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Advanced Electronic Circuit Design for Visual Classification Modeling Using CNN

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Abstract

Convolutional Neural Networks are integrated into the image processing module of the system, which uses OpenCV for sophisticated categorization. While auxiliary parts such as infrared sensors for item detection, LCD display for user feedback, and SD card module for data storage. In addition to interactive controls via push buttons to improve functionality and user experience servo motors enabled the sorting mechanism by the designed arm. To guarantee dependability the electronic circuit design integrated creative wiring methods and effective power management. This design was innovative because it combined several sensor technologies with cutting-edge processing power in a small package, enabling effective sorting using complex visual analysis. Through the practical use of machine learning, it searched to offer a flexible solution for automation in many domains such as manufacturing and inventory management. The function of electronic circuit design in guaranteeing system dependability and smooth integration of various components has been highlighted. The design improved the efficiency of the system by carefully taking into account compatible characteristics including voltage and resistance. Maintaining signal integrity reduces noise and interference, which is important for accurate data processing, particularly in systems that use the CNN for image classification. The combination of several sensing technologies and sophisticated processing powers such as the CNN into a small system made this contribution. This study presented a 30-day evaluation of the proposed model for distinguishing between cube and sphere objects. The

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system achieved a consistent accuracy of 96% with a low error rate of 4% and also a high precision of about 99%. These results indicated the strong capability for model classification regardless of variations in sample numbers. When compared to existing CNN-based classification methods, the proposed model demonstrated its robustness and suitability for real-world applications.

Keywords: Electronic Circuit Design, Convolutional Neural Networks, Object Classification, Embedded Systems, Power Management.

1 Introduction

Arduino's efficiency in a wide range of applications has drawn a lot of attention to its electronic circuit design for sorting systems (Martinez & Garcia, 2024). These sorting systems are based on the Arduino microcontroller that allows for automatic object classification in conjunction with sensors as mentioned in (Borkar, 2022; Kadhim et al., 2024). The Arduino Nano microcontroller, which defines the TCS3200 color sensor and servo motors, is used in a standard color sorting system (Meymari et al., 2015). The Arduino receives data from the color sensor, which determines the object's color and then turns on the proper motors to sort it into its proper place as mentioned in more detail in (Borkar, 2022). The electronic circuits are based on Arduino have added servo motors in addition to color sensor arrays, which are applied in the sorting of 1,800 samples of vegetables, such as tomatoes according to their size and color as explained in (Kalnar et al., 2022; Mehta & Malhotra, 2024; Masjedi, 2015). The sorting process could be modified not only for color detection but also to include environment a monitoring in greenhouses as suggested by authors (Mohite et al., 2020). Arduino was applied for a variety of sorting tasks due to its reliability by using and adding different function sensors. Sorting systems using Arduino provide a better solution, because it has been greatly increased consistency in addition to increasing cost compared to manual sorting procedures as explained and studied more in (Borkar, 2022; Kalnar et al., 2022). In (Agrawal et al., 2016), the proposed Arduino systems was the traditional system that just included segmentation with common classification stages, that were found in industrial fields. In another work, authors provided additional utilization of machine vision and deep learning (DL) for object classification was growing as presented (Chang et al., 2021; Wu et al., 2022). Some methods have been produced in that interval such as the Ball Sorting System Based on the Ball Plate Control Model (BSBCM), when authors use just an actuator to reduce system complexity by combining Machine Learning (ML). This combination was to recognize the features of spherical objects in addition to position calibration as given (Ni et al., 2018). In (Wu et al., 2022), the authors used a coordinate axis manipulator mixed with an RGB/D camera to classify objects, this design gained great success rates in sorting objects (Chopra & Patil, 2025). Some technologies ought to be added such as cutting edge, which increase processing rates through using FPGA architectures and hyperspectral photography. While FPGA-based solutions provide better performance over programmable DSP implementations for real-time video tasks as suggested in (Mccurry et al., 2001). Feature extraction speed in addition to image preprocessing as a main step to be handled has been benefits from the use of OpenCL acceleration on FPGA hardware, which was described in (Wang et al., 2019).

Different programming models have been used to fit on some specific hardware architectures for a specific requirement used in the design of sorting systems (Priyadharshini & Rathinam, 2020). Three hardware sorting algorithms have been combined in a sorting library designed for FPGAs utilizing the OpenCL programming model. This method concluded a baseline sort by 1.09x despite more hardware resources being required as produced (Kobayashi et al., 2021). CUDA programming was used in the context of graphics processing units (GPUs) to apply specific memory and computation models to develop the process of sorting but in parallel form, as suggested in (Gopi, 2017). In this article, the authors used Bitonic Sort, which was a different programming model with different effects on the operation of hardware Cache Coherent Shared Address Space (CC-SAS) multiprocessors (Marzuki et al., 2019). In (Shan & Singh, 1999), authors compared radix and sample sorting under load store and discovered that the sorting process was highly affected by the programming model while sorting objects, especially in sample sorting. A unified method for developing scalable parallel sorting algorithms across various parallel machines has also been suggested (Gerbessiotis & Siniolakis, 1998). The target hardware architecture determined which programming model was used for sorting system design. Different methods for putting effective sorting algorithms into practice were provided by OpenCL for FPGAs and BSP for general parallel systems. To maximize performance in a variety of computer settings, the right model must be selected, where CNNs, for example, have strong image processing capabilities with better classification skills, making them useful for designing sorting systems. An enhanced CNN method for license plate recognition, as proposed in (Shimizu et al., 2017), has been modified for object recognition in a sorting system. Isolating objects benefit greatly from the preprocessing step, which includes edge detection and morphological processes, as produced by (Shimizu et al., 2017). Hyperparameter optimization in CNN architectures was studied by authors (Pandey et al., 2021; Aritonang et al., 2023). The RMSprop optimizer that contained an APL dropout value of 0.05 and a dense layer of 64 nodes was explicitly mentioned in (Aritonang et al., 2023) as having produced a high accuracy of about 97.81% for the categorization of skin diseases. In (Hadjam et al., 2022; Feng et al., 2019), the system was implemented on hardware using FPGAs to increase the sorting system performance, especially for embedded systems. In (Zhu et al., 2018) authors suggested a design using genetic programming for an automated CNN architecture search to identify the CNN structure for a more complex sorting process.

