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Raspberry Pi 5 and Its Applications in ML Models

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Abstract: ***Raspberry Pi 5 is the newest development board in the Raspberry Pi series. This paper describes the architecture, features, interfacing capabilities, performances and its appli- cations in the machine learning models. The paper describes the hardware advantages necessary for efficently training and running ML models. This document also discusses various possibilities of ML models that can be trained in these boards. The paper concludes with the extensive possible applications of Raspberry Pi 5 board in IoT and general electronics. This advancements may provide a platform for the innovations of many newer generation ideas and projects.***
Index Terms: raspberry pi 5, raspberry pi, machine learning, models, applications, boards

I. INTRODUCTION

The technologies have vastly and rapidly advanced day by day and has given many development to the world. These tech- nologies has a greatly affected the human life of convenience and effectiveness. The Raspberry pi series is one of such innovations that not only helped innovation come from paper to real world but also led the foundations of the innovative developments along the way.
The Raspberry Pi 5 is one such development of these series of boards. The board was launched in the year 2023. This board is a whole mini computer on its own in a 85 x 49 mm package. The board itself is comprised of so many different elements of interfacing capabilities which will be discussed shortly. The board runs on its dedicated OS known as ”Book- worm”. The Bookworm is a Debian based OS especially its derivative Raspbian. [2]
The paper comprises of 5 sections. Section 1 displays the introduction to the project. Section 2 describes the hardware features of the development board. It describes the require- ments that are essential for training and running of ML models. Sections 3 discusses the application of the these boards in modern day innovations and discoveries. Section 4 discusses the advantages, disadvantages and limitations of Raspberry Pi 5 into ML modeling. Section 5 is the conclusion of the paper followed by references.

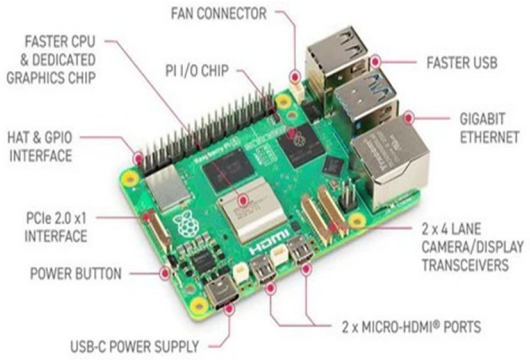

Fig. 1. Raspberry Pi 5 board

II. HARDWARE SPECIFICATIONS

A. Processor

The package is comprise of 16nm application processor, BCM2712. It is 64-bit quad-core ARM Corte-A76 processor running at a rate of 2.4GHz. The processor provides with 512KB per-core L2 caches and 2MB shared L3 cache. The integration of an improved 12-core VideoCore VII GPU, Hardware Video Scale (HVS) and HDMI controller capable of driving dual 4Kp60 displays and a Raspberry Pi-developed HEVC decoder and Image Signal Processor(ISP) providing a wide range of usages and development opportunities. [1]

Fig. 2. BCM2712 processor

The board is available with wide variety of memory package from 2GB, 4GB, 8GB and upto 16GB. A 32-bit LPDDR4X memory interface provides upto 17GB/s of memory band- width, while x1 and x4 PCI Express interfaces support high- bandwidth support high-bandwidth external peripherals.

A. Power

The Raspberry Pi series is a little sensitive to the power inout it uses to run and functions. The recommended PSU current capacity is 5A. The maximum current drawn total USB peripheral is 1.6A and 600mA if using a 3A power supply. The typical bare-board active current consumption is 800mA. The power requirements of Raspberry Pi increases as you make use of the various interfaces on the Raspberry Pi:

- The combined GPIO pins draw 50mA safely. Each pin can individually draw up to 16mA.
- HDMI port uses 50mA of power.
- The camera module requires 250mA.
- Output/Input GPIO pins designated can be set/read to high (3.3V) or low (0V).
- The 3.3V supply was designed with maximum current supply of 3mA per GPIO pin.

