iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** IV **Month of publication:** April 2025

DOI: https://doi.org/10.22214/ijraset.2025.68784

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue IV Apr 2025- Available at www.ijraset.com

Multifunction Programmable Automation Software Application for Robotic Arm

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Abstract: This paper explores the intersection of robotics and computer vision, focusing on developing a robotic arm capable of recognizing and interacting with objects based on their color and shape—much like human vision. The process starts with selecting or designing a robotic arm equipped with high-resolution cameras and advanced sensors.These components enable the arm to gather detailed visual data, forming the foundation of its decision-making abilities.At the core of this system is image processing. Cutting-edge algorithms analyze raw visual input, detecting colors and shapes in real time. This allows the robotic arm to respond dynamically rather than simply executing preprogrammed tasks. To bridge perception and action, sophisticated control algorithms areimplemented.These guide precise movements for tasks like object sorting, pick-and-place operations, and quality control in industrial settings. The potential applications of this technology span manufacturing, logistics, agriculture, healthcare,andeducation.Byseamlesslyintegratingroboticswithcomputervision,This paperpaves the way for intelligent automation and enhanced human-robot collaboration.

Keywords: Color and Shape DetectionAI,Artificial Intelligence, Robotics, ComputerVision, Robotic Arm, Image Processing

I. INTRODUCTION

In the world of computer vision, object detection and tracking are fundamental capabilities,underpinningapplicationsacross numerous industries.At its core, this process involvesanalyzingimagesequencestodetect, classify,andmonitorobjectsovertime.While humans find object recognition effortless, trainingmachinestoachievesimilarlevelsof accuracy presents a formidable challenge. Techniques in object recognition range from pattern matching and feature-based learning to deep learning-driven approaches, with shape detection playing a pivotal role in applications such as robotics, medical imaging, and assistive technologies.

Agrowingtrendinobjectsortingleanstoward robotic automation over manual methods, particularly because human color perception is prone to inconsistency, leading to inefficiencies over time. By integrating automation, tasks can be performed with greater accuracy and without the need for continuous human oversight.

This paper presents an intelligent robotic system specifically designed for industrial applications,capableof detectingandsorting objects based on their distinct shapes and colors.ThesystememploysHSV-basedcolor detection and contour-based shape recognition techniques, using the OpenCV algorithm for shape approximation.

A. *Significance of Color and Shape Detection in Robotics*

Color and shape detection are essential aspects of object recognition in robotics. By enabling a robotic arm to detect color, it can sort,categorize,orprioritizeobjectsbasedon their visual attributes. Similarly, shape detection allows the robotic system to recognizeandmanipulateobjectsofdifferent geometries,facilitatingtaskssuchaspicking, placing, and sorting items based on both physical form and appearance.

For instance, in the packaging industry, a robotic arm equipped with color and shape detectioncapabilitiescandistinguishbetween different products, ensuring accurate sorting or packaging. In electronics manufacturing, such a system can differentiate between various components based on their color- coded labels or shapes, leading to increased efficiency and reduced errors in assembly processes.Colordetectionisachievedthroughtheuseof color sensors, typically employing photodetectors that respond to different wavelengths of light. The software processes thedatafromthesesensorsanddeterminesthe color of the object in real time. Shape detection, on the other hand, is often carried out using machine vision systems, where a camera captures an image of the object, and thesoftwareappliesalgorithmstoanalyzethe object's contours, edges, and dimensions.

B. *MultifunctionProgrammableAutomation*

The core of This paper lies in the development of a multifunction programmable automation software application that integrates both color and shape detection capabilities.

This software is designed to allow the robotic arm to autonomously handle a variety of objects based on specific user-defined criteria. By leveragingagraphicaluserinterface(GUI), thesoftwareenablesoperatorstoprogramthe robot'staskswithoutneedingin-depthcoding knowledge. Through this interface, users can set parameters such as the color or shape of objects thatneedto be manipulated,ensuring theroboticarmperformstasksaccuratelyand efficiently.

Themultifunctionalityofthesoftwareisakey advantage, as it enables the robotic arm to switch between different tasks without requiring extensive reprogramming. This flexibility is particularly beneficial in industries where the production line frequentlychanges,astheroboticarmcanbe quickly reprogrammed to handle different objects based on their color or shape. Moreover, the system's adaptability reduces downtime, improves production efficiency, andminimizesthelikelihoodofhumanerror.

