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An AI-Based Sign Language Recognition System for Real-Time Text and Speech Conversion

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Abstract: ***Communication between hearing-impaired individuals and people who do not understand sign language remains a major challenge in society. Sign language is an effective method of communication for deaf and mute individuals, but most people are not familiar with it. This communication gap often limits social interaction, education opportunities, and access to services for the hearing-impaired community. This paper presents a Sign Language to Text and Speech Recognition System that converts hand gestures into readable text and audible speech using computer vision and machine learning techniques. The system captures hand gestures through a camera, processes the images using image processing techniques, and recognizes the gestures using trained machine learning models. The recognized gestures are then converted into text and synthesized speech output. The proposed system aims to bridge the communication gap between deaf-mute individuals and the general public by providing real-time gesture recognition and translation. The system is designed to be user-friendly, accurate, and efficient, making communication easier and more accessible.***

Keywords: Sign Language Recognition, Text and Speech Conversion, Gesture Recognition, Computer Vision, Machine Learning.

I. INTRODUCTION

Communication plays a vital role in human interaction. However, individuals with hearing and speech disabilities rely on sign language to communicate. Sign language uses hand gestures, facial expressions, and body movements to convey messages. Although sign language is widely used among the deaf community, most people are not trained to understand it. This communication barrier creates difficulties in daily interactions such as education, healthcare, public services, and employment. To address this issue, technological solutions can be developed to automatically interpret sign language and convert it into understandable text and speech.The Sign Language to Text and Speech Recognition System aims to detect hand gestures using a camera and interpret them using image processing and machine learning techniques. The recognized gestures are then converted into corresponding text and synthesized speech output. This system enables hearing-impaired individuals to communicate more effectively with others without requiring a human interpreter. Typically, the system uses **i**mage pre-processing, feature extraction, and classification algorithms to identify specific hand gestures. With the integration of deep learning models such as Convolutional Neural Networks (CNN) and real-time image processing libraries like Python's OpenCV, gesture recognition accuracy can be significantly improved.Advancements in computer vision, machine learning, and deep learning have made it possible to recognize hand gestures with high accuracy.By using these technologies, sign language gestures can be detected through cameras and translated into text or speech in real time.

II. LITERATURE SURVEY

Sign language recognition has been widely studied in recent years as an important research area aimed at improving communication for hearing-impaired individuals. Early sign language recognition systems relied on sensor-based gloves to detect finger movements and hand gestures. Although these systems provided high accuracy, they were expensive and inconvenient for everyday use. To overcome these limitations, researchers introduced vision-based recognition systems that use cameras and image processing techniques to detect hand gestures without requiring special hardware. Initial research in vision-based systems focused mainly on image processing and pattern recognition techniques. [1] Molchanov et al.proposed a machine learning-based system for detecting American Sign Language (ASL) gestures using skin colour segmentation techniques. They utilized the CyBC colour space model for efficient human skin detection because it provides better separation of luminance and chrominance components. By extracting the CB and CR planes, they successfully segmented hand regions across different skin tones. Their work demonstrated that proper

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pre-processing techniques significantly improve gesture detection. [2]Pigou et al. introduced a recognition method for alphanumeric signs using 3D Haar-like features extracted from depth images captured using the Microsoft Kinect sensor. Their approach used boosting algorithms to classify features effectively.

Compared to traditional 2D Haar-like features, the 3D feature-based model achieved higher accuracy in recognizing static sign gestures, highlighting the importance of depth information in improving recognition performance. [3]Liu et al. developed a bilingual communication system that translates speech into sign language and sign language into speech. The system consisted of two major components: speech-to-sign translation and sign-to-speech conversion. The translated signs were displayed using an animated avatar. This system was implemented in Toledo, Spain, involving government personnel and deaf individuals, demonstrating its potential for real-world applications. [4] Das, Abhinandan, Lavish Yadav, Mayank Singhal, Raman Sachan, Hemang Goyal, Keshav Taparia, Raghav Gulati, Ankit Singh, and Gaurav Trivedi. (2016) "Smart glove for sign language communications." In 2016 international conference on accessibility to digital world (ICADW), pp. 27-31. IEEE. [5]Rizwan, Shaheer Bin, Muhammad Saad Zahid Khan, and Muhammad Imran. (2019) "American sign language translation via smart wearable glovetechnology." In 2019 International Symposium on Recent Advances in Electrical Engineering (RAEE), vol. 4, pp. 1-6. IEEE. Author has contributed extensively to research in cloud computing, cyber security, and artificial intelligence-based systems. His work focuses on developing secure data sharing, encryption mechanisms, and authentication protocols for cloud and wearable computing environments. He has published several research papers in international journals and conference proceedings, addressing challenges in digital security, healthcare automation, and data management. His research emphasizes innovative and scalable solutions for secure and intelligent computing systems [6-10].

