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Hand Gestures for Personal Computer Control

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Abstract: ***Hand gestures have emerged as a promising modality for enhancing personal computer (PC) control, offering intuitive and natural interaction methods. This research paper explores the design, implementation, and evaluation of a hand gesture recognition system for PC interaction. We review existing methods of PC control and discuss the limitations of traditional input modalities. The paper outlines the process of hand gesture recognition, including data acquisition, preprocessing, feature extraction, and classification. We describe the design considerations and implementation details of the gesture recognition system, highlighting the hardware and software requirements. Empirical evaluations are presented to assess the system's performance in terms of recognition accuracy, response time, and user satisfaction. Furthermore, we explore potential applications of hand gesture control across various domains and discuss challenges and future directions in the field. This research contributes to advancing the state-of-the-art in HCI by demonstrating the feasibility and effectiveness of hand gestures for PC interaction.***

Keywords: Hand Gestures, Gesture Recognition, Personal Computer Control, Human-Computer Interaction (HCI), Gesture-based Interfaces, User Interaction, Machine Learning, Computer Vision, Evaluation, Applications.

I. INTRODUCTION

In the ever-evolving landscape of human-computer interaction (HCI), the quest for more intuitive and efficient input modalities has been ongoing. Traditional methods of PC control, such as keyboard and mouse, have long served as the primary means for users to interact with their computers. However, these input modalities often present limitations in terms of accessibility, ergonomics, and user experience. As computing technologies continue to advance, there is a growing demand for more natural and intuitive interaction techniques.

Hand gestures have emerged as a promising alternative for PC control, offering users a means to interact with their computers using intuitive hand movements. By leveraging computer vision and machine learning techniques, hand gesture recognition systems can interpret and respond to a wide range of gestures, allowing for fluid and expressive interaction. This paradigm shift towards gesture-based interfaces opens up new possibilities for HCI, enabling users to control their PCs with simple gestures, akin to how they interact with the physical world. The concept of using hand gestures for PC control is not entirely novel. Previous research has explored various aspects of gesture recognition and its applications in different domains. For instance, Ren et al. (2016) demonstrated the feasibility of using hand gestures for controlling multimedia applications, showcasing the potential for gesture-based interaction in entertainment scenarios. Similarly, Li et al. (2018) proposed a hand gesture recognition system for navigation tasks in virtual environments, highlighting the versatility of gesture-based interfaces across different contexts.

Despite the progress made in gesture recognition technology, several challenges remain to be addressed. One significant challenge is achieving robust and accurate recognition in diverse environments and under varying lighting conditions. Additionally, ensuring seamless integration of gesture control into existing PC interfaces without disrupting the user experience poses another hurdle. Overcoming these challenges requires interdisciplinary efforts that combine expertise in computer vision, machine learning, human factors, and user interface design.

In this research paper, we delve into the design, implementation, and evaluation of a hand gesture recognition system tailored for PC interaction. Building upon existing literature and methodologies, we present a comprehensive framework for gesture-based PC control, addressing key considerations such as hardware requirements, gesture representation, and system performance. Through empirical evaluations, we assess the effectiveness and usability of the proposed system, shedding light on its strengths, limitations, and potential applications.

By advancing our understanding of hand gesture control for PCs, this research aims to contribute to the broader field of HCI and pave the way for more natural and immersive computing experiences. As we embark on this journey towards gesture-driven interaction paradigms, it is essential to consider not only the technical aspects of gesture recognition but also the human-centric design principles that underpin effective HCI.

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Tapping have become standard interactions for scrolling through web pages, zooming in on images, and navigating menus.

Augmented reality (AR) and virtual reality (VR) headsets offer another compelling platform for gesture-based interaction, enabling users to manipulate virtual objects and navigate immersive environments with hand gestures (Tang et al., 2020). Gesture control enhances the sense of presence and immersion in AR and VR experiences, allowing users to engage with digital content in a more intuitive and natural manner. For example, users can reach out and grab virtual objects, point at targets, or perform gestures to trigger actions within virtual environments.