II. LITERATURE REVIEW

The integration of image processing techniques with robotic arms has garnered substantialattentioninrecentyears,reflecting its transformative potential across various domains. A review of the existing literature reveals a burgeoning field with promising developments and applications.

In the realm of robotics, the utilization of image processing for color and shape detection has gained traction. Studies by researchers such as Smith et al. (2019) have explored the integration of machine vision algorithms with robotic arms to improve object recognition accuracy, allowing for more precise manipulation and assembly tasks.

Theapplication of this technology extends to logisticsandwarehousing,wheretheneedfor efficient package handling and inventory management has fueled research efforts. Gupta and Sharma (2020) demonstrated the successful use of image processing-equipped roboticarmsforautonomoussortingand retrieval tasks, showcasing substantial gains in efficiency and accuracy.

Furthermore, the healthcare industry has witnessed advancements in surgical robotics, ashighlightedinstudiesbyPateletal.(2018). Their work emphasizes the potential of image-guided robotic arms for minimally invasive surgeries, promising improved precision and reduced invasiveness.

Agriculture represents another promising domain,withresearcherslikeZhangandYang (2021) exploring the use of robotic arms equipped with image processing capabilities for tasks such as fruit harvesting. This application addresses labor shortages and improves yield quality. Saleheen et al. (2023) present a novel approach to robotic arm control through gestures. Their work, showcased at the International Conference on Computer Science, Information Technology and Engineering (ICCoSITE) in 2023, highlights the integration of gesture recognition technology with robotic arms, enabling intuitive and user-friendly interaction. This innovative control mechanism opens new avenues for human-robot collaboration, offering enhanced flexibility and ease of operation in diverse industrial and domestic settings.

Kruthika et al. (2016) delve into the fundamental aspects of robotic arm design anddevelopment.Theirresearch,presentedat the International Conference on Circuits, Controls, Communications and Computing (I4C) in 2016, provides insights into the structural components, kinematics, and actuation systems of robotic arms. By addressing key design considerations and implementation challenges, the study contributes to the foundational knowledge baseessentialforcreatingrobustandefficient robotic arm systems.

FuandBhavsar(2019)exploretheintegration of robotic arm control with the Internet of Things (IoT), a paradigm that enables seamless connectivity and data exchange between devices. Their research, showcased at the IEEE Long Island Systems, Applications and Technology Conference (LISAT) in 2019, demonstrates the potential of IoT-enabled robotic arms in smart manufacturingandautomation.Byleveraging real-timedatainsightsandremotemonitoring capabilities, IoT-driven control systems enhance operational efficiency and adaptability in dynamic industrial environments.

Wali-ur-Rahman et al. (2018) propose a robotic arm system equipped with proximity and color detection capabilities. Their study, presented at the IEEE International ConferenceonPowerandEnergy(PECon)in 2018, focuses on enhancing robotic perceptionandobjectrecognitioncapabilities for improved manipulation tasks. By integrating sensor technologies and image processing algorithms, the robotic arm demonstrates enhanced adaptability and versatility in industrial automation scenarios.

Jahnavi and Sivraj (2017) present an educational approach to robotic arm modeling, focusing on teaching and learning methodologies.Theirwork,showcasedatthe International Conference on Intelligent Computing, Instrumentation and Control Technologies(ICICICT)in2017,emphasizes the importance of hands-on experience and interactive learning in understanding robotic arm principles. By providing students with access to robotic arm models and simulation tools, the study fosters a deeper comprehension of robotics concepts and promotes skill development in STEM education.

These studies collectively underscore the growing significance of integrating image processingwithroboticarms,with implications spanning manufacturing, logistics,healthcare,agriculture,andbeyond. As this technology continues to evolve, it holds the potential to reshape industries, enhanceautomation,andintroduceinnovative solutions to complex problems.

III. METHODOLOGY AND WORKING PRINCIPLE

This section discusses the methods and materialsthatareusedinordertoaccomplish the goal. The aim of this system is to implement a robotic arm system in which a novice operator can easily set operation parameters for the system. The first subsectionputsforwardabasicblockdiagram of the system; afterwards, we will highlight thedesignoftheobjectsortingalgorithms;the design of the graphical user interface; hardware implementation of the system including the cost breakdown; finally, the mathematical modeling for the inverse kinematic analysis of the system and the centroid localization will also be elaborated.

