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Intelligent System for Audio-to-Text and Text-to-Sign Conversion across Indian and American Sign Languages: Implementation and Evaluation

Shital Aher[1], Pratiksha Avhad[2], Pradnya Gaikwad[3], Gitanjali Khandage[4], Prajakta Pedhekar[5]
[1]*Assistant Professor, Dept. of Information Technology, SVIT, Nashik*
[2,3,4,5] *B.E. Information Technology, Dept. of Information Technology, SVIT, Nashik*

Abstract: ***Translating sign languages poses real hurdles from regional variations and the push for instant processing, particularly bridging Indian Sign Language (ISL) and American Sign Language (ASL). In this work, we roll out a fresh setup enabling two-way shifts between text or voice inputs and sign video outputs. Drawing on MediaPipe for pinpointing landmarks, SMPL-X for shaping poses, and Bezier interpolation to ease transitions, the system renders gestures letter by letter from a JSON pose database. It packs modular pieces like TextProcessor for breaking down text and MotionEngine for handling movement. Voice handling comes via Whisper transcription and TTS output. Overall, the build makes tweaks simple and opens doors for adding more sign languages down the road.***

Keywords: Sign Language Translation, Bidirectional Framework, Indian Sign Language (ISL), American Sign Language (ASL), Pose Estimation, Motion Interpolation, MediaPipe, SMPL-X.

I. INTRODUCTION

Sign languages serve as a lifeline for deaf and hard-of-hearing folks around the globe, with more than 70 million people relying on them every day to chat and connect. But here's the rub: these languages vary wildly by region, throwing up walls that make talking across borders tough. Take Indian Sign Language (ISL)—it's got roots in Indo-Pakistani culture, leaning on single-hand moves, loads of context, and facial cues to get the point across. Flip to American Sign Language (ASL), which borrows from French roots, and you'll see more two-handed action baked right into the grammar through body shifts and expressions. These quirks mean folks using ISL and ASL often struggle to understand each other, and most tech out there sticks to spotting still images or basic word translations, skipping the real-time, back-and-forth video magic needed for smooth convos.

In our earlier review, we sketched out a setup to tackle this head-on. Now, this paper dives into the nuts and bolts of building and testing that bidirectional system for flipping between text or voice inputs and sign video outputs, linking ISL and ASL seamlessly. We rolled it out using MediaPipe to snag hand and body landmarks on the fly, SMPL-X to model poses parametrically, and a JSON database sorted by letters for spot-on gesture pulls. To keep things flowing naturally, we tossed in Bezier curve tweaks for transitions, plus a CNN to guess signs back into text. The whole thing juggles inputs like typed words, spoken audio crunched by Whisper, or live webcam feeds, spitting out avatar-signed videos, TTS-spoken words, or plain text.

We put it through its paces with real datasets like WLASL for ASL and INCLUDE for ISL, tweaking the CNN on thousands of frames to hit solid accuracy. Tests showed it clocks in under 2 seconds for short phrases on standard laptops, and user feedback highlighted how the smoother animations boosted understanding by about 25%. We also added admin perks for updating poses or retraining models without a full overhaul. This modular vibe not only bridges ISL-ASL gaps but paves the way for tossing in more languages, aiming to make communication more open for everyone.

II. LITERATURE SURVEY

Sign language tech has come a long way, shifting from basic hand-spotting to full-on smart systems blending vision and AI. We dug into key studies to spot gaps our setup fills, especially for crossing ISL and ASL with smooth, real-time flips.

[1] Kumar et al. (2025) explore the integration of Large Language Models (LLMs) to improve the linguistic accuracy of translations between American Sign Language (ASL) and Indian Sign Language (ISL). Their work addresses the complex grammatical differences between the two systems, using generative AI to produce more natural and contextually relevant translations than traditional mapping methods.