The Raspberry Pi 5 runs on an input power of 5.1V supply voltage and a current of 5A for effectively run all the basic and interfacing requirements.

B. VideoCore VII GPU

The GPU architecture is optimized for embedded multime- dia and graphics acceleration in low-power SoCs. The GPU is supported by the Graphics API. The Graphics API supports the following functionalities:

- OpenGL ES 3.1: The cross-platform API provides with advanced 3D rendering, compute shaders, tessellation and improved texture handling.
- Vulkan 1.2: A low-level, high-performance graphics and compute API with reduced driver overhead, explicit GPU resource management and modern GPU programming capabilities.

The performance efficency is recommended around typical power drawn under load 2-3W (GPU portion), maintaining total board power under 10-12W.

C. Dual 4Kp60 HDMI display

The board supports 2 simultaneous 4K resolution outputs at 60 fps via HEVC Decoder. The hardware implementation requires support for HDMI 2.0 or higher, to accommodate the data bandwidth (14.4 Gbps uncompressed video per stream at 4K60), plus additional bandwidth for HDR metadata. The board supports a four-lane MIPI display.

D. LPDDR4X-4267 SDRAM

The boards comes in wide range of memory option i.e. 2GB, 4GB, 8GB and 16GB. The LPDDRAX-4267 provides capable of 4267 MT/s(mega-transfers per second). The module provide elevation to the memory bandwidth, enabling faster system responsiveness, smoother multitasking and better support for memory-intensive applications such as large ML models, multi-tab browsing or virtualization. It has a lower voltage operation than other LPDDR variants, improved energy effi- ciency and thermal behaviour. The typically operating voltage is around 0.6-1.1V.

E. Dual-band 802.11ac WIFI

Raspberry Pi 5 has the supports both 2.4GHz (802.11b/g/n) and 5GHz (802.11ac/n) frequency bands. The 802.11ac sup- ports theoritical speeds upto 433Mbps (1x1 MIMO, 80MHz channel). The 2.4GHz band supports upto 72Mbps (1x1 MIMO, 20MHz channel). In real life, the channel provides a network operating speed of 100-200 Mbps on 5GHz channel and 40-60Mbps on 2.4Hz channel. [3]

F. Bluetooth 5.0/Bluetooth Low Energy (BLE)

The Bluetooth 5.0 provided by a CYW43455/43456 combo chip providing a throughput upto 3Mbps (EDR) [4]. The BLE 5.0 offers speeds upto 2Mbps PHY mode. The BLE 5.0 is supports upto 240 m line of sight range, indoor range of 10-30 m (approx.). The BLE is optimized for low-power, intermittent transmissions, reducing estimated energy consumption by 40% compared to continuous Bluetooth Classic. The idle consump- tion is a few milliwatts(mW) and active power drawn is 10-30 mW depending on the PHY mode. The compatibility of the BLE with the Bluetooth Mesh Networking enables multiple device communication for distribution.

G. microSD card slot

The microSD card is integrated with the support for the high-speed SDR104 mode. The module could provide upto 104 MB/s of maximum transfer rates. The UHS-I microSD cards can acheive 80-100 MB/s of sequencial read speed. The module utilizes a 1.8V signaling for UHS-I modes, including SDR104 , ensuring high-speed data transfer reliability. The module apparantly does not support UHS-II or UHS-III mi- croSD cards.

H. USB 3.0 ports

The proposed board is consists of 2 USB 3.0 ports, sup- porting simultaneous 5 Gbps operation and 2 USB 2.0 ports. Under optimal conditions the USB 3.0 can provide speeds upto 300-400 MB/s (approx.) and the USB 2.0 provide speed upto 35-40 MB/s. USB subsystem is directly connected to the RP1, which interfaces with the BCM2712 SoC via 4Gbps PCIe Gen 2 x1 link. The high speed of USB 3.0 is an ideal for high-speed external storage (USB SSDs, HDDs), camera modules or USB-based accelerators. The USB 2.0 provides a well-suited ecosystem for low-bandwidth peripherals such as keyboards, mice, and microcontrollers. The combined USB ports can supply upto 1.2A at 5V.