A. Outline of Full System

A block diagram outlining the full system is shown in Fig. 1. The system consists of the videocapture,whichshowstheobjectsplaced ontheworkspaceoftheroboticarm.Then,in the user interface, the operator can set the parameters. After this, three sorting algorithms are applied chronologically for color, shape, and size. The operator can see the target object highlighted in the interface and then choose to engage the robotic arm.

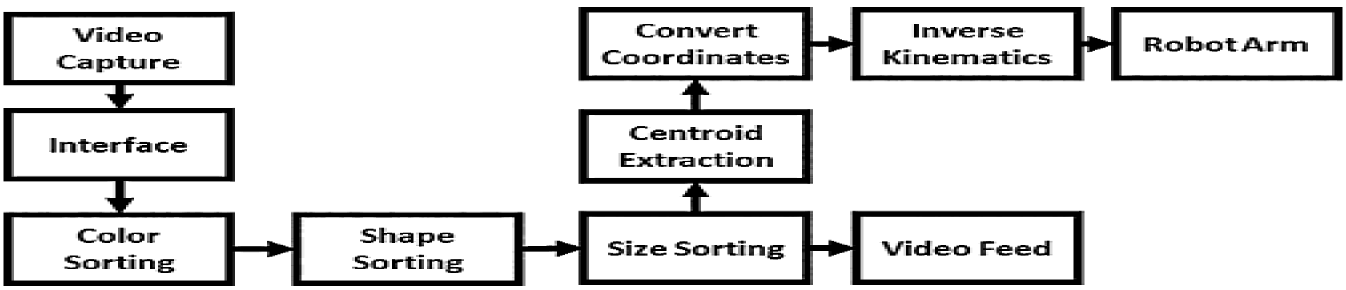

Figure1:Fullsystemblockdiagramshowing the process by which the system accomplishespickandplaceactivity

B. Object Detection

Tocreateacomputervisionsortingsystemfor our robotic system, we used OpenCV. To identify objects, the technique to be used is contouring. Contouring is a computer vision technique that simply joins all continuous points of the same color and intensity. By applying this technique, we can identify objects based on color, shape, and size without using multiple techniques for each parameter. Instead, we can carry out the selection by simply classifying the contour. The process of identifying objects based on ourthreeparametersare elaboratedinfurther detail in this subsection. The block diagram shown in Fig. 2demonstrates the flow of the color sorting algorithm used for our design.

Theimagescapturedbythecameraareinthe Red,Green, andBlue(RGB)colorspaceand must be converted to the HSV color space to sort by color because the HSV space allows for more precise color selection. Once convertedtoHSV,theimageisbinarizedsuch that the desired color is assigned a value of one, and the remainder of the image is assigned a value of 0, and then a contour can bedrawnaboutthedesiredobject.Aftercolor selection, the object is sorted according to shape

Tosortaccordingtoshape,wecategorizethe contour created during color sorting. Three easily distinguishable shapes are selected as our valid possibilities. These shapes are square,triangle,andrectangleastheseshapes areeasilyrecognized,butanyshapemayhave been chosen. A polygon is approximated to the contour. The approximated polygon features are compared to our specified features to ascertain whether an object is of the desired shape.