2 Methods and Materials

2.1 Methods

The first step for designing this model and sorting system was the circuit design by several steps. By determining key parts such as the Arduino microcontroller, camera module, servo motors for sorting, infrared sensors for detecting objects, an LCD for user input, and an SD card module for data storage. The second step was the schematic design by drawing a schematic design that shows how parts are connected. This involved managing the power supply to guarantee that the right voltage and current were delivered to every component. Also, the configurations for connecting the sensors and camera module to the microcontroller should be identified. In addition, the servo motor connections guarantee precise control signals for the sorting process. After all of the circuit design steps the PCB plan is used, planning the layout to maximize available space and reducing interference which is important by adding sufficient grounding for example. The second step after circuit design is the development of software which is done by configuring the programming environment by preparing the required libraries as OpenCV for image processing and any libraries required for sensor integration and also setting up the Arduino IDE to prepare the loading program. The next step in this process is writing code to take pictures from the camera module and preparing them for analysis. The objects should be also categorized based on visual features, training CNN with an appropriate dataset which was used for cubic and circle shapes for this article. In addition, integrated CNN which was trained to enable the software to classify real-time photos. Moreover, giving feedback on the state of the system, including the categories of classified objects and the result of sorting to create an interface for the LCD. The last step in the proposed method was the component integration by putting together all hardware by the schematic design, sure that all parts are mounted correctly and have secure connections. For further testing and calibrations, making tests to calibrate the system to prove that the sorting mechanism reacts appropriately to control signals and that sensors in turn should detect objects with higher accuracy. The system integration was done by combining hardware and software to guarantee the best communication between all parts (camera, motors, sensors, and Arduino). The last step for the integration part was confirming the overall system functionality by conducting many tests using different items. Moreover, analyzing the efficiency of sorting by making several modifications if required. The proposed method of identification of two objects using Arduino-Uno are shown in Figure 1.

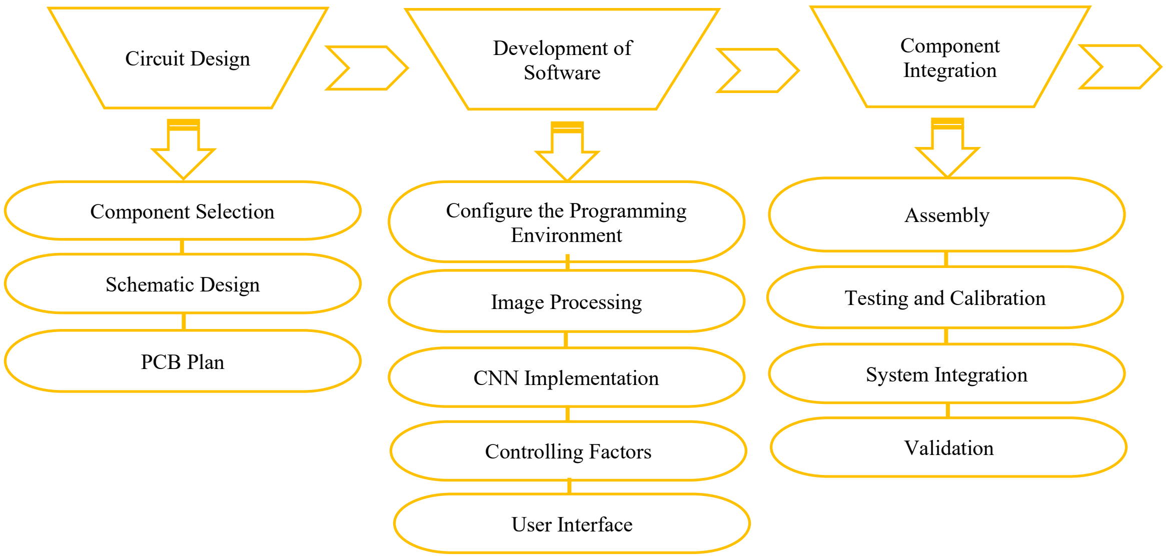

Figure 1: Proposed Method of Identification of Two Objects Using Arduino

2.2 Materials

The circuits that have been used in this project are shown in Figure 2 and explained as follow2:

1- The Arduino Uno Board was considered the main microcontroller in this project, the Arduino board was in charge of controlling inputs and outputs and enabling communication between different parts.
2- A camera that is compatible with Arduino for taking pictures of the objects that have to be categorized and arranged. The Arduino-compatible camera OV7670 was used due to the lesser resolution ability of about VGA (640x480). It is also appropriate for more straightforward applications where direct Arduino integration is desired and high resolution is not important.
3- Module for image processing to manage the examination of taken pictures and to categorize objects according to preset standards which is considered a powerful library for processing images in real-time.
4- Servo motors to physically sort objects in accordance with the classifications established by the image processing module. They provided exact control over where the things being sorted were placed. Rotational movement of the applied servo between 0 and 180 degrees is provided by the standard version and is considered ideal for applications where moving things to designated locations is a part of the sorting process. The controlling process is made by the Servo library.
5- Infrared (IR) is used to measure distances and identify whether objects are found in the system. These sensors assist in identifying when an object is ready for sorting and recognize any change with alerts to the microcontroller.