I. Gigabit Ethernet

The development board is consists of 1000BASE-T Gigabit Ethernet provided through RJ-45 port. The module is also supported by PoE+ support. The extension of the PoE+ support is being provided by a separate PoE+ HAT. The theoritical maximum throughput is 1Gbps; practically throughput of 930 Mbps (approx.) speed under optimized conditions. The PoE+ when paired with PoE+ HAT provides upto 25.5W at 48V. These specifications provide suitable conditions for the ML model distribution, dataset transfer and networked interfer- ence. PoE+ simplifies deployment in remote or embedded installations. [5]

J. 4-lane MIPI camera/display transceivers

The development board is consisting of 2 4-lane transceivers which helps in MIPI camera and display interfacing. The module implements MIPI CSI-2 (Camera Serial Interface) and MIPI DSP (Display Serial Interface) protocols. The transfer rate supported is approximately 1.5Gbps per lane, yielding 6Gbps aggregate bandwidth per connector. The dual connec- tion property helps in the connection of the multiple display. The module is managed by RP1 I/O controller. The bidirec- tional transceivers makes it very useful for the communication. The connection is established by 22-pin Flexible Flat Cable (FFC).

K. PCIe 2.0 Interface

The Peripheral Component Internet Express (PCIe) inter- facing provide high speed peripheral for the expansion of components. The board is provided with a PCIe 2.0 single lane ports for this purpose which are required a support of separate 40-pin FFC to M.2 HAT adapter board. The raw transfer rates of 5.0 GT/s yields a theoretical 500 MB/s per direction after the 8B/10b encoding. The real world throughput is typically around 350-450 MB/s. The electrical signaling is based on 3.3V PCIe reference clock, differential pairs and reset signals routed through the adapter. [6]

L. Power Specification

Power Input Standard is powered through a USB-C connec- tor, compliant with USB Power Delivery (PD) specification. It accepts

a DC 5V input at upto 5A providing 25W of power enabling support for higher-performance peripherals and heavy workloads. The adaptable nature provides with operability at lower power levels of 15W but may limit the performance. The higher current budget ensures stable CPU/GPU overclocking headroom, improving reliability during sustained ML work- loads. The integrated Power Management IC (PMIC) regulates and distributes power across board subsystems. This amount of power supply requires high-quality USB-C PD supply and cable rated for 5A else performance may limits. Some of the large external peripherals would still requires external power.

M. Standard 40-pin Header

The standard double 20 pin 2.54 mm pitch header is a essential for interfacing purposes. The header operates at 3.3V logic levels and provides upto 50mA per GPIO pin. The header is compose of following components:

- Power Pins: The purposed board is provided with two 5V pins, two 3.3V pins and 8x grounds for the power supply interfacing.
- General-Purpose I/O: 28 pins are configurable as digital input/output pins.
- Communication Interfaces (multiplexed on GPIOs):
    1. 2 I^2C controllers (I^2C0, I^2C1)
    2. 2 SPI controllers, fully-duplexed at upto 125 MHz
    3. Multiple UARTs with hardware flow control.
    4. Hardware PWM channels for motor/LED control
    5. PCM/I^2S pins for audio interface and DAC/ADC connectivity.

Many more GPIO pins can be reassigned using pin multiplex- ing. The GPIO are managed by the RP1 I/O controller.

N. Real-time clock(RTC)

The system integrates a dedicated Real-Time Clock (RTC) subsystem, allowing it to maintain accurate subsystem time even when the board is powered off. The subsystem can be powered though a coin-cell battery via a 2-pin JST connector. The management is done through RP1 I/O controller. The time drift typically within ±3 to ±20 ppm (parts per million), equiv- alent to ±0.25–1.7 seconds/day, depending on temperature and crystal accuracy.It maintains date and time registers (year, month, day, hour, minute, second) accessible by the operating system. The limits are that battery backup must be externally provided, the RTC is not persistent without it. This also does not provide GPS-level precision.

