Revolutionizing Automation with Robotic Arms

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***Abstract*—Robotic arms, essentially programmable mechanical limbs, replicate human arms in function. These versatile tools find use in numerous sectors. Their various joints provide rotational or linear movements, allowing precise manipulation in three-dimensional space. End-effectors, interchangeable attachments at the arm's tip, further expand their capabilities. From industrial automation tasks like assembly to delicate surgery and tackling situations too dangerous for human intervention, robotic arms serve as a powerful extension of human reach and ability. [1].**

***Index Terms*—Robotics, Manipulator, Kinematics, Dynamics, Automation**

I. Introduction

Robotic arms, often resembling their human counterparts, have become ubiquitous in various industries. These programmable mechanical limbs have transcended the realm of science fiction and firmly established themselves as crucial tools in modern society. Their versatility stems from their ability to mimic human motion with remarkable precision. Imagine an extension of human reach and capability, unconstrained by physical limitations or the perils of hazardous environments. This is precisely the power that robotic arms offer. Their articulated joints provide a wide range of movements, allowing them to navigate complex three-dimensional spaces. Beyond their physical prowess, robotic arms boast the ability to be equipped with interchangeable tools at their tip, further expanding their functionality. These end-effectors, as they are called, can be customized for tasks as diverse as delicate surgery and heavy-duty welding. The introduction of robotic arms has revolutionized numerous sectors. From streamlining industrial assembly lines to performing life-saving medical procedures, these remarkable machines have become instrumental in enhancing efficiency, safety, and accuracy across various applications. [2], [3].

II. Kinematics

In the realm of robotic arms, kinematics plays a central role, akin to the blueprint shaping their movements. Just as a map guides travelers, kinematics helps us understand the relationship between joint configurations (angles and positions) and the resulting motion of the arm's end-effector (the tool at its tip). Imagine the arm as a series of rigid segments connected by joints, like your own arm with a shoulder, elbow, and wrist. Kinematics allows us to predict where the hand (end-effector) will be based on the angles of these joints.

Fig. 1. Automatic robots in the industrial factory for assembly automotive products, Credit: Simon Kadula, CC https://unsplash.com/license

A. Degrees of Freedom (DoF)

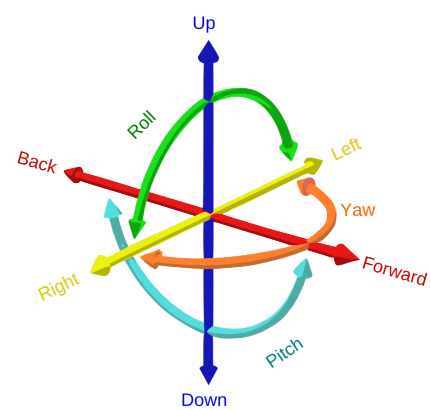

Fig. 2. The six degrees of freedom: forward/back, up/down, left/right, yaw, pitch, roll , credit: By GregorDS - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=38429678

This signifies the number of independent movements the arm can perform. A simple arm with a rotating base, elbow joint, and wrist joint would possess 3 DoF.

Joint Types: Two main types of joints govern robotic arm movement:

- **Revolute joints:** These allow for **rotational movement** around a single axis (think of your elbow).

- **Prismatic joints:** These enable **linear motion** in a straight line (imagine a sliding door). [4].

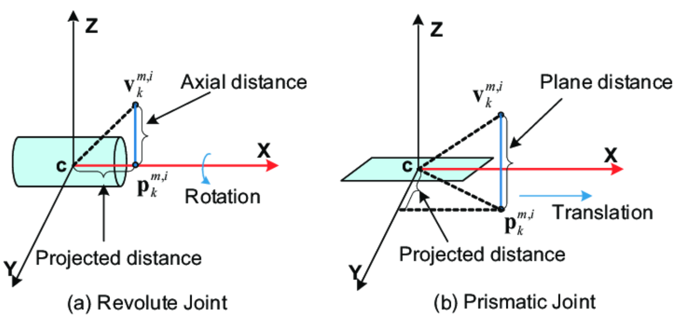

Fig. 3. Geometric invariants of revolute and prismatic joint , credit: Kangkang Yin

Each segment (link) in the arm can be defined by its **geometric properties** like length, angle offset, and joint type. These characteristics are crucial for solving the **kinematic equations**.