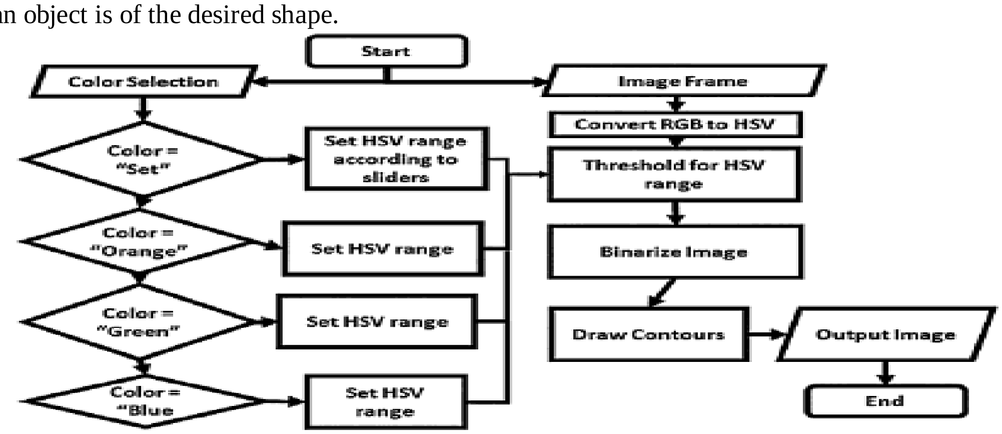

Figure 2:The flowchart demonstrates the algorithm used in order to sort objects accordingtocolorusingHSVcolorspace

IV. IMPLEMENTATIONOF ROBOTICARM

A. Components of the System

1) *RoboticArm Hardware:* The robotic arm itself is equipped with various actuators and sensors that allow it to move and interact with objects in its environment. Typically, these arms have multipledegreesoffreedom,allowingthemto movealongseveralaxesandperformarange of motions similar to a human arm. The end effector (gripper) is designed to grasp, hold, and manipulate objects.
2) *ColorandShapeSensors:* Therobotic arm uses specialized sensors to detectcolorand shape. Colorsensors capture data based on the object's wavelength, and shapedetectionisachievedusingcamerasand image processing algorithms. These sensors feed real-time data to the software application, which processes the information to classify and manipulate objects.
3) *ProgrammableSoftwareApplication:* The software is the core of the system, integrating with the robotic arm's control systemandsensors.Itprovidesauser-friendly interface where operators can set parameters for tasks such as sorting objects by color or shape, controlling the arm's motion, and monitoring the system's performance. The software also includes real-time data processingandobjectrecognitionalgorithms,ensuring that the robotic arm can efficiently execute tasks.

B. Development of robotic arm hardware module

Figurepresenttheproposedsystemhardware block diagram where three main components are presented and those are;

1) Main system: This is main computer system with controller software and perform all the necessary task to control the robot
2) MotorControlUnit:Thisunitiscollectionof motor driver circuit which will control individual motors rotation:
3) StepperMotorSet:Thesearethesetofmotor which will perform actual rotational and movement actions