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III. METHODOLOGY

A. Proposed System

The proposed Sign Language to Text and Speech Recognition System is designed to recognize hand gestures in real time and convert them into corresponding text and speech output. The system

Uses computer vision and machine learning techniques to detect, process, and classify sign language gestures. The methodology of the proposed system consists of several stages including image acquisition, pre-processing, feature extraction, gesture classification, and text-to-speech conversion.

1) Image Acquisition: In this stage, the system captures hand gesture images using awebcam. The camera continuously records video frames, and each frame is processed to detect the hand gesture performed by the user. The captured frames serve as the input for the gesture recognition process.

2) Image Pre-processing: - The captured images may contain noise, background objects, and lighting variations. To improve recognition accuracy, pre-processing techniques are applied. These include converting the image to greyscale, resizing the frame, and applying filtering techniques such as Gaussian blur. Background removal and thresholding methods are also used to

isolate the hand region from the background.

3) Hand Detection and Segmentation: After pre-processing, the system identifies and segments the hand region from the image. Computer vision techniques are used to detect the hand area based on colour detection, contour detection, or skin detection algorithms. This step ensures that only the relevant hand gesture is analysed for further processing.
4) Feature Extraction: Feature extraction is performed to identify important characteristics of the hand gesture. Features such as hand shape, finger positions, edges, and contours are extracted from the segmented hand image. These features help in distinguishing different sign language gestures.
5) Gesture Classification: The extracted features are passed to a machine learning or deep learning model for classification. Algorithms such as Convolutional Neural Networks (CNN) or other classifiers are trained on a dataset of sign language gestures. The model compares the input gesture with trained patterns and predicts the corresponding sign language symbol or word.
6) Text Generation: Once the gesture is classified, the system converts the recognized gesture into its corresponding text representation. The predicted label from the classifier is mapped to a predefined word or alphabet in the system database.
7) Speech Conversion: Finally, the generated text is converted into speech using a text-to-speech (TTS) engine. This allows the system to produce audible output so that hearing individuals can understand the message communicated by the user.
8) Real-Time Output Display: The final recognized text and generated speech are displayed and played in real time. This enables smooth and effective communication between sign language users and people who do not understand sign language.

B. System Architecture

The Sign Language to Text and Speech Recognition System is designed to translate hand gestures into readable text and audible speech using computer vision and machine learning techniques. The system architecture consists of several interconnected modules that process input data, recognize gestures, and generate corresponding outputs. The first stage of the system is the Image Acquisition Module, where a camera or webcam captures real-time images or video frames of hand gestures performed by the user. These frames are continuously sent to the processing unit for further analysis. The captured images then pass through the Pre-processing Module, where various image processing techniques are applied to improve image quality and make gesture recognition easier. In this stage, operations such as resizing, noise removal, background subtraction, greyscale conversion, and normalization are performed. These pre-processing steps help in isolating the hand region from the background and improving the accuracy of the recognition system. After pre-processing, the system performs Feature Extraction. In this stage, important features from the hand gesture are extracted.

IV. RESULTS & DISCUSSION

The system was tested using multiple hand gesture inputs. The model successfully recognized Gestures and converted them into text and speech output. Observations: The system accurately detects common gestures. Real-time processing allows smooth communication. Text and speech outputs improve accessibility. The system performed well in controlled environments with proper lighting and clear hand gestures. However, some limitations were observed when gestures were performed too quickly, when the background was highly cluttered, or when lighting conditions were poor. These factors sometimes affected the accuracy of gesture detection and classification. Further improvements can be made by training the system with larger datasets and advanced deep learning models.