6- Module for SD Cards to store classified images on the SD card module which is important for data logging and any retrieval process for additional analysis.
7- Energy source is also should be carefully connected to guarantee that every component runs efficiently without any interruption. Every component has a different voltage need that should be guaranteed that the power source can provide enough current to manage high loads, especially when moving parts such as servo motors are operating.

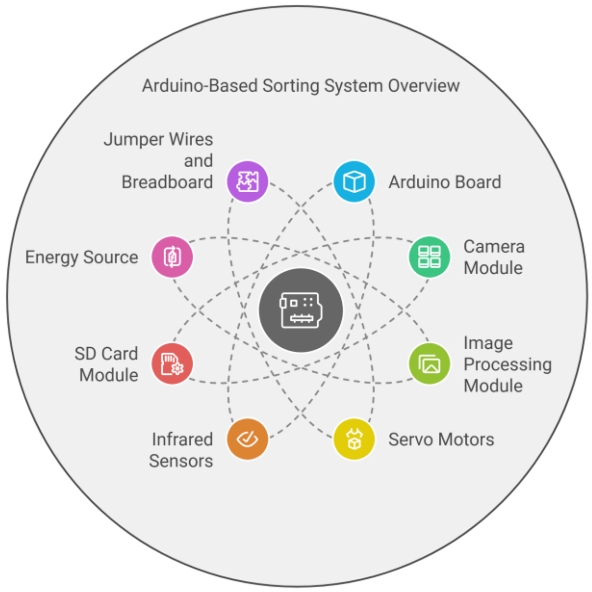

Figure 2: Overview of Arduino-based Object Sorting System Components

Figure 3 shows a labeled diagram of an Arduino microcontroller board with different connected components. The diagram included labels for two servos plus sensors and a camera. In addition, Figure 3 shows an SD card module that interfaced with the Arduino. Power connections are also highlighted, with "+5V" and "GND" pins marked for voltage supply. This setup was used for this work which involved motion control using servos with data collection (using sensors and a camera).

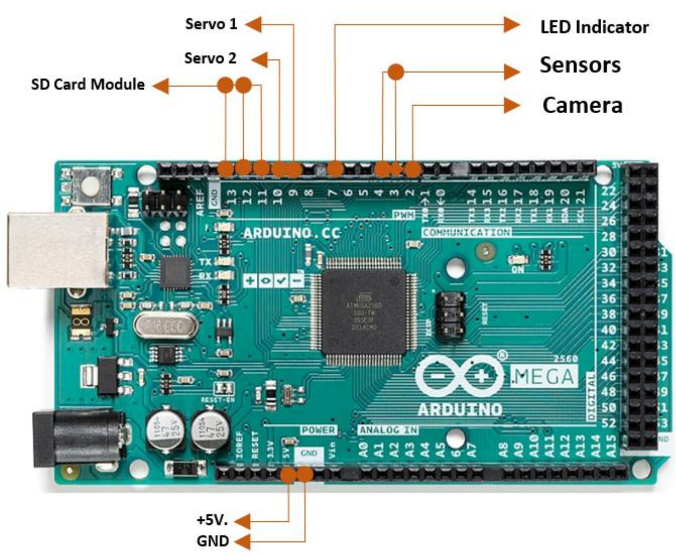

Figure 3: Arduino Connection Diagram for an Object Identification System

2.3 Flowchart of the object identification and sorting process

This code summarizes comprehension of the relationships between various system components and acts as a basis for creating the actual required code. All components must first be selected carefully to make sure they are suitable for this type of application. The categorization process was started by the main loop continuously checking for user input values. When the system is turned on, it uses the sensor of object variances to start identifications and then give acknowledgment of it. When an object is detected, the camera module takes the image, which is processed to classify it. An LCD will show the results of it, giving the user feedback to understand the process steps. The categorization results are also recorded on an SD card for other knowledge and information that could be used by users. The servo motor is turned on to sort the object into its assigned box or any container that could be sorted based on the categorization result. To handle any changes where the item is not there, the system incorporates an error alert for this issue. Lastly, LED provides visual input about the system's state referring to whether an error has occurred or not. This Figure shows the pseudocode steps that contain the framework for effective object classification according to the proposed model. The flowchart of the object identification and sorting process is shown in Figure 4.