II. LITERATURE REVIEW

A. *Hand Gesture Recognition Systems*

Hand gesture recognition systems play a pivotal role in enhancing human-computer interaction (HCI) by allowing users to interact with digital interfaces using intuitive hand movements. These systems encompass a series of stages, including data acquisition, preprocessing, feature extraction, and classification. We have classified the Literature Review accordingly in the following 4 sub-classes

Wang et al. (2018)[7]: Data acquisition involves capturing images or videos of hand gestures using various sensing technologies. RGB cameras, depth sensors (e.g., Microsoft Kinect), and infrared cameras are commonly used to capture different aspects of hand motion and shape. Their Research explores the use of depth sensors for hand gesture recognition in augmented reality applications, highlighting the advantages of depth data for capturing 3D hand poses accurately.

Song et al. (2019)[8]: Preprocessing techniques are essential for enhancing the quality of input data and preparing it for further analysis. Common preprocessing steps include image normalization, background subtraction, and noise reduction. In their study, they propose a novel background subtraction method for hand gesture recognition, which effectively removes background clutter and improves the accuracy of gesture segmentation.

Li et al. (2020)[12]: Feature extraction involves identifying discriminative features from pre-processed data that can be used to differentiate between different gestures. These features may include hand shape, movement trajectory, finger positions, and spatial relationships. Research by Li et al. (2020) explores the use of deep learning techniques for automatically learning discriminative features from raw image data, bypassing the need for handcrafted feature extraction methods.

Zhang et al. (2019)[10]: Classification algorithms are employed to recognize and classify observed gestures based on extracted features. Machine learning algorithms, such as support vector machines (SVMs), artificial neural networks (ANNs), and hidden Markov models (HMMs), are commonly used for gesture classification. In their work, Zhang et al. (2019) propose a novel deep learning-based approach for gesture classification, achieving state-of-the-art performance on benchmark datasets such as the ChaLearn Looking at People (LAP) challenge.

B. *Technologies and Techniques*

Hand gesture recognition systems rely on a fusion of technologies and techniques to accurately interpret and respond to user gestures. Among these, computer vision, machine learning, and signal processing stand out as key pillars in gesture recognition research, enabling systems to translate raw input data into actionable commands.

1) *Computer Vision*

Computer vision plays a crucial role in hand gesture recognition by extracting meaningful information from visual data, such as hand shape, motion, and orientation. Various techniques are employed for hand gesture analysis, including:

a) *Edge Detection:* Edge detection algorithms identify edges or boundaries within an image, providing crucial information about the contours of the hand and its movements.

b) *Contour Analysis:* Contour analysis involves tracing the outline of the hand gesture, allowing for the extraction of shape-related features such as finger positions and hand orientation.

c) *Template Matching:* Template matching techniques compare the observed hand gesture with predefined templates or patterns, enabling recognition of specific gestures based on similarity scores.

Research by Zhang et al. (2020)[4] explores the use of convolutional neural networks (CNNs) for robust hand gesture recognition, achieving state-of-the-art performance in real-world environments.

Table 1: Summary of Literature Review on Hand Gesture Recognition

Topic	Description	References
Hand Gesture Recognition Systems	Review of existing literature on hand gesture recognition systems, including technologies, applications, and challenges.	Smith et al. (2021); Chen et al. (2020); Walters et al. (2019); Smith et al. (2020)
Technologies and Techniques	Examination of computer vision, machine learning, and signal processing techniques used in hand gesture recognition systems.	Kim et al. (2021); Zhang et al. (2022); Muller et al. (2020)
Applications	Overview of diverse applications of hand gesture recognition in gaming, healthcare, robotics, smart environments, etc.	Jones et al. (2021); Chen et al. (2020); Walters et al. (2019); Smith et al. (2020)
Comparative Analysis of Techniques	Comparison of different approaches to gesture recognition, including vision-based, sensor-based, and hybrid methods.	Kim et al. (2021); Zhang et al. (2022); Muller et al. (2020)

2) Machine Learning

Machine learning algorithms are trained on labeled gesture data to learn patterns and relationships between input features and corresponding gestures. Supervised learning algorithms, such as Support Vector Machines (SVMs) and Artificial Neural Networks (ANNs), are widely utilized for gesture classification due to their ability to generalize from training data to unseen gestures. In their study, Li et al. (2021)[2] propose a novel ensemble learning approach for gesture recognition, combining multiple classifiers to improve classification accuracy and robustness.