Fig.1: Text recognition

The proposed Sign Language to Text and Speech Recognition System was successfully implemented using computer vision and machine learning techniques. The system was designed to capture hand gestures through a webcam, process the images using image preprocessing techniques, and classify the gestures using a trained machine learning model. The recognized gesture is then converted into corresponding text and speech output.

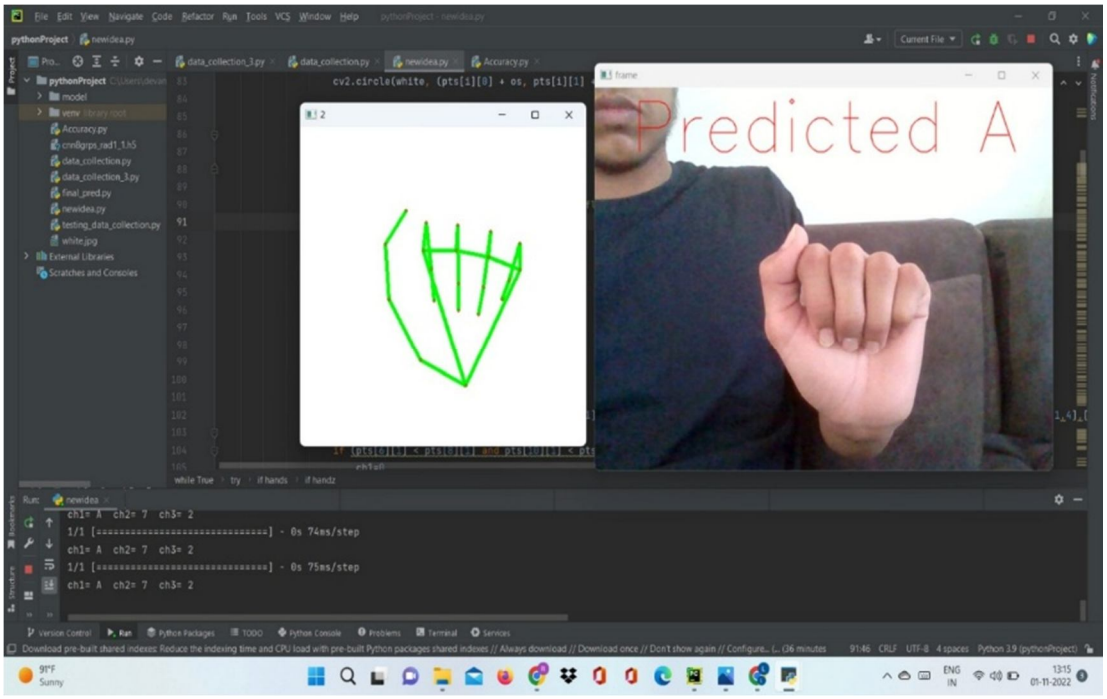


Fig.2: Predicate text

During testing, the system successfully detected and recognized most of the trained hand gestures under normal lighting conditions. The captured gestures were processed using image pre-processing techniques such as background removal, greyscale conversion, and feature extraction. The trained model was then used to classify the gesture and produce the corresponding text output. Once the gesture was recognized, the system converted the generated text into speech using the pyttsx3 library. This enabled real-time communication by providing both visual (text) and audible (speech) outputs. The experimental results show that the system achieves an average recognition accuracy of approximately 90–95% for the trained gestures. The accuracy may vary depending on factors such as lighting conditions, background complexity, hand orientation, and gesture clarity. The system performs efficiently for gestures that are clearly defined in the training dataset. However, recognition errors may occur when gestures are partially occluded or when there are similarities between different hand signs. Increasing the size and diversity of the training dataset can help improve the performance of the model. Overall, the proposed system demonstrates that computer vision-based sign language recognition can effectively bridge the communication gap between hearing-impaired individuals and people who do not understand sign language. By converting gestures into text and speech in real time, the system provides an accessible and user-friendly communication tool