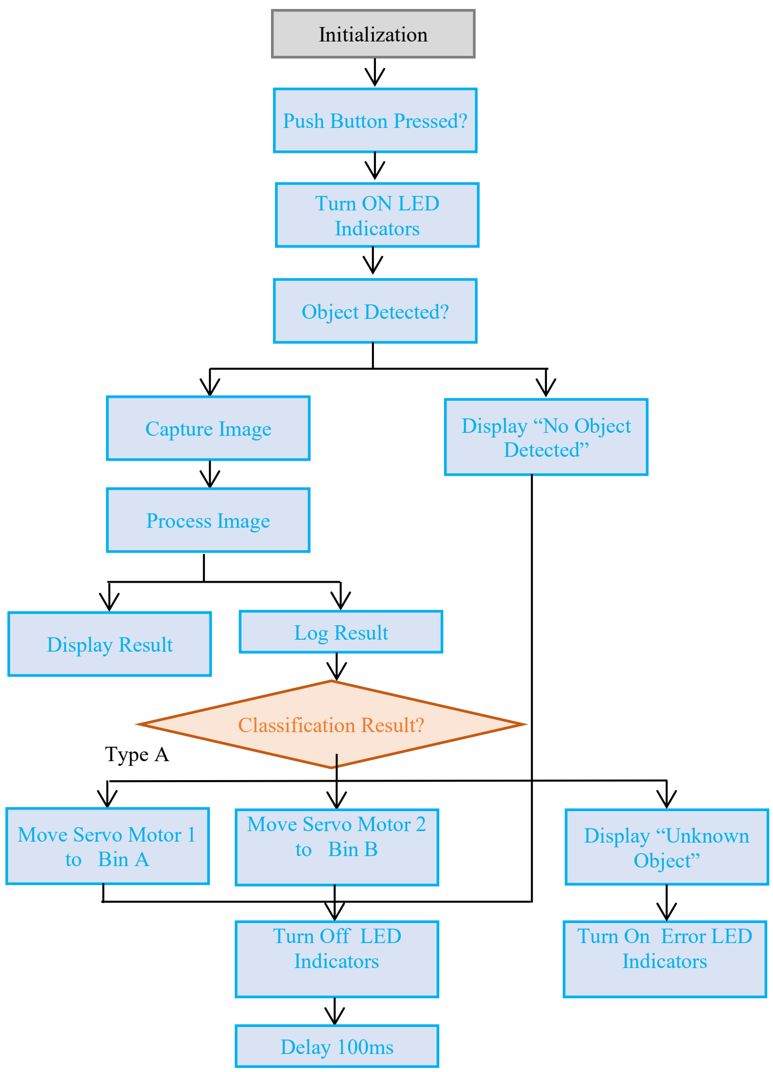

Figure 4: Flowchart of the Object Identification and Sorting Process

2.4 Performance Evaluation and System Advantages

The performance of the visual classification and sorting system needs some parameters to be evaluated, by employing classification accuracy to find the ratio of correctly classified instances to the total samples. Also to measure the processing time that represents the time taken to process a single image and classify it which is calculated in milliseconds. In addition to other metrics as the error rate which represents the proportion of incorrect classifications to the total samples.

1. Using CNN to classify images in real time using an electronic circuit design is a major goal for many researchers. This integration enables more complex processing capabilities especially when compare to traditional techniques.
2. Cameras and infrared sensors are uses in the design to create a stable system that used these several sensors and sorting is improved by this integration process.
3. This paper offers effective power management procedures to ensure the stability of the system while lowering energy consumption.
4. The system can deal with images in real-time by using CNN which makes it appropriate for dynamic settings like manufacturing.
5. The design provides a flexible solution that employed in the future for several and plenty types of uses, which opens the door for the automation of numerous fields.
6. The system is stable enough to accommodate changing technological requirements due to the stable circuit architecture which contains present functioning and potential future expansions.

3 Results

For materials such as cubes and spheres that have been proposed for this design, the overall performance summary for the identification test using CNN was recorded for 200 tests as shown in Figure 5 and Table 1. This high number of tests proved exhaustive and offered a strong basis for the results. Overall accuracy was 96.0% which is considered to be a very high result which refers to accurately identifying the materials with high stability. The rate of error overall was about 4.0% which also demonstrated the ability to reduce misclassifications. This design guarantees that errors are unfound and increases confidence in its working. In addition, the high precision lowers the possibility of FPR by ensuring that when the system produces + identification, it is in general accurate. The recall rate was about 99% which refers to the system consistently detecting every positive case by capturing all provided cases. The average processing time of this design about 143 ms which was also demonstrated the system speed. The performance measured provided an effective system that can precisely with high speed to recognize objects (cubes and spheres).

Table 1: Daily evaluation of cube and sphere identification performance

Day	Total Tests	Positive sample numbers	Negative sample numbers	(FP)	(FN)	Accuracy (%)	Error Rate (%)	Precision (%)	Recall (%)	Time (ms)
1	25	20	5	1	0	96%	4%	100%	100%	140
2	25	19	6	0	0	100%	0%	100%	100%	145
3	25	20	5	1	0	96%	4%	100%	100%	138
4	25	17	8	1	0	96%	4%	100%	100%	142
5	25	20	5	0	1	96%	4%	95%	95%	150
6	25	20	5	1	0	96%	4%	100%	100%	140
7	25	25	0	1	0	96%	4%	100%	100%	138
8	25	21	4	1	0	96%	4%	100%	100%	145
9	25	18	7	1	0	96%	4%	100%	100%	140
10	25	19	6	1	0	96%	4%	100%	100%	142
11	25	22	3	1	0	96%	4%	100%	100%	150
12	25	20	5	0	0	100%	0%	100%	100%	145
13	25	25	0	1	0	96%	4%	100%	100%	138
14	25	15	10	1	0	96%	4%	100%	100%	140
15	25	15	10	1	0	96%	4%	100%	100%	145
16	25	15	10	0	1	96%	4%	94%	94%	150
17	25	10	15	1	0	96%	4%	100%	100%	140
18	25	10	15	1	0	96%	4%	100%	100%	142
19	25	15	10	1	0	96%	4%	100%	100%	138
20	25	12	13	1	0	96%	4%	100%	100%	145
21	25	16	9	0	1	96%	4%	94%	94%	150
22	25	14	11	0	1	96%	4%	93%	93%	145
23	25	13	12	1	0	96%	4%	100%	100%	138
24	25	15	10	1	0	96%	4%	100%	100%	140
25	25	17	8	1	0	96%	4%	100%	100%	145
26	25	20	5	1	1	92%	8%	95%	95%	150
27	25	15	10	0	1	96%	4%	94%	94%	145
28	25	13	12	1	0	96%	4%	100%	100%	138
29	25	12	13	1	0	96%	4%	100%	100%	140
30	25	14	11	1	0	96%	4%	100%	100%	145
Total	**25**	**16.9**	**8.1**	**1**	**0**	**96%**	**4%**	**99%**	**99%**	**142.9667**

