Prototype Design and Research Collection

Series 1

Universiti Teknologi MARA
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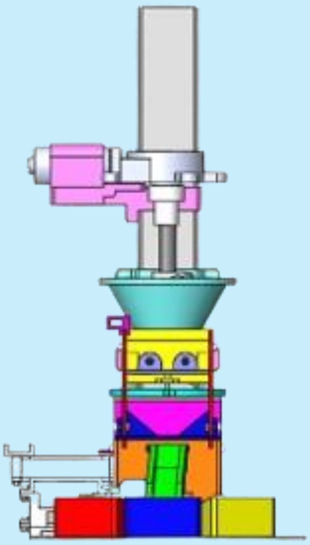
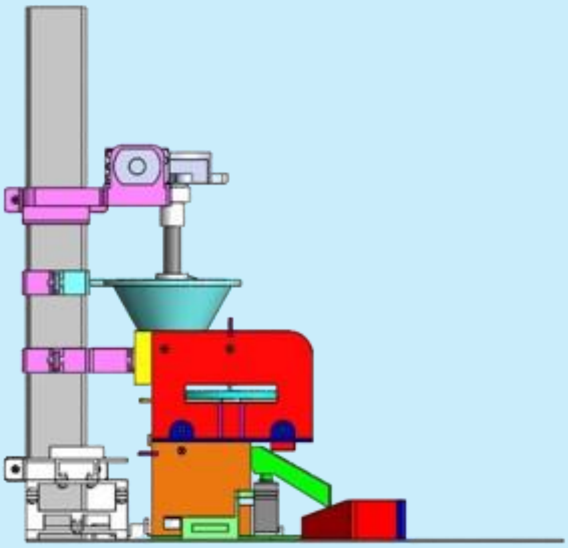
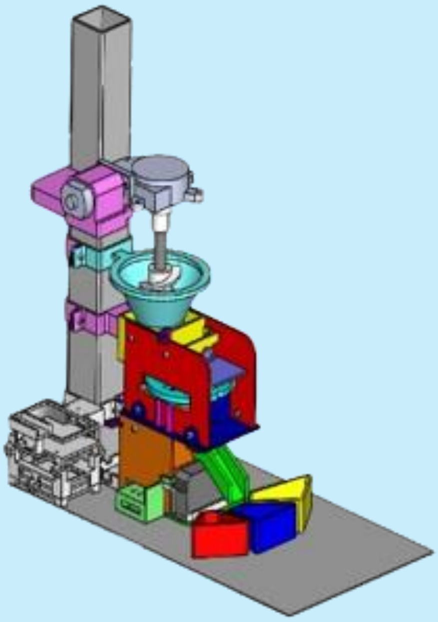

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FOREWORD

This digital book on Prototype Design and Research Collection Series 1 (PDRC Series 1), is designed as a comprehensive reference for mechanical engineering students. The designs featured in this collection undergo an extensive analysis process, incorporating both prototype development and research to ensure a thorough understanding of design principles. Each project is carefully analysed before the prototype fabrication with detailed summaries of the project description and design parameters. The design and research products presented in this series cover a wide range of tools and equipment for various applications including household, workshop and entrepreneurial purposes.

This collection aims to foster innovation by offering students valuable insights into both the technical and research aspects of product design. It is hoped that this book will inspire future engineers and designers to approach product development with a deeper understanding of the design and research processes.

CHAPTER 17

Design and Development of Robotic Arm Car for Lightweight Object Handling

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ABSTRACT

Traditional robotic arm systems provide challenges for application in educational enviroments since they frequently remain stationary with limited workspace and need sophisticated technical expertise to handle. This project addresses these challenges through the design and development of an integrated robotic arm car specifically designed to pick and move lightweight objects in indoor conditions. The goal is to build a robotic arm car with a working grabber that ensure structural stability, controlled movement, and simplicity of usage. The methodology involved a systematic design approach using SolidWorks for 3D modelling and stress analysis, followed by fabrication using laser-cut acrylic and 3D-printed PLA components. The robotic system integrates a grabber and 3-DOF arm on a four-wheeled platform with a Bluetooth connectivity and a custom MIT App Inventor interface as controller. The results from stress analysis verified the structural integrity of critical components, which demonstrates minimal deformation for all components. The successful implementation validates that the integrated design approach successfully creates a prototype of robotic arm car capable of executing basic object manipulation tasks while offering useful hands-on experience with robotic fundamentals.

