visibility or when carried constantly is impractical. To meet the demand for real-time digital character input, particularly in diverse HCI environments, this paper proposes a novel air-writing character recognition wearable system based on edge computing and deep learning. The system leverages the Arduino Nano 33 BLE Sense, combining IMUs and microcontrollers, worn on the index finger to detect dynamic movements and conduct air-writing recognition using TensorFlow Lite. The system's unique five-layer Convolutional Neural Network (CNN) achieves high recognition accuracy, recognizing 10 digits and 26 lower-case letters in real-time, offering users a natural and user-friendly alternative for character input without space limitations. The subsequent sections delve into the research status, system description, data acquisition experiments, data preprocessing, neural network structure, and a comprehensive analysis of the results, concluding with future prospects.

[12]Ye Zanmd et al (2013)This paper introduces an innovative system, termed "finger-writing-in-the-air," designed for character recognition using Kinect technology. The system allows users to input characters through virtual air-writing, offering a novel and intuitive mode of interaction. To address challenges faced by traditional vision-based methods, a sophisticated mixture model for hand segmentation is proposed, leveraging depth, colour, and motion information. This model proves effective in overcoming issues like illumination variation, hand-face overlapping, and the colour-depth mismatch problem specific to Kinect devices.

The system further enhances accuracy through the introduction of a dual-mode switching algorithm dedicated to precise fingertip detection. This algorithm exhibits resilience to noise along the segmented hand contour and adapts to various hand poses, ensuring robust performance in real-world scenarios. Beyond mere fingertip detection, the system reconstructs fingertip positions to form inkless character strokes. These reconstructed trajectories are then subjected to recognition using cutting-edge handwriting character recognition methods. Experimental results showcase the system's proficiency, enabling users to perform real-time air-writing of Chinese characters, English letters (both upper and lower case), and digits with an accuracy rate surpassing 90% for the top five candidates.

The finger-writing-in-the-air system represents a significant leap forward in natural and intuitive character input methods, offering a promising avenue for the development of gesture-based interaction systems. By leveraging Kinect technology and overcoming traditional limitations, this system opens up new possibilities for user-friendly interfaces, paving the way for enhanced human-computer interaction experiences in diverse applications.

It introduces a unique approach to character input, allowing users the freedom to write in the air without the need for physical devices such as pens or touchscreens. The mixture model for hand segmentation not only addresses traditional challenges but also facilitates a seamless and immersive air-writing experience. The dual-mode switching algorithm's ability to accurately detect fingertip positions adds a layer of precision to the system, making it resilient to environmental noise and adaptable to various hand gestures.

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III. ANALYSIS TABLE

Sr No.	Paper Title	Techniques	Addressed Issue
1.	Air-Writing Recognition Based on Deep Convolutional Neural Networks [4]	Hybrid Motion Tracking System Feature Normalization Hidden Markov Models (HMMs) Ligature Modelling	Recognition of Air-Writing Patterns, Comprehensive Capture of 6-DOF Motion Data Features Normalization, HMMs, Ligature Modelling
2.	Finger-writing-in-the-air system using Kinect sensor	Frequency-Modulated Continuous-Wave (FMCW) Radar Multistream Convolutional Neural Network (MS-CNN) Architecture Range-Time, Doppler-Time, and Angle-Time Spectrograms Comparative Analysis of CNN Variants Non-contact Solution for Mid-Air Writing in HCI	In-Air Digits Recognition using FMCW Radar, Multistream Convolutional Neural Network (MS-CNN) Architecture
3.	Multi - Touch in the Air: Device-Free Finger Tracking and Gesture Recognition via COTS RFID	COTS RFID Technology, CNN-Based Algorithm, Extensive Experiments.	Recognition of intricate finger movements and multi-touch gestures, Overcoming challenges of traditional vision-based methods, Resolving color-depth mismatch problem with Kinect technology.
4.	Airwriting recognition modeling and recognition of characters, words and connecting motions	. Accelerometer-based Tracking, Analysis of Acceleration Signals,	Performance evaluation,Gesture recognition with digital pen, Evaluation of system components.
5.	Real-time recognition of sign language gestures and air-writing using leap motion	Framework for recognizing manual signs and finger spellings,Utilization of Leap Motion sensor for capturing hand and finger movements, Comprehensive exploration of combined manual signs and finger-spelling	Framework for recognizing manual signs and finger spellings, Utilization of Leap Motion sensor for capturing hand and finger movements, Comprehensive exploration of combined manual signs and finger-spelling
6.	Reverse time ordered stroke context for air-writing recognition	Reverse time ordered stroke context, Stroke weighting scheme, Hierarchical classification scheme	Elimination of reliance on pen-starting-lift information, Handling of the multiplicity problem in air-writing recognition, Resolution of the confusion problem in air-writing recognition
7.	An End-to-End Air Writing Recognition Method Based on Transformer	Real-time finger air-writing recognition system, Utilization of Arduino Nano 33 BLE Sense as an edge device, Implementation of TensorFlow Lite for on-device recognition and classification	Continuous air-writing recognition challenges, Performance improvement in WiTA task, Integration of Transformer model in air-writing recognition
8.	Wearable Real-Time Character Recognition System Based on Edge Computing-Enabled Deep Learning for Air-Writing	For identification, the system combines SVM with deep learning. It extracts face descriptors from the pictures using the VGG-Face deep architecture and utilizes CNN for face recognition.	Real-time finger air-writing recognition system challenges, Challenges associated with utilizing Arduino Nano 33 BLE Sense as an edge device, TensorFlow Lite implementation challenges for on-device recognition

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			and classification
9.	Finger-writing-in-the-air system using Kinect sensor	Mixture model for hand segmentation, Dual-mode switching algorithm for precise fingertip detection, Reconstruction of fingertip positions to form inkless character strokes	Challenges faced by traditional vision-based methods, Illumination variation in vision-based systems, Hand-face overlapping in vision-based systems
10.	Criminals and Missing Children Identification Using Face Recognition And Web Scrapping [10]	The system makes use of web scraping, facial recognition, and machine learning.	Challenges faced by traditional vision-based methods, Illumination variation in vision-based systems, Hand-face overlapping in vision-based systems

IV. CONCLUSION

In this study, the implementation of in-air digit recognition using FMCW radar sensor technology is introduced, featuring a multistream CNN model that effectively utilizes information from range-time, Doppler-time, and angle-time patterns. The MS-CNN model, by combining features from multiple input streams, demonstrates superior performance compared to traditional CNN approaches. Experimental results, conducted with diverse participants in different physical environments, exhibit a high classification accuracy of 94.20% for recognizing the ten base digits.

However, the study acknowledges challenges, such as addressing unwanted noise introduced by the micro-Doppler effect in nonrigid hand structures. The computational cost of the deep learning model is also noted, with CNN latency ranging between 400 and 500 ms.

While the proposed in-air writing system successfully classifies single-digit gestures, it currently treats each performed digit gesture discretely. Recognizing continuous digit writing and exploring finger-tracking-based digit recognition are identified as potential areas for future research. The study envisions the development of a contactless in-air writing system for continuous digit and alphabet recognition. Additionally, the aim is to implement a real-time version of the proposed air-writing recognition system and extend the MS-CNN-based classification approach to similar problems. In conclusion, the study provides valuable insights into the challenges and achievements of in-air digit recognition, paving the way for future advancements in contactless gesture recognition system

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