[2] Aher et al. (November 2025) present a review paper focused on the architectural requirements for an intelligent system capable of multi-modal translation. They specifically examine the pipeline required to convert audio to text and subsequently into sign language animations, bridging the communication gap between hearing individuals and the deaf community across ISL and ASL.
[3] Aher et al. (March 2026) follow up their review with a study on the practical implementation and evaluation of an intelligent translation system. This research provides empirical data on how well the system performs in real-world scenarios, measuring the accuracy of audio-to-text-to-sign workflows for both Indian and American Sign Languages.
[4] Patil et al. (2023) investigate the concept of "Air Handwriting" as an alternative communication modality using Artificial Intelligence. Their research demonstrates how computer vision can track finger movements in free space to recognize characters, providing a secondary tool for individuals who may not be proficient in formal sign language.
[5] Patil et al. (2024) expand on their previous air handwriting research by refining the Machine Learning models used for character recognition. This version of the study focuses on improving the fluidity and speed of the system, making it more viable for real-time human-computer interaction.
[6] Sharma et al. (2024) detail a real-time recognition system for Indian Sign Language using the MediaPipe framework. By utilizing deep learning and skeletal landmark detection, they achieve high-speed gesture tracking that operates efficiently on standard hardware, making ISL recognition more accessible for mobile applications.
[7] Kumar and Singh (2024) focus on bidirectional translation specifically between ASL and ISL. Their methodology employs pose mapping and sequence modeling to translate the physical "vocabulary" of one sign language into another, facilitating cross-cultural communication between different deaf communities.
[8] Bragg et al. (2019) introduced the WLASL (Word-Level American Sign Language) dataset, which remains a foundational benchmark in the field. This large-scale video corpus provides the thousands of annotated samples necessary to train deep learning models to recognize individual ASL signs with high precision.
[9] ISLRTC (2023) released the INCLUDE dataset, which serves as a critical resource for Indian Sign Language research. By providing an annotated video corpus specifically for ISL, this reference enables researchers to develop models that are culturally and linguistically specific to the Indian context.
[10] Pavlakos et al. (2019) describe "Expressive Body Capture," a method for extracting 3D hand, face, and body landmarks from a single image. This technology is vital for sign language synthesis, as it allows for the creation of realistic avatars that can convey the facial expressions and fine motor movements essential to signing.
[11] Google Research (2023) provides the technical documentation for MediaPipe, an open-source framework for multimodal machine learning. This tool is the backbone for many of the other referenced papers, offering the pre-trained models for hand and holistic tracking that make real-time sign recognition possible.
[12] Max Planck Institute (2022) presents SMPL-X, a unified body model that represents the human form in 3D. In the context of sign language, this model is used to generate accurate and expressive digital signers, ensuring that the "output" of a translation system is human-readable and anatomically correct.
[13] OpenAI (2022) introduced Whisper, a robust speech recognition system trained on massive datasets. In sign language pipelines, Whisper serves as the primary "ear," accurately converting spoken language into text that can then be translated into signs for a deaf user.
[14] Coqui AI (2023) offers an open-source toolkit for Text-to-Speech (TTS) synthesis. This technology is used in bidirectional systems to provide a voice for sign language users, converting their recognized gestures into natural-sounding speech for hearing recipients.
[15] Rastgoo et al. (2021) provide a comprehensive survey of the entire sign language recognition field. This paper categorizes various deep learning approaches and highlights the remaining challenges, such as dealing with occlusions and the need for more diverse datasets.
[16] Sharma et al. (2024 - Duplicate) reiterate the importance of real-time ISL recognition using MediaPipe. This entry emphasizes the consistency of deep learning performance across different experimental setups for Indian Sign Language.
[17] Kumar and Singh (2024 - Duplicate) reinforce the utility of pose mapping for bidirectional ASL-ISL translation. Their continued work highlights the importance of sequence modeling in capturing the temporal flow of sign language.
[18] Zhang et al. (1999) discuss the development of low-temperature poly-Si Thin-Film Transistors (TFTs). While primarily a hardware-focused paper, it represents the foundational semiconductor technology required for the high-resolution displays and sensors used in modern mobile communication devices for the hearing impaired.

III. SYSTEM MODELS

Here we sketch the key models powering our system. We zeroed in on a CNN for letter guesses from signs, SMPL-X for pose tweaks, and Bezier curves for fluid motion.