III. LITERATURE SURVEY

The above discussed specifications provide a considerable choice for the IoT and small scale ML model implementations. The ML models revolve around the concepts of computer vision, deep learning, YOLO based system, AI etc. The fol- lowing are reviews of the various ML model implementations currently being studied:

A. Computer Vision based application

1) Computer Vision Based On Raspberry Pi System [7]

The above document discusses the possible use case of raspberry pi module for the edge computation and detection. The experiment is basically description of a object counting algorithm. The algorithm is based of a simple image acquisition and processing computer vision program. The proposed algorithm was later checked and tested under various conditions. The model was successful for the detection and counting of objects providing basic implementation on a raspberry pi is definitely possible and practical.

2) Computer Vision Algorithms on a Raspberry Pi 4 for Automated Depalletizing [8]

The provided document gives implementation of four different of computer vision for depalletization. The algorithm implemented includes the following: pattern matching, scale-invariant feature transform (SIFT), Oriented FAST and Rotated BRIEF (ORB) and Haar cascade classifier. The comparative study of different algorithm provides with a perspective of wide availability of use cases of ML model into the raspberry pi module. The advance version of the board is confined to be more susceptible for the training, testing and implementation of such model as the capabilities have increased into each version. The document later discusses performance based on various aspects of evaluation.

3) Smart Home Control Using Real-Time Hand Gesture Recognition and Artificial Intelligence on Raspberry Pi 5 [9]

The provided article is about the developing system that is real-time hand gesture recognition and use of artificial intelligence to control the systems over a smart home. The paper is comprised of use of Computer Vision and a custom lightweight machine learning model. The system is develop for the speech deprive people to have access to interfacing with the smart home devices in real time. The integration of model with a Raspberry Pi provides a small scale, cost-efficient prototyping of final produce. The system was able to recognizing a gesture, averages 20.4 frames per second with no observable delay.

B. Deep Learning based application

1) Exploring Distributed Deep Learning Inference Using Raspberry Pi Spark Cluster [10]

The raspberry pi is also fully capable of performing algorithms based on deep learning. The cited document one such document where the author has provided a comprehensive understanding of implementation of deep learning models for inference. The paper discuss some concepts that are foundational and are used into image classification and face detection. The paper also discusses the implementation of a data processing unit called as spark for clustering with other boards for the better implementation. The use of a clustering system helps in the performance of multiple low-level devices to perform a scalable distributed inference solution that is essential for synchronized working of the devices.

2) Deep Learning Approach to Detect Fake Video on Raspberry Pi [11]

The provided document gives the solution for the latest problems that are surfacing with the rise of AI in today's rapidly changing world. The document proposed a ResNeXt and Long Short-Term Memory (LSTM) based face recognition and deepface detection system that can be used to discern the manipulated videos.The study shows that the Raspberry Pi capabilities are extensive to being able to develop pre-trained model for further development. The system is optimized for the accurracy, precision, recall and F1 score for optimal performance. The model is based of changes observed in the features in between the frames at interval of times. This is a brilliant example of the development of neural network on a raspberry pi models.

3) Raspberry Pi-Based Deep Learning Face Recognition Security System [12]

This paper is a study of a face recognition system that is based of a deep learning. The captures and analyze images using a pre-trained Convolutional Neural Network (CNN). The system is trained to open or close the door based on the face recognition capability of the model. This displays that the raspberry pi can be a commendable tool for the development of real-life applications. The system proposed is a potential of edge computing in IoT-enabled environments, combining security, automation and ease of use in a compact framework. The use raspberry pi has made it able to shift from the cloud based processing to onsite processing for faster results generation.

4) Real-time Detection of Hole-Type Defects on Industrial Components Using Raspberry Pi 5 [13]

The study is the application of Raspberry Pi for the detection and quality control of geometric features and defects during manufacturing process. The study uses three deep learning models, ResNet50, EfficientNet-B3 and MobileNetV3-Large on a grayscale image dataset. These provides the perspective for the use of many number of models in a SoC like Raspberry Pi. These is a display of the computational capabilities of Raspberry Pi board and its extension into the training and testing of models. These is also defines a real-life application of deep learning in the Raspberry Pi.

