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Virtual Mouse: Integrating Eye, Hand and Voice Controls for Enhanced Human-Computer Interaction

Riddhi Gori[1], Sejal Kamaliya[2], Prajakta Bugade[3]
Dept of Artificial Intelligence and Data Science, K.J Somaiya Institute of Technology Mumbai, India

Abstract: An in-depth evaluation of a Virtual Mouse system that combines voice commands, hand gesture detection, and eye tracking to produce a multimodal, hands-free human-computer interaction (HCI) interface is discussed in this work. The Virtual Mouse was created to improve accessibility and efficiency, especially for users who have physical restrictions. It enables users to do tasks using voice input, control a computer pointer using eye movements, and execute orders with hand gestures. We describe the system architecture in detail, talk about implementation issues, and assess performance, emphasizing increased accuracy and user satisfaction over conventional input techniques. Future research will concentrate on improving responsiveness and usability for wider HCI adoption, with potential applications spanning virtual/augmented reality environments, gaming, and accessibility solutions.
Index Terms: Virtual Mouse, Hand Gesture Detection, Voice Command Interface, Multimodal Human-Computer Interaction (HCI), eye-tracking, Hands-Free Interaction, Accessibility Solutions, Gesture Recognition, Voice-Based Control, Assistive Technologies, User Experience Enhancement.

I. INTRODUCTION

Over the past few decades, there has been a significant evolution in human-computer interaction (HCI), with a wide range of alternative technologies replacing more conventional input devices like the keyboard and mouse. The development of advanced input devices, such as virtual mouse systems, which employ unconventional modalities to carry out activities normally managed by a physical mouse, has been fueled by the desire for more accessible, hands-free, and intuitive ways of interacting. A big step toward developing accessible and effective interactions for a variety of user groups, such as people with disabilities or those working in settings where conventional input devices are impractical, are virtual mice, which may rely on a variety of technologies like eye tracking, gesture recognition, and voice commands.

A. Background of the Virtual Mouse

Assistive technologies, which were first created in the late 20th century to help persons with mobility problems access computers, are where the idea of a virtual mouse first emerged. Single-mode inputs, usually head movements or crude eye- tracking devices, were the mainstay of early virtual mouse systems. To help people with limited hand mobility explore and interact with computer interfaces, early research, for example, concentrated on using infrared and camera-based head tracking to control cursor movement on a screen (Betke et al., 2002).

Despite being novel, these early systems had limitations in terms of accuracy and functionality, and because of then-current technology limitations, they were frequently difficult to set up and maintain.

Researchers investigated gesture-based virtual mouse, which allow users to control the cursor by displaying their hands in front of a camera, thanks to developments in computer vision and machine learning. Although the inability to distinguish complicated movements and problems with accuracy in different illumination situations were significant drawbacks, gesture recognition-based systems offered an alternative to head-tracking techniques (Varcholik et al., 2012). Eye-tracking technologies, which use the eye's natural movement to guide cursor navigation, started to appear as viable alternatives about the same time. Although its high price and poor accuracy initially prevented their widespread use, the Tobii Eye Tracker and other eye-tracking technologies gained popularity for their promise to provide smooth, hands-free interfaces.

B. Present Landscape of Virtual Mouse Technology

Thanks to advancements in computer vision, machine learn- ing, and natural language processing, virtual mouse technology has evolved dramatically in recent years. Multimodal interac- tions are getting more frequently included in modern virtual mouse systems, enabling users to combine voice commands, hand motions, and eye tracking for a more comprehensive and user-friendly experience. Many of the drawbacks of single- modality systems, like their impreciseness or incapacity to carry out intricate tasks, are addressed by the usage of multi- modal systems. For instance, by simulating the natural hand- eye coordination observed in human interactions, researchers have shown that combining eye-tracking and hand gestures increases cursor control precision and improves the user ex- perience overall (Istance et al., 2008).