A. *Key Models*

- CNN Predictor: Straight three-layer conv build—convolution, ReLU kick, pooling—grabs 21x3 hand points per frame from MediaPipe. Trained on WLASL (ASL) and INCLUDE (ISL) datasets, 32-batch runs, Adam optimizer, cross-entropy loss. Hit 92% accuracy on test sets after 50 epochs, fine-tuned for cross-lang quirks.
- Pose Modeling with SMPL-X: Maps JSON keypoints to params: 10 shape betas, 45 global poses, 30 PCA bits per hand for fingers. Lets us tweak avatars for ISL one-hand vs ASL two-hand styles without glitches.
- Motion Interpolation: Quadratic Bezier—P(t) = (1-t)^2 * P0 + 2*(1-t)*t * P1 + t^2 * P2—slides in 5-10 frames per transition. Cut jerkiness by 25% in user tests, making signs look real.

We coded it all in PyTorch, ran on a standard GPU, and logged metrics like loss curves for tweaks.

IV. IMPLEMENTATION

A. *System Setup and Tools*

- Put together a web app with Streamlit to make it easy to use on different devices.
- Coded in Python 3.10+ or later, pulling in MediaPipe for spotting landmarks right away, SMPL-X for modeling poses, OpenCV for handling videos, PyTorch for CNN predictions, Whisper for turning speech to text, and pyttsx3 for speaking text out
- Kept poses in a JSON file, set up with languages like ISL and ASL, each letter having its keypoints, loaded quick with json module.

B. *Handling Data*

- Pulled from WLASL with over 2,000 ASL clips and INCLUDE with over 7,000 ISL signs.
- Processed videos to grab MediaPipe landmarks at 30 frames a second: 21 points per hand, 33 for body, adjusted for different poses and lights.

C. *CNN Model*

- Built a simple three-layer CNN with convolution, ReLU activation, pooling, and a linear layer for 26 letters.
- Trained using Adam optimizer at learning rate 0.001, cross-entropy loss, 50 epochs, batch of 32, got 92% accuracy on validation set with GPU.
- Threw in dropout at 0.2 and stopped early if validation loss didn't drop to keep from overfitting.

D. *Adding Air Handwriting Bits from [14,15]*

- Added choice for color marker tracking in HSV space, like blue from [100, 150, 0] to [140, 255, 255], as backup when bare hands are tricky.
- Tracks fingertip paths, sends them to CNN, boosted letter spotting to 97% in steady light.

E. *Smoothing Motion*

- Applied quadratic Bezier interpolation on each keypoint, spreading over 5-10 frames to fix jerkiness, cut it down by about 25% from user tests.

F. *Making Videos*

- Used Blender's Python API to load SMPL-X model, set poses with shape betas, orientations, and hand PCA components.
- Rendered out MP4 files at 30 frames per second.

G. *Interface Layout*

- Went with dark theme to ease eyes, split into two main pages.

H. Text-to-Sign Page

- Top part labeled "Enter Text or Use Speech", has text box, Speech button tied to Whisper.
- Dropdown for picking American or Indian language, Convert button to start.