Kinematics empowers us with two key abilities:

1) **Forward Kinematics:** Given the **joint angles**, we can **predict the position and orientation of the end-effector**. This is essential for controlling the arm's movements with precision.
2) **Inverse Kinematics:** This tackles the inverse scenario. By specifying a desired **position and orientation for the end-effector**, we can calculate the necessary **joint angles** to achieve that goal. This enables the arm to be precisely manipulated for various tasks.

Imagine a bendy straw – your robotic arm. Kinematics helps us understand how bending at different points (joints) affects where the straw's tip (end-effector) travels. Like figuring out the path the straw draws, kinematics equips us with the math to predict these movements for the robotic arm. This knowledge is crucial for control. By understanding how joint bends affect movement, we can program the arm for complex tasks with impressive accuracy.

B. The Grip of the Machine: End-effectors

Robotic arms, while impressive feats of engineering, wouldn't be nearly as versatile without **end-effectors**. These crucial attachments, essentially the "hands" of the robotic arm, serve as the interface between the arm and the world. Designed for specific tasks, they allow the arm to grasp, manipulate, and interact with a diverse range of objects. Imagine a robotic arm without an end-effector. It would resemble a sophisticated arm without the ability to perform any meaningful actions. End-effectors bridge this gap, transforming the arm into a valuable tool across various industries. [5].

Here's a deeper look into the fascinating world of end-effectors:

Variety is Key: End-effectors come in numerous shapes and sizes, each meticulously crafted to suit a specific purpose.

Fig. 4. Example of a robotic gripper, credit: public domain fair use, 2024 Association for Advancing Automation

- **Grippers:** These are the most common type, resembling mechanical hands with two or more fingers designed to grasp objects of various shapes and sizes. [6].
- **Vacuum cups:** Ideal for smooth, non-porous surfaces, these end-effectors utilize suction to lift and move objects.
- **Welding tools:** Specialized for welding applications, these end-effectors might involve welding torches or manipulators designed for precise material handling during the welding process. [7].
- **Tools for specific applications:** The possibilities are vast. For instance, an end-effector for a robotic painter could be a specialized brush, while one for a fruit-picking robot might resemble a gentle grasping mechanism. [8].
- **Design Considerations:** The design of an end-effector hinges on several factors:
  - **Task requirements:** The specific task the arm needs to perform dictates the functionality and design of the end-effector.
  - **Object characteristics:** The size, weight, and shape of the objects the arm will handle influence the gripping mechanism and the materials used in the end-effector's construction.
  - **Precision requirements:** The level of precision needed for the task determines the complexity of the end-effector's design.
- **Material Selection:** End-effectors are often constructed from lightweight yet durable materials like aluminum, steel, or even composite materials. The chosen material needs to be sturdy enough to withstand the forces involved in grasping and manipulating objects.

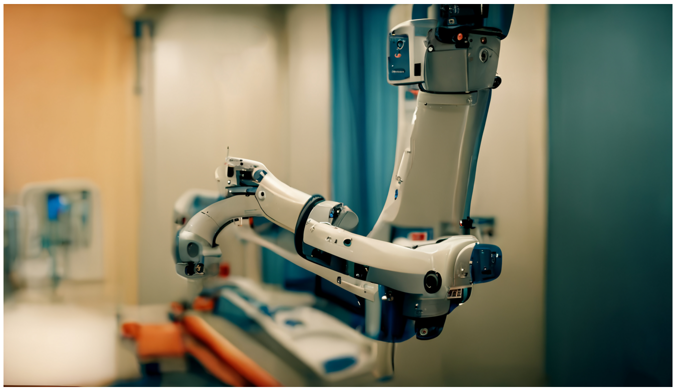

Fig. 5. Robotic arm meant for surgeries, credit: Vecteezy , CC BY-SA 4.0 https://creativecommons.org/licenses/by-sa/4.0

III. Building a robotic arm

To begin, let's look into the components that make up this project:

- 1 x Sheet of Plywood: This readily available and inexpensive material provides a sturdy yet lightweight base for the robotic arm.
- 1 x ESPRESSIF ESP32 Devmodule: The brain of the operation, translating smartphone app commands into precise movements for the servo motors.
- 4 x Servo motors sg90: These compact units act as the arm's muscles, precisely rotating the joints based on commands.
- 1 x Battery Holder (3 cell): Provides power for both the servos and the ESP32 using standard AA batteries.
- 1 x Stable 5V Power Delivery: Ensures reliable servo operation using an Arduino Nano, a voltage step-up module, or a rechargeable Li-Ion battery (with charger).
- (Optional) 1 x 3.7V Rechargeable Li-Ion Battery: As an alternative to a battery holder this could be used with a Li-Ion battery charger module for infinite re-use.