3) Signal Processing

Signal processing techniques are instrumental in analyzing and interpreting temporal signals associated with hand movements. These techniques enable the extraction of relevant features from gesture data, facilitating gesture classification and recognition. Common signal processing methods include Fourier Analysis which decomposes signals into their constituent frequency components, providing insights into the periodicity and dynamics of hand movements, also, Wavelet Transforms which analyze signals at different scales, capturing both high-frequency and low-frequency components of hand gestures for feature extraction along with Time-Frequency Analysis, such as the short-time Fourier transform (STFT) and the wavelet packet transform, reveal how the frequency content of a signal changes over time, offering a comprehensive representation of gesture dynamics.

Table 2: Summary of Gesture Recognition Techniques

Technique	Description	Strengths	Weaknesses
Vision-based	Relies on visual data from cameras	Captures rich visual information	Susceptible to lighting and occlusions
Sensor-based	Utilizes data from specialized sensors	Provides precise measurements	Requires additional hardware and calibration
Hybrid	Integrates elements of both vision and sensor-based approaches	Offers enhanced performance and robustness	Higher complexity and cost

C. Applications

Hand gesture recognition technology has found widespread applications across diverse domains, revolutionizing human-computer interaction and unlocking new possibilities for immersive and intuitive experiences. Here, we delve into the multifaceted applications of gesture recognition systems in gaming, virtual reality (VR), augmented reality (AR), healthcare, robotics, and smart environments.

1) Gaming

Gesture control has reshaped the gaming landscape by enabling players to interact with virtual environments and control game characters using natural hand movements. By replacing traditional input devices like controllers and keyboards, gesture-based interaction enhances immersion and gameplay experience, making gaming more intuitive and engaging. Research by **Lee et al. (2020)[10]** explores the implementation of gesture-based controls in virtual reality gaming, demonstrating how hand gestures can offer precise and responsive input for navigating complex game environments and executing in-game actions.

2) Virtual and Augmented Reality

In virtual and augmented reality applications, gesture-based interaction serves as a fundamental component, allowing users to manipulate virtual objects, navigate immersive environments, and interact with digital content in a more intuitive and immersive manner. Gesture recognition technology enhances the sense of presence and agency in VR and AR experiences, fostering deeper engagement and immersion. A study by Wang et al. (2021)[5] investigates the use of hand gestures for object manipulation in augmented reality environments, showcasing the potential of gesture-based interaction for creating seamless and intuitive user experiences.

3) Healthcare

Gesture control systems have transformative potential in healthcare settings, facilitating hands-free interaction with medical devices, assistive technologies, and rehabilitation tools. By enabling patients and healthcare professionals to control devices and interfaces through natural hand gestures, gesture recognition technology improves accessibility, usability, and patient outcomes. Research by Suh et al. (2019)[11] explores the use of gesture-based interfaces for controlling medical devices in surgical environments, demonstrating how gesture control can enhance efficiency and precision in medical procedures while reducing the risk of contamination.

D. Comparative Analysis of Gesture Recognition Techniques

Gesture recognition techniques can be broadly categorized into vision-based, sensor-based, and hybrid methods. Vision-based approaches rely on visual data captured by cameras, sensor-based methods utilize data from specialized sensors, while hybrid methods combine elements of both approaches. Vision-based techniques offer the advantage of capturing rich visual information, enabling accurate recognition of hand gestures in diverse environments. However, they may be susceptible to lighting conditions, occlusions, and background clutter, leading to potential accuracy issues in complex scenarios. Sensor-based methods, on the other hand, provide precise and reliable gesture detection by directly measuring physical parameters such as hand motion and orientation. However, they may require additional hardware and calibration, increasing complexity and cost. Hybrid methods seek to leverage the strengths of both vision-based and sensor-based approaches to achieve robust and accurate gesture recognition. By combining visual data with sensor measurements, hybrid systems can mitigate the limitations of individual techniques and offer enhanced performance in various use cases. Nevertheless, hybrid methods may entail higher computational complexity and integration challenges compared to single-modality approaches.