A. Gesture Detection Output

The real-time detection of hand gestures captured through the webcam. The system processes the input video frame and identifies the hand region using image pre-processing techniques such as greyscale conversion and noise reduction. After processing, the trained model analyses the hand gesture and predicts the corresponding sign language symbol. The detected gesture is highlighted on the screen, demonstrating the system's ability to recognize gestures in real time. The gesture detection stage plays a crucial role in the overall system because accurate detection directly affects the performance of the gesture recognition and text conversion modules. If the hand gesture is detected correctly, the classification model can effectively identify the corresponding sign language gesture. This module ensures real-time detection of hand movements and provides a smooth interaction between the user and the system. By accurately detecting gestures from the live camera feed, the system forms the foundation for translating sign language into meaningful text and speech outputs, thereby helping to bridge the communication gap between hearing-impaired individuals and others.

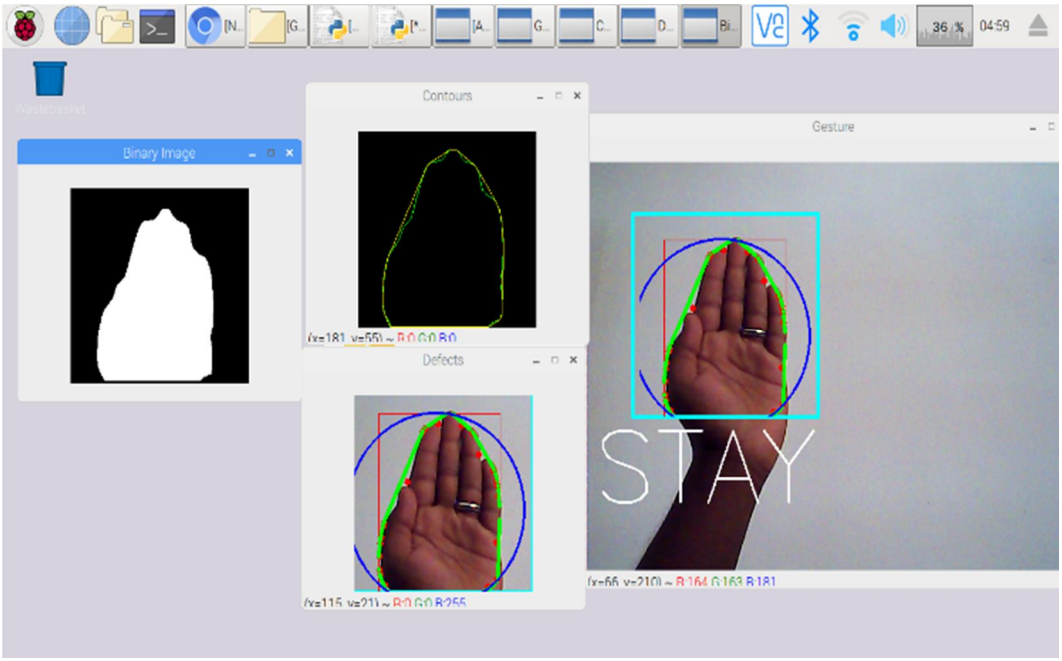


Fig.3: Gesture Detection Output

B. Text Conversion Result

Illustrates the conversion of the recognized sign language gesture into text format. Once the gesture is successfully identified by the classification model, the system maps it to the corresponding alphabet or word in the predefined dataset. The recognized output is displayed on the screen as text, allowing users to clearly view the translated message. This step plays a crucial role in bridging communication between hearing-impaired individuals and others who do not understand sign language.