Keywords: Robotic arm car, Grabber, Lightweight object

1 INTRODUCTION

The robotic arm combined with mobile platforms have produced versatile systems that combine spatial mobility with manipulation capabilities, therefore providing potential across industrial manufacturing and service applications. However, many of the current designs are too complicated and require specialized technical knowledge, which limits the accessibility of robotic arm car in education settings where hands-on experiences with robotic principles is valuable. This project develops an integrated robotic arm car with a working grabber to solve this challenge. The design focuses on small sizes, structural stability, controlled motion, and operational safety. The prototype integrates four key components which are a base structure, 3 degrees of freedom (3-DOF) robotic arm, a four-wheeled mobility system, and a functional grabber mechanism. The design process focused on material selection and structural integrity using SolidWorks software, and user-friendly control through a Bluetooth-enabled mobile interface. The following sections outline the relevant literature (Section 2), methodology (Section 3), results and discussion (Section 4), and conclusion (Section 5).

2 LITERATURE REVIEW

Robotic arm systems have advanced significantly from stationary industrial manipulators to transportable platforms with diverse applications. Traditional robotic arms excel in production settings where repeatability and accuracy are vital [1], but their fixed nature restricts workspace flexibility. This limitation has driven research aimed at combining mobile platforms with robotic arms for manipulation capabilities. Kruthika et al. [1] have established fundamental design principles for robotic arms, while more recent work by Comari et al. [2] demonstrated successful integration of robotic arms with mobile platform for autonomous material handling.

Educational applications give a significant opportunity for the robotic arm development, where systems must balance between functionality with accessibility. Zeng et al. [3] created iArm, an instructional robotic kit aimed at fostering computational thinking. In addition, Benitez et al. [4] created a cost-effective open-source robotic arm for online education emphasizes user-friendly design interfaces. These educational and indoor platforms often use 3-DOF or 4-DOF arm configurations, which offer ideal balance of simplicity, functionality, and cost-effectiveness [5].

The choice of suitable materials, mobility systems, and control interfaces significantly impacts the efficacy of educational robotic platforms. In this project, acrylic was selected as the primary structural material for the robotic arm and base based on practical engineering considerations including its ease of machining, low-cost, transparency (for educational purpose), and lightweight structure [6]. This material choice enabled accurate fabrication through laser cutting. For mobility system of robotic arm cars, four-wheeled mobility system is commonly used for indoor applications due to their balance of stability, maneuverability, and ease of control [7]. The four-wheeled configuration can provide a solid platform that can sustain the weight and dynamic movements of robotic arms [8]. In education and prototyping settings, robotic arm cars driven by Arduino Uno with Bluetooth-enabled and Android apps created using MIT App Inventor have grown even more popular [9-10]. These systems often utilize Arduino Uno microcontroller as the primary processing unit, interacting with Bluetooth modules like HC-05 to facilitate wireless communication between the robot and smartphone app. The Android app, which is frequently designed with MIT App Inventor because of its simplicity of use, delivers instructions to the robot that control both the mobility system, the robotic arm’s motors, and the grabber’s motor.

3 METHODOLOGY

The robotic arm car prototype was designed based on four sub-systems, which are the base, the wheel and mobility system, the arm, and the grabber. Each sub-system had specific functional and dimensional criteria. The base structure required a compact and stable platform (27–44 cm in length) fabricated from acrylic to house internal electronics and support the robotic arm. The wheel and mobility system featured four rubber wheels (approximately 10 cm in diameter) driven by four worm gear DC motors each, enabling smooth indoor movement. The robotic arm offered 3 degrees of freedom (3-DOF), comprising a rotating base and two pitch joints, with a reach of approximately 20–30 cm. It was constructed using lightweight acrylic material and actuated through servo motors. The grabber mechanism was designed using PLA filament (3D-printing), capable of gripping objects up to 55 mm wide and 187 g in weight. Control integration involved an Arduino UNO microcontroller paired with Bluetooth connectivity, controlled through a MIT App Inventor interface.

The methodology followed a systematic product development cycle as illustrated in Fig.1. It began with defining user and environmental requirements, followed by sketching early design concepts. Through Morphological analysis and the Pugh decision matrix, component options were shortlisted and evaluated against criteria such as size, safety, cost, and functionality. The selected design was then developed in SolidWorks to create 3D models and assembly drawings. Material selection and stress analysis were conducted to validate design strength. Fabrication involved laser cutting and 3D printing of structural and functional parts, followed by mechanical and electronic integration. Programming was performed using Arduino IDE to control motion, gripping, and wireless communication. The final prototype underwent testing for functionality, user-friendliness, and structural integrity. Based on test results, refinements were implemented to ensure optimal performance for its intended setting.

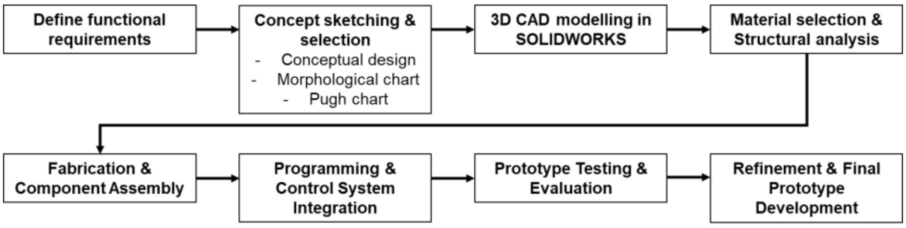


Fig.1: Robotic arm car prototype design flowchart

Fig.2 illustrates the layered schematic diagram of the robotic arm car prototype, showing how each functional layer contributes to the integrated system. The top layer defines the major sub-systems, including the base, mobility, robotic arm, and grabber. Supporting these sub-systems, the structure layer identifies key mechanical elements such as the frames, rotating base, arm's shoulder, arm's elbow, and gripper frame, which provide physical support and alignment for components. The actuator layer consists of worm gear DC motors and servo motors, responsible for motion in both locomotion and manipulation tasks. These actuators are governed by the control layer, which includes the Arduino board and Bluetooth module to enable signal processing, communication, and system coordination. The bottom software layer integrates programming through Arduino IDE and a user interface developed in MIT App Inventor, allowing real-time control through a mobile device.

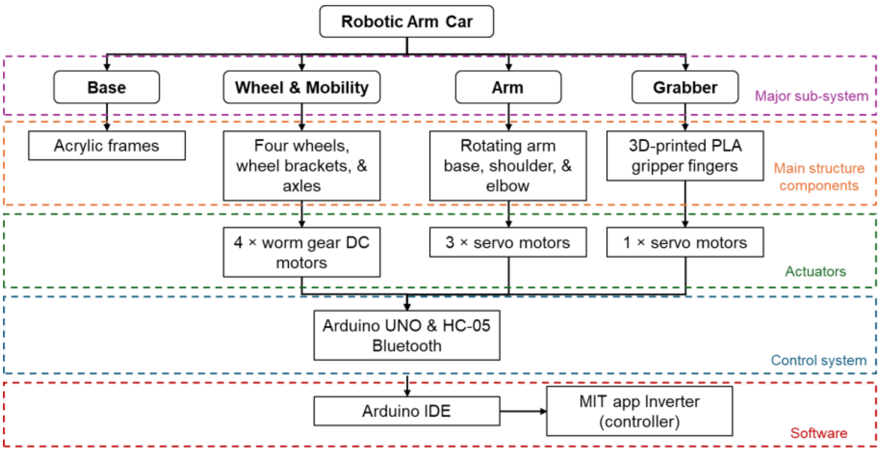
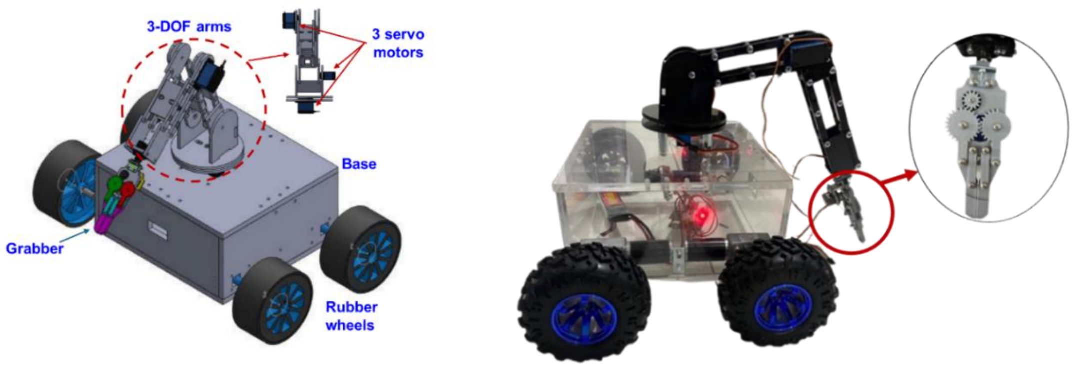


Fig. 2: The schematic diagram of robotic arm car system

4 RESULTS AND DISCUSSION

The final 3D model and the robotic arm car prototype displayed in Fig. 3, demonstrate successful integration of major subsystems, base, wheels, robotic arm, and grabber, into a compact and functional platform. The chassis supports the full assembly and houses internal wiring, while the robotic arm (3-DOF) is anchored on a rotating base and actuated through servo motors for vertical and rotational movement. The gripper, made of PLA, is positioned at the end of the arm and designed to manipulate lightweight objects. Four rubber wheels which each connected to a DC worm gear motor provide ground mobility. This layout validates the functional requirements discussed in earlier sections.



(a) (b)

Fig 3: The robotic arm car, (a) 3D model, and (b) the built prototype

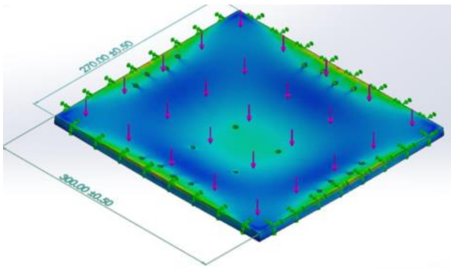
The structural integrity and reliability of the robotic arm car critically depend on several key components which are the base, the robotic arm, and the grabber. Stress analyses were conducted using SolidWorks software which highlights critical regions subjected to operational forces. This analysis aimed to verify whether the chosen materials and dimensions are sufficient for the robotic arm to lift and move the object (maximum 1 kg mass). The summary of simulation results is presented in Table 1, while Fig. 5 visually illustrates the corresponding stress distribution across critical components.

Table 1: SolidWorks simulation analysis of critical part

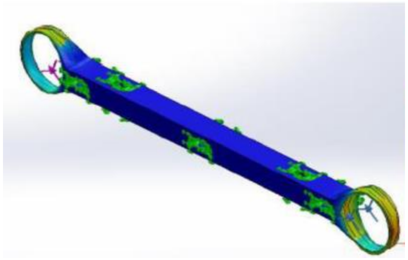
Component	**Analyzed Part**	**Dimensions (mm)**	**Material**	**Applied Force (N)**	**Max Stress (MPa)**	**Max Deformation (mm)**
Base Structure	Upper platform	300 × 250 × 10	Acrylic	50	25.5	0.2
Robotic Arm	Second member arm	200 × 40 × 5	Acrylic	98.1	49.5	1.3
Grabber Mechanism	Grabber lips	80 × 30 × 5	PLA	9.81	49.52	9.15

The applied forces used in the stress analysis were determined based on practical operational scenarios to reflect realistic loading conditions under realistic loading conditions. The base structure was applied with a distributed force of 50 N to represent the static and dynamic loads from the arm, grabber, and any objects during operation. The robotic arm received a force of 98.1 N, representing the total effective load applied through two faces during extension and listing tasks. Meanwhile, a force of 9.81 N was applied to the grabber mechanism to represent the gripping load needed to securely handle the operations of grabbing and moving objects up to 1kg of mass.

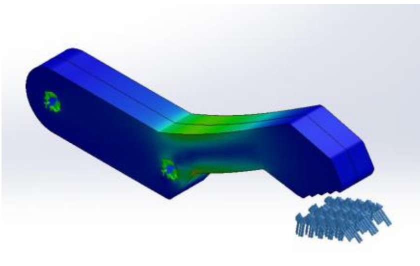
As summarized in Table 1, the upper platform of the base structure exhibited minimal deformation (0.2 mm) and a maximum stress of 25.5 MPa which is lower than the yield strength of acrylic material of 70 MPa. This confirms the selected material and dimension of the upper part of base structure demonstrates outstanding load-bearing capacity. The members of robotic arm experienced moderate deformation (1.3 mm) and a maximum stress of 49.5 MPa, approaching the limit of yield strength of acrylic's material. This indicates that this part needs to be reinforced in terms of its dimension. The grabber mechanism recorded the deformation of 9.15 mm with a maximum stress of 49.52 MPa, nearing the PLA yield strength of 60 MPa. This justified structural dimension improvements in the final design, which include the increase in lip thickness, a reduction in opening width from 80 mm to 62 mm, and a decrease in overall size to better match the lifting capability of the arms.



(a)



(b)



(c)

Fig. 5: Stress distribution analysis on the critical components, (a) upper platform of the base structure under 50 N load, (b) arm member under 98.1 N load, and (c) grabber lips under 9.81 N gripping load

The robotic arm car integrates several key electrical components to enable remote-controlled operation. The electrical system was developed using an Arduino UNO board, four DC motors for wheels system, and six servo motors (TD-8230MG for the arm and MG95s for the grabber) for articulated movements, as shown in Fig. 6. Communication between the microcontrollers and user interface was established using a Bluetooth receiver connected to a custom mobile application developed with MIT App Inventor, enabling remote control of the robotic car through a smartphone or a tablet.

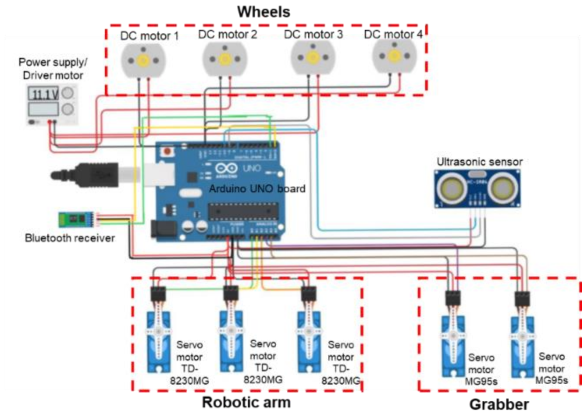


Fig 6: Electrical wiring diagram showing integration of Arduino UNO, DC motors, servo motors, Bluetooth module, and ultrasonic sensor

5 CONCLUSIONS

This project outlines the design, construction, and validation of a robotic arm car prototype designed for handling lightweight objects in indoor settings. The prototype successfully integrates four primary subsystems which are a base platform, wheels system, 3-DOF robotic arm, and functional grabber, into a compact and operational unit. The mechanical design was verified by finite element stress analysis, which also proved that important parts such as the base and arm structure operate within the limits of material strength under certain loads. For grabber, the modifications to its design, including adjusted dimensions and reinforced structure, were implemented based on stress analysis and deformation findings. The control system is constructed using an Arduino UNO microcontroller, servo and DC motors, and a Bluetooth-enabled mobile interface via MIT App Inventor. The combination of mechanical functionality and electrical coordination produced a reliable robotic arm car prototype capable of performing basic object manipulation tasks. This prototype offers a practical solution for educational and service-oriented robotics applications, establishing a basis for future enhancements in automation, sensor integration, and autonomous behaviour.

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