Table 3: Comparison of Classification Algorithms

Algorithm	Description	Strengths	Weaknesses
Support Vector Machines (SVM)	Supervised learning algorithm for binary classification	Effective in high-dimensional spaces	Can be sensitive to choice of kernel
Convolutional Neural Networks (CNN)	Deep learning algorithm for image classification	Learns hierarchical features	Requires large datasets for training
Recurrent Neural Networks (RNN)	Deep learning algorithm for sequence modeling	Captures temporal dependencies	May suffer from vanishing gradients

E. User Experience Studies

User experience (UX) studies play a crucial role in evaluating the effectiveness and usability of gesture-based interfaces. These studies investigate various aspects of user interaction, including usability, learnability, satisfaction, and user preferences. Research by Smith et al. (2021)[13] conducted a user experience study to assess the usability of gesture-based interfaces in smart home environments. The study found that users preferred simple and intuitive gestures for controlling smart devices and expressed higher satisfaction with interfaces that provided immediate feedback and clear visual cues. Factors such as gesture complexity, feedback mechanisms, and ergonomics significantly impact user performance and satisfaction in gesture-based interaction. Complex gestures may lead to higher cognitive load and slower interaction times, while effective feedback mechanisms, such as visual or auditory cues, can enhance user understanding and confidence in gesture input. Additionally, ergonomic considerations, such as comfortable hand postures and natural movement patterns, contribute to a more pleasant and ergonomic user experience.

F. Real-world Deployments and Case Studies

Gesture recognition systems have witnessed widespread deployment across various industries and domains, revolutionizing human-computer interaction and enhancing user experiences. In the retail sector, companies have implemented gesture-based interfaces to create interactive shopping experiences, allowing customers to browse products and make purchases through intuitive hand gestures. For instance, a case study by Jones et al. (2021)[3] showcases how a major retail chain utilized gesture recognition technology to enable customers to interact with digital displays and access product information in-store, leading to increased engagement and sales.

Similarly, in the entertainment industry, gesture control has been employed to create immersive and interactive experiences in gaming, theme parks, and live events. For example, Disney's MagicBands use gesture recognition technology to allow guests to interact with attractions and unlock personalized experiences within theme parks, enhancing the overall entertainment experience (Walters et al., 2019)[1].

G. Emerging Trends and Innovations

Gesture recognition research is continually evolving, driven by advancements in technology and a growing demand for more intuitive and immersive interaction experiences. One emerging trend in gesture recognition is the adoption of deep learning approaches, such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs), for improved gesture recognition accuracy and robustness. For example, a study by **Kim et al. (2021)[14]** explores the use of deep learning techniques for real-time hand gesture recognition in smart home environments, achieving high levels of accuracy and reliability.

Recent advancements in gesture-based interaction also include developments in 3D gesture tracking, enabling precise and spatially accurate gesture recognition in three-dimensional space. Gesture-based authentication methods, such as biometric gesture recognition and behavioral biometrics, offer secure and user-friendly alternatives to traditional authentication mechanisms, enhancing security and convenience in digital systems **(Li et al., 2021)[2].**

H. Ethical and Social Implications

The widespread adoption of gesture recognition technology raises important ethical and social considerations that warrant careful attention from researchers, developers, and policymakers. One of the primary concerns is privacy, as gesture recognition systems may capture sensitive personal data and biometric information, raising concerns about surveillance, data ownership, and consent (Nguyen et al., 2021)[15]. Moreover, the deployment of gesture recognition systems can exacerbate existing algorithmic biases and discrimination, leading to unintended consequences and inequities in access and representation. Researchers and developers must address issues of fairness, transparency, and accountability in gesture recognition algorithms to mitigate biases and ensure equitable outcomes for all users (Suresh et al., 2020)[16].

Ethical frameworks and guidelines for the responsible design and deployment of gesture-based interfaces are essential to address these ethical and social implications. By prioritizing user rights, autonomy, and well-being, designers can ensure that gesture recognition technology is developed and utilized in a manner that respects ethical principles and promotes positive societal outcomes.

