



# **AN-NAJAH NATIONAL UNIVERSITY**

**Computer Engineering Department**

## **Hardware Graduation Project**

### **Image -Processing Controlled Robot**

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## **Disclaimer**

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## **Abstract**

Modern automation relies heavily on the integration of perception, communication, and actuation to perform tasks that traditionally require human intervention. This project introduces Image-Processing Controlled Robot, an autonomous robotic system designed for intelligent object detection, classification, and sorting. The system separates vision from actuation: an external camera performs real-time image processing to identify objects such as balls and trash, then transmits commands directly via Bluetooth to the robot's HC-05 module equipped with a robotic arm. Based on the received instructions, the robot navigates toward the detected object, picks it up, and sorts it into the appropriate bin.

The robotic car and arm assembly are both controlled by an Arduino Mega, with an HC-05 Bluetooth module handling wireless communication. Users can operate the robot manually through a dedicated mobile application, or allow the external camera to guide it autonomously. However, the camera-guided mode and mobile-app control cannot function simultaneously, ensuring that only one controller manages the robot at a time. This dual-mode design highlights the flexibility of the system, demonstrating both manual and automated capabilities.

Key hardware elements include the robotic arm for manipulation, the mobile car platform for navigation, and the external camera for vision processing. Software components manage wireless communication, object classification, and control logic for actuation. While the prototype faced constraints such as limited Bluetooth range, low-quality camera performance, and reduced battery runtime, it successfully demonstrated the feasibility of low-cost object detection and sorting using a modular, distributed system.

This project underscores the potential of combining image processing, wireless communication, and robotic actuation to solve real-world automation challenges. Future improvements include integrating higher-resolution cameras, shifting processing onto the robot itself, and adopting more advanced wireless protocols to enhance autonomy and scalability.

# 1 Introduction

Automation and robotics are increasingly being applied to tasks that require both perception and physical interaction with the environment. Sorting and classification of objects, which traditionally depend on human labor, present opportunities for developing cost-effective robotic solutions that integrate vision, communication, and manipulation. This project introduces the Image-Processing Controlled Robot, a system designed to detect, classify, and sort objects such as balls and trash using a combination of external vision and embedded control.

The system architecture separates vision from actuation. An external camera performs real-time object detection and sends motion and sorting commands via Bluetooth to an HC-05 module connected to an Arduino Mega, which directly controls both the mobile car and the robotic arm. Depending on the command, the robot navigates to the detected object, picks it up, and sorts it into the correct bin. The design also supports an alternative mode of operation: users can manually control the robot and arm through a dedicated mobile application connected over Bluetooth. To prevent conflicts, the camera-guided mode and mobile-app control cannot operate simultaneously, ensuring that only one controller is active at a time.

With its modular design, wireless control, and dual operation modes, this system demonstrates how image processing and embedded systems can be combined to achieve low-cost object sorting automation. Although constrained by factors such as Bluetooth range, camera quality, and limited battery runtime, the project highlights the feasibility of distributed vision and control, offering a scalable foundation for more advanced robotic applications in the future.

## Organization of the Report:

This report is organized into six main chapters. Chapter 1 introduces the project motivation and objectives. Chapter 2 outlines the constraints faced during development and summarizes the relevant coursework that supported the project. Chapter 3 details the methodology, including the system design, hardware architecture, communication protocols, and control logic. Chapter 4 presents the implementation, testing, and results of the robotic system. Chapter 5 discusses conclusions, lessons learned, and recommendations for future improvements. Chapter 6 lists the references cited throughout the report.

## 2 Constraints and Earlier course work

### 2.1 Constraints

During the development of this project, several practical constraints were encountered that shaped the design and performance of the system:

- **Low-Quality Components:** Due to budget limitations, some components had restricted performance, which reduced overall system efficiency and reliability.
- **Camera Limitations:** The external camera used for object detection had low resolution and accuracy. In particular, it failed to consistently recognize the robotic arm on top of the car, which limited motion precision.
- **Bluetooth Restrictions:** Since all communication relied on an HC-05 Bluetooth module connected to the Arduino Mega, the system was constrained by Bluetooth's short communication range and occasional interference. Only one controller (camera or mobile app) could be active at a time.
- **Power Constraints:** The robot was powered by rechargeable lithium batteries with limited operating time, requiring frequent recharging during testing and demonstrations.

### 2.2 Early Courses

While we benefited from a wide range of courses throughout our academic journey, certain ones proved particularly impactful in the successful development of our image-processing controlled robot. These courses provided the necessary balance between theoretical knowledge and practical application, enabling us to design a system that integrates computer vision, wireless communication, and robotic control in a functional and efficient manner.