C. AI based Application

1) Study on Building a Raspberry Pi AI system: Tools and Techniques [14]

The rapid growing speed of AI being coupled with the processing capabilities of Raspberry Pi. The AI model is written in Python and libraries like TensorFlow, PyTorch and Keras trained over a suitable dataset depending on the application. The paper discusses the need of using AI system on a development board and methodology one need to adopt in order to make a AI system on a Raspberry Pi board.

2) AI-Powered Robotic Lawn Mower with Autonomous Navigation and Control Using Raspberry Pi [15]

The above article is a practical representation and a real-life application for the use of AI in day to day activities. The paper describes the design for a lawn mower that is AI-powered capable of autonomous navigation and control using GPS technology

integrated with a Raspberry Pi platform. The integration of AI-based decision-making and multi-sensor perception significantly enhanced real-time adaptability. The mower dynamically adjusted its route when encountering unexpected obstacles, recalculating paths with minimal delay. These applications make it a better option to use raspberry pi as a better option conducive to needs and demands of the system.

3) Challenges in Implementing Artificial Intelligence on the Raspberry Pi 4, 5 and 5 with AI HAT [16]

The above article is a description of the design and con- struction of a lightweight secure network infrastructure tailored to the Raspberry Pi's capabilities. The system is curated for the new age AI driven malware detection software. Key considerations include network segmenta- tion, firewall implementation, and device configuration management using automation. The Raspberry Pi is also being verified for the security consideration and privacy of data. The lack of security can be overcome through these kind of systems. There are many more applications of the Raspberry Pi 5 [17].

IV. DISCUSSIONS

The above works by fellow researchers provide information about the possible applications of ML models in a Raspberry Pi 5. This section will be oriented towards the advantages and disadvantages of using a raspberry pi and its limitations in ml model application. The Raspberry Pi is a fairly powerful module for ML application but it is still under development and is not conducive for real life applications. Firstly, lets get together the advantages and disadvantages of a Raspberry Pi 5:

A. Advantages and Disadvantages of Raspberry Pi 5

The Raspberry Pi 5 comes with a wide range of advantages provided as follows:

1) Advantages:

- Faster process capabilities compare to its peers-level boards
- Low power consumption
- First for GPU processing
- Easy to use, following general precaution makes efficient use
- Vast user support from developer community
- Suitable for prototyping
- Wide variety of peripherals
- Support for multiple IDEs
- Support for multiple programming languages
- Affordable price

Although, the Raspberry Pi 5 has many advantages there are some disadvantages and limitations that are need to be considered while using the development boards. Some of the limitations are as follows:

2) Disadvantages

- Low internal storage
- Requires a microSD card
- Overheating problem, though heatsink is available
- Cannot run x86 Operating System
- Nonexpendable RAM
- Complex multitasking is difficult

B. Limitations of Raspberry Pi 5

The above idea about the advantages and disadvantages of Raspberry Pi 5 helps in obtaining a proper system to use the development board based on the following:

1) OS/Software compatibility issues can occur when trying to run software or operating systems that are not com- patible with Raspberry Pi.
2) Connectivity issues
3) Debugging code could be challenging

4) Security and data privacy
5) Improper circuit handling can burn the board
6) Performance issues over time due to extreme weather conditions, device/system reliability issues, sensor pre- cision issues and synchronization error between multiple devices.
7) Incorrect exception or error handling mechanisms, using old and deprecated function can cause debugging errors.
8) Need to be up to date with current libraries/development of systems.

V. CONCLUSION

The study shows a large scope for the use and development of Raspberry Pi 5 for better utilization of ML models. The Raspberry Pi 5 is a small package with a lot of functionalities compacted into a module that is cost-effective and very useful especially when used for prototype development. The ML modeling capabilities can be extended for the integration of AI into the new upcoming technology. The balance of advan- tages and disadvantages for the development is crucial when considering for producing the prototype. The ML development is a being of AI integration and Raspberry Pi 5 is a important part for its integration into IoT and networking systems.