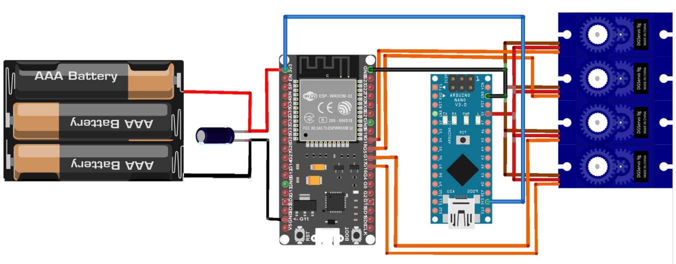

Fig. 6. Scheme for how each individual part of the project is connected

This project brings a robotic arm to life, controlled by a custom smartphone app. An ESP32 microcontroller acts as the brain, translating your app commands into precise movements for the arm's servo motors. These motors mimic muscles, allowing smooth joint manipulation. A gripper attachment grants the arm an extra hand for grabbing and holding objects. The user-friendly app, built with MIT App Inventor, sends two-digit codes to the ESP32. The first digit tells it which button you pressed (and its corresponding movement), while the second acts like an on/off switch for the movement. The ESP32 interprets these codes and sends control signals to the servo motors, making the arm move with impressive accuracy. This project exemplifies the power of combining readily available hardware with custom software for a truly interactive and precisely controlled robotic arm.

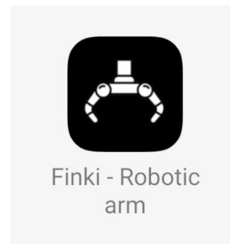

Fig. 7. Phone app logo

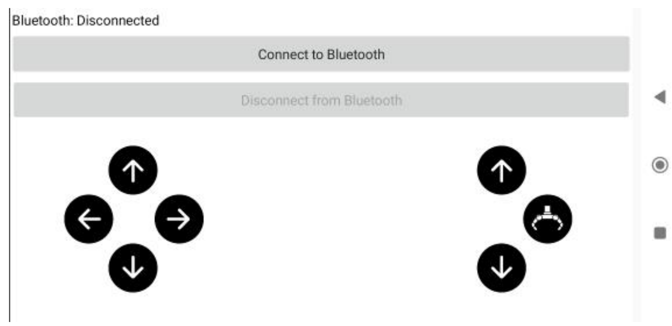

Fig. 8. The phone application interface

The ESP32 deciphers your commands from the smartphone app, accurately directs the servo motors for precise arm movements, and controls the gripper's actions. It's the brain of this meticulously controlled robotic system. We've crafted a compact and adaptable design using a solderable PCB breadboard. This not only creates a visually elegant and integrated unit but also allows for easy replacement of the ESP32 microcontroller for future projects. At its core, this project showcases the potential unleashed by combining accessible hardware with custom software. The user-friendly smartphone app and Bluetooth communication seamlessly link your commands to the ESP32's processing power, enabling the robotic arm to execute them with remarkable precision. It's ready to respond to your every instruction. [9].

IV. Future improvements

Building an improved robot:

To optimize our robotic arm's power supply for future growth, we propose the following improvements:

- **Upgrade to Li-ion Battery Pack:** Replacing the AA batteries with a Lithium-ion battery pack offers a significant advantage. Li-ion batteries boast a higher voltage (around 3.7V per cell) and substantially greater current capacity, ensuring adequate power for both the ESP32 and the servo motors.

- **Consolidate Microcontrollers:** Further exploration of the ESP32's capabilities is recommended. If the ESP32 can effectively manage both Bluetooth communication and servo control, the need for a separate Arduino Nano can be eliminated.
- **Implement a Robust Voltage Regulator:** Replacing the current step-up modules with a more robust voltage regulator is crucial. Selecting a regulator with a higher current output rating will guarantee sufficient power delivery for all components.
- Upgrade Servo Motors for Increased Capacity: As we envision our robotic arm handling greater payloads, consideration should be given to incorporating higher-torque servo motors. These motors will require a more robust power supply, further emphasizing the need for the aforementioned upgrades.

