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Creation of an Educational Robot kit

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First at all thanks to GOD

قال الله تعالى. " لئن شكرتم لازيدنكم. " قال رسول الله صلى الله عليه وسلم: ". لا يشكر الله من لا يشكر الناس. " الحمد والثناء والشكر لله العلي القدير على نعمه

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And each by his name

Lastly, I wish to thank my family for their patience, understanding, and moral support, without which I could not have successfully completed this thesis.

DEDICATION

I dedicate my graduation to the soul of my beloved and friend, my late **father**. May God have mercy on you and make your abode in heaven.

To my beloved **mother**, who has always been my inspiration and strength, thank you for all the support and love you have given me.

I dedicate this thesis to my **family** and **friends**, whose continued support and encouragement made this project possible.

To all the **children** and **future innovators**, may this work inspire their creativity and passion for science and technology.

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GENERAL INTRODUCTION

Robotics has emerged as a dynamic and interdisciplinary field that combines mechanics, electronics, and computer science. Beyond its industrial and scientific applications, robotics has become a powerful educational tool, capable of stimulating curiosity, creativity, and problem-solving skills among learners of all ages.

In this context, the present work focuses on the design and development of an **educational robotic arm kit**, named **CLY**, intended to serve as a scalable and interactive learning platform. The goal is to simplify the introduction to robotics through hands-on experimentation, without requiring prior technical knowledge, thus making it accessible to a broad audience — from school children and university students to self-learners outside traditional classrooms.

The CLY robotic arm combines mechanical structure, programmable electronic control, and a user-friendly interface. Its modular and educational design enables learners to explore key concepts such as movement coordination, actuator control, modeling, and basic programming logic, either directly or through guided activities.

Through this project, we aim to support **STEM** (science, technology, electronic, math) education by offering a tangible and engaging approach to learning robotics, while also contributing to the democratization of technical knowledge and innovation. The thesis covers all stages of development — from conception and modeling to experimentation and pedagogical integration — to validate the system's potential as an effective educational tool.

CHAPTER 1

CHAPTER 1: GENERAL INFORMATION ON ROBOTICS AND MODELING

1.1 Introduction

In the past few decades, the field of robotics has developed and changed a wide range of industries including manufacturing, healthcare, education, and even domestic use. Out of these applications, ER (Educational Robotics) serves as a critical resource for improving STEM (Science, Technology, Engineering, and Mathematics) education and programming a robot as an educational tool [1].

The integration of robotics in education enables learners to engage in hands-on practices such as programming, mechanical design, problem solving and computational thinking.

With this dissertation, I aim to create an educational robot kit that provides a new dimension to learning by making it interactive and fun. The kit is intended to be modular, cost-efficient, and appropriate for a range of educational levels, And to act as an introduction for students to core concepts of robotics while stimulating their creativity and innovative thinking.

1.2. Generality about Educational Robotics

Robotics is a branch of science and engineering that deals with the design, construction, operation and use of robots. It integrates several sub-disciplines like mechanical engineering, electrical engineering, computer science and artificial intelligence.

A robot is generally understood as an autonomous or semi-autonomous machine which performs certain activities sequentially either based on the actions of humans or based on its own perception of the surroundings. Industrial robots include arms in assembly lines, humanoid assistants, drones and robotic vehicles.

As we said, educational robotics concentrates on the pedagogical robotic systems approaches and regards robots as tools for teaching and learning. It motivates students to learn programming, control systems, electronic and mechanical design in a hands-on way through projects and challenges

1.3 Background

The integration of robots in education has gained speed over the past decade, spurred by the rising prominence of STEM (Science, Technology, Engineering, and Mathematics) disciplines in current curriculum. Educational robotics not only boosts students' technical knowledge but also develops critical thinking, creativity, and cooperation. It allows learners to engage in hands-on activities that relate theoretical ideas to real-world applications.

Educational robots cover a wide range of education levels from children's to higher education, and some robots share certain characteristics including the focus on assistive functions like buttons, grayscale sensors, and cameras. Some robots are equipped with client software, and some are capable of Python and ROS (Robot Operating System) programming [2].

Despite the increased interest in robotics education, there remains a gap between current instructional resources and the demands of students, especially at early and intermediate levels. Many commercial robotic kits are either too costly, too difficult, or inadequately adaptable to different age groups and learning contexts. As a result, schools and educational institutions typically struggle to deliver effective robotics teaching that spans from basic to high levels.

This project arises as a response to this difficulty. It intends to build a cheap, scalable, and user-friendly robotic arm kit built primarily for educational usage. offers a realistic platform where learners may interact with real hardware, study programming logic, and acquire a knowledge of robotic movement and control. By combining a series of exercises with practical implementation, the initiative seeks to enhance accessibility and educational effectiveness.

This background provides the foundation for the design decisions and development methodologies implemented throughout the project.

It underscores the necessity of establishing specialized instructional tools that bridge the gap between learning theory and hands-on application in a relevant and engaging way, students combined engineering concepts with practice and explored notions of robot design [3].

1.4 Brief History of Robotics

The notion of robotics stretches back to ancient times, with early myths and legends picturing artificial entities endowed with human-like qualities. One of the first known examples is the tale of Talos, a giant bronze automaton built by Hephaestus to guard the island of Crete in Greek mythology [4].

Similarly, ancient Chinese and Arabic innovators envisioned mechanical systems capable of emulating human or animal movements, (Hakimov, Karimov, & Reshetnikov, 2024) – when highlighting broader engineering innovation [5].

The name "robot" itself was first established in 1921 by Czech writer Karel Čapek in his science fiction drama R.U.R. (Rossum's Universal Robots). Derived from the Czech word "robota", meaning compelled labor or work, the phrase defined robotic laborers created to service humans [6].

The contemporary age of robotics began in the mid-20th century, as improvements in electronics and computers permitted the development of robots that could perceive, process information, and execute tasks independently. In 1954, George Devol designed the first programmable robotic arm, subsequently marketed as the Unimate, which was deployed in 1961 in a General Motors facility – marking the beginning of industrial robotics [7].

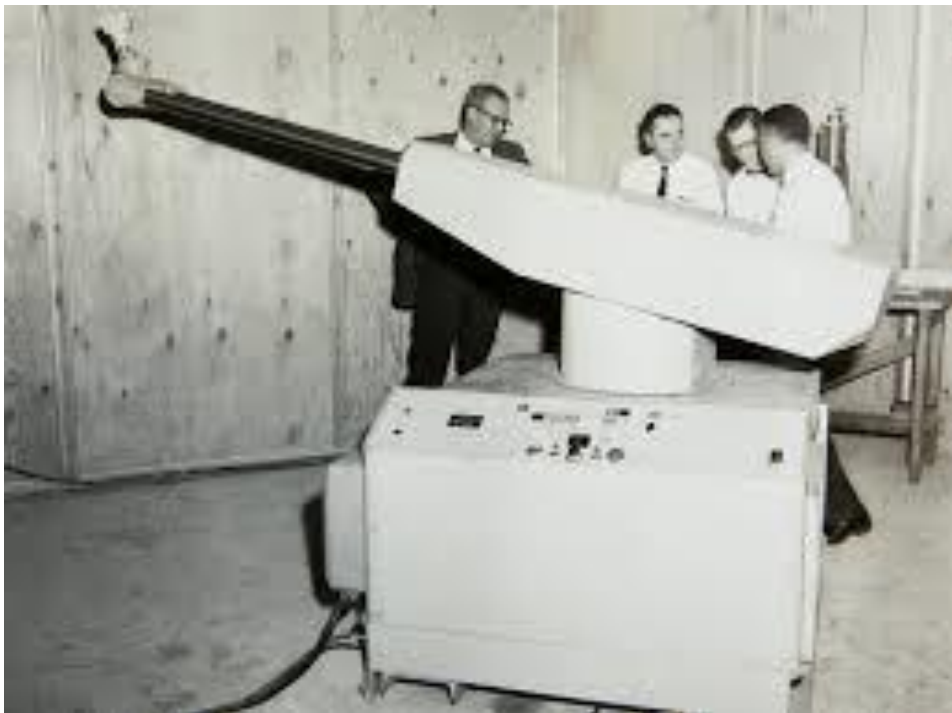


Figure 1: UNIMATE General Motors 1961 the 1st robot arm

From that moment on, robots advanced rapidly:

In the 1970s and 1980s, robots were extensively employed in production, notably in the automobile sector [8].

The 1990s and 2000s witnessed the emergence of mobility and service robots, along with robotic systems used in space exploration, surgery, and research [9].



Figure 2: SHAKEY 1967 the 1st robot mobile

More recently, breakthroughs in artificial intelligence, sensor technology, and machine learning have led to the creation of intelligent, adaptable, and collaborative robots employed in a wide range of areas including education [8].

Today, educational robots has become a useful tool in schools throughout the world, encouraging students to experiment with real-world systems while learning computational and problem-solving abilities. The Educational Robotics Projects maintain this heritage by making robots more accessible, participatory, and suited to pedagogical requirements [10].

1.5 Context and Motivation

The project intends to create an instructional robotic kit called CLY. Essentially, is meant to give an intriguing and futuristic entrance into robotics and programming through a programmable robotic arm. The kit is a marriage of simulation and practical hardware experience in that the user actually uses the real robotic system in gaining better experience in developing algorithmic reasoning and problem-solving skills.

The project incorporates the mechanical design of the 4+1 DOF robot arm, careful selection of electronics components, and we aim to the construction of a graphical interface to control the arm.

Furthermore, a series of guided educational exercises that fit different learning levels has been developed.

This initiative marks a significant flight approach in advancing STEM education with a practical orientation, cheap, and scalable to fit the profile of schools. The entire development of this project was carried out by a methodical approach from theoretical research and practical design to the iterative test.

2 Purpose and target from CLY

The greater part of the other robotic arms used in teaching today are commercial ones. They were unsuitable for massive use in education because of the exorbitant prices, their being closed-source, etc.