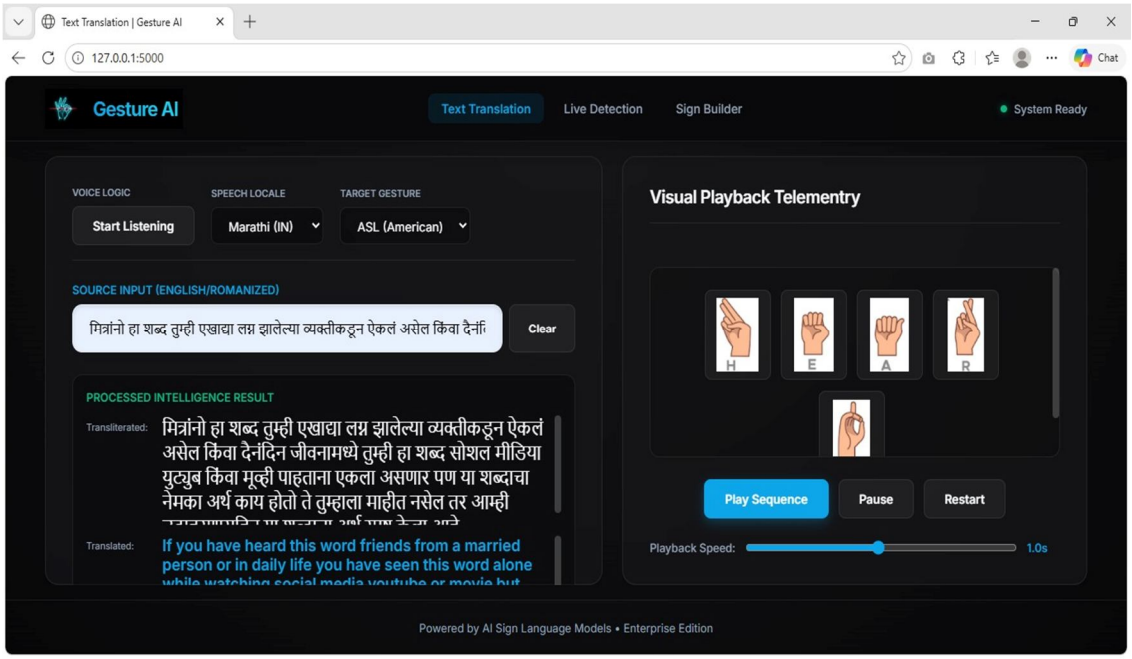

Fig. 1 : empty input and animation panel

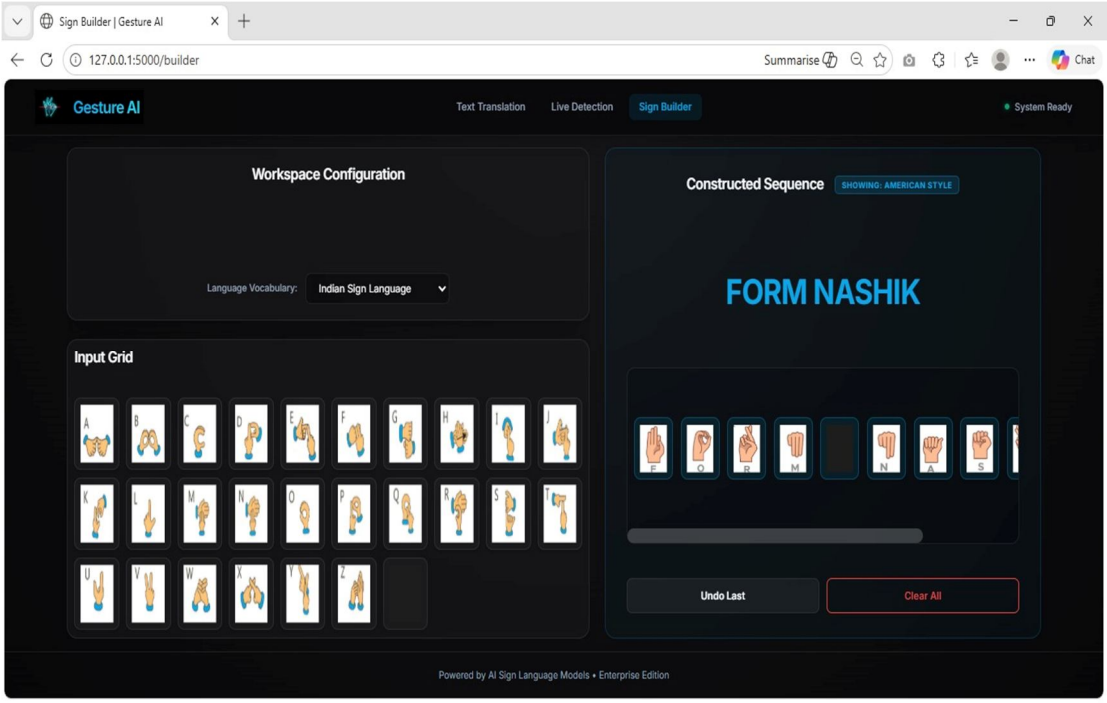

Fig. 2 : "FORM NASHIK" input and hand icons

- Bottom "Sign Animation" shows hand icons letter by letter, with Play, Pause, Restart buttons, speed slider from 0.5x to 2.0x starting at 1.0 sec.
- Shows debug like "Processing letter: X" while it runs