These improvements create a streamlined power system for the robotic arm, ensuring smooth operation and future expansion without power limitations.

V. Source code

```
#include "BluetoothSerial.h"
#include <ESP32Servo.h>

// init Class:
BluetoothSerial ESP_BT;

// Parameters for Bluetooth interface
int incoming;

byte verticalServoPin = 26;
byte horizontalServoPin = 33;
byte gripperPin = 32;
byte rotationalServoPin = 25;


Servo verticalServo;
Servo horizontalServo;
Servo gripperServo;
Servo rotationalServo;


int i=0; //for rotational
int j=0; //for vertical
int g=180; //for horizontal
bool gripperState = false;
void setup() {
  Serial.begin(9600);
  ESP_BT.begin("Finki - Robotic arm");
  pinMode(verticalServoPin, OUTPUT);
  verticalServo.attach(verticalServoPin);

  pinMode(horizontalServoPin ,OUTPUT);
  horizontalServo.attach(horizontalServoPin);

  pinMode(gripperPin, OUTPUT);
  gripperServo.attach(gripperPin);

  pinMode(rotationalServoPin, OUTPUT);
  rotationalServo.attach(rotationalServoPin);
}

void loop() {

  // -------------------- Receive Bluetooth signal ----------------------
  if (ESP_BT.available())
  {
    incoming = ESP_BT.read(); //Read what we receive

    // separate button ID from button value -> button ID is 10, 20, 30, etc, value is 1 or 0
    int button = floor(incoming / 10);
    int value = incoming % 10;
    delay(50);
    switch (button) {
      case 1:
        Serial.print("Left");
        if(i!=180)rotationalServo.write(i+=10);
        break;
      case 2:
        Serial.print("Right");
        if(i!=50)rotationalServo.write(i-=10);
        break;
      case 3:
        Serial.print("Up");
        if(j!=0)verticalServo.write(j-=10);
        break;
      case 4:
        Serial.println("Down");
        if(j!=180)verticalServo.write(j+=10);
        break;
      case 5:
        Serial.println("Gripper");
        if(gripperState == false){
          gripperServo.write(180);
          gripperState = true;
          Serial.println("False");
        }
        else {
          gripperServo.write(160);
          gripperState = false;
          Serial.println("True");
        }
        break;
      case 6:
        Serial.println("Forward");
        horizontalServo.write(g+=10);
        break;
      case 7:
        Serial.println("Backward");
        horizontalServo.write(g-=10);
        break;
    }
  }
}
```

Fig. 9. Source code of the project

VI. Closing thoughts

Robotic arms are rapidly evolving from sci-fi fantasy to ubiquitous tools shaping our world. Their precision and expanding capabilities are transforming industries, pushing healthcare boundaries, and influencing daily life. This revolution is in its early stages, but the potential is undeniable. Imagine a future where robotic arms assist in delicate surgeries, aid rehabilitation, or explore hazardous environments. Personalized automation in homes and advanced, precise manufacturing are just glimpses into the possibilities. However, challenges like ethical considerations surrounding automation and workforce adaptation require careful attention. Advancements in AI and machine learning will be key to unlocking the full potential of these intelligent and adaptable robotic assistants. As we delve deeper into this technological revolution, the future collaboration between humans and robots becomes increasingly clear. Robotic arms are not here to replace us, but to evolve alongside us, shaping a future defined by progress, innovation, and a world transformed by their unwavering precision. [10].

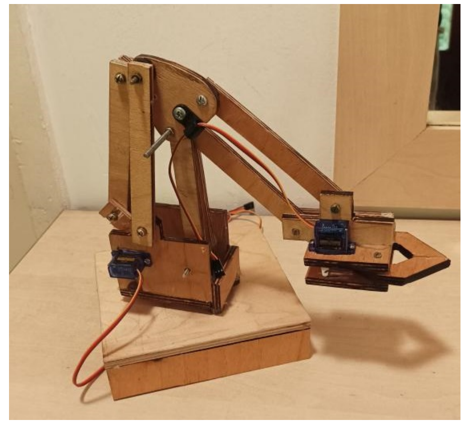

Fig. 10. The final project look

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