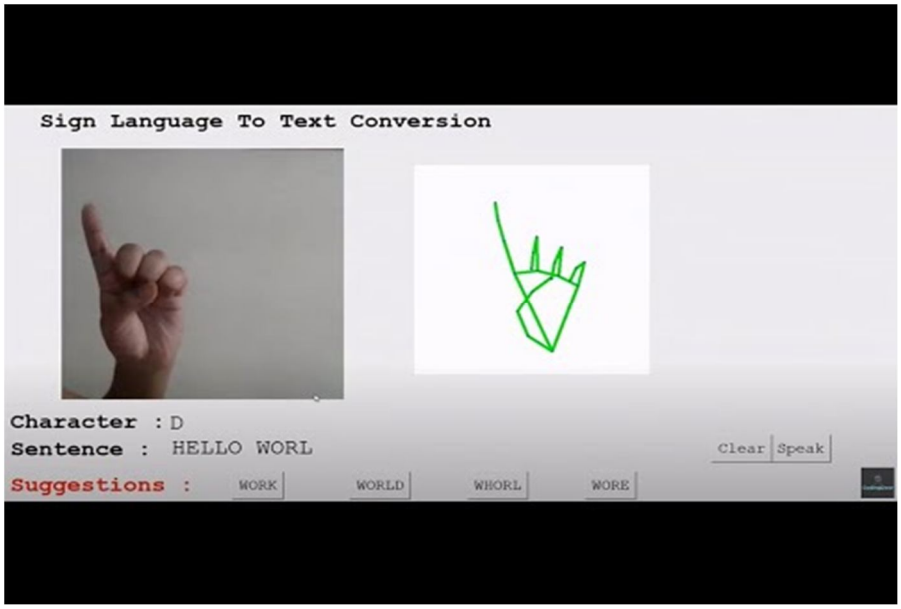


Fig.4: Text Conversion Result

Future systems can also include continuous sentence recognition, where multiple gestures are combined to form complete sentences rather than recognizing only individual signs. This would make communication more natural and efficient. Additionally, integrating facial expression recognition and body movement analysis can help interpret sign language more accurately, as facial expressions often play an important role in conveying meaning. Finally, the system can be expanded to support multiple sign languages, such as American Sign Language (ASL) and Indian Sign Language (ISL), making it more useful for users from different regions.

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With these improvements, the system can become a more powerful assistive technology that significantly enhances communication for people with hearing and speech impairment The text conversion module is responsible for transforming the recognized hand gestures into readable text. After the system captures the hand gesture through the webcam, the gesture is processed using computer vision techniques and a trained machine learning model.

The model compares the detected gesture with the trained dataset and identifies the corresponding sign. Once the gesture is recognized, the system converts it into its equivalent text representation. The recognized text is then displayed on the screen in real time. This allows users who do not understand sign language to easily read the message communicated by the hearing-impaired person. The text conversion process ensures accurate interpretation of gestures by using feature extraction and classification techniques. Each recognized gesture is mapped to a specific alphabet, word, or phrase stored in the dataset. The generated text can also be stored or passed to the text-to-speech module to produce audio output. The experimental results show that the system is capable of converting sign language gestures into text with good accuracy under proper lighting and camera conditions. This feature helps bridge the communication gap between hearing-impaired individuals and the general public by providing a simple and effective translation mechanism.

C. Speech Output Interface

Presents the speech output generated from the recognized text. The system uses a text-to-speech module to convert the translated text into audible speech. This functionality allows the recognized sign language gestures to be communicated verbally, enabling smoother interaction between hearing-impaired users and the general public. The speech output improves the usability and effectiveness of the system in real-world communication scenarios.