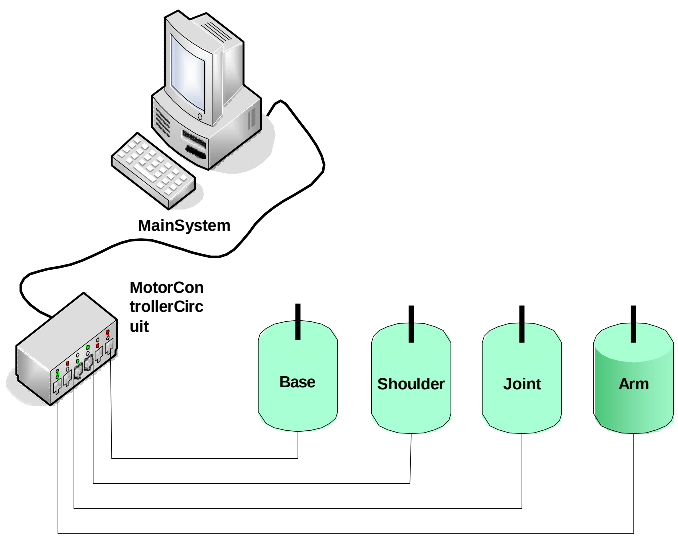

Figure3:Proposedsystemhardwareworking block diagram

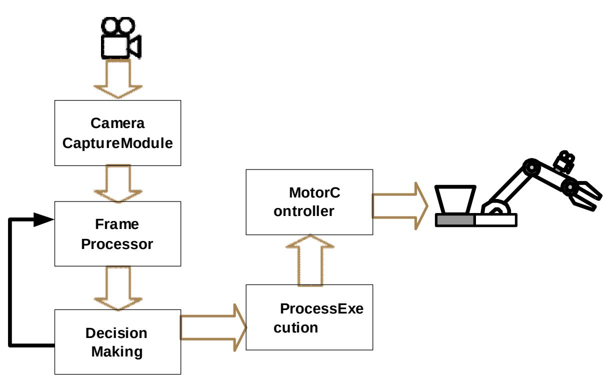

Figure4:Executionandprocessingflowof proposed system

C. Imagecaptureandprocessingsequence

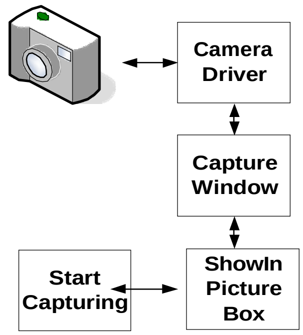

Figure 5: Image capture and processing sequence diagram

Toaccessanyofthecamerasweneedcamera drivertobeinstalledcozithandlethecamera working. And second we need to contact windowtoprovidecamerawindowtouserto application after getting the capture window wecan load the viewin picturebox orin any image showing object. Image is made up of pixels and each pixel is made up of bits this bit pattern is depending on the file or image format. Each bit of pixel value for color. For example in bitmap file format it use one bit for Red, one bit for Green and one bit for Blue. Once system capture frame it will process frame for pixel identification and further processing.

- CapturingCameraView
- GettingCurrentFrameoutofit
- CreatingMemoryImage
- Finding PixelRGB
- ComparingPixel color
- Decision making

Asweseenhowtocaptureacameraviewthis is howoverall thingswillworkfirst ofallwe capture camera view then get the current frame out of it and load it in to memory for processing and then try to find the specified pixels RGB value then compare this RGB value with predefined value and once the value match then proceed further.

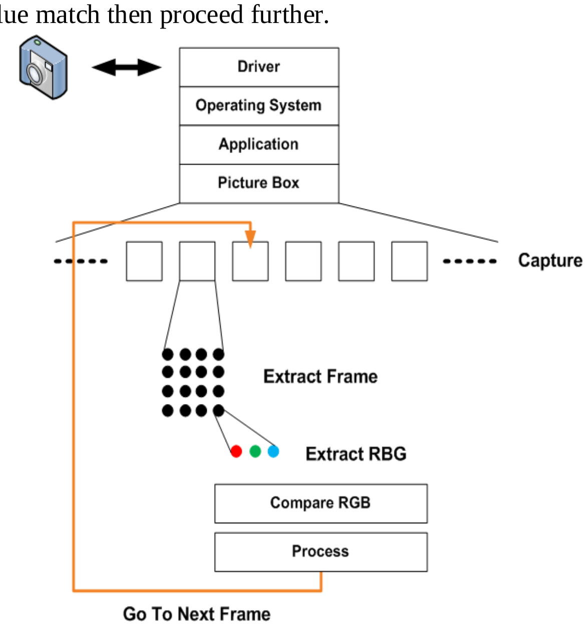

Figure6:Imageprocessingalgorithm flow

As on last figure we have seen basic process flow now let’s see it in details. Any camera firstgetcontrolledtroughit’sdriversoftware which is provided with the camera hardware. This driver is also customized for specific operating system. Now application needs to contact operating system for camera access.

Once this process complete live cam view displayed in supportable control like picture box but this is real time live view so it is not possible to process it directly so we need to getthecurrentframeoutoflivestreamingfor processing. This is what we called it frame extraction and we load this frame in memory for fast processing. Even we got the frame it is not easy to identify the color from it so we needtoperformimageprocessinghereandas we know each pixel is made up of 3 bit of RGBsowetrytoextractRGBvalueforeach pixel and we also try to compare those value with predefined value like what we do in pattern matching. If we get the desired result we process for drawing and all this process will executed for next frame, here we are doing frame capturing and frame processing both, it should be compulsory both process should be synchronous for smooth performance. This is how real time image processing work and utilized in our project.

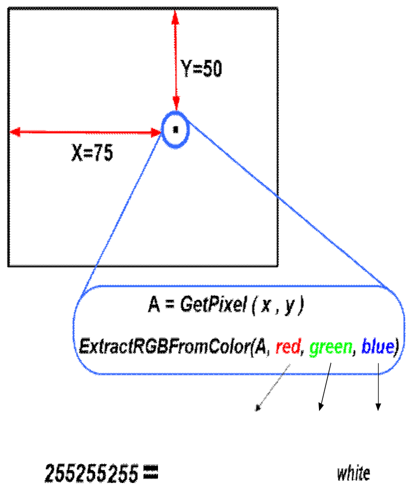

Figure7:Pixelcolorextractionmethod

Asonlastslidewehadseenallaboutrealtime video processing let see a basic or pixel extractionandcomparison.Asweknowpixel madeupof3bitofRGBandthisisdependon the image format like JPG, BPM etc. identifyingsinglepixeliseasybutitismatter of more number of pixel so. Let take an example.