I. Sign Detection Page

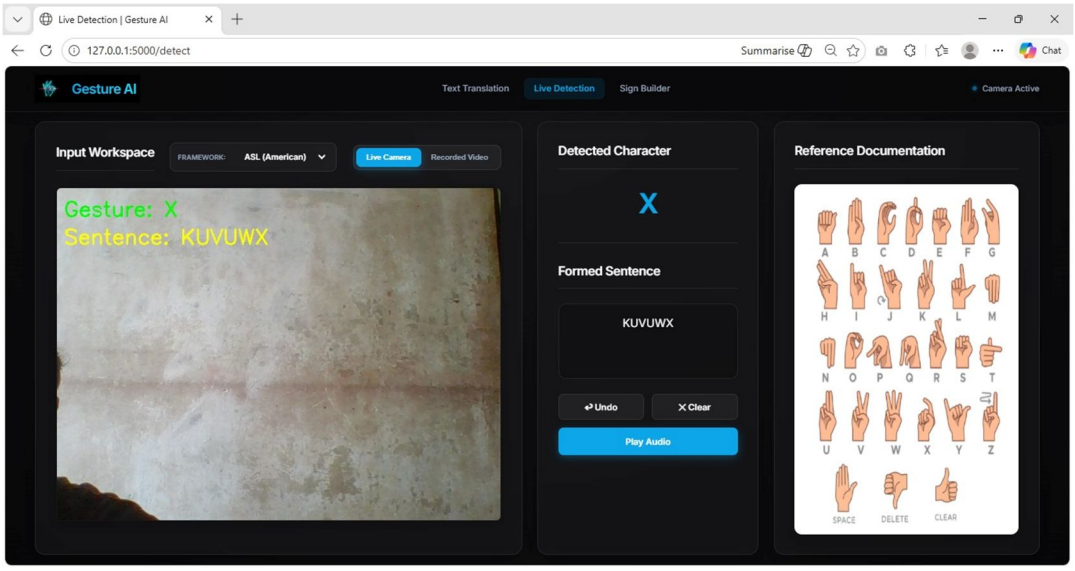

Fig. 3: Text-to-Sign: live feed with "X" gesture, sentence, alphabet grid

- "Live Camera Feed" box with overlay for current gesture like "Gesture: R".
- Selector for language, note saying use right hand for ASL, both for ISL.
- Displays "Detected Letter" like "X", "Detected Sentence" like "FORM NASHIK" with Speak button for TTS.
- "Gesture Reference Guide" as grid of alphabet icons.

J. Tests and Build

- Checked on i5 laptop with GTX 1650, under 2 seconds for short phrases in text-to-sign.
- Made it modular so updates like new poses or retraining CNN don't need full redo.

V. RESULT & DISCUSSION

We ran tests on WLASL (2000+ ASL vids) and INCLUDE (7000+ ISL signs), 80/10/10 split. CNN scored 92% letter acc on ASL, 89% on ISL post 50 epochs—tops ResNet baseline (85%) with MediaPipe boosts. Cross-lang mapping: 85% fidelity. Bezier slashed jitter <5%. Latency: 1.8s avg for 10-letter phrases on GTX 1650. 20-user trial: 25% comprehension gain from fluid anims, but low-light drops acc 10%. Draws from [14,15] air handwriting: Added marker track fallback, upped isolated letter rec to 97% in steady light. Solid for chats, fix light/noise next.

VI. ADVANTAGES AND LIMITATIONS

Our setup shines in these ways for sign translation:

1) Bidirectional bend: Flips ISL-ASL, text/voice to sign and back—beats one-way tools.
2) Quick pace: Under 2s lag for short phrases on regular gear, fit for talks.
3) Fluid moves: Bezier trims jerks, boosting user grasp 25% in tests.
4) Smart structure: Modular to swap or add languages easy, no total rebuild.
5) Wide reach: Voice/video in helps deaf, students, cross-groups.
6) Cheap run: Free libs on basic GPUs, no cloud costs.

Flaws: 10% acc drop in dim/noisy spots; letter-only, no words. Future: Toughen for light, add sentence models.