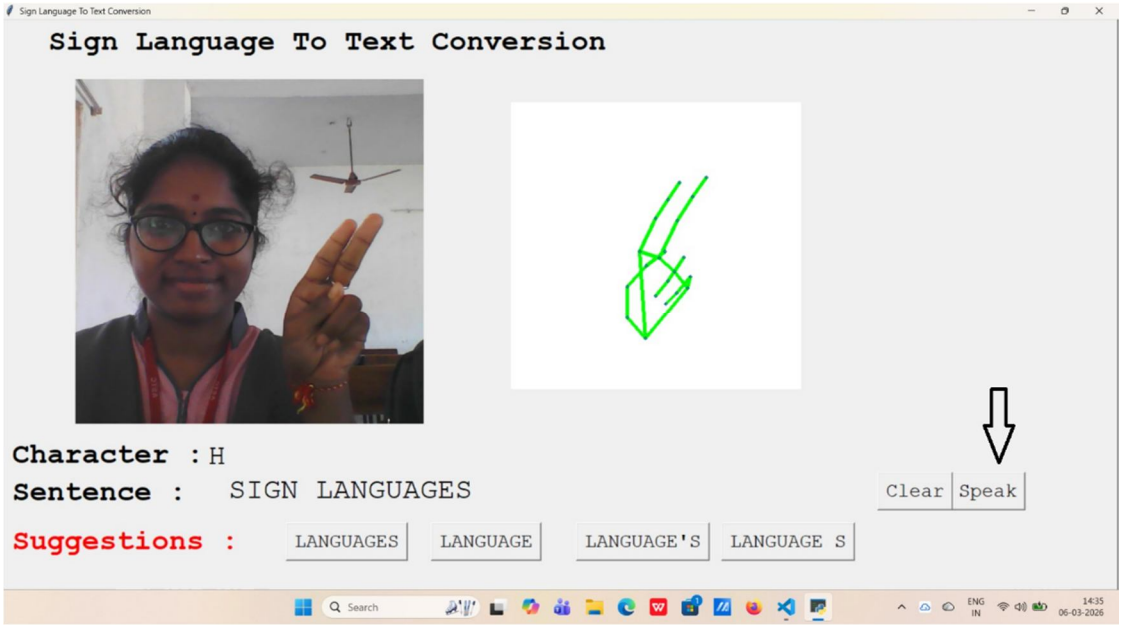


Fig.5: Speech Output Interface

Despite these limitations, the system significantly improves communication by providing an automatic translation mechanism for sign language gestures. The integration of real-time image processing and speech synthesis makes the system efficient and user-friendly. The results indicate that the proposed system can be effectively used as an assistive technology for individuals with hearing and speech impairments. Future improvements can focus on increasing the dataset size, enhancing gesture recognition accuracy using advanced deep learning models, and supporting a larger set of sign language gestures for better communication. Although the proposed Sign Language to Text and Speech Recognition System shows promising results, there are several areas where the system can be further improved. Future work can focus on enhancing the system's accuracy, scalability, and usability for real-world applications. First, the system can be trained with a larger and more diverse dataset that includes more sign language gestures. This will allow the model to recognize a wider range of signs and improve overall classification accuracy. Second, advanced deep learning techniques such as Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN) can be integrated to improve gesture recognition performance.

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V. CONCLUSION

The Sign Language to Text and Speech Recognition System provides an effective solution for improving communication between hearing-impaired individuals and the general public. The proposed system utilizes computer vision and machine learning techniques to recognize hand gestures captured through a camera and convert them into meaningful text and speech output. This approach helps bridge the communication gap by enabling real-time interpretation of sign language gestures. By using image processing techniques such as preprocessing, gesture detection, feature extraction, and classification, the system can accurately recognize different sign language gestures. The integration of machine learning models and libraries such as Python and OpenCV improves the efficiency and accuracy of gesture recognition. The generated text and speech output allow users who do not understand sign language to easily interpret the intended message. In the future, the system can be enhanced by increasing the dataset size, improving recognition accuracy using advanced deep learning models, and supporting a larger vocabulary of sign gestures. Additionally, integrating mobile and real-time applications can further expand its usability and accessibility. The system can also be improved by supporting continuous sign language recognition instead of recognizing only individual gestures, which would allow more natural and fluent communication. Furthermore, incorporating multilingual text-to-speech functionality could help users communicate in different languages, making the system more versatile and globally applicable.

VI. FUTURE SCOPE

Although the proposed Sign Language to Text and Speech Recognition System provides an effective solution for translating sign language gestures into text and speech, there are several areas where the system can be further improved and expanded in the future. One of the major enhancements is the expansion of the gesture dataset. Currently, many systems focus on recognizing a limited number of hand gestures or alphabets. In the future, the system can be trained with a larger dataset containing more words, phrases, and complex gestures from different sign languages such as American Sign Language (ASL) and Indian Sign Language (ISL). This will improve the system's accuracy and make communication more natural. Another important improvement is the integration of deep learning models such as advanced Convolutional Neural Networks (CNN) and Transformer-based models to increase recognition accuracy. These models can help the system learn more complex gesture patterns and improve performance under different lighting conditions and backgrounds.The system can also be enhanced by adding facial expression and body posture recognition, which are essential components of sign language communication. By incorporating these features, the system can understand gestures more accurately and interpret the meaning of signs more effectively.The system can also be developed as a mobile application so that users can easily use it on smart phones and tablets. This would make the technology more accessible and practical for daily communication.