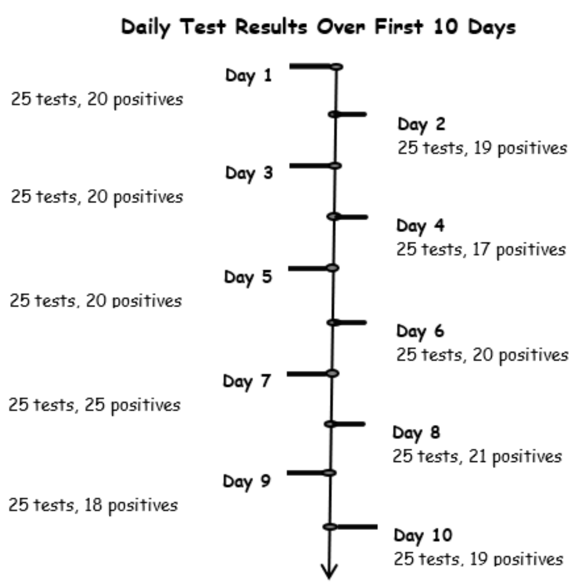

Figure 5: Daily Test Results Summary for CNN-based Object Identification System

Figure 6 shows a robotic arm that was in action was equipped to grip the pink cubic from a designated input area specified by the system. The system was mounted on a wooden platform and provided a look at the entire automated sorting setup. It highlighted the input area with a specific zone and the output area with sorted items based on two objects. The robotic arm was positioned at the center and capable of rotating plus moving to transfer objects accurately.

The results provided useful information on the ability to distinguish between two objects (Sphere and cubic) during a 30 days. The highly accurate identifications between the two objects were indicated by the highest 96% accuracy across all tests. Moreover, the error rate was low among all provided tests at 4%, which refers to very low misclassifications. The frequency of FP and FN was approximately one per day on average among all testing days and the number of testing times. The FNs were rare for the testing days, referring to a high sensitivity in detection for this purpose. The precision as well was about 99% which refers as well to a high probability of accuracy when it predicts a positive sample as shown in Figure 7 and Figure 8.