Therefore, the aim of the research is to develop an open-source and cost-efficient robotic arm kit. This kit should be available for the students' use. We want to instruct students in programming techniques along with robotic arms to help facilitate computational thinking. Students learn many skills through the process of completing projects in our curriculum programming and algorithm design, and enhancement of thinking literacy, which encompasses critical and creative thinking. In keeping with the idea of constructionism, which holds that working with tangible artifacts may lead to a more effective learning process as suggested by Papert [11], learners are stimulated to be more technologically literate through the construction and interaction with robots.

The basic teaching robotic arm kit combines arm-based curriculum, gripper, and a 4+1 DOF robotic arm known as 'CLYArm'. The program demonstrates how to employ the robotic arm and its tools to fulfill different tasks.

Secondary school students who have enough mathematical foundation and a bit of logical thinking are the main target users of the robotic arm kit, with the stages for children's and beginners also. The kits are also used in extended classes computer technology courses by students who want to learn about robotics or programming.

2.1 The key objectives of this project:

- Design and fabricate for educational purposes a robotic
- Design a simulation environment for testing and learning.
- Physically implement the robot arm using cheap and readily available materials.
- Design an interface suitable for programming and controlling the robot.
- Implement pedagogical activities keyed to learners

2.2 Contribution of the project

The project contributes markedly to educational robotics by seeking the design of a full-fledged and yet user-friendly and scalable robotic kit specifically for teaching and learning activities in education at different levels. The principles in which this product projects are mainly focused on the following areas:

2.2.1 Educational Value

The arm designed to be a hands-on learning environment for students to grasp important concepts in robotics, programming, and automation. Through well-planned exercises and a gradual increase in complexity, students develop from simple understanding of logic and mere commands of motion to the conception of algorithmic approaches and control methods. It can either be a self-study tool or serve as an assistant tool for the teacher in the regular classroom.

2.2.2 Physical Implementation and Simulation

Many educational tools are only virtual in nature, but this project has provided an actual hardware (a robotic arm) and a simulated environment.

This approach greatly aids understanding because the learners are able to view and compare the behavior of a virtual model with a real one, thus allowing learners to marry theory with practice.

3 Related works

Numerous topics pertaining to computational thinking and educational robotics have been covered. The following is a description of the relevant publications that address the educational computational thinking, robotic arms, and the use of arms in teaching.

3.1 Robotic Arm for Education

Although articulated robots have also been created for educational purposes, mobile robots are the most common type of educational robot. Multi-DOF arms with an arm gripper are typical robotic arms. Many studies take into account the expense of robots.

Cocota et al. [12] created a 4 + 1 DOF serial manipulator with a two-finger acrylic gripper. The inexpensive \$150 price tag acted as a challenge to encourage students' capacity to create and assemble the manipulator. Students may use it to solve forward and inverse kinematic issues as well.

All of the WayBotDu components created by Adinandra et al. [13] might be purchased locally or accessed online.

3.2 Existing educational robotic arms

A number of instructional robotic platforms, including **LEGO Mindstorms** [14], which provides a modular, kid-friendly system for constructing and programming robots using visual bricks, have cleared the path in schools.

While platforms like **Raspberry Pi Probot** expose students to more complex ideas like computer vision and networked control [15].

Arduino-based kits give older students more flexible options to experiment with electronics and code [16].

The CLY project seeks to take a similar approach to these previous experiments with a more equitable, user-friendly, and scalable solution. These technologies are effective, but may be limited by cost, complexity, or age-appropriateness.

4. MODELING THE CONTROLLED MANIPULATOR ROBOT

The manipulator we wish to model consists of a simple open chain of type: RRRR.

The figure below shows the geometric representation diagram and the positioning of the reference points.

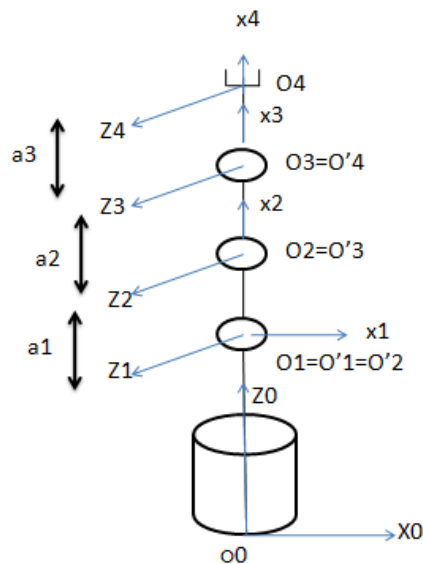


Figure 3: DH landmarks of the manipulator

The DH parameters of the manipulator in Figure are shown in the following table:

Segment	a_i	α_i	d_i	θ_i
1	0	$\pi/2$	0	θ_1
2	a_1	0	0	$\theta_2 + \pi/2$
3	a_2	0	0	θ_3
4	a_3	0	0	θ_4

Table 1: DH parameters of the manipulator

4.1 Forward kinematics

The geometric model of a manipulator robot is a mathematical representation of the robot's geometry and its motion. This model used to describe the position and the orientation of the robot's end effector (e.g., a gripper) as a function of the rotation angles of its joints. The MGD model written:

$$\mathbf{X} = \mathbf{f}(\boldsymbol{\theta})$$

Such that, \mathbf{X} is the vector of coordinates chosen to represent the position of the end organ and $\boldsymbol{\theta}$ is the vector of joint coordinates.

To calculate the Forward kinematics, it is sufficient to determine the elements of the homogeneous transformation matrix 0T_n that describe the position of the manipulator arm relative to its base, by indicating the position of its end organ in the base coordinate system.

$${}^0T_n = {}^0T_1 \cdot {}^1T_2 \cdot \dots \cdot T_n^{n-1} \qquad T_n = \begin{vmatrix} sx & nx & ax & px \\ sy & ny & ay & py \\ sz & nz & az & pz \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

In our configuration we have:

$${}^0T_4 = {}^0T_1 \cdot {}^1T_2 \cdot {}^2T_3 \cdot {}^3T_4$$

For the first body we obtain:

$${}^0T_1 = \begin{vmatrix} \cos\theta_1 & 0 & \sin\theta_1 & 0 \\ \sin\theta_1 & 0 & -\cos\theta_1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

For the second body we obtain:

$${}^1_2T = \begin{vmatrix} \cos(\theta_2 + \frac{\pi}{2}) & -\sin(\theta_2 + \pi/2) & 0 & a_1 \cos(\theta_2 + \pi/2) \\ \sin\theta_2 & \cos\theta_2 & 0 & a_1 \sin\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

For the third body we obtain:

$${}^2_3T = \begin{vmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & a_2 \cos\theta_3 \\ \sin\theta_3 & \cos\theta_3 & 0 & a_2 \sin\theta_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

For the fourth body we obtain:

$${}^3_4T = \begin{vmatrix} \cos\theta_4 & -\sin\theta_4 & 0 & a_3 \cos\theta_4 \\ \sin\theta_4 & \cos\theta_4 & 0 & a_3 \sin\theta_4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

We will have:

$${}^0_4T = {}^0_1T \cdot {}^1_2T \cdot {}^2_3T \cdot {}^3_4T = \begin{vmatrix} sx & nx & ax & px \\ sy & ny & ay & py \\ sz & nz & az & pz \\ 0 & 0 & 0 & 1 \end{vmatrix}$$

5. Conclusion

This first chapter has provided a general overview of robotics and modeling. We began by exploring the historical roots of robotics, emphasizing the significant contributions made by innovators in designing mechanical systems that emulated human or animal movements. This historical perspective illustrates that the quest to create autonomous mechanisms is not a new phenomenon but a longstanding human endeavor.

Modeling allows engineers to predict and improve a robot's behavior, ensuring greater functionality, adaptability, and robustness.

This foundation sets the stage for subsequent chapters, where we will delve into the design, control, and implementation of a robotic arm, applying the theoretical knowledge presented here to a realistic and educational context.

CHAPTER 2

CHAPTER 2: GENERAL PRESENTATION OF THE PROJECT

2.1 Introduction

This chapter provides a general overview of the **CLY Educational Robotic Arm** project. It outlines the overall structure, pedagogical objectives, and technical components, including the mechanical design, electronic architecture, and programming environment. The goal is to demonstrate how these elements integrate to deliver an effective educational tool suited for various academic levels.

 Long U-shaped bracket	3pcs	 Side cover bracket	1pcs	 Small U-shaped bracket	1pcs	 Multifunctional Bracket	2pcs
 Rotational station	A Set	 Bearing	1pcs	 Power Adapter	1pcs	 Large bottom plate	1pcs
 Clamper	1pcs	 LDX-218 digital servo	2pcs	 LFD-06 digital servo	2pcs	 LD-1501 MG digital servo	1pcs
 Wireless handle and handle receiver	A Set	 Controller	1pcs	 Winding tube	Several	 Screwdriver	1pcs
 M4*40 Copper Column 4pcs	 M4*8 Copper Column 4pcs	 M3*8 Nylon Column 10pcs	 M4*35 Screw 5pcs	 Small Bearing 1pcs	 M4 Screw Nut 20pcs	 M3 Screw Nut 10pcs	 M2 Screw Nut 10pcs
 M4*15 Copper Column 4pcs	 M3*15 Nylon Column 4pcs	 M4*20 Screw 5pcs		 M4*8 Screw 12pcs	 M3*10 Screw 1pcs	 M3*8 Screw 10pcs	 M3*6 Screw 20pcs
					 M2*5 Screw 35pcs		

Figure 4: overview of the CLY all pieces

2.2 Mechanical Structure of the Robotic Arm

The mechanical design of the CLY arm based on simple yet efficient principles inspired by industrial robotic arms.

A modular architecture has been adopted, allowing for easy assembly and maintenance, with a focus on durable components made via Cutter CNC Machine.

The arm incorporates multiple Degrees of Freedom (4+1 DOF), enabling it to replicate essential motions such as rotation, lifting, gripping, and pushing. Joints strategically placed to ensure motion flexibility and balance.

2.2.1 Key features of the mechanical design

- Open and modifiable structure.
- Low-cost materials.
- 3D-printable components (In future updates).
- Easy to assemble and disassemble.