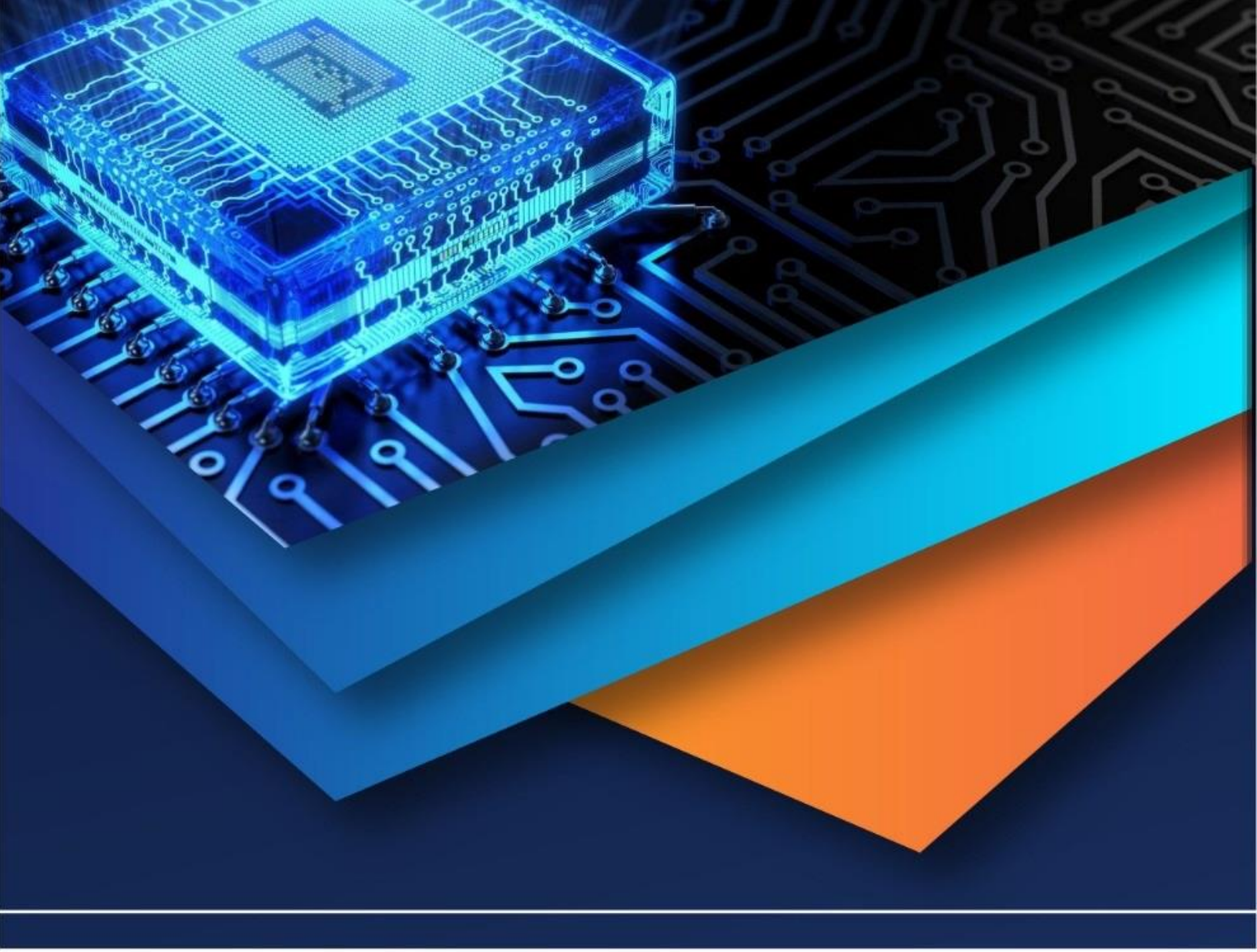
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