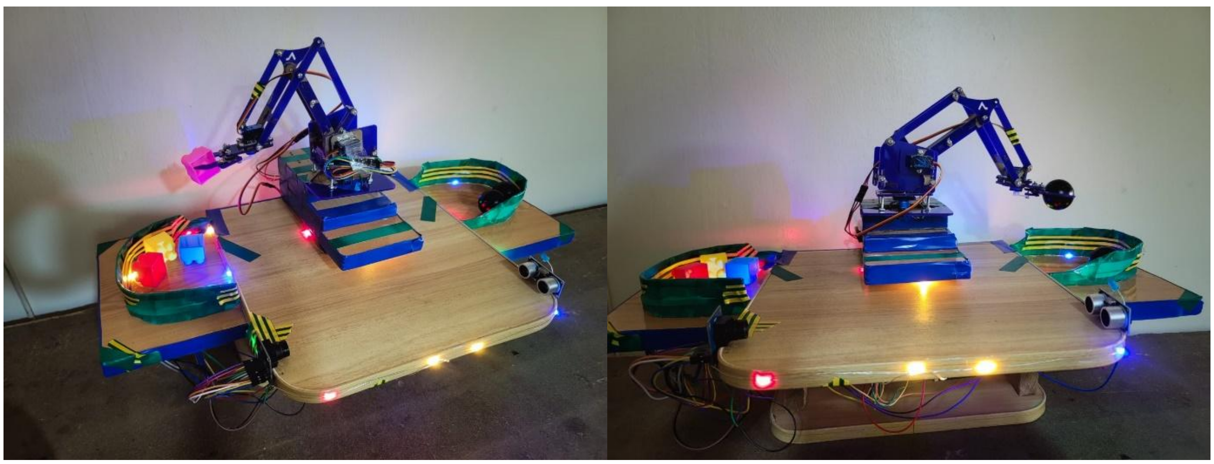

Figure 6: Robotic Arm to Grip Object (Cube and Sphere) from a Specific Zone

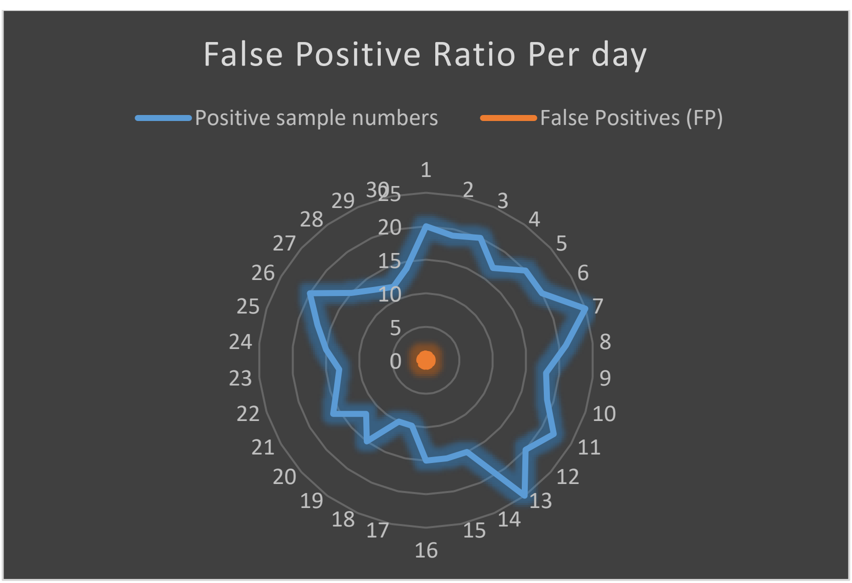

Figure 7: Daily FP and Precision Rates over 30 Days Testing Period

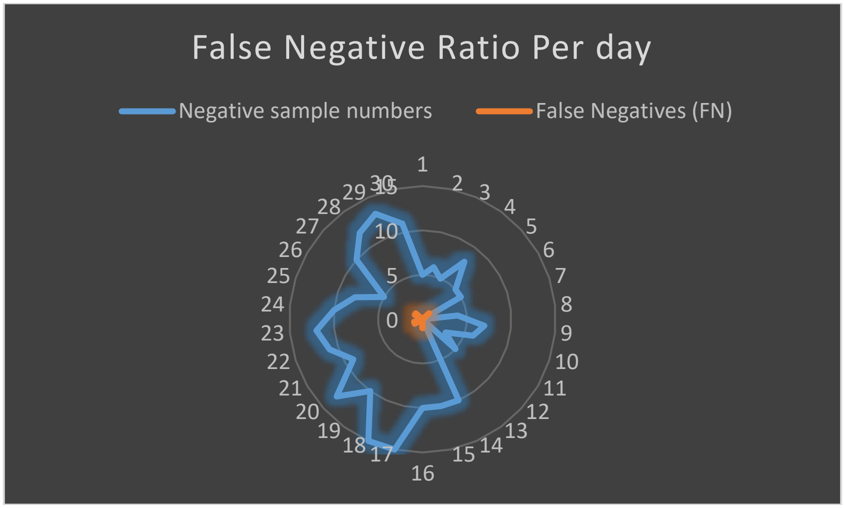

Figure 8: Daily FNR and Precision Rates Over 30 Days Testing Period

The constant processing times implied the steady performance over the testing days and for these two objects. Also, the constant accuracy and low error rate value among the testing provide additional proof of the performance stability. The system demonstrated robustness against input changing and high accuracy has been stable with (92%-100%) regardless of differences in sample quantities. Consistent performance indicators demonstrated the stability in classifying the two required items as shown in Figure 9.

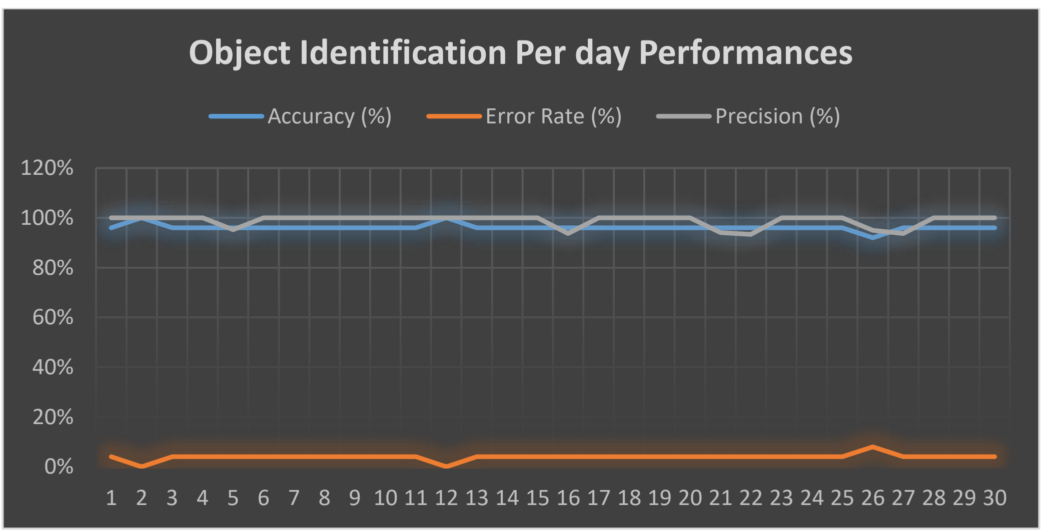

Figure 9: Stability of Accuracy and Processing Time Over the 30-day Testing Period

The Arduino Uno Microcontroller, which served as the CPU of the system, typically took around 50-100 mA depending on the peripherals connected to this part which operates at 5V, leading to 0.25-0.5 W. While the microcontroller ran continuously, it formed the main part of the overall power requirements, though it was considered as the most power-hungry component. While, the camera module (OV7670), used for capturing images of objects, typically operates at 60-150 mA at 3.3V with 0.2-0.5 W power consumption due to fluctuation based on the frame rate and processing load. The camera's power consumption impacts energy efficiency, especially when capturing high-resolution images over time. On the other hand, the servo motors used for sorting objects were not the most power-intensive components in this model which took about 100-200 mA when idle, but it got the highest value during operation, particularly when moving items. A fully active servo motor drew up to 500 mA per motor, meaning the total power consumption from servo motors reached the highest at 1W. Since two servos have been used for sorting, the total power for these motors was 2 W during the active process. Also, the infrared (IR) Sensors, which were used for detecting objects are considered as low-power components with about 5-10 mA at 5V, with an average power of 0.025-0.05 W per sensor. These parts had low power consumption compared to other components compared to the SD card module, which consumed about 50-100 mA at 5V, with a power of 0.25-0.5 W. The power consumption of the SD card increases during read/write operations, especially when storing image data. The power management handled the changing power requirements of the system, particularly when motors have been in operation. The system's overall power changes depending on whether the servos are moving and also when the camera is active. The power supply provided a stable 5V with sufficient current, which peaks at around 2-3 A during motor activation. By turning on all components, the total power consumption for the system has been approximately between 3 W to 4.5 W during peak operation. This represents a relatively energy-efficient design, especially for embedded systems, though the system's power demand depended on the frequency of servo motor use and image capture. The above information is given in Table 2.