When we use GetPixel() function it returns pixel color value in integer or hexadecimal. ThisvalueiscombinationofRGBsobyusing anotherfunctionweneedtoseparatetheRGB value from this color value. So we can use ExtractRGBFromColor() function this functionwillseparatetheRGBandstoreitin different variable which can further used for comparison. As in example we can see all value 255 generates white color.

V. RESULTS AND ANALYSIS

A. Experimental Setup and Testing Procedure

Toevaluatetheeffectivenessoftheproposed robotic arm system, a series of experiments were conducted in a controlled environment. The system was tested with various objects differing in color and shape, including red squares, blue triangles, and green rectangles. Theroboticarm'sperformancewasmeasured in terms of detection accuracy, sorting precision,andresponsetime.Atotalof100 objects were used for testing, ensuring a diverse range of parameters for evaluation.

B. ColorandShapeDetectionAccuracy

The first phase of the testing involved evaluatingtheaccuracyofthecolordetection algorithm.Thesystemsuccessfullyidentified andclassifiedcolorswithanaccuracyof98%, demonstrating high reliability in distinguishing between different hues within the HSV color space. The use of HSV over RGB proved advantageous due to its robustness against variations in lighting conditions.

For shape detection, the contour-based classification approach was analyzed. The system correctly classified shapes with an accuracy of 95%. The discrepancies were primarily due to variations in object orientationsandslightdistortionsincontours. However, fine-tuning the contour approximation algorithm improved accuracy significantly, reducing misclassification errors.

C. SortingEfficiencyandProcessingTime

The robotic arm’s sorting mechanism was assessedbyanalyzingthetimetakentodetect, classify, and place objects in their respective bins. The average processing time per object was recorded as follows:

Parameter	Average Time (seconds)
ColorDetection	0.5
Shape Detection	0.7
PickandPlace	2.3
Total Processing Time	3.5

The results indicate that the robotic arm is capable of handling multiple objects within a short timeframe, making it suitable for industrial applications requiring high-speed automation.

D. SystemRobustnessandAdaptability

Thesystemwastestedunderdifferentlighting conditions to evaluate its robustness. The HSV-based color detection algorithm exhibited strong adaptability, maintaining consistent performance across varying light intensities. Similarly,thecontour-based shape detection algorithm performed reliably, with onlyminordeviationsunderextremelighting conditions.

Thesoftwareinterfacewastested for usability and flexibility. Novice operators could set sorting parameters without prior codingexperience,confirmingthesystem's user-friendly design. The ability to reconfiguretheroboticarmfordifferent tasks without extensive reprogramming enhances its practical applicability in dynamicindustrialenvironments.

E. ComparativeAnalysis

Tofurthervalidatetheeffectivenessofthe proposedsystem,acomparisonwasmade against conventional manual sorting and other automated systems using similar methodologies.Theroboticarm demonstrateda40%increaseinsorting efficiency comparedtomanual sortinganda 15% improvement over traditional RGB- basedautomatedsortingmethods.

VI. CONCLUSION

Thispaperpresentedamultifunctionalrobotic arm system capable of detecting and sorting objectsbasedoncolorandshapeusingHSV-based color detection and contour-based shape recognition techniques. The experimental results confirmed the system's high accuracy, efficiency, and adaptability, making it a viable solution for industrial automation.

Thekeyfindingsofthestudyinclude:

- Ahighaccuracyrate of98%forcolor detection and 95% for shape recognition.
- Anaverageobjectprocessingtimeof 3.5 seconds, enabling rapid sorting operations.
- Robust performance across varying lighting conditions, demonstrating system adaptability.
- A user-friendly software interface allowing easy reconfiguration of sorting parameters.