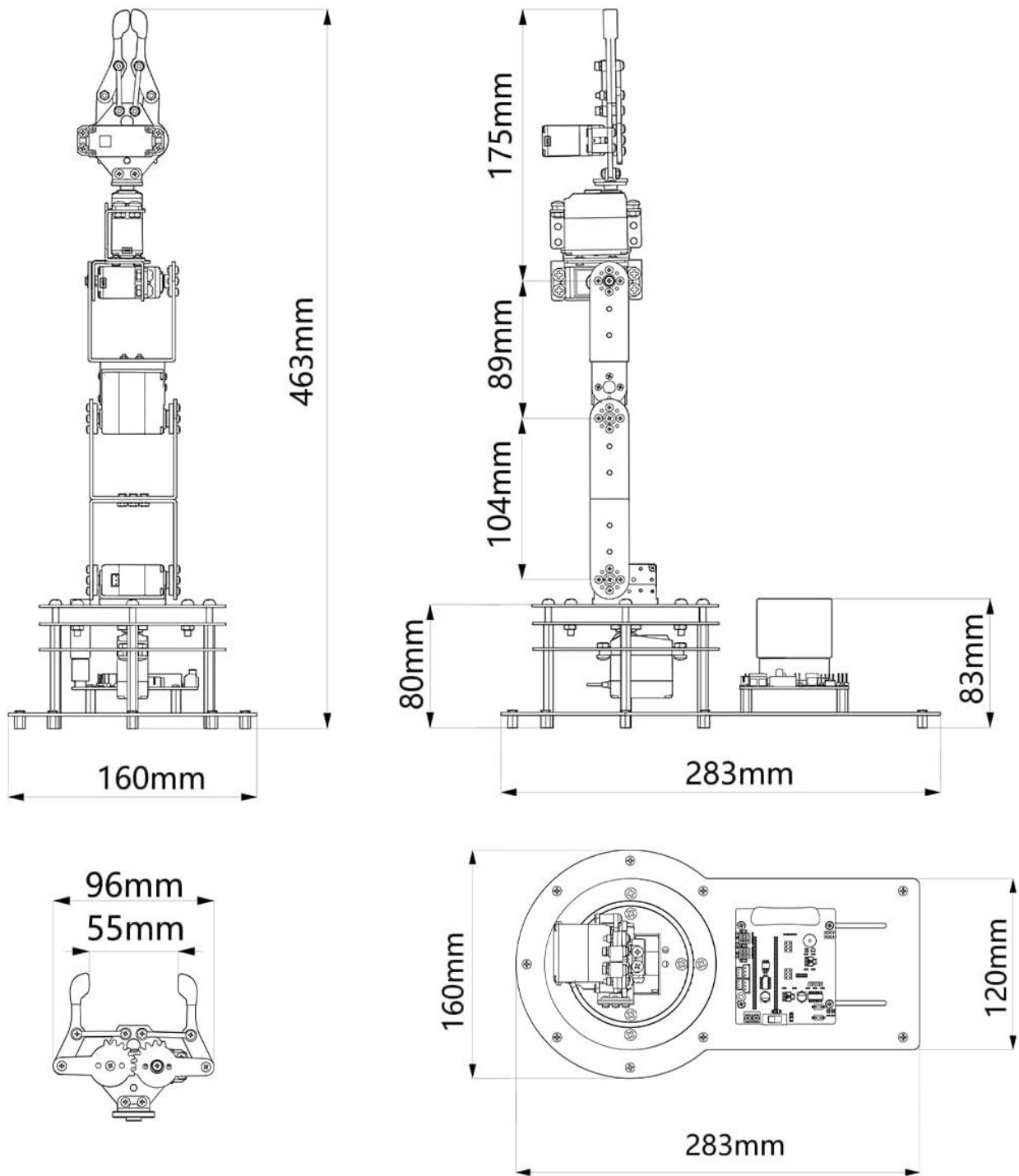


Figure 5: The CLYARM mechanical design

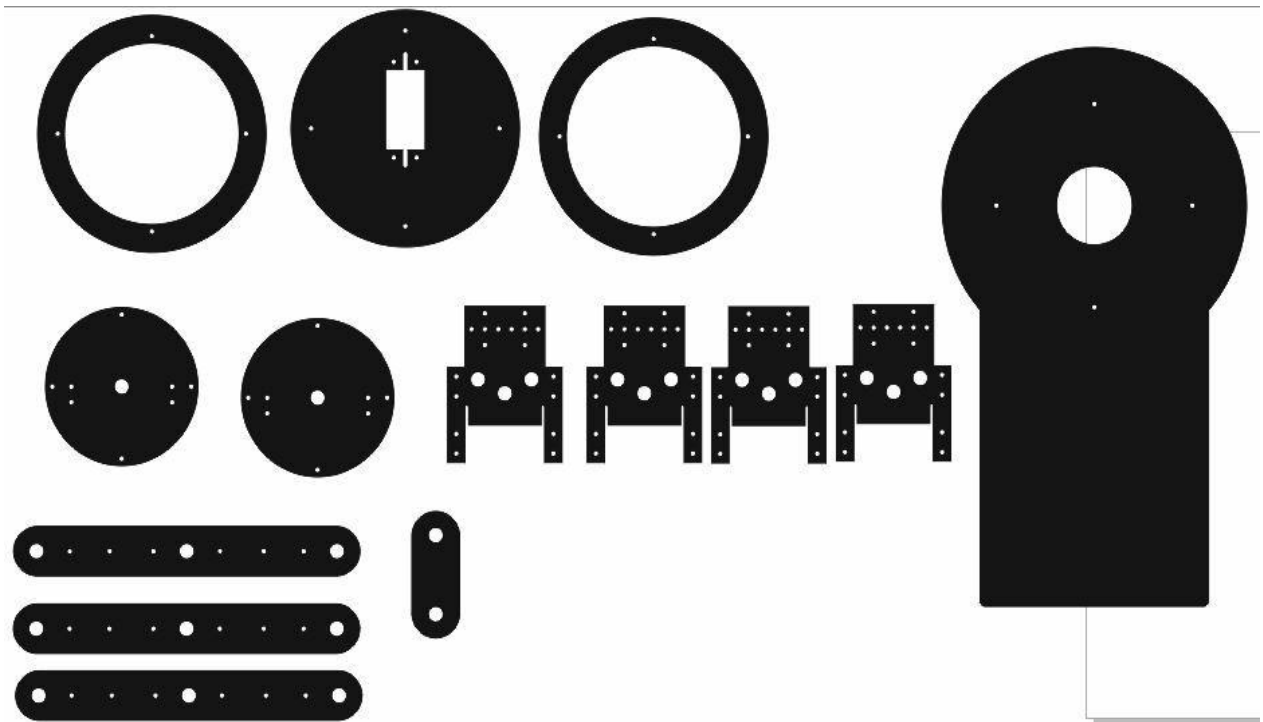


Figure 6: The CLYARM 2D mechanical design

2.3 Electronic Components and Control

The electronic aspect of this project relies on a simple yet flexible architecture that enables precise and smooth control of the robotic arm's movements, while allowing for future expansion into more advanced features such as vision or environmental sensing.

The system is composed of three main parts: the **control unit (microcontroller)**, **actuation units (servomotors)**, and **(power/connectivity) modules**.

2.3.1 Main components:

- Microcontroller unit (MCU).
- Multiple servo motors.
- Power supply.

This architecture can be expanded in the future by adding Bluetooth or Wi-Fi modules, or even cameras or the intelligent artificial opening doors to more advanced applications in computer vision or remote control.

2.3.2 Microcontroller

The microcontroller serves as the "brain" of the system, where the control programs for the robotic arm are uploaded. In this project, a controller compatible with the **Arduino** platform was chosen due to several reasons:

- **Ease of programming** via the Arduino IDE.
- **Availability of ready-to-use libraries** for motor and sensor control.
- **A large support community** that facilitates development and debugging.
- **Scalability** through additional I/O units.

2.3.2.1 Chosen microcontroller: Arduino (ATmega2560) –

The Arduino Mega 2560 is a powerful microcontroller board based on the ATmega2560 chip. Designed with a large number of input/output pins, it features 54 digital I/O pins (15 of which support PWM), 16 analog inputs, and four UARTs for serial communication [17]. It also, the Arduino Mega is well suited for robotics, automation, and educational systems project, where multiple actuators, sensors, and modules may be used simultaneously with the possibility of upgrading to boards that are more powerful

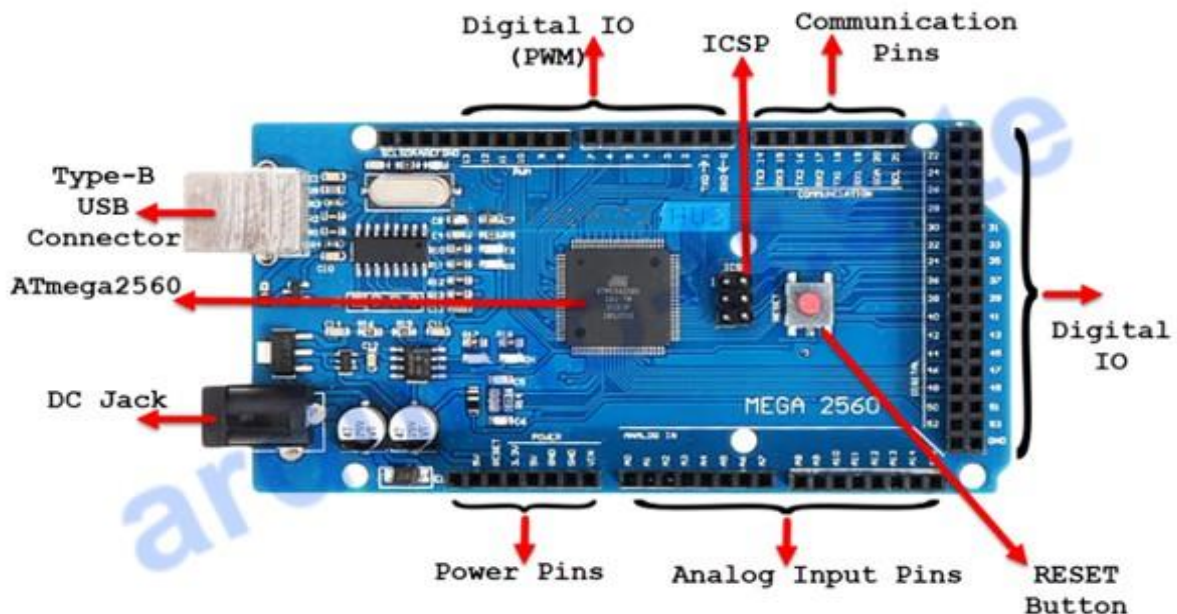


Figure 7: Description of Arduino Mega 2560.

