Design of Six DOF Watering Robotic Arm

Junfeng Yuan
School of Engineering, University of Glasgow, Glasgow, UK
Yjf1121995443@outlook.com

Abstract. As an important automation device, the mechanical arm plays a pivotal role in enhancing efficiency and precision across various industries, including industrial production lines, medical surgeries, and service robot applications. Recognizing its versatility and significance, this study will work on design a robotic arm system. This research encompasses a holistic approach, addressing both the mechanical and electronic aspects of the mechanical arm system. Beginning with the mechanical design phase, advanced Computer-Aided Design (CAD) software is employed for meticulous modeling and simulation. This phase is crucial for ensuring the structural integrity, stability, and movement flexibility of the mechanical arm, thereby laying a solid foundation for subsequent stages. In parallel, the circuit control design aspect of the study is meticulously planned and executed. By designing the layout of Printed Circuit Boards (PCBs) with precision, we aim to optimize the integration of electronic components for seamless functionality. The adoption of Arduino microcontroller technology further enhances our ability to precisely control the movement and operation of the mechanical arm. Through the integration of mechanical and electronic design considerations, our aim is to develop a reliable and efficient robotic arm system capable of autonomously completing the flower-watering task with precision and accuracy. By leveraging cutting-edge technologies and innovative design principles, we aspire to contribute to the advancement of automation technology, with practical implications spanning diverse industries and applications.

Keywords: Robotic arm, modeling of robotic arm, control system.

1. Introduction

In recent years, robotics has made remarkable progress, and its application has completely changed all industries. In these advances, the development of the robotic arm became an important innovation. These robotic arms mimic the function and flexibility of the human arm, allowing it to perform a variety of tasks accurately and efficiently. The introduction of robotic arms has significantly transformed fields such as industrial automation, medical surgery, and service robotics. In industrial environments, robotic arms optimize manufacturing processes by performing repetitive tasks with high precision and at high speed. They have become indispensable to complex operations such as assembly lines, material handling, and welding and painting. In the medical field, the robotic arm has revolutionized the surgical procedure, providing surgeons with greater precision and control capabilities. In addition, the robotic arm is not only used in traditional industries, but also into agriculture, logistics and home services. From harvesting crops to packaging goods to the aid of domestic work, these multifunctional machines are redefining how industries work. However, the efficacy and performance of the robotic arm depend not only on its mechanical design, but also on the complexity of its circuitry and control system. The synergy between mechanical and electrical engineering is essential to develop robust, efficient, and adaptable robotic arm systems that can meet the needs of modern applications.

The robotic arm is a set of objects connected by a rigidity, capable of taking different configurations and moving between these configurations under prescribed speed and acceleration limits [2]. Figure 1 is shown the components of a robotic arm, which often used in repetitive industrial production and in deep water or radioactive contaminated areas inaccessible to humans. It has been suggested that the imitation of human arm movement is achieved by having a motor equipped with a control unit [3].

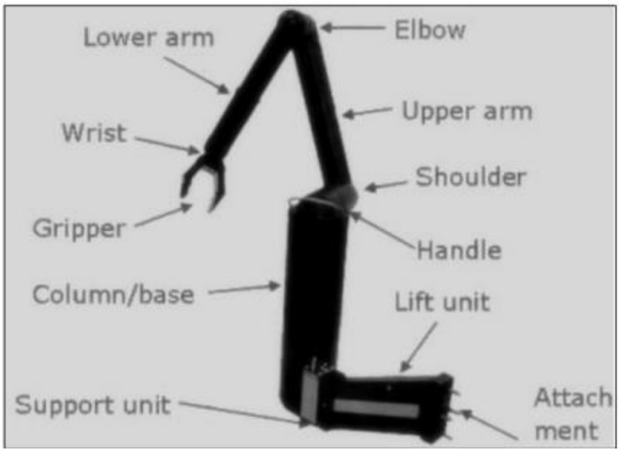

Fig. 1 A robotic arm with labels [1]

A mobile robot with picking and placing operation functions can be controlled by a wireless PS2 controller. The development of the robot is based on the Arduino Mega platform [4], it can move forward, draw back, turn right, and turn left for specific distances according to the controller specification, which will be connected to the wireless controller to a mobile robotic arm to analyze the speed, distance, lifting load, understand its performance, and then optimize it.

About the range of motion of the robotic arm and the flexibility of the joints, the behavior of physical systems in many cases can be better represented by analytical models. Modeling and analysis of the robot essentially involves its kinematics. For a manipulator with a high degree of freedom (DOF) on one or more joints. The analytical solution of the inverse kinematics is probably the most important topic in robot modeling, can making it possible to control the manipulator in an unstructured environment to achieve any reachable position and orientation [5].

There are also some robotic arm control methods using natural dynamics [6]. The method involves the use of a compliant arm whose joints are controlled by a simple