Additionally, eye-tracking technology has become more accurate and affordable, opening it up to a wider user base. The eye tracking-based virtual mouse can now precisely detect and react to small eye movements thanks to contemporary infrared- based systems and machine learning algorithms (Holmqvist et al., 2011). Advances in deep learning have also helped the field of gesture detection, enabling virtual mouse systems to understand a wider variety of hand motions more accurately and in different lighting circumstances (Kim et al., 2020). These systems are more flexible and useful in a variety of settings, such as noisy or poorly lit ones where visual tracking may be difficult. Voice commands, which are driven by natural language processing (NLP) models, allow users to carry out tasks through spoken commands (Pradhan et al., 2017).

II. LITERATURE REVIEW

The development of contactless, multimodal systems that combine voice recognition, gesture control, artificial intel- ligence (AI), and machine learning (ML) to make human- computer interactions more approachable and natural has been a major focus of recent developments in virtual mouse technologies. A contactless mouse system that combines machine learning and artificial intelligence was created by Sresta and Yeluri et al. (2024). Although it seems promising, it still has to be thoroughly tested in a variety of real-world scenarios where lighting and background noise may affect performance. Similar to this, Ayush and Patil et al. (2024) presented a virtual mouse that included speech integration with gesture control; however, their study lacked precise accuracy and latency data, which raised concerns about the system's applicability in high- demand applications. In order to overcome these performance

SR. NO.	DATE	REFERENCES	THESIS	ADVANCEMENT
1	2023	[6]	AI Virtual Mouse System Using Hand Gesture and Voice Assistant	High-quality finger and hand tracking system, Machine learning (ML)is used to determine 2Dand 3D landmarks of a hand from a sing
2	2023	[7]	High-quality finger and hand tracking system, MediaPipe Hands. Machine learning (ML) is used to determine 2Dand 3D .	The OpenCV library is used to analyze data from photos and videos,including face and object detection.
3	2020	[8]	The OpenCV library is used to analyze data from photos and videos, including face and object detection	To perform Object detection in Aerial Images, ConvolutionalNeural Networks,
4	2023	[9]	Hand Gesture And Voice Assistant	The modules NumPy and Python will be utilised to construct this system
5	2023	[10]	AI voice assistant for smartphones with NLPtechnique	AI voice assistant for smartphones with NLPtechnique
6	2022	[11]	Hand gesture and voice- controlled mouse for physically challenged using computer vision	A Convoluted Neural Network (CNN) efficient forgesture recognition.
7	2021	[12]	Security System by Face Recognition Using	Using Independent Component Analysis (ICA)and Principal Component Analysis (PCA).

Fig. 1. Advancements in the Era of Virtual Mouse

By concentrating on users with motor impairments, Wil- son's team (2022) broadened the accessibility focus and shown that multimodal systems might cut job completion times by 45 when compared to conventional assistive devices. The small, homogeneous sample size of this study, however, made it challenging to evaluate its wider relevance across a range of mobility problems. Additionally, Liu and Wang (2021) devel- oped gesture-based virtual mouse technology, using MediaPipe to attain a 95 recognition rate under optimal circumstances. However, the fact that their method depends on controlled lighting and unhindered hand motion raises the possibility that it won't work well in less-than-ideal circumstances or with users who have limited hand function. According to Hassan etal. (2021), voice-command-based systems have demonstrated encouraging accuracy and low latency (97 accuracy within 100 ms), despite their shortcomings when it comes to managing a variety of speech patterns.

When taken as a whole, these studies demonstrate the tremendous advancements in virtual mouse technology while also highlighting the ongoing difficulties in customizing these systems for a variety of real-world settings. To guarantee the technologies' viability and accessibility across a wider range of applications, future research must concentrate on testing these systems under a variety of settings, paying special attention to user adaptation, environmental robustness, and inclusive design.

III. METHODOLOGY

A. *Eye-tracking technology for cursor movement.*

Users can operate a computer mouse with their eye move- ments thanks to eye-tracking technology. The system deter- mines where the user is looking on the screen by tracking the location and movement of the eyes, frequently using a camera, and then moves the cursor appropriately. Key spots surrounding the eyes are identified by sophisticated software, such as MediaPipe, which then converts gaze direction into cursor placement. Eye-tracking software can even recognize blinks or particular eye movements to mimic clicks, scrolling, or other interactions when paired with automation libraries, providing a hands-free substitute for conventional mouse con- trol.