Table 2: Power consumption for the related circuit elements:

Component	Power Consumption	Approximate Power Usage
Arduino Uno	Continuous operation	0.25-0.5 W
Camera Module (OV7670)	During active capture	0.2-0.5 W
Servo Motors (x2)	During active movement	2 W (for both motors)
Infrared Sensors	Continuous operation	0.025-0.05 W per sensor
SD Card Module	During read/write operations	0.25-0.5 W

To manage the power consumption of related elements as explained in Table 2, the system used power sleep modes for low-power components such as the camera and microcontroller when they are not working. As an example the camera was powered off between image captures, as well as the Arduino was put into a low-power state during the idle process. It helped to reduce overall energy consumption and improve the system's efficiency in real-time applications. The servo motors contribute the most to power consumption due to the movement process and their efficiency is enhanced by selecting low-power servos to minimize the duration of high-power operations. The camera module and IR are relatively low in power consumption by further optimization of the camera resolution and frame rate that reduced its power while image processing.

With a high 96% accuracy value, the suggested model in this article has shown an improvement in classifying two objects. The novel design, based on the proposed CNN model that has been tuned for highly accurate item separation, was responsible for its high efficacy. Compared to previous studies, as shown in Table 3, the suggested model made use of CNNs that improved the capacity to pick up characteristics unique to the two items under classification, which could be further increased for more improvements. The suggested model incorporates techniques in addition to CNN, such as data augmentation and transfer learning, which increased the overall sensitivity in classifying between similar object classes. Many of the referenced studies, such as (Ismail et al., 2019; Khaing et al., 2018), focused on achieving high accuracy in fields like image classification taken by CNNs but did not integrate hardware or real-time sorting utilization. These studies primarily rely on software-based approaches without addressing embedded systems. Authors (Zhu et al., 2018; Ahmed et al., 2023), for example, used CNNs for image classification tasks, while authors (Faleh & Kachouri, 2023) applied a hybrid CNN with the LDA model for gas classification; however, all of these articles lack related components for real-time sorting. Also, authors (Aritonang et al., 2023; Shimizu et al., 2017; Maulana, 2024) used

CNNs for medical imaging, egg freshness detection, and industrial applications. However, these articles didn't include hardware-based solutions for real sorting. In contrast, the proposed model in this paper applied hardware with Arduino and demonstrated real-time sorting capabilities by achieving 96% accuracy in sorting objects. This hardware integration provided key points, allowing this model to handle real-time object sorting tasks.

Table 3: Ccomparison of CNN Models in Classification Tasks for Two Objects

References	Field	Accuracy	Method	Hardware Used	Real-time Sorting Efficiency
(Ismail et al., 2019)	Image Classification	83%	MiniVGGNet CNN Decay Factor.	None	No real-time sorting
(Faleh & Kachouri, 2023)	Gas Classification	93%	Hybrid CNN-LDA Model	None	No real-time sorting
(Ahmed et al., 2023)	Image Classification	85%	CNN	None	No real-time sorting
(Khudhair et al., 2025)	Medical Imaging	87%	MiniVGGNet	None	No real-time sorting
(Maulana, 2024)	Egg Freshness Detection	90%	CNN	None	No real-time sorting
(Shimizu et al., 2017)	Industrial Product Quality Inspection	92.3%	CNN	None	No real-time sorting
(Khaing et al., 2018)	Fruit Detection	94%	CNN	None	No real-time sorting
(Das et al., 2019)	Brain Tumor Classification	94.39%	CNN	None	No real-time sorting
Proposal, 2024	Object Classifications	96%	CNN	Arduino	Yes, real-time sorting

Moreover, the selected articles were chosen due to their relevance to the same field of processing and how they compare to these articles based on accuracy and proposed models. Ismail et al., 2019 and by using a hybrid CNN model, researchers were able to classify gases with 93% accuracy. In (Faleh & Kachouri, 2023; Khudhair et al., 2025), using CNNs also produced excellent results in fruit/egg detection, which was also high but not as much as the proposed model in this article. This development focused on detecting a larger pattern in image classification, where training the model resulted in higher performance, especially for challenging tasks involving more object classifications. The suggested model established a new standard in the field by analyzing these developments, as compared to other studies, as shown in the above table and Figures 10 and 11.

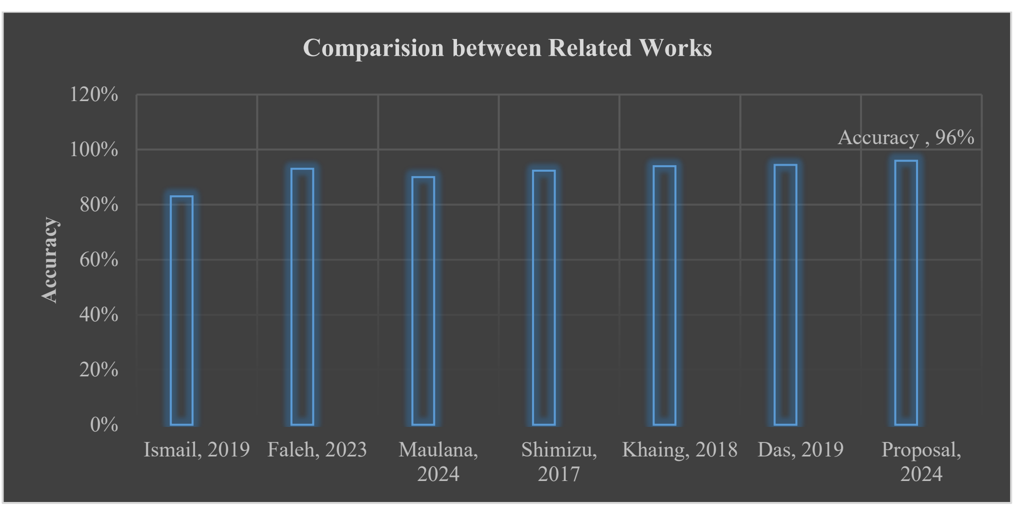

Figure 10: Accuracy Comparison of CNN Models in Classification tasks with the proposed model of 96%