Our introduction to microcontrollers and automation began with the **PIC Lab**, where we gained hands-on experience working with the Arduino Uno and developed a strong understanding of sensor-based logic and hardware-software integration. This foundation was later expanded through the **Microcontrollers and Microcontrollers Lab** courses, where we learned to implement more complex systems involving multiple peripherals and communication modules. These skills were directly applied in our project, as the Arduino Mega served as the central controller for both the robotic car and its mounted arm.

The **Wireless Communication course** introduced us to essential concepts of data transmission and connectivity, which became crucial for establishing the link between the robot and external devices.

On the other hand, the **Digital 3 course** focused on developing our ability to interpret datasheets, calculate current and voltage requirements, and design circuits that meet system specifications. These skills proved invaluable when working with the Arduino Mega and its peripherals, ensuring reliable power distribution and proper interfacing between the robotic platform, its arm, and the HC-05 Bluetooth module.

Our ability to manage the system's power requirements and ensure stable hardware performance was strongly supported by the **Electronic Circuits course**, which enhanced our understanding of circuit design and electrical behavior. Similarly, the **CPU Lab** equipped us with practical skills such as soldering, wiring, and debugging—capabilities that were invaluable during the assembly and troubleshooting phases of the robotic platform.

Equally important was our exposure to advanced computing topics. The **Image Processing and Artificial Intelligence courses** provided us with the theoretical and practical background needed to implement object detection. By applying these concepts, we were able to design a camera-based system that could distinguish between balls and trash and issue the appropriate movement and sorting commands to the Arduino-controlled robot via Bluetooth.

Finally, the **Technology Project Management course** contributed to the business-oriented side of the project. It guided us in conducting feasibility studies, managing costs, and planning the overall system workflow—ensuring that our work extended beyond a purely technical prototype into a structured, project-managed product.

Together, these courses formed the backbone of our knowledge and expertise. They allowed us to approach the image-processing controlled robot not only as an engineering challenge but also as a practical system that bridges electronics, artificial intelligence, and project management.

### 3 Methodology

The methodology for developing the image-processing controlled robot was structured to achieve accurate object detection and reliable object-sorting operations. The system integrates a camera running image processing for object recognition, an Arduino Mega for motor and arm control, and an HC-05 Bluetooth module for wireless communication. Commands generated by the camera are transmitted via Bluetooth to the HC-05, enabling the Arduino Mega to navigate the robot toward detected objects and classify them as either balls or trash for sorting. In addition, a mobile application provides an alternative manual control mode through the same Bluetooth interface, though only one control source (camera or mobile) can be active at a time.

#### 3.1 Standards and Specifications

In developing the image-processing controlled robot, we adhered to relevant engineering standards to ensure reliable operation and safe integration of hardware and software. The **Bluetooth Serial Port Profile (SPP)** standard, implemented through the HC-05 module, governed wireless communication between the Arduino Mega and external devices. This ensured stable short-range command transmission from either the image-processing camera or the mobile application, with the limitation that only one control source could operate at a time. Internally, communication between the HC-05 and the Arduino Mega followed the **UART (Universal Asynchronous Receiver Transmitter)** protocol, a widely adopted serial communication standard that provided consistent and error-free data transfer for real-time robotic control.

The image detection system applied established practices in **image processing** to identify and classify objects as either balls or trash. Once processed, commands were transmitted to the Arduino Mega for execution by the robotic car and arm. All electrical components were designed to operate within **standard low-voltage DC ranges (5V and 12V)**, ensuring compliance with safety practices while maintaining compatibility across motors, servomotors, and control circuits. These standards collectively ensured that the system was efficient, safe, and consistent with widely accepted engineering practices.

### 3.2 Design Overview

The project is divided into three main subsystems:

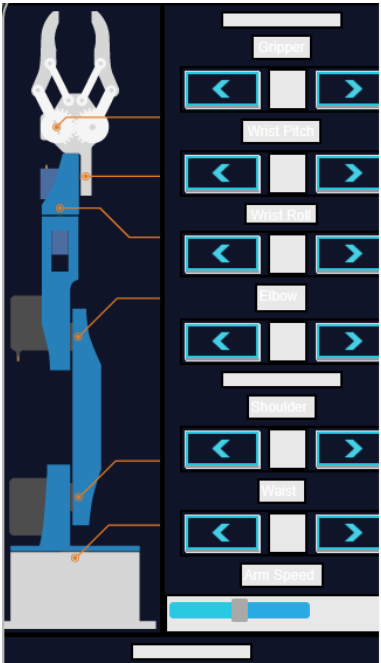
1. **Image Processing and Object Detection:** A camera equipped with image processing is used to detect and classify objects such as balls and trash. Based on the classification, the camera generates movement and sorting commands, which are transmitted wirelessly via Bluetooth to the robot through the HC-05 module.
2. **Robotic Platform and Arm:** The mobile robotic platform is driven by NEMA17 motors and controlled by the Arduino Mega. Mounted on top is a robotic arm, adopted from an existing online design, which performs the sorting operation by placing detected objects into the appropriate bins. Both the platform and arm receive their commands from the Arduino Mega, ensuring coordinated navigation and manipulation.
3. **Control and Communication System:** Communication is established through the **HC-05 Bluetooth module**, which interfaces directly with the Arduino Mega. Commands can originate either from the camera system (automatic control mode) or from a mobile application (manual control mode). Due to the single-connection limitation of the HC-05, the system can only be operated by one source at a time.
4. **Hardware Design (Modeling Phase):** Before implementation, the hardware layout was planned using digital design tools to visualize the placement of components, wiring, and system structure. This modeling stage provided insights into mechanical integration, power distribution, and potential challenges in the assembly phase.

### 3.3 Control and Automation

- The Arduino Mega serves as the central controller for both the robotic platform and the mounted arm, receiving commands exclusively through the HC-05 Bluetooth module. The system supports two control modes: automatic and manual.
- In automatic mode, a camera connected to a device with image processing tools performs object detection and classification. Once an object is identified as either a ball or trash, the camera transmits movement and sorting commands via Bluetooth to the HC-05 module. The Arduino Mega then executes these commands by driving the platform toward the object, activating the robotic arm, and placing the object into its designated bin.
- In manual mode, a mobile application communicates with the HC-05 Bluetooth module to provide direct user control of both the robotic platform and the arm. Users can navigate the robot, position the arm, and operate the gripper to perform object manipulation tasks. Due to the single-connection limitation of the HC-05.
- The camera, running on a connected device such as a Raspberry Pi or laptop, processes the image data and sends commands via Bluetooth through the HC-05 module to the Arduino Mega, which controls both the robotic platform and the arm operations.

### 3.4 Programming and Circuit Integration

- The Arduino Mega was programmed to control both the robotic platform and the mounted arm, executing movement and sorting operations based on commands received via the HC-05 Bluetooth module. The control logic included driving NEMA17 motors for navigation, operating the arm's joints, and activating the gripper to place objects into their designated bins.
- For object detection, Python was used to implement image processing on a connected device such as a Raspberry Pi or laptop. The detection program classified objects as either balls or trash and transmitted corresponding movement and sorting commands to the HC-05 Bluetooth module, which relayed them to the Arduino Mega.
- The mobile application, inspired by an online design and developed using MIT App Inventor, provided a manual control interface. Through this app, users could send navigation and arm control commands directly to the HC-05 module, enabling real-time manual operation. Due to the single-connection limitation of the Bluetooth module, the system could only operate in one mode at a time—automatic (camera-based) or manual (mobile app).
- Circuit integration was carefully designed to ensure stable power distribution and reliable signal flow. All actuators and peripherals were connected to the Arduino Mega through dedicated motor drivers and control pins, while the HC-05 module was interfaced via UART communication. The system was powered within standard low-voltage DC ranges (5V and 12V), ensuring safe and consistent operation.



### 3.5 Safety Measures

- All wiring and power rails were insulated, and appropriate motor drivers were used to safely control the NEMA17 motors and robotic arm without exceeding current limits.
- The robotic arm and gripper were tested under different load conditions to confirm safe current consumption and reliable mechanical performance.

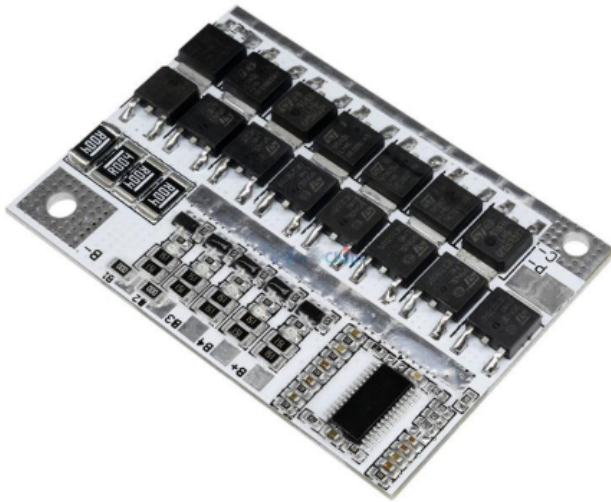
### 3.6 Component List and Description

The system is built using the following key hardware components:

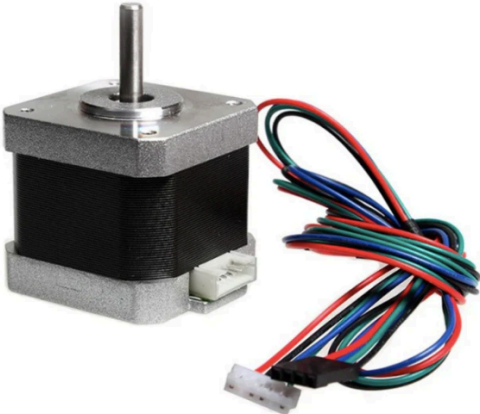
- **Arduino mega:**



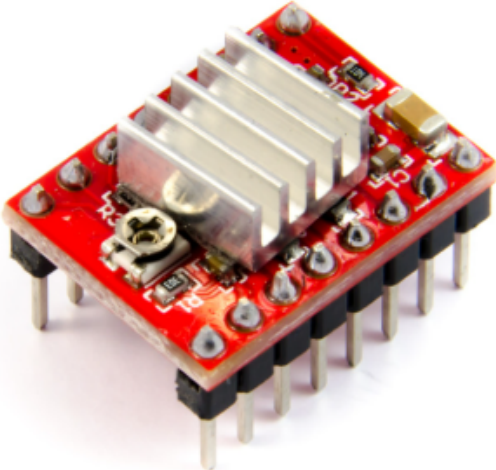
- **BMS 3S:**



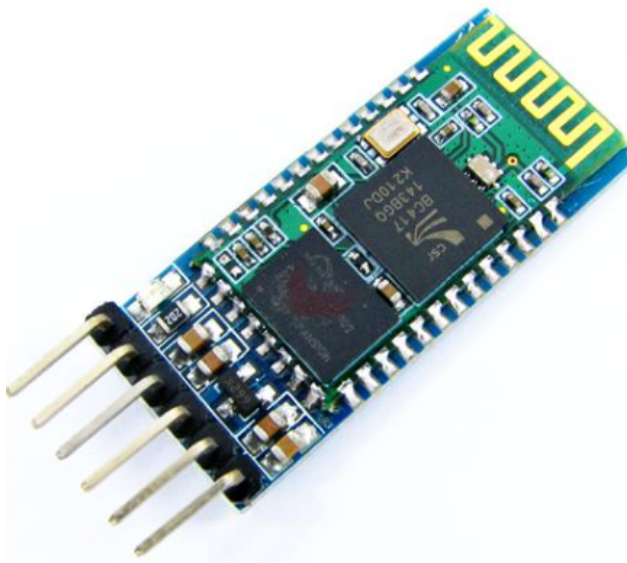
- **NEMA 17:**



- **A4988 DRIVER:**



- **HC-05:**



- **18650 Li-ion Battery:**



- **MG 996R:**



- **SG90:**



- **XL4015:**



- **Philips spz2000:**



## 4 Results and Discussion

### 4.1 The Design

The mechanical design of the image-processing controlled robot emphasized stability, modularity, and reliable motion control to support both autonomous and manual operation modes. The system integrates a mobile robotic platform with an articulated robotic arm, designed to manipulate and classify objects based on camera-guided detection.

The base of the robot is constructed with a rigid chassis fitted with Mecanum wheels, allowing omnidirectional mobility and smooth navigation in confined spaces. This wheel system was chosen for its maneuverability and precise control of motion in forward, backward, lateral, and diagonal directions.

Mounted on the platform is a multi-degree-of-freedom robotic arm, designed for flexibility in object grasping and placement. The arm structure was fabricated using lightweight but durable materials to ensure stability while minimizing load on the servomotors. High-torque servo motors power each joint, providing controlled movements for lifting and sorting tasks.

To maintain safe and efficient performance, A4988 motor drivers equipped with heat sinks were installed to prevent overheating during extended operation. Power is managed through a step-down XL4015 module, capable of supplying up to 5A, ensuring stable operation of the Arduino Mega and connected peripherals.

The control architecture is centered on an Arduino Mega microcontroller, which interfaces with both the robotic arm and the mobile base. Wireless communication is achieved using an HC-05 Bluetooth module, enabling the system to operate in two distinct modes:

- Camera-Guided Mode: Commands are received from an external camera performing real-time object detection.
- Mobile-App Mode: Users can manually control the robot and arm via a dedicated mobile application.