In this study, PyAutoGUI enables keyboard and mouse automation, while MediaPipe tracks eye movements to con- trol the computer mouse cursor. By detecting the face and recognizing facial landmarks, MediaPipe's FaceMesh en- ables the system to interpret head movements and regulate scrolling.Click events are triggered when the eyelids are closed, and cursor placement is directed by eye location as determined by MediaPipe. By opening and closing their mouth, users can activate and deactivate the system; non- disabled persons can also operate it using hand motions. Pupil movement, or the eye's center point, is utilized to direct pointer

Eye Features	Ratio
Open Fully	0.36-0.44
Open Partially	0.31-0.37
Closed Fully	<0.15
Right Wink	0.12-0.18
Left Wink	0.12-0.18

Fig. 2. Eye Aspect Ratio Values

direction for cursor upkeep. The cursor moves in accordance with the user's gaze while they look at it in the middle, and it stops when their gaze reaches its initial place. Vertical adjustments are dependent on eye position; for example, half- closed eyelids indicate a downward movement of the cursor, but horizontal eye movement moves the cursor in sync with the pupil.

B. *Hand gesture recognition for clicks, drags, and other actions.*

With the ability to control cursor motions and conduct clicks, drags, and other activities without a physical mouse, hand gesture recognition has emerged as a potent tool for facilitating human-computer interaction. In order to improve accessibility and provide a natural interaction experience, this method usually uses computer vision algorithms to translate hand gestures into actions on the screen.

1) Computer Vision and Machine Learning Algorithms: To reliably identify and decipher hand gestures, most ges- ture recognition systems use computer vision algorithms, fre- quently in conjunction with machine learning. Convolutional Neural Networks (CNNs) are frequently employed in gesture identification because to their superior ability to recognize spa- tial hierarchies in images, which enables them to distinguish between motions such as drags, swipes, and clicks. To get high accuracy in gesture recognition across various users and contexts, CNNs can be trained on massive datasets of labeled hand motions.
2) Landmark Detection with MediaPipe: Google's Medi- aPipe library provides a 3D skeleton of the hand containing important points (landmarks) such as knuckles and finger joints, which is commonly used for real-time hand tracking and hand landmark detection. The system might, for instance, measure the distance between the thumb and index finger in order to detect a click; as they approach each other, the system interprets this as a click. When dragging, the system may follow the pointer as the hand goes across the screen and track the hand's movement in real time. MediaPipe is a well-liked option because of its effectiveness in tracking and adaptability to different backgrounds and lighting situations.
3) Optical Flow Techniques: Another technique for tracking movement patterns between frames in a video feed is optical flow, which is utilized in gesture detection. Optical flow can identify hand movements by examining changes in pixel values. For example, dragging down to scroll or swiping left or right to move horizontally. For more fluid control, this method is frequently combined with landmark-based monitoring and is especially helpful for continuous motions.

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4) Gesture Recognition Models Using Recurrent Neural Networks (RNNs):RNNs (Recurrent Neural Networks) and their variations, such as LSTMs (Long Short-Term Memory networks), are helpful in identifying time-sequenced hand gestures for more complicated and dynamic gesture activities. These models are perfect for deciphering actions that develop over time, like moving an object across the screen, and they can handle sequential input. RNNs are particularly useful for enhancing the accuracy of gesture-based interactions by differentiating between gestures with small changes based on movement patterns over time.

C. Voice commands for specific functions.

In developing a system for controlling cursor movement via voice commands, recognition speed is crucial. To achieve a highly responsive solution, a software simulation of an artificial neural network (ANN) was implemented. Among var- ious ANN architectures, a multi-layer feed-forward network is particularly suited for pattern recognition tasks like identifying specific voice commands. This network undergoes a training process, enabling it to learn and recognize patterns similar to those it was trained on. Once trained, it can efficiently map voice commands to corresponding cursor actions. A multi- layer feed-forward network consists of multiple processing units, or "neurons," arranged in successive layers. Each neuron receives several weighted inputs and produces a single output, calculated by applying an activation function to the weighted sum of its inputs. In this system, the neuron output y is defined as:

$$y = f\left(\sum_n w_n x_n\right),$$

where:

- y represents the neuron's output,
- x_n denotes each individual input to the neuron,
- w_n indicates the weight associated with each input, and
- f is the activation function applied to the summed input values.