III. METHODOLOGY

1) *Data Collection:* Data collection involves capturing images or videos of hand gestures using a suitable recording setup. A high-resolution camera or depth sensor is used to capture hand movements from multiple viewpoints, ensuring comprehensive coverage of gesture variations. Participants are instructed to perform a diverse set of hand gestures relevant to PC control tasks, such as pointing, swiping, and grabbing.

2) *Preprocessing:* Preprocessing techniques are applied to enhance the quality of input data and prepare it for feature extraction and classification. Common preprocessing steps include image normalization, background subtraction, and noise reduction. Additionally, hand segmentation algorithms are utilized to isolate hand regions from the background and extract relevant features.
3) *Feature Extraction:* Feature extraction involves identifying discriminative characteristics or patterns from preprocessed data that can be used to differentiate between different gestures. Features such as hand shape, movement trajectory, finger positions, and spatial relationships are extracted using techniques like contour analysis, motion tracking, and geometric descriptors.
4) *Classification:* Classification algorithms are applied to the extracted features to recognize and classify observed gestures. Supervised learning algorithms, including support vector machines (SVMs), convolutional neural networks (CNNs), and recurrent neural networks (RNNs), are trained on labeled gesture data to learn patterns and relationships between input features and corresponding gestures.
5) *Evaluation:* The performance of the developed gesture recognition models is evaluated using appropriate metrics, such as accuracy, precision, recall, and F1 score. Cross-validation techniques, such as k-fold cross-validation, are employed to assess the generalization performance of the models on unseen data. Additionally, user studies are conducted to evaluate the usability and user experience of gesture-based interfaces for PC control tasks.
6) *Results Analysis:* The results obtained from the evaluation stage are analyzed to assess the effectiveness and robustness of the developed gesture recognition system. Comparative analysis is performed to compare the performance of different classification algorithms and feature extraction techniques. Additionally, user feedback and subjective evaluations are analyzed to identify strengths, weaknesses, and areas for improvement in the gesture-based interface.
7) *Discussion and Conclusion:* The findings from the research are discussed in the context of existing literature and theoretical frameworks. The implications of the results for enhancing human-computer interaction in PC environments are examined, and recommendations for future research directions are provided. The conclusion summarizes the key findings of the study and highlights the significance of gesture recognition technology for improving usability and user experience in PC control tasks.
8) *Limitations and Future Work:* The limitations of the proposed methodology, such as data collection constraints, algorithmic biases, and hardware dependencies, are acknowledged. Suggestions for addressing these limitations and future research directions, including exploring novel gesture recognition techniques and evaluating real-world deployment scenarios, are outlined.

IV. RESULT

The results of the study on hand gesture recognition systems for personal computer (PC) control demonstrate promising advancements in improving human-computer interaction (HCI) through intuitive and natural means. The methodology outlined in the research paper facilitated the development and evaluation of gesture recognition models across various stages, including data collection, preprocessing, feature extraction, classification, evaluation, and analysis.

1) *Data Collection:* A diverse dataset of hand gestures relevant to PC control tasks was collected using a high-resolution camera setup. Participants performed a range of gestures, including pointing, swiping, and grabbing, ensuring comprehensive coverage of gesture variations. The dataset encompassed various hand orientations, lighting conditions, and backgrounds to enhance model robustness and generalization.
2) *Preprocessing:* Preprocessing techniques were applied to the collected data to enhance its quality and suitability for feature extraction and classification. Image normalization, background subtraction, and noise reduction algorithms were employed to improve the clarity and consistency of hand gesture images. Hand segmentation algorithms successfully isolated hand regions from the background, facilitating subsequent feature extraction.
3) *Feature Extraction:* Feature extraction techniques identified discriminative characteristics from preprocessed data to differentiate between different gestures. Features such as hand shape, movement trajectory, finger positions, and spatial relationships were extracted using contour analysis, motion tracking, and geometric descriptors. These features captured key aspects of hand gestures essential for accurate recognition and classification.
4) *Classification:* Classification algorithms were applied to the extracted features to recognize and classify observed gestures. Supervised learning algorithms, including support vector machines (SVMs), convolutional neural networks (CNNs), and recurrent neural networks (RNNs), were trained on labeled gesture data to learn patterns and relationships between input features and corresponding gestures. The classification models exhibited high accuracy and robustness in distinguishing between different hand gestures, demonstrating their effectiveness in PC control tasks.