Only one mode operates at a time, preventing command conflicts. This dual-mode design ensures flexibility, combining manual control with autonomous decision-making capabilities.

This integration of mechanical robustness, modular electronics, and intelligent control resulted in a versatile platform capable of demonstrating both image-based automation and user-directed manipulation.



## 4.2 Final Project

The final outcome of the Image-Processing Controlled Robot:

- A mobile robotic car equipped with Mecanum wheels for omnidirectional movement.
- A multi-joint robotic arm mounted on the car for grasping and sorting objects.
- Arduino Mega controller to manage both the robotic car and arm.
- HC-05 Bluetooth module for wireless communication.
- Dual operation modes:
  - Camera-guided mode, where an external camera performs object detection (balls vs. trash) and sends movement/placement commands via Bluetooth.
  - Mobile application mode, allowing manual control of the robot and arm via smartphone.
- A4988 motor drivers with heat sinks for safe, stable motor operation.
- A step-down XL4015 power module to regulate power supply up to 5A.

## 4.3 Project Outcomes

The project successfully met its key objectives:

- Demonstrated a working prototype of an autonomous object detection and sorting robot.
- Enabled dual operation modes: autonomous camera-guided control and manual mobile application control.
- Validated reliable Bluetooth communication between the external camera, the HC-05 module, and the Arduino Mega.
- Showcased smooth robotic arm manipulation for picking and placing detected objects into designated bins.
- Achieved stable mobility using Mecanum wheels for precise omnidirectional movement.
- Prove the feasibility of integrating image processing, embedded control, and robotics into a unified system.

# 5 Conclusions and Recommendation

## 5.1 Conclusions

This project successfully demonstrated the development of an image-processing controlled robot capable of autonomously detecting, classifying, and sorting objects while also supporting manual operation through a mobile application. By integrating computer vision, Bluetooth communication, a robotic arm, and Mecanum-wheel mobility, the prototype achieved the primary objective of showcasing a flexible and intelligent robotic system.

The system fulfilled its design goals by achieving:

- **Autonomous Sorting Capability:** The external camera accurately detected objects (balls and trash) and guided the robot to pick and place them in their designated bins.
- **Reliable Communication:** Commands were transmitted effectively from the camera and mobile application to the Arduino Mega through the HC-05 Bluetooth module.
- **Dual-Mode Operation:** The system allowed both autonomous control via image processing and manual control via the mobile app, with mutual exclusivity to ensure safe operation.
- **Efficient Robotic Arm Control:** The robotic arm, powered by the Arduino Mega, successfully manipulated objects with reasonable accuracy and stability.
- **Safe Power Management:** The inclusion of heat sinks and a step-down XL4015 module guaranteed safe operation and stable current supply to all components.
- **Interdisciplinary Integration:** The project validated the effectiveness of combining image processing, embedded electronics, and mechanical design into a single functional system.

## 5.2 Recommendations

While the project objectives were met, several improvements are recommended to enhance performance, usability, and reliability:

- **Upgrade Vision System:** Use a higher-resolution camera and improved algorithms to achieve more accurate object detection under varying lighting conditions.
- **Improve Communication:** Explore alternative wireless communication protocols with greater range and stability to overcome the limitations of Bluetooth.
- **Enhanced Object Detection:** Implement advanced image-processing techniques to classify more object types and improve sorting accuracy.
- **Robotic Arm Precision:** Redesign or upgrade the robotic arm to handle objects of varying sizes, weights, and shapes more effectively.

## 5.3 Future Work

The current prototype establishes a solid foundation, but future efforts could expand its capabilities by exploring:

- **Upgrade Vision System:** Employ high-resolution cameras and improved image-processing algorithms for greater accuracy and robustness.
- **Improve Communication:** Explore advanced communication protocols (e.g., Wi-Fi or ESP-NOW) to overcome Bluetooth's limited range and bandwidth.
- **Enhanced Object Detection:** Implement more advanced machine learning techniques to detect and classify a wider variety of objects.
- **Onboard Processing:** Integrate a dedicated processor (e.g., Raspberry Pi or Jetson Nano) to perform image processing locally, reducing latency and improving autonomy.
- **Robotic Arm Upgrade:** Redesign the arm for higher precision, greater payload capacity, and smoother motion control.
- **Battery Optimization:** Develop an improved power management system to extend battery life and ensure consistent performance.
- **Mobile App Enhancements:** Add features such as real-time video streaming, advanced control options, and performance monitoring through the mobile application.
- Utilize all omnidirectional movements of the robot wheels.
- Utilize the five degrees-of-freedom arm which we couldn't do, due to the lack of a depth camera.

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