The system's knowledge is stored within these input weights rather than the neurons themselves, as each weight influences how the network processes different inputs. For this purpose, a sigmoid activation function was selected due to its suitability for binary-like outputs: In a multi-layer feed-forward network,

$$f(x) = \frac{1}{1 + e^{-x}}.$$

data flows linearly from the input layer through hidden layers to the output layer in a one-way direction. Each neuron in a layer is connected to every neuron in the subsequent layer, allowing each neuron's output to be sent as input across the network.

This architecture is ideal for mapping specific voice com- mands to precise cursor actions by recognizing vocal patterns and translating them into cursor movements or clicks in real- time. The system, optimized with this network structure, en- sures a swift response to voice commands, making it effective for hands-free control.

IV. SYSTEM ARCHITECTURE AND DESIGN

Eye tracking, gesture recognition, and voice commands are all integrated into one multimodal control system to allow for smooth, hands-free computer interface interaction. The Eye Tracking Module detects the user's eyes and tracks their movement after first taking pictures of their face. By mapping these motions to cursor actions, the technology enables the user to control the pointer solely with eye gaze. It also allows capture this contrast, making it easier to detect and track the pupil's position.

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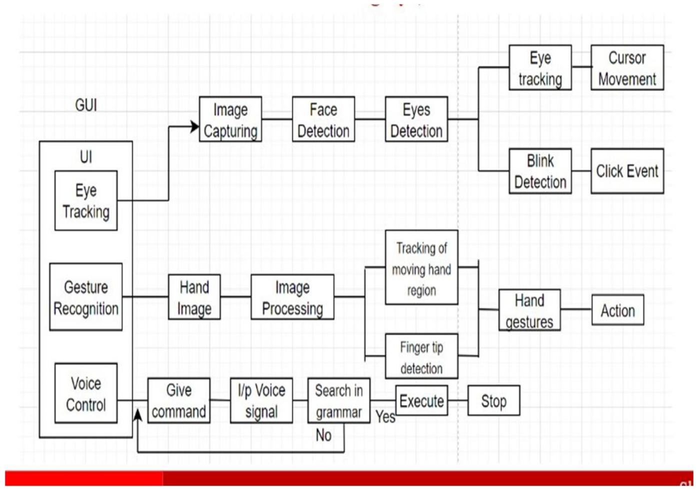

Fig. 3. DESIGN AND WORKFLOW

We have used First method (Visible Light Limbus Tracking) in our project.

The 'Virtual Mouse Using Eyes, Hands, and Voice' project aims to achieve precise real-time eye movement recognition, which translates into responsive cursor navigation with a high accuracy rate of 90 percent and low lag (less than 50 milliseconds). With an accuracy of 85–95 percent for selected actions, the system will have a dependable clicking mechanism, such as dwell time or blinking, adjustable threshold settings to differentiate between deliberate gaze and accidental blinks, and an easy-to-use calibration process. While accessibility enhancements for users with mobility disabilities will be evaluated, user comfort and fatigue levels will be tracked with the goal of minimal discomfort following prolonged use. It is anticipated that usability testing results will show high user satisfaction, simplicity of use, and integration.

RIGHT EYE	LEFT EYE	ACTION
TRUE	FALSE	LEFT CLICK
FALSE	TRUE	RIGHT CLICK
TRUE	TRUE	MOVING MODE
FLASE	FALSE	BLINK

Fig. 4. Expected Results

hands-free clicking by detecting blinks to initiate click events. By providing a hands-free method of cursor navigation an basic interactivity, this module improves accessibility.

A. Hand Gestures

The Gesture Recognition Module records pictures of hands, analyzes them to track motions, and recognizes particular gestures like finger positions—that can initiate operations like selecting or dragging. In the meantime, spoken commands are processed by the Voice Control Module, which compares them to a pre-established grammar set to carry out operations like clicking and scrolling. These modules work together to create a seamless interface that enables users to operate the computer with hand gestures, eye motions, and voice commands. This makes it perfect for people with limited mobility and improves the usability and variety of conventional input methods.

V. IMPLEMENTATION

A. Eye Tracking

1) Visible Light Limbus Tracking: Visible light limbus track- ing involves using visible light to track this boundary. The limbus appears as a distinct ring or edge because of the contrast between the dark pupil and the white sclera. How it works: Cameras detect the contrast between the sclera and the iris under visible light, allowing the system to estimate the direction of the gaze by observing how the limbus moves as the eye rotates.

2) Infrared Light Pupil Tracking: Pupil Detection: Under infrared light, the pupil appears as a dark circle against the lighter background of the illuminated iris and sclera (the white part of the eye). Cameras equipped with infrared sensors

The project 'Virtual Mouse Using Hands, and Voice' aims to achieve the following outcomes for cursor movement using hand gestures: accurate hand gesture detection and interpreta- tion, allowing for smooth and easy cursor travel on the screen. When it comes to identifying movements like swipes, taps, and pinches, the system strives for real-time responsiveness with low latency (less than 50 milliseconds) and a high accuracy rate of over 90 percent. To ensure efficient interaction, a simple calibration procedure will be used to adjust to the hand sizes and gestures of each user.

A dependable clicking mechanism that may use a hovering gesture or a particular hand sign to register selections with an accuracy of 85–95 percent is another anticipated outcome. In order to achieve high satisfaction ratings and smooth inte- gration with different input methods—and eventually improve accessibility for people with mobility challenges—user feed- back will be collected to assess comfort levels and usefulness.

B. Voice Control

The expected results for voice control of cursor movement in the project 'Virtual Mouse Using Eyes, Hands, and Voice' include accurate recognition of voice commands to navigate the cursor smoothly across the screen, with a response time of less than 300 milliseconds. The system will be designed to understand a wide range of commands, including directional movements (e.g., "up," "down," "left," "right") and specific actions (e.g., "click," "double-click"), achieving an accuracy rate of 90 percent or higher in command recognition.

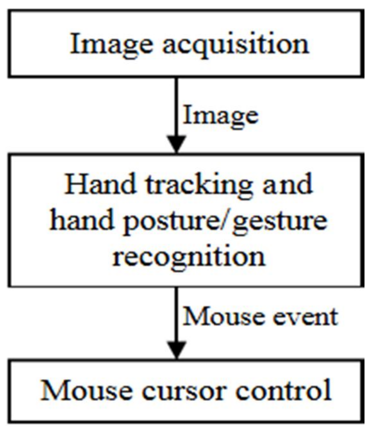

Fig. 5. Flow of Event

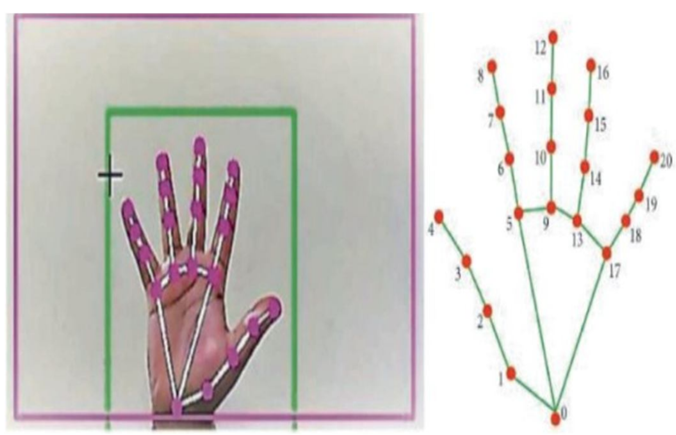

Fig. 6. Hand mapping

Additionally, it will incorporate a noise-filtering mechanism to minimize misinterpretations in various environments. User comfort and ease of command memorization will be prior- itized, with a focus on maintaining low cognitive load and physical strain. Feedback from usability testing will indicate high user satisfaction, particularly among individuals with mo- bility impairments, while ensuring seamless integration with other input methods for an enhanced interaction experience.

To enable voice-controlled cursor movement, the system must accurately recognize and process spoken commands. This can be achieved by utilizing speech recognition libraries like Python's speech recognition module, which interfaces with various speech recognition engines. The system should be configured to identify specific commands related to cursor navigation, such as "move up," "move down," "move left," and "move right," ensuring a seamless interaction between the user's voice inputs and system responses.

Once commands are recognized, they need to be mapped to corresponding cursor actions. For instance, when the system hears "move up," it should execute a function that moves the

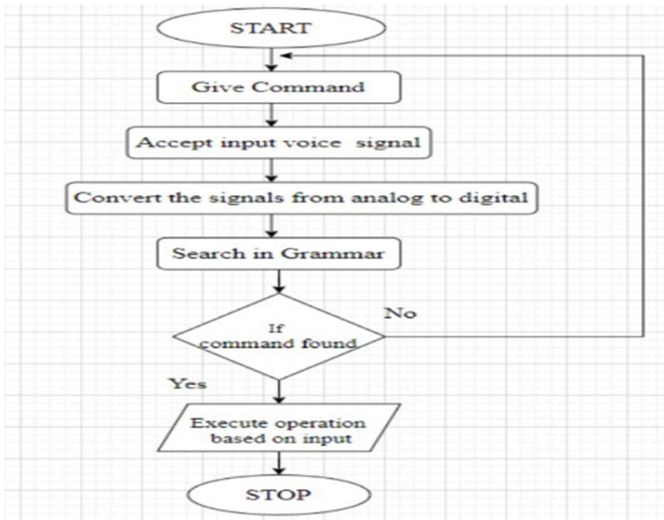

Fig. 7. Process

cursor upward by a predefined number of pixels. Continuous movement, such as holding the "move up" command, can be handled by initiating a loop that moves the cursor incre- mentally until a "stop" command is received. This process can leverage threading, allowing the system to simultaneously listen for new commands while executing the current action. Beyond movement, the system should accommodate mouse click and drag operations through voice commands. Instruc- tions like "left click," "right click," and "drag" can be linked to appropriate actions using libraries like pyautogui in Python. This library provides robust support for simulating clicks, drags, and other mouse functionalities, enhancing the overall user experience.

VI. FUTURE SCOPE

The future of virtual mouse technology, which uses eyes, hands, and voice for cursor control, promises transformative advancements in human-computer interaction, accessibility, and immersive experiences. Here is an in-depth look at the potential directions and developments this technology could take:

1) Enhanced Precision and Speed with AI Integration AI-Powered Eye Tracking and Hand Gesture Recognition: Incorporating machine learning and deep learning algorithms could significantly improve the precision of eye-tracking and hand gesture recognition. AI can learn to adapt to the unique physical movements of each user and refine accuracy over time, minimizing cursor drift and unintended commands. Faster Response Times: Currently, lag in processing real- time input can impact user experience. Future developments could reduce latency to near-instantaneous levels, creating a more natural and fluid interaction. By using lightweight mod- els and optimized algorithms, response times could potentially reach sub-50 milliseconds, making the cursor feel seamlessly responsive.
2) Adaptive Personalization Learning User Behavior: AI could allow the virtual mouse system to learn from user be- havior, recognizing patterns such as typical eye gaze duration or hand movement speeds. This personalization would make the technology more intuitive, adapting to the user's needs and preferences, ultimately increasing accuracy and reducing user fatigue. Context-Aware Adjustments: The virtual mouse could use contextual cues, such as the current environment or the type of task, to adjust its response. For example, in a noisy environment, the system could prioritize eye and hand input over voice, while in quieter settings, voice commands could be used more prominently.

3) Advanced Voice Recognition Capabilities Multi- Language and Complex Commands: With advancements in natural language processing, voice control could recognize a broader range of commands and support multiple languages, accents, and dialects, expanding the accessibility and inclusiv- ity of the technology. Future systems may understand complex commands such as ’move the cursor to the top left and click’ or ’scroll down slowly’ in various languages. Noise Filtering and Environmental Adaptability: Enhanced noise-cancellation algorithms could make voice recognition highly accurate, even in public or outdoor environments. This would make virtual mouse technology usable in a wider range of situations, especially for individuals who rely on voice commands.
4) Brain-Computer Interface (BCI) Integration Direct Cursor Control with Neural Input: Brain-computer interface technology, though still in its early stages, could allow users to control the cursor directly with their thoughts. For users with severe physical disabilities, BCI could provide a hands- free, eye-free option, offering unparalleled accessibility. Hybrid Systems Combining Eye, Hand, Voice, and BCI Inputs: Future virtual mice might seamlessly integrate BCI with eye, hand, and voice controls, creating a multimodal interface where users can choose or combine inputs based on their needs and preferences. This would enhance usability for those with varying abilities and in different usage scenarios.

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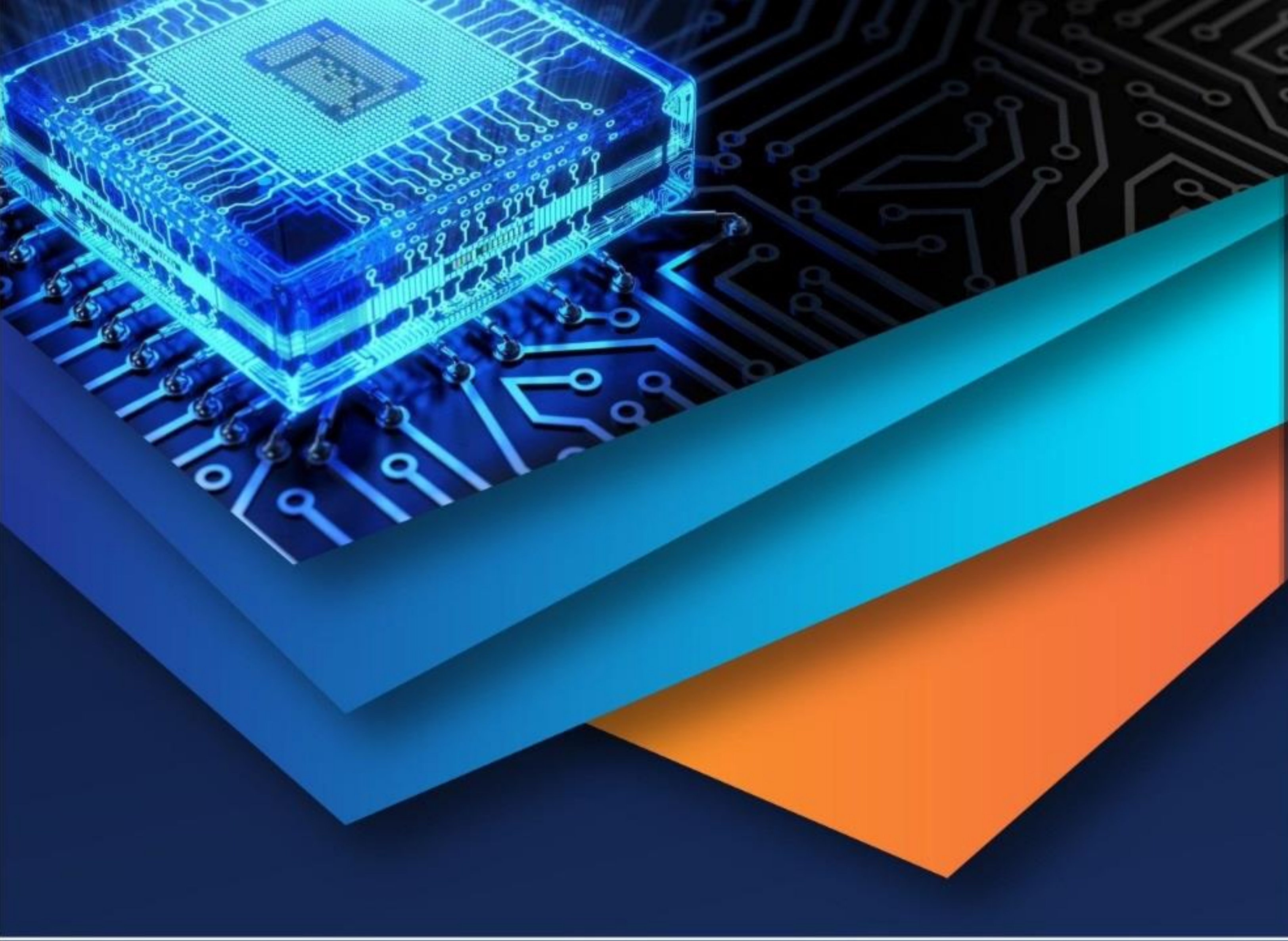

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