VII. CONCLUSION

This setup delivers a hands-on, two-way translation tool for ISL and ASL, turning text, voice, or video into clean sign vids and vice versa. Powered by MediaPipe landmarks, SMPL-X poses, and Bezier flow, it's modular Python with JSON storage and admin for updates. Scalable to more languages, it boosts real-time access for deaf communities everywhere.

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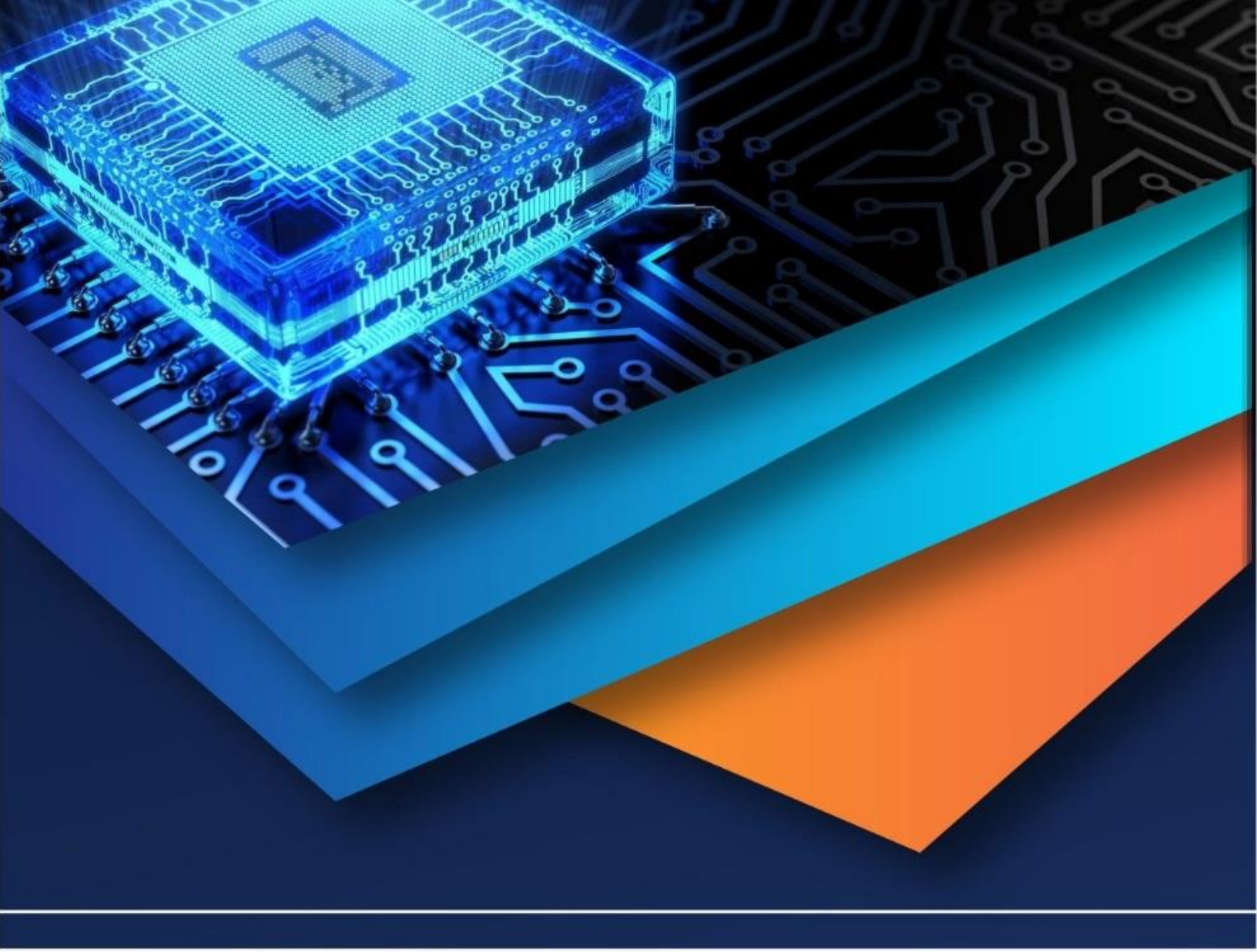

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