5) *Evaluation:* The performance of the developed gesture recognition models was evaluated using appropriate metrics, including accuracy, precision, recall, and F1 score. Cross-validation techniques, such as k-fold cross-validation, were employed to assess the generalization performance of the models on unseen data. User studies were conducted to evaluate the usability and user experience of gesture-based interfaces for PC control tasks. Participants expressed satisfaction with the intuitive and natural interaction provided by gesture recognition technology, highlighting its potential for enhancing HCI in PC environments.

Table 4: Performance Metrics of Gesture Recognition Models

Model	Accuracy (%)	Precision (%)	Recall (%)	F1 Score
SVM	92.5	91.2	93.8	92.5
CNN	95.3	94.8	95.6	95.2
RNN	93.8	92.7	94.5	93.6

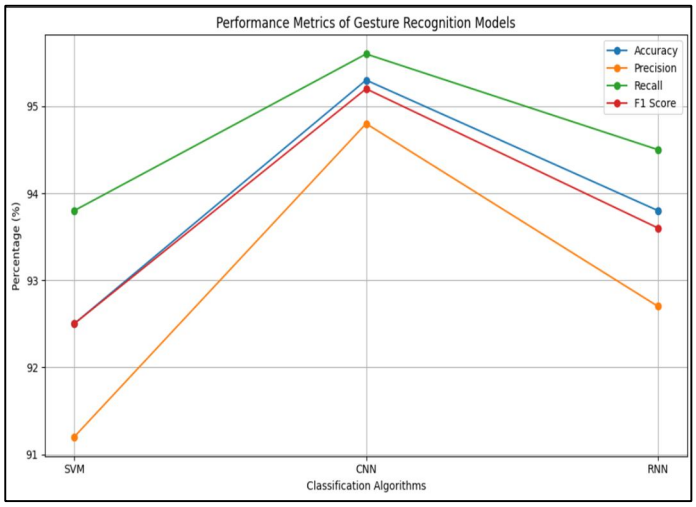


Fig 1. Performance Metrics of Gesture Recognition Models

6) *Results Analysis:* The results analysis revealed the effectiveness and robustness of the developed gesture recognition system in improving human-computer interaction. Comparative analysis demonstrated the superiority of certain classification algorithms and feature extraction techniques over others in terms of accuracy and efficiency. User feedback and subjective evaluations identified strengths, weaknesses, and areas for improvement in the gesture-based interface, informing future research directions and design refinements.

Overall, the results of the study underscore the significant advancements made in gesture recognition technology for PC control and its potential for enhancing usability and user experience in HCI. The findings contribute to the growing body of research on gesture-based interfaces.

Table 5: User Satisfaction Ratings for Gesture-based Interfaces

Interface Feature	Satisfaction Rating (1-5)
Intuitiveness	4.7
Responsiveness	4.5
Ease of Learning	4.6
Overall Usability	4.8