Theimplementationofthisroboticsystemhas significantimplicationsforindustriessuchas manufacturing, packaging, and logistics, where automated sorting can reduce errors andenhanceefficiency.Futureenhancements may focus on integrating deep learning models for more complex object recognition tasks, improving real-time decision-making, andexpandingtherange ofdetectableshapes and colors. Additionally, implementing a reinforcement learning framework could optimize the robotic arm's movement for improved speed and precision.

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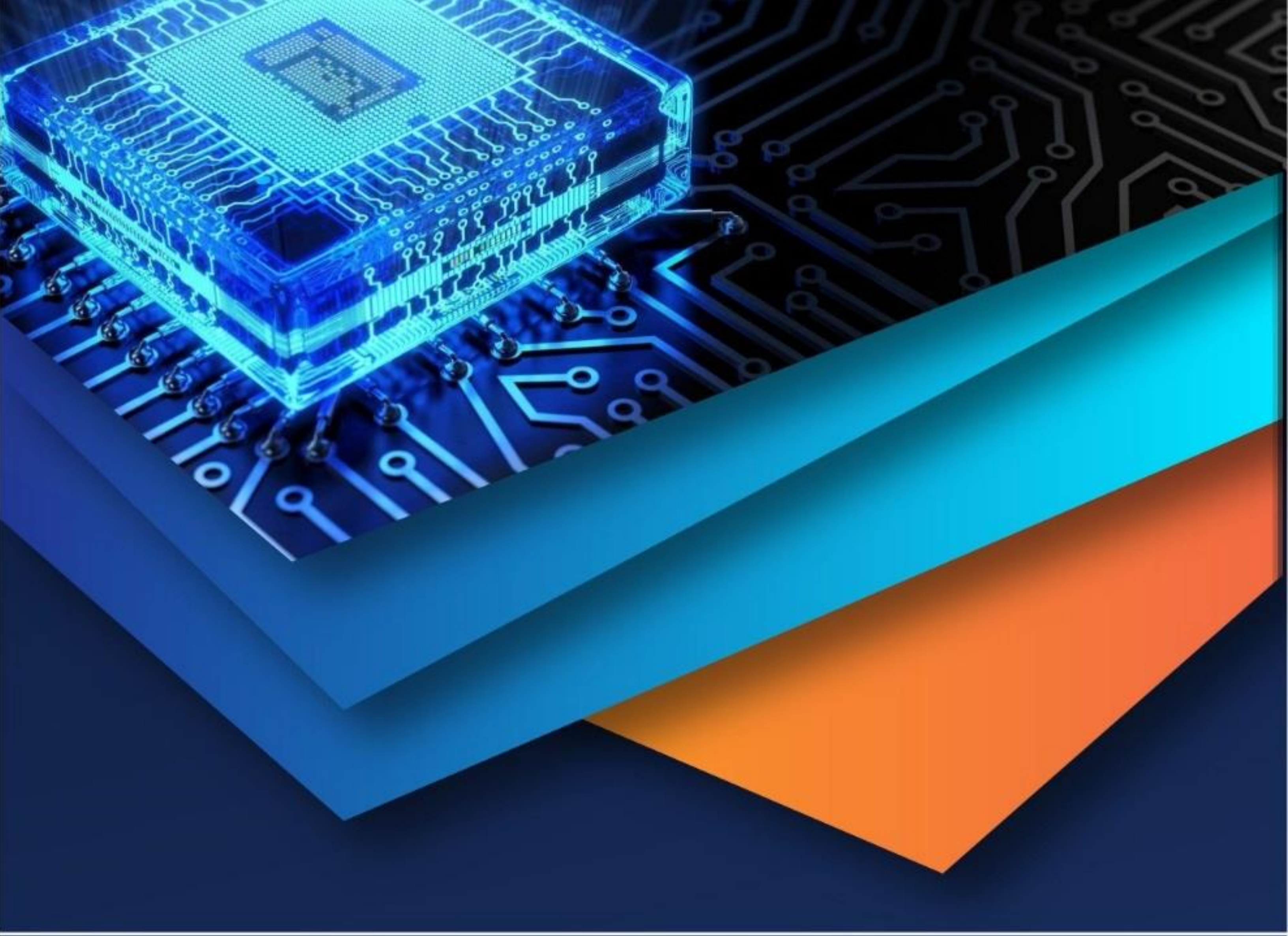

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