2.3.2.2 Table: The characteristics of the Arduino Mega board.

Feature	Specification
Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7–12V
Input Voltage (limits)	6–20V
Digital I/O Pins	54 (15 PWM output)
Analog Input Pins	16
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB (8 KB used by bootloader)
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz
Communication Interfaces	4 UARTs, SPI, I2C, USB
USB Connection	Type-B USB
Dimensions	101.52 mm x 53.3 mm

Table 2: The characteristics of the Arduino Mega board.

2.3 Arduino shields

Arduino shields are modular circuit boards designed to be plugged directly on top of Arduino boards, expanding their functionality without the need for complex wiring. These shields provide plug-and-play solutions for adding features like **motor control**, **wireless communication (Bluetooth, Wi-Fi, GSM)**, **display interfaces (LCD, OLED, touchscreen)**, **sensors**, or even **GPS modules**. They are stackable, allowing multiple shields to be combined on a single Arduino to build systems that are more sophisticated [18]. In educational robotics projects like CLY, we use the **Arduino 2 Motor and 16 Servo** shields help accelerate development by simplifying integration of additional capabilities.

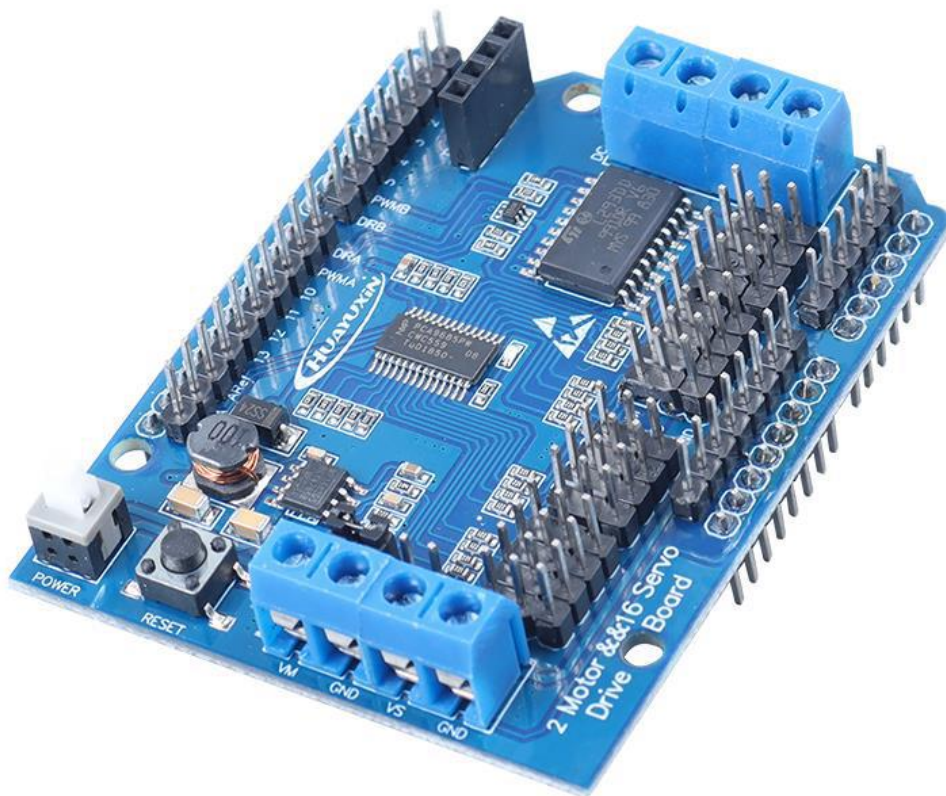


Figure 8: 2 Motor and 16 Servo Arduino Shield

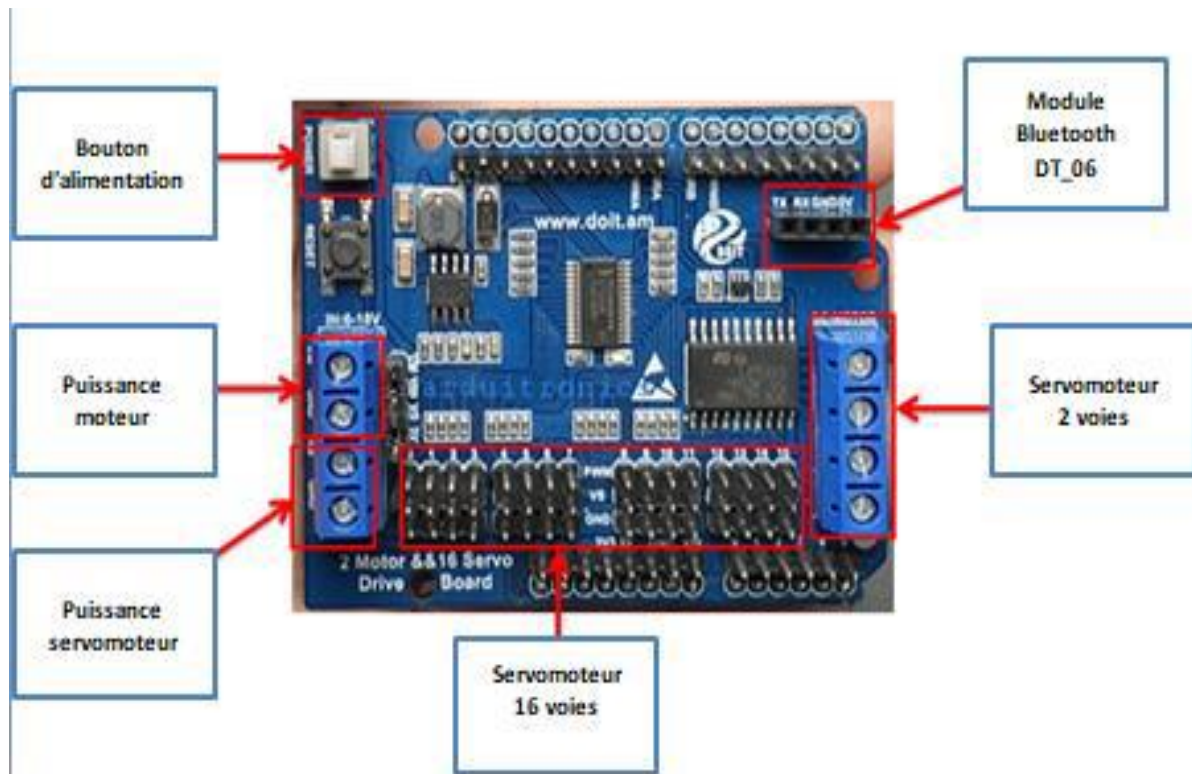


Figure 9: The components of the 2 Motor and 16 Servo Arduino shield

2.4 ServoMotors

To ensure precise and controlled movement, **servomotors** were selected instead of regular DC motors. A servomotor includes an **internal control system and a position sensor**

- **(Potentiometer)**, which allows for accurate angle targeting.
- **Number of motors:** Between 4 to 6, depending on the degrees of freedom required.
- **Types used:** MG90S
- **Range of motion:** Typically 0° to 180° per joint.

The servos represent the joints of the robotic arm, where each motor is programmed to perform a specific movement within a defined sequence [19].



Figure 10: Servomotor MG90s.

2.4.1 Servomotors characteristics


Characteristic Type	
Dimensions	40 mm × 19mm × 43mm
Weight	56 gr
Supply voltage	4.8 V à 7.2 V
Speed	0.17 s /60° below 4.8 V
Couple	13 / cm below 4.8V

Table 3: Servomotors characteristics

2.4.2 Functioning of Servo Motors

Servomotors are precise actuators used to control angular or linear position, velocity, and acceleration. Each servo contains a DC motor, a gearbox, a position sensor (usually a potentiometer), and a control circuit. When a control signal (usually a PWM – Pulse Width Modulation signal) sent to the servo, the internal controller compares the desired position (based on the signal) to the current position (measured by the sensor). It then adjusts the motor's rotation until the desired position is reached. The most common hobby servos rotate between 0° and 180°, making them ideal for robotic joints.