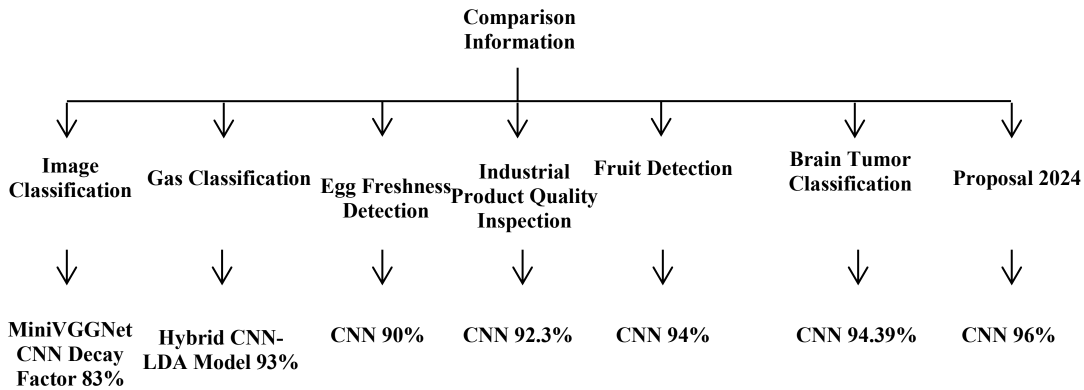

Figure 11: Comparison of CNN Models in Classification Tasks with Similar and Different Techniques

4 Conclusion

This design has been successfully implemented and shown the efficient ability to accurately categorize the two objects including cubic and circles. Intelligent categorization was made possible by the utilization of CNN which allowed the system to accurately distinguish between the required shapes with 96% accuracy shapes. The effectiveness of this design has been demonstrated by the sorting mechanism and moved the classified objects to their appropriate sides left and right side. This design also provided the potential for adaption to increasingly challenging sorting missions in practical fields in factories. This design demonstrated the effectiveness of applying ML technology with electronic circuit design which referred to Arduino cards. This design also opened the door for further advancements in automation in the development of intelligent systems that can improve operations in a variety of industries. The electronic circuit components were carefully selected and then simulated through the modeling phase to visualize the interactions between components using techniques. This method optimized the circuit performance by reducing errors during the prototyping design. This design developed models that captured each component's parameter through the repeated testing processes. Perfect matching of electronic circuit boards has been important to the success of this to avoid possible errors that could occur. The mechanical efficiency was also increased by using several sensors and electronic parts such as servo motors that fitted the speed requirements required for efficient sorting. The proposed model presented in this article with simulation actual results improved the overall performance by analyzing the most important parameters for performance increment. The knowledge gained from this design builds a strong basis for additional ideas in sorting and automated systems in this field.

Over the 30-day of simulation calculations and design, the proposed model for classifying two specific objects (cubes and spheres) proved the stability of this system with high performance across the different calculated metrics. The system maintained a stable rate of 96% accuracy with low error rates of just 4%. This referred to strong predictions regardless of changes in the number of positive and negative samples in 30 days. Precision was about 99%, which confirmed the ability to correctly identify both cubes and spheres with low FP or even low FN. The FN was already rare to be found, which referred to the high sensitivity in predicting the TP samples. The average of data processing and finalizing the whole process time was about 143ms, which was stable for the whole evaluation period. These results and calculations have been reflected in the operational efficiency for real-time applications even when sample distributions altered. Despite these changes, performance metrics did not significantly affect which referred to strong generalization capabilities that could be applied for different objects and more samples. When compared to other CNN-related studies, the proposed model provided higher accuracy from 83% to 94.39%. This high performance was due to the use of optimization techniques in addition to data augmentation and transfer learning which specified the feature space. These techniques have been combined with tuned CNN, which allowed the model to extract more impact features compared to traditional CNN. The design's high accuracy with low error in addition to the stable performance under different conditions indicated a promising application in classification tasks.

By optimizing sorting mechanisms, the combination of ML with advanced electronic circuit design for CNNs aimed to get beyond these limitations. An electronic circuit that efficiently combines many elements to facilitate the classification of objects in real-time. To ensure precise and quick sorting, provide a sorting system that uses CNN outputs to automatically route categorized objects to required places. Establish standards for accuracy and efficiency by conducting experiments to assess the effectiveness of sorting different objects. The system, as designed, was primarily optimized for sorting cubes and spheres using CNN, but its architecture was adaptable and can generalize to more complex objects with some adjustments to the underlying model and hardware. To do this, several steps can be followed: first, the current CNN model, trained specifically on cubes and spheres, would need to expand its training dataset to include a wider variety of objects with different shapes and sizes, allows the CNN to learn broader features and improve its ability to generalize to new object types. Second, transfer learning could be applied, where a pre-trained CNN model is fine-tuned with the new dataset, thus reducing the need for training from scratch and taking the existing knowledge of image classification from the proposed model. Third, to handle more complex objects, the system incorporates advanced techniques like feature-based recognition that allowing classification based on size and color, in addition to shape. Fourth, the CNN model would need to be adapted for several object classifications to sort multiple objects. Fifth, hardware needs adjustments depending on the complexity and size of objects, such as higher torque servo motors for varying object weights with a higher-resolution camera module to better handle diverse lighting conditions and textures. Finally, with more complex objects, processing time and accuracy will be important, requiring the system to be optimized for faster classification and sorting, possibly using advanced image processing techniques like edge detection, contour analysis, or parallel processing machine learning models.

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