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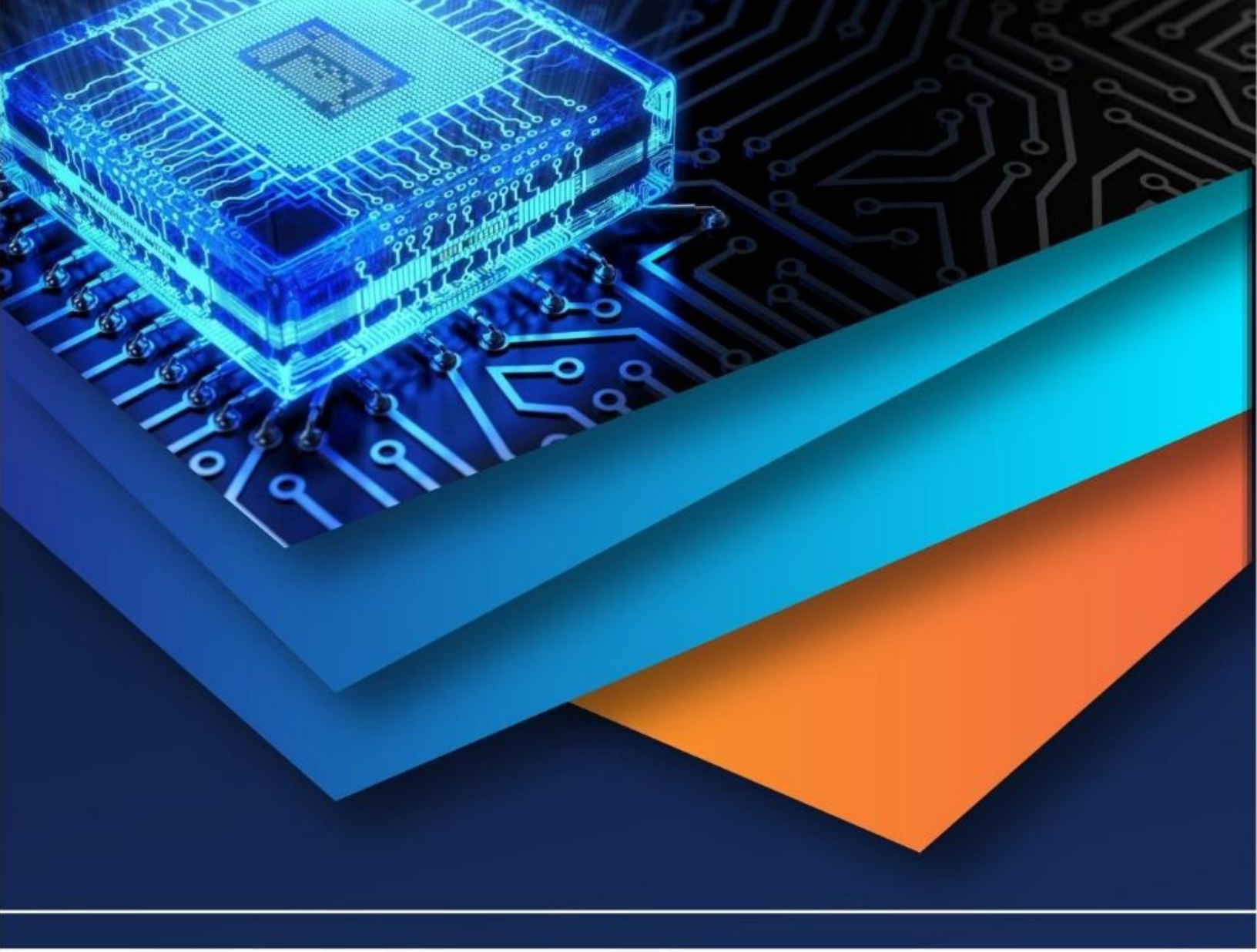

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