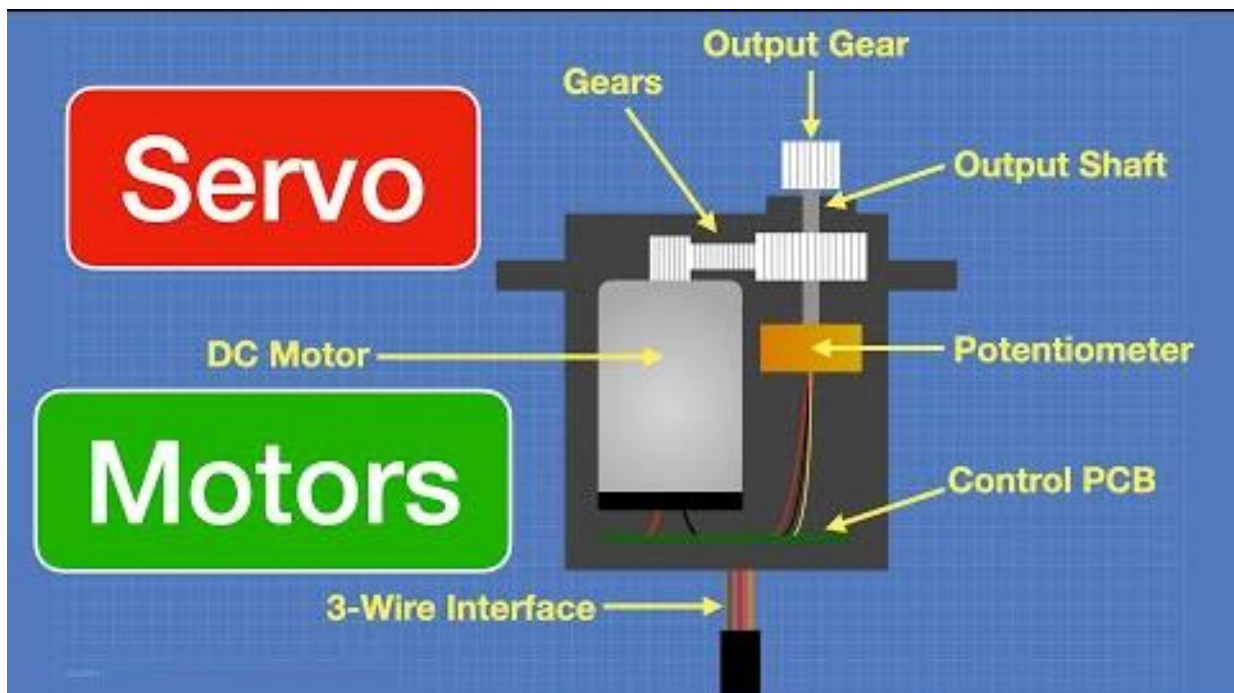


Figure 11: Composition of a servomotor

2.5 Power Supply Circuitry

We are using a specific alimentation arrangement for each component in our project. The Arduino Mega card is powered by a 5 volt supply that is specifically designed for the Arduino card, ensuring its stability and proper operation.

A 12-volt transformer supplies power to the electroaimant's control relay. This relais enables us to control the electroaimant's activation and deactivation, which is our robot's main tool. We have an alimentation specifically for servomotors. The tension required to feed and regulate the servomotors used in our project is provided by this alimentation.

Since motors draw more current than the USB port can provide, an external power circuit was designed to ensure stable voltage:



Figure 12: Power supply of 5v-10A



Figure 13: Transformer of 12V-2A

2.6 Optional Expansion Units

The system can be upgraded later with additional components such as:

- **Sensors:** like ultrasonic distance sensors or angle sensors.
- **Wireless communication modules (Bluetooth, Wi-Fi):** for remote control.
- **Display modules (LCD or OLED):** to show system status or data.
- **Camera:** for machine vision applications in advanced phases.

2.7 Servomotor with Arduino diagram

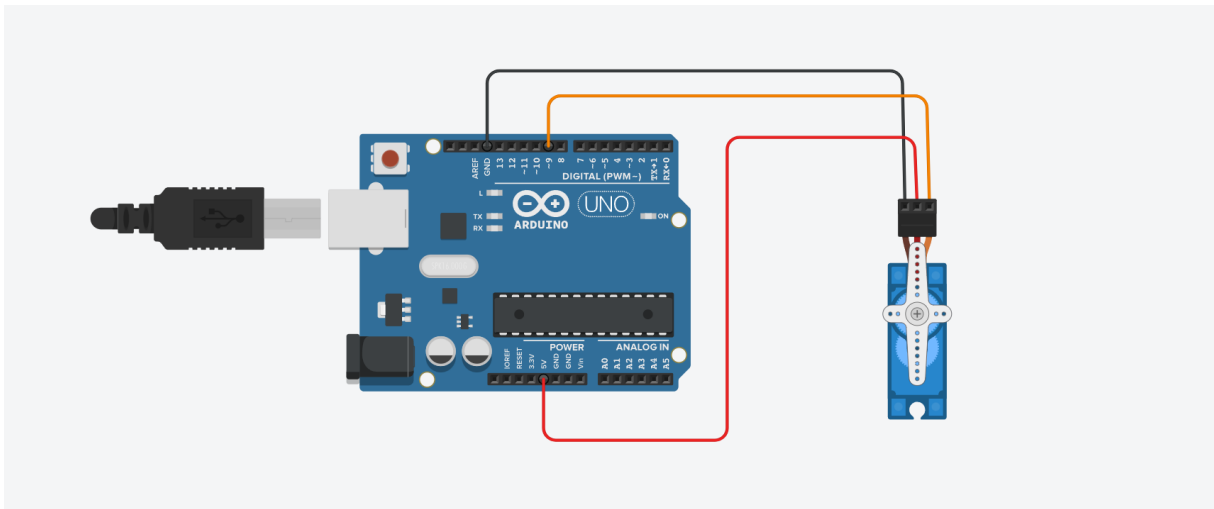


Figure 14: Servomotor with Arduino diagram

3. Software part

3.1 Programming via the Arduino IDE

The programming aspect plays a pivotal role in controlling the CLY robotic arm. It relies primarily on the Arduino IDE, an open-source development environment used for programming Arduino-based microcontrollers such as the Arduino UNO or MEGA 2560.

3.2 Arduino IDE Features:

- The supported programming language is C/C++, with a great deal of simplification suitable for beginners.
- It provides ready-made libraries for controlling motors, sensors, and displays.
- It has a built-in text editor, a tool for uploading code directly to the board, and a serial monitor interface for monitoring data.
- It supports code verification before uploading to reduce errors.
- It is compatible with multiple operating systems (Windows, Mac, Linux).

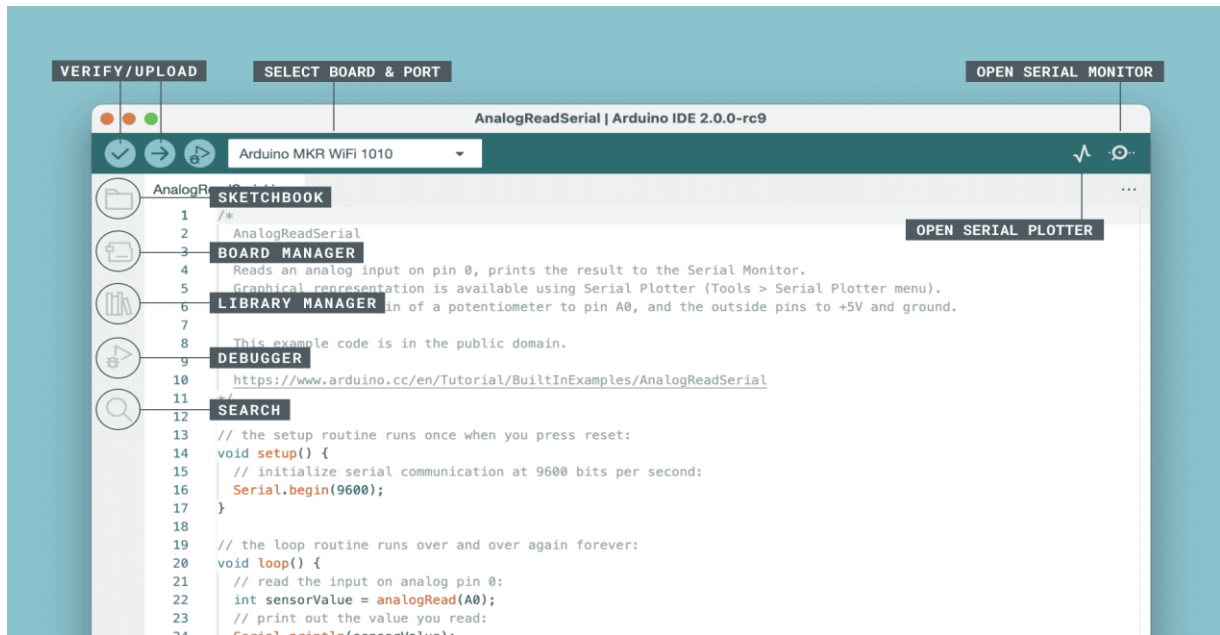


Figure 15: Arduino ide 2 interface

3.3 Integration with the electronics side:

The Arduino IDE allows the user to fully integrate the software and electronics by allowing them to create instructions to operate each motor separately, in a certain order, or to connect motions to signals from external sensors.

4. Assembly, Usage, and Programming Guide

4.1 Assembly Guide

The CLY robotic arm is designed for easy assembly, focusing on simplicity and durability. All mechanical components are structured to be mounted using basic tools (screwdrivers, screws), and a visual guide is provided to walk users through each assembly step:

- **Step 1:** Mounting the base of the arm onto the platform.
- **Step 2:** Installing the joints and axes in order.
- **Step 3:** Placing the servomotors into their designated slots and connecting them to the moving arms.
- **Step 4:** Wiring the motors to the control board.
- **Step 5:** Performing an initial mechanical movement test manually.