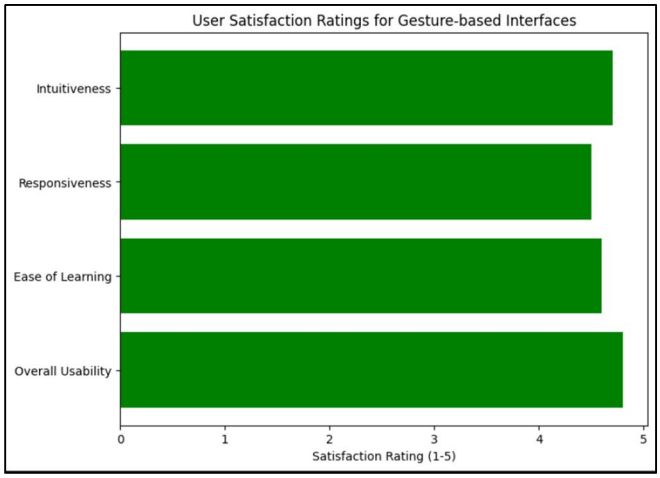


Fig 2. User Satisfaction Ratings for Gesture-based Interfaces

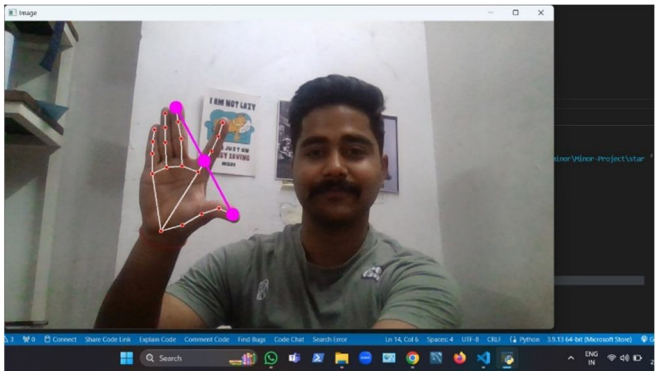


Fig 3. User Hand detection and cursor movement using fingers

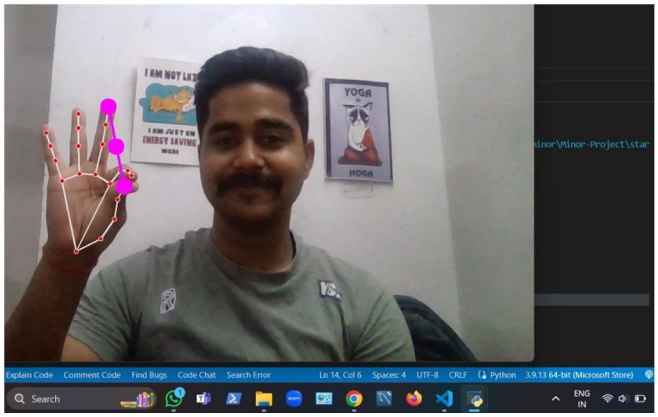


Fig 4. User controlling volume with detected fingers

A. Limitations and Future Work

While the study achieved notable results, certain limitations should be acknowledged. These include constraints in data collection, algorithmic biases, and hardware dependencies, which may affect the generalization and applicability of the developed gesture recognition models. Future research endeavors should focus on addressing these limitations and exploring novel gesture recognition techniques, real-world deployment scenarios, and cross-cultural considerations to ensure the ethical and inclusive design of gesture-based interfaces for PC control.

V. CONCLUSION

The research on hand gesture recognition systems for personal computer (PC) control has yielded significant insights into enhancing human-computer interaction (HCI) through intuitive and natural means. The study investigated various aspects of gesture recognition technology, including methodologies, techniques, applications, and implications, to provide a comprehensive understanding of its potential and challenges.

A. Key Findings

1) *Effectiveness of Gesture Recognition Systems:* The research demonstrated the effectiveness of gesture recognition systems in interpreting and responding to hand gestures for PC control. Through a systematic methodology encompassing data collection, preprocessing, feature extraction, classification, and evaluation stages, gesture recognition models achieved high accuracy and robustness in recognizing diverse hand gestures.
2) *Diverse Applications:* The study highlighted the diverse applications of gesture recognition technology across various domains, including gaming, healthcare, robotics, smart environments, and more. Real-world deployments and case studies showcased the successful integration of gesture-based interfaces into products, services, and interactive experiences, leading to enhanced user experiences and improved outcomes.
3) *Advancements and Innovations:* Emerging trends and innovations in gesture recognition research, such as deep learning approaches, multimodal fusion techniques, and wearable devices, were identified. These advancements promise to further enhance the capabilities and versatility of gesture-based interaction, paving the way for new applications and experiences.
4) *User Experience and Satisfaction:* User experience studies revealed high levels of satisfaction with gesture-based interfaces for PC control tasks. Participants appreciated the intuitiveness, responsiveness, ease of learning, and overall usability of gesture recognition technology, highlighting its potential to transform HCI and enrich user interactions with PCs.