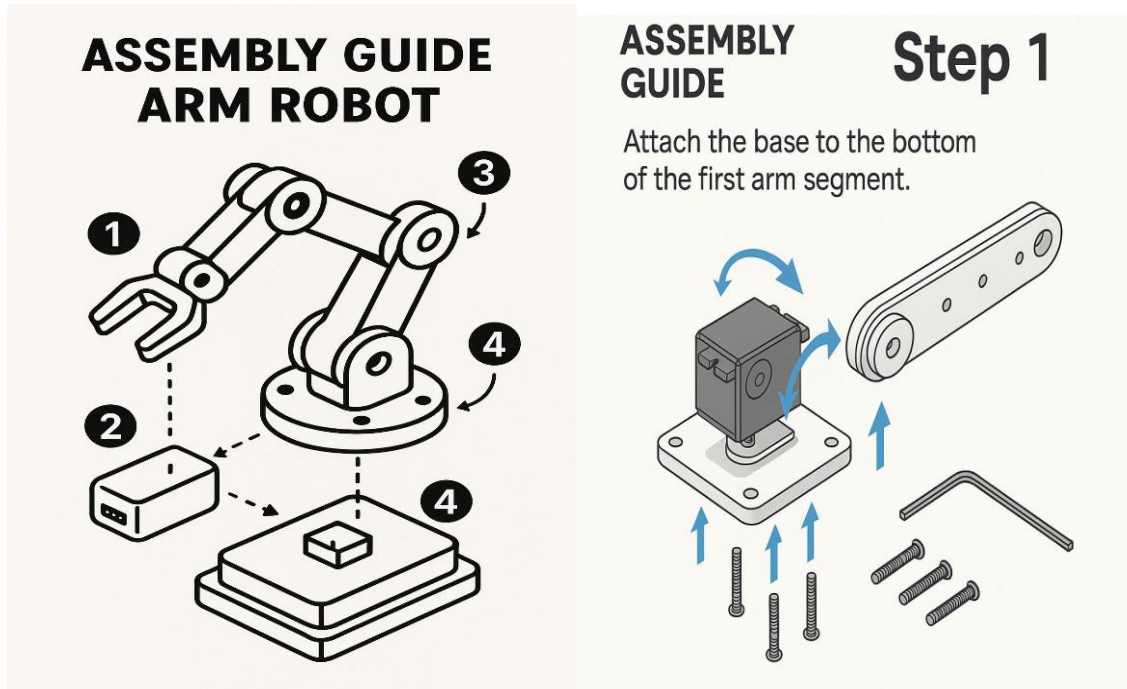


Figure 16: Assembly guide example

4.2 User Guide

Once assembled, the robotic arm can be operated through the following steps:

- Switching on the external power supply.
- Connecting the Arduino board to a computer via USB.
- Uploading the basic control code to the microcontroller.
- Opening the graphical interface (if available) or using the Serial Monitor.
- Sending simple commands to test each joint's movement individually.

The interface is designed to be educational, highlighting cause-effect relationships (e.g., pressing a button = servo rotates 90°).



Figure 17: User guide casing & content

4.3 Programming Guide

Programming is done using the Arduino IDE, a free and beginner-friendly development environment.

- Programming language: Based on C/C++.
- Code structure: Utilizes `setup()` to initialize components and `loop()` to run repeated instructions.
- Libraries: Uses the `Servo.h` library for motor control.

Code examples:

- Code to move a single joint.
- Code for a movement sequence (e.g., Pick and Place).
- Code for sensor or button-based interactions.

Users can progressively enhance their programs, starting from basic commands to more advanced control algorithms.

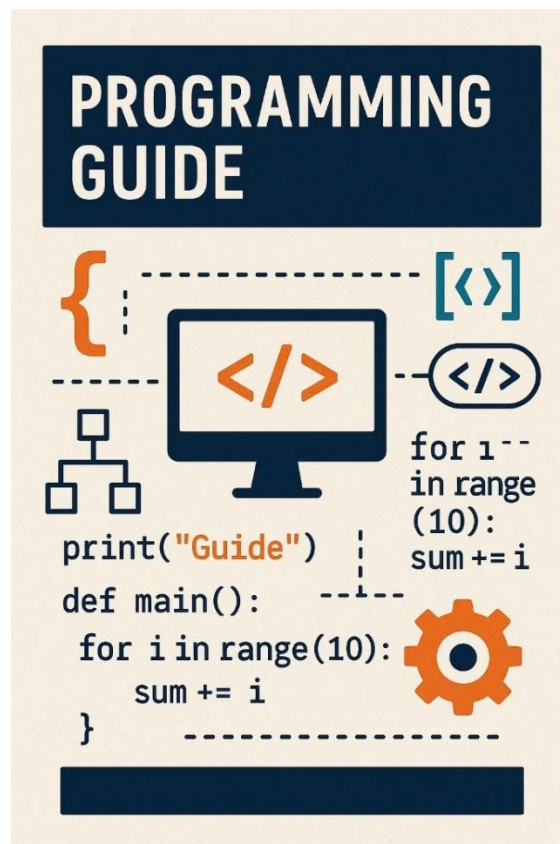


Figure 18: Programming guide casing

5. Conclusion

In Chapter 2 we provided a detailed overview of the CLY educational robotic arm project by outlining its key components and system architecture. From the mechanical structure designed for modularity and accessibility, to the electronic subsystems—such as the microcontroller, servomotors, and power supply—each element was selected to balance simplicity, cost-effectiveness, and educational value. Furthermore, the programming environment, based on the Arduino IDE, supports gradual learning through hands-on coding and real-time interaction with the hardware.

In addition, the chapter introduced practical user guidance on how to assemble and operate the robot, making it not only a technical tool but also a pedagogical resource accessible to students and educators alike. This project demonstrates how robotics can be both functional and formative, laying the foundation for further development in the following chapters, which will delve deeper into implementation, testing, and educational applications.

CHAPTER 3

CHAPTER 3: PRACTICAL EXPERIMENTS (MANIPULATIONS)

This chapter presents a series of practical educational experiments designed to enhance Learners' hands-on understanding by using the CLY educational robotic arm.

These experiments are arranged progressively in terms of difficulty, enabling students to gradually acquire programming, mechanical, and electronic skills gradually.

3.1 About Robot Fabrication and Assembly:

This robot was built using CNC laser-cutting metal, followed by bending and hand assembling some of the pieces. Servomotors actuated the joints and were precisely positioned within the arm structure. These motors were connected to the Arduino Mega board via appropriate wiring, and the motor functions were gradually tested before fully programming. Basic assembly tools include precision screwdrivers, heat shrink tubing, jumper wires, and a stable power supply.



Figure 19: The cutting part



Figure 20: The cutting of all part



Figure 21: All pieces needed for the arm robot

3.1.2 Required Parts

- **2x Circular Base Plates** (large round disks)
- **1x Base Support Plate** (the largest flat part with central hole)
- **4x Joint Brackets** (U-shaped parts)
- **4x Arm Links** (elongated holes for joints)
- **2x Medium Circular Rotation Plates**
- **1x Servo Mount Plate** (rectangular slot in the middle)
- **1x Spacer or Connector Plate** (small part with 2 holes)



Figure 22: Bend the pieces

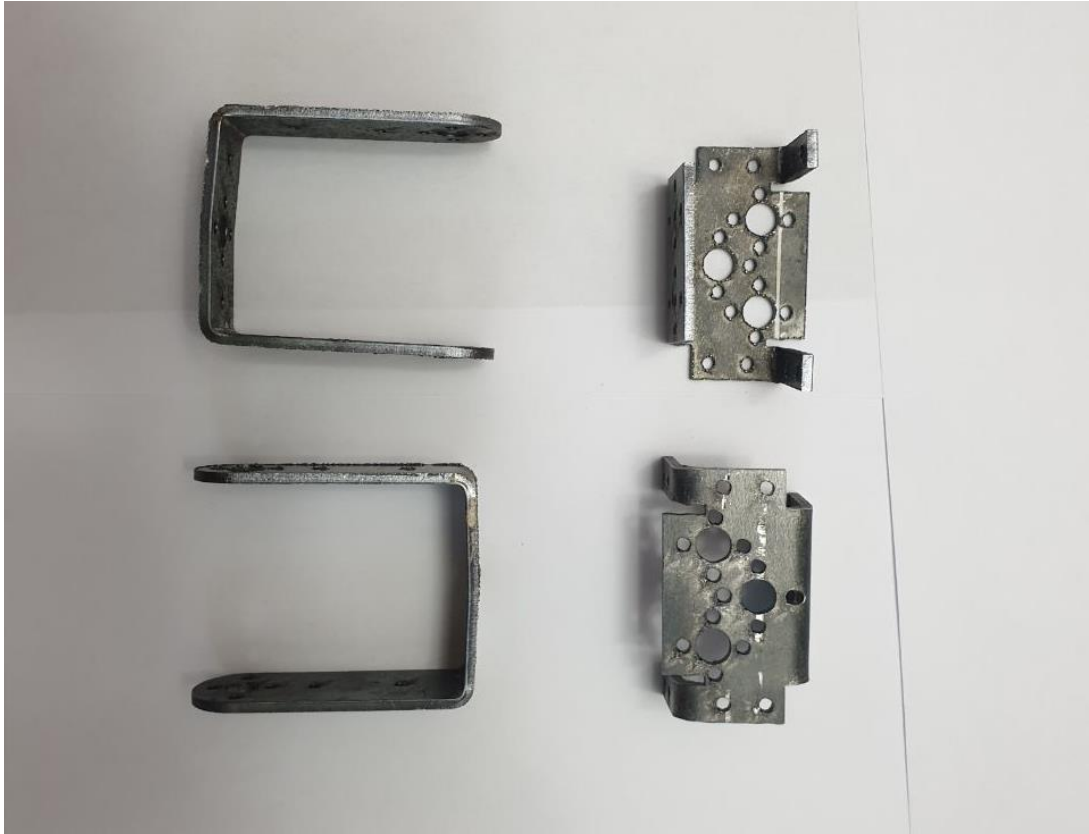


Figure 23: Bend the pieces 2



Figure 24: Nails and screws that used



Figure 25: The final prototype

4. Children's Experiments with the Robotic Arm

This chapter is dedicated to simplified experiments aimed at children, with the goal of introducing them to the concept of robotics, its components, and functions in a fun, practical, and safe way. These activities are designed without the need to teach programming, relying instead on a pre-programmed robot to perform interactive movements.

4.1 Experiment One: “Hello! The Robot Waves!”

Educational Objectives:

- Introduce the child to the concept of a robot.
- Explain the function of a motor as a means of movement.
- Understand the relationship between commands and motion.

Components:

- A single-joint robotic arm.
- Large push button.
- Pre-programmed Arduino board.
- Power supply.

Activity Steps:

- The child presses the button.
- The robot performs a simple waving motion.

Key Concepts:

- Robots move only when they receive a command.
- We can design robots to perform useful or fun movements.

Assessment Questions:

- What did the robot do when you pressed the button?
- Can the robot move without a command?

4.2 Experiment Two: “Rescue Zone!”

Educational Objectives:

- Introduce the concept of task execution by robots.
- Distinguish between the human (who gives commands) and the robot (who executes them).
- Encourage cooperation and interaction with the robot.

Components:

- A simple robotic arm (2 degrees of freedom).
- A small figurine representing a person to be rescued.
- Push button.
- A platform simulating a "danger zone".

Activity Steps:

- The child presses the button.
- The robot picks up the figurine and moves it to a "safe zone".

Key Concepts:

- Robots assist humans in difficult or dangerous tasks.
- Every movement must be pre-programmed.

Assessment Questions:

- What did the robot rescue?
- What other tasks could a robot perform?

4.3 Experiment Three: “The Robot Delivers Gifts!”

Educational Objectives:

- Reinforce the child's understanding of the robot as a distributor.
- Connect technology with daily life.
- Understand the logical sequence of actions.

Components:

- A robotic arm capable of gripping.
- A small box or token (gift).
- Push button.
- A platform with a “storage zone” and “delivery zone”.

Activity Steps:

- The child presses the button.
- The robot picks up the gift and moves it to the delivery zone.

Key Concepts:

- Robots execute human instructions.
- Robots can be used in distribution and assistance tasks.

Assessment Questions:

- Who gave the order to the robot?
- Does the robot know the task on its own?

Teacher's Guide:

- These experiments should be accompanied by simple verbal explanations and visual aids (pictures or drawings).
- Avoid technical or complex terminology.
- Encourage children to share their own ideas about robots and their potential uses.
- A classroom corner can be set up to display the robot as an ongoing interactive activity.

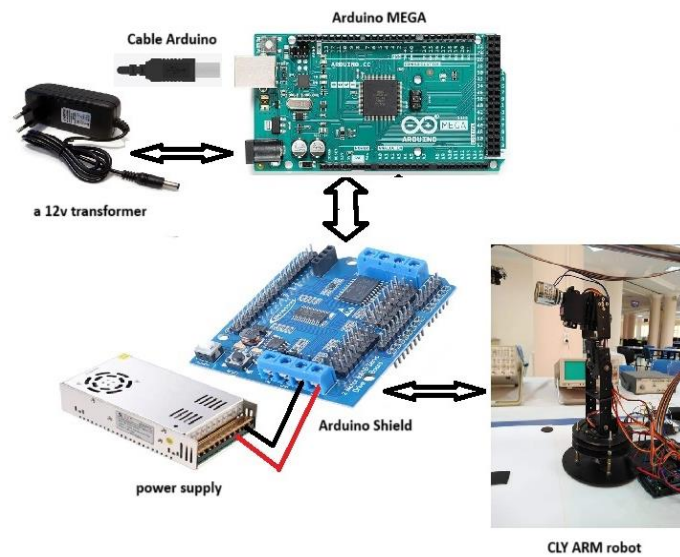


Figure 26: Communication between components with (1 & 2 Dof)

5. Interactive Experiments for Middle School Students

Introduction:

This chapter aims to introduce middle school students to programming concepts, precision, and logical sequencing through interactive and simplified experiments using a **pre-programmed robotic arm**. The activities are carried out without the need for direct coding or sensor integration, relying instead on observation, interaction, and basic inputs like push buttons or preset modes.

5.1 Experiment One: The Robot Follows a “Daily Routine”

Educational Objective:

- Understand the concept of a programmed routine.
- Distinguish between programming and execution.
- Recognize the link between command order and outcomes.

Components:

- Fixed robotic arm (3 or 4 DOF).
- Push buttons or selector switch.
- Small objects representing daily items (cup, book, phone...).

Activity Steps:

- The student chooses a simple daily routine (e.g., tidying a desk).
- They press a button to activate the pre-programmed routine.
- The robotic arm performs a series of movements: pick up, move, place.
- The student is asked to analyze the order of the executed actions.

Key Concepts:

- The robot executes instructions exactly as programmed.
- Complex tasks are made up of simple, ordered commands.

Evaluation Questions:

- What was the first thing the robot did?
- What would happen if we changed the order of actions?
- Can the robot adapt to changes? Why or why not?

Teacher’s Guide:

- Discuss the concept of daily routines with the students.
- Highlight the difference between "intent" and "instruction".
- Ask students to write out the steps before running the robot.

5.2 Experiment Two: “The Drawing Robot”

Educational Objective:

- Learn about the precision of robotic motion.
- Understand that robots execute predefined commands without creativity.
- Stimulate imagination on how robotic arms can be used.

Components:

- Robotic arm with a mountable pen.
- Blank sheet of paper on a flat surface.
- Pre-programmed drawing options (square, circle, triangle).

Activity Steps:

- Students fix the pen onto the robotic arm.
- They select a shape via a switch or button.
- The robot draws the chosen shape.
- Students compare and analyze the results.

Key Concepts:

- Precise movement leads to accurate results.
- Every motion is controlled by predefined numerical instructions.

Evaluation Questions:

- Did the shape change when repeated?
- Can the robot draw a heart? Why or why not?
- What’s the difference between what the robot and a human can do?

Teacher’s Guide:

- Explain that each shape is the result of numeric programming.
- Encourage students to suggest new shapes.
- Use the activity to spark discussion on creativity vs. automation.

5.3 Experiment Three: “Human vs. Robot Challenge”

Educational Objective:

- Understand robot performance compared to human performance.
- Develop measuring and analytical skills.
- Learn the limits and strengths of robotic systems.

Components:

- Pre-programmed robotic arm for object transfer.
- 3 small cubes or balls.
- Stopwatch.
- Platform with area A (start) and area B (destination).

Activity Steps:

- A student manually transfers the objects from A to B while being timed.
- Then, the robot performs the same task.
- The results are compared in terms of time and accuracy.

Key Concepts:

- Robots are fast and consistent, but inflexible.
- Humans are adaptive and contextual thinkers.

Evaluation Questions:

- Who was faster? Why?
- Could the robot adapt to different object shapes?
- What are the strengths and weaknesses of each?

Teacher’s Guide:

- Encourage accurate note taking and observation.
- Facilitate discussion on robotic automation in real-life applications.
- Use this to initiate debates about the future of human-robot collaboration.

General Notes for the Teacher:

- These experiments are suitable for classrooms with basic equipment.
- Students can be encouraged to imagine new use cases for robotic arms.
- Results can be documented via drawings or videos for enhanced engagement.

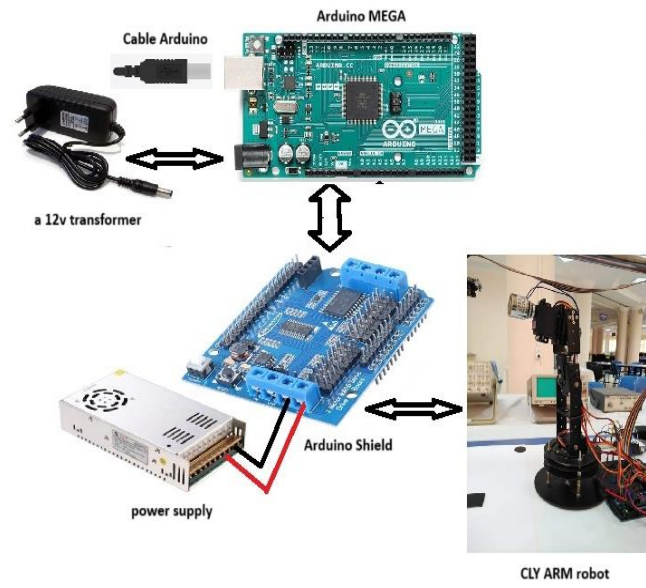


Figure 27: Communication between components with (4 & 5 Dof)

6. Educational Experiments for Secondary Students with CLY Robotic Arm

This chapter introduces educational experiments specifically designed for high school students. These activities combine interactive use of the robotic arm with a gradual and structured introduction to the fundamentals of programming, automation, and problem solving. The aim is to foster logical thinking, computational skills, and an understanding of robotics systems through real-world applications.

Introduction to Programming and Robotics

Before conducting the experiments, students will be introduced to the essential concepts of programming and how it applies to robotics:

What is Programming?

Programming is the process of writing instructions that a computer (or robot) can understand and execute. It involves using specific syntax and logic to solve problems and automate tasks.

Key Programming Concepts:

- **Algorithm:** A step-by-step procedure to solve a problem.
- **Variable:** A storage location that holds data.
- **Conditional Statements (if/else):** Used to make decisions in a program.
- **Loops (for, while):** Repeat actions multiple times.
- **Functions:** Reusable blocks of code that perform a specific task.

Students will use the **Arduino IDE** (Integrated Development Environment), which is a platform to write and upload code to Arduino boards. It uses a simplified version of C/C++.

6.1 Experiment 1: "Pick and Place with Buttons"

Educational Objective:

- Understand how code controls motor actions.
- Learn the logic of triggering predefined motions.
- Components:
 - CLY robotic arm (3 DoF minimum)
 - Arduino Mega (pre-programmed)
 - 2 buttons (start and reset)

Steps:

- Press the first button to start the pick-and-place sequence.
- The robotic arm moves to pick an object and place it in another location.
- Press the second button to reset the arm position.

Key Concepts:

- Sequential execution
- Basic motion control through I/O pins

Evaluation Questions:

- What happens when you press the start button?
- How can you change the sequence in code?

Teacher's Guide:

- Use diagrams to explain each robot movement.
- Discuss the link between code and physical motion.
- Encourage students to imagine real-world uses for pick-and-place systems.

6.2 Experiment 2: "Color Sorting Simulation (without sensor)"

Educational Objective:

- Simulate conditional logic.
- Reinforce the role of programming in decision-making.

Components:

- robotic arm
- Three colored cards (red, green, blue)
- Three predefined positions
- Button to trigger motion

Steps:

- Student selects a color card.
- Press the button.
- The robot executes a motion corresponding to the selected color.

Note: the teacher (or user) enters the color choice via serial monitor, simulating a sensor.

Key Concepts:

- Use of if statements
- Interaction via serial input

Evaluation Questions:

- What would happen if we had a real color sensor?
- How would you update the code for more colors?

Teacher's Guide:

- Explain the concept of simulation vs. real input.
- Let students manually edit the value in the code or serial monitor.
- Discuss how sensors can automate these steps.