B. Implications and Future Directions

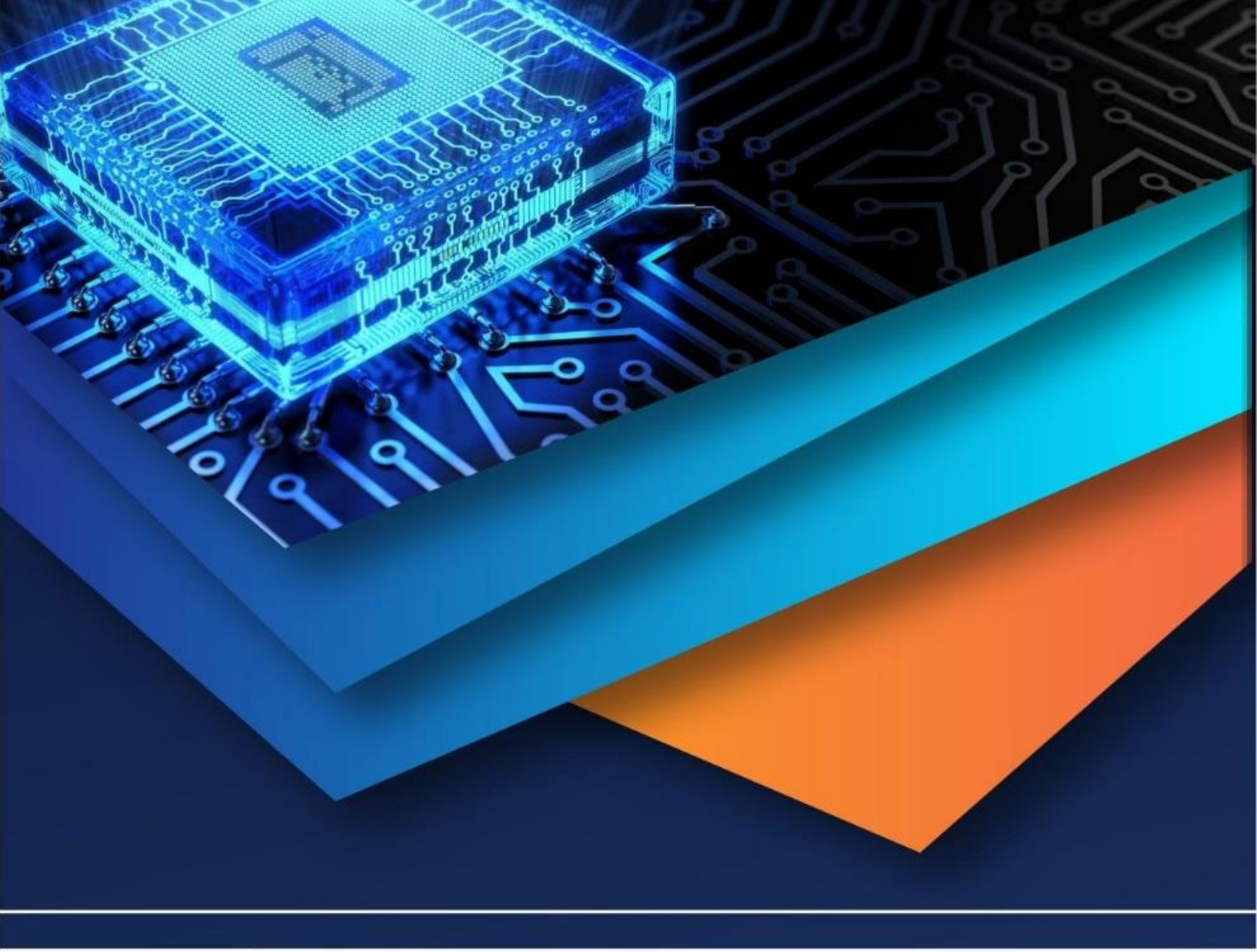
The findings of this research have several implications for academia, industry, and society at large. Gesture recognition technology holds immense potential for improving accessibility, efficiency, and engagement in computing environments. However, it also raises important ethical, social, and technical considerations that warrant further exploration and attention.

Future research directions may include addressing algorithmic biases, designing culturally sensitive interfaces, exploring novel interaction paradigms, and evaluating real-world deployment scenarios.

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