6.3 Experiment 3: "Pattern Programming Challenge"

Educational Objective:

- Practice algorithm design.
- Encourage creative and logical thinking.

Components:

- robotic arm
- Buttons or Serial Monitor input

Steps:

- Students write a sequence of moves using basic Arduino code.
- Upload the program to the board.
- The robot performs the user-defined pattern.

Key Concepts:

- Functions and loops
- Motor control using angles

Evaluation Questions:

- How can we optimize the code for shorter sequences?
- What's the difference between `delay()` and real-time control?

Teacher's Guide:

- Provide a basic template code.
- Encourage students to use loops to avoid repetition.
- Allow group work to promote teamwork and creativity.

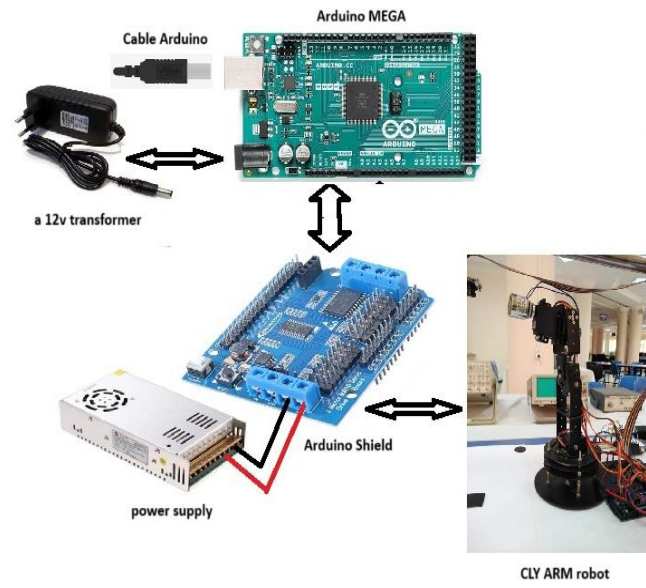


Figure 28: Communication between components with (4 & 5 DoF)

7. Educational Experiments for University and higher education

Practical Lab – TP: Forward and Inverse Geometric Modeling (FGM / IGM) of the CLY Robotic Arm

■ TP Title:

Forward and Inverse Geometric Modeling of a 2-DOF Robotic Arm – Implementation and Validation in MATLAB

🎯 Learning Objectives:

- Understand the concepts of forward and inverse kinematics applied to robotic arms.
 - Model the FGM and IGM equations for a planar 2-joint robot.
 - Apply mathematical knowledge in a simulation environment (MATLAB).
 - Analyze the accuracy and consistency of the theoretical model against simulated movements.
-

□ Required Materials and Tools:

- MATLAB software (Symbolic Toolbox recommended).
 - Paper, pen, scientific calculator.
 - Robot arm technical sheet (link lengths, joint limits, etc.).
-

📖 Theoretical Reminder:

- Consider a planar 2-DOF robotic arm. Parameters:
- L_1, L_2 : lengths of segments 1 and 2.
- θ_1, θ_2 : joint angles (input for FGM, output for IGM).
- (x, y) : end-effector position (output for FGM, input for IGM).

FGM (Forward Geometric Modeling):

$$x = L1 \cdot \cos(\theta 1) + L2 \cdot \cos(\theta 1 + \theta 2)$$

$$y = L1 \cdot \sin(\theta 1) + L2 \cdot \sin(\theta 1 + \theta 2)$$

IGM (Inverse Geometric Modeling):

- Trigonometric solution from (x, y) to find $\theta 1$ and $\theta 2$.
 - Note: Two possible solutions (elbow-up / elbow-down).
-

🔧 TP Procedure:

Part 1: FGM

1. Implement a MATLAB function

2. Test with: `L1 = 10; L2 = 7; theta1 = 45; theta2 = 30`

3. Plot the arm using `plot()`, linking points: origin, elbow, end-effector.

Part 2: IGM

1. Implement a MATLAB function

2. Test with `x = 13; y = 10`.

3. Use the resulting angles in the FGM to check consistency.

📊 Expected Results

- Agreement between positions obtained from FGM and IGM.
- Awareness of numerical error and joint angle constraints.

? Analysis Questions:

- Does the IGM function always return a solution? Why?
- What is the uncertainty caused by numerical rounding?
- What physical limits must be considered on a real robot (motors, angles, collisions)?

🔧 Instructor Notes:

- You can increase difficulty with randomized test points within reach.
- Suggest building an interactive GUI with sliders (using `uicontrol` in MATLAB).
- Emphasize the difference between joint space and operational space.

8. CLY for Self-Learners: Your Robotic Journey Begins Here

📖 Introduction:

This guide is designed specifically for self-learners — curious minds, hobbyists, students, and makers who want to explore robotics through hands-on experience with the CLY robotic arm. Whether you're just starting or aiming to build smart, interactive systems, this roadmap will help you take control of your learning journey.

👤 Who Is This For?

- High school or university students exploring robotics independently
 - Hobbyists and tinkerers with a passion for technology
 - Educators or workshop leaders seeking flexible content
 - Anyone eager to learn-by-doing outside the classroom
-

🔧 What You Need:

- CLY robotic arm (assembled or DIY version)
 - Arduino board (Mega recommended)
 - Basic electronics (servo motors, power supply, jumper wires)
 - Arduino IDE (free software)
 - Optional: Bluetooth module, sensors, MATLAB/Python
-

📖 Learning Path Overview:

● Level 1 – Getting Started

Skills: Assembly, connections, safety, basic movement

Projects:

- Plug-and-play movement demo

- Robot waves or lifts an object

● Level 2 – Hands-On Coding

Skills: Arduino basics, serial communication, servo control

Projects:

- Write your first movement sequence
- Pick-and-place task
- Create a button-controlled interface

● Level 3 – Interactive Systems

Skills: Sensor integration, GUI design, conditional logic

Projects:

- Control the robot with light or distance sensors
- Build a GUI in MATLAB or Python
- Bluetooth-based remote control

● Level 4 – Creative Challenges

Skills: Design thinking, prototyping, optimization

Projects:

- Design a sorting robot
- Create a simple game using the robotic arm
- Build and share your own mini robotic assistant

🎯 Self-Learning Tips:

- Set micro-goals (e.g., "Make the arm move in 3 directions")
 - Watch open-source tutorials (YouTube, GitHub, Instructables)
-

9. Conclusion

The experiments successfully demonstrated the functionality and educational potential of the CLY robotic arm. The results confirmed the reliability of the system and its ability to engage users in interactive learning. These outcomes support the project's goals and open the door to future improvements, such as adding sensors or integration of intelligence artificial enhancing user interaction.

GENERAL CONCLUSION

GENERAL CONCLUSION

This study presented the design, implementation, and control of an educational robotic arm (CLY). The main objective was to provide a platform for developing technical skills and fostering creativity among students, while offering them a hands-on experience with robotics, programming, and mechatronics.

Through this project, we successfully demonstrated the process of designing a robotic arm from concept to implementation, integrating mechanical components, electronic control, and software programming. The CLY arm can perform a range of movement tasks, reflecting its potential as a powerful educational tool. Furthermore, by employing a combination of physical modules and programming routines, we enable users — especially children and beginners — to safely explore and understand the fundamentals of robotics in a realistic context.

This work shows that educational robotics can be a valuable medium for developing problem-solving skills, creativity, and enthusiasm for science and technology. CLY serves not only as a teaching aid, but also as a platform for further innovations and experiments, adding depth and engagement to STEM education. The project paves the way for future enhancements, whether by adding sensors, integrating wireless control, or extending its range of applications in the classroom or laboratory setting.

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ملخص

تقدم هذه المذكرة تصميم وتطوير ذراع رباتيه تعليمية تُسمى CLY ، وتهدف إلى تعزيز تعليم وتعلم الروبوتات والبرمجة والأتمتة بطريقة عملية وسهلة المنال. يسعى المشروع إلى معالجة قيود منصات الروبوتات التعليمية الحالية - مثل التكلفة العالية، والتعقيد، والقيود المتعلقة بالعمر - من خلال تقديم بديل معياري، وقابل للتطوير، وسهل الاستخدام، ومناسب لمختلف المستويات التعليمية.

يتضمن البحث دراسة نظرية للروبوتات والتقنيات التعليمية، يتبعها التصميم الميكانيكي والإلكتروني للذراع الروبوتية، بالإضافة إلى تطورات مستقبلية كتنفيذ واجهة برمجة متاحة. وقد طُوّر مسار تعليمي تدريجي، يُمكن الطلاب من التطور من التحكم الأساسي في الحركة إلى التفكير الخوارزمي وتكامل الأنظمة.

تم بناء واختبار ذراع CLY في ظروف واقعية، مما يُظهر إمكاناته كأداة للتعلم الذاتي ومساعد في الفصل الدراسي. وتؤكد النتائج فعالية الروبوتات التعليمية كأداة في تعزيز مشاركة الطلاب، والتفكير المنطقي، والمهارات العملية. يساهم هذا العمل في جعل تعليم الروبوتات أكثر شمولاً وقابلية للتكيف ومتوافقاً مع الاحتياجات التربوية لمناهج العلوم والتكنولوجيا والهندسة والرياضيات الحديثة.

Abstract

This thesis presents the design and development of an educational robotic arm called CLY, which aims to enhance the teaching and learning of robotics, programming, and automation in a practical and accessible manner. The project seeks to address the limitations of current educational robotics platforms—such as high cost, complexity, and age restrictions—by offering a modular, scalable, user-friendly alternative suitable for various educational levels.

The research includes a theoretical study of robotics and educational technologies, followed by the mechanical and electronic design of the robotic arm, as well as future developments such as the implementation of an accessible programming interface. A progressive learning path was developed, enabling students to progress from basic motion control to algorithmic reasoning and systems integration.

The CLY arm was built and tested in real-world conditions, demonstrating its potential as a self-learning tool and classroom assistant. The results confirm the effectiveness of educational robotics as a tool for enhancing student engagement, logical reasoning, and practical skills. This work contributes to making robotics education more inclusive, adaptable, and compatible with the pedagogical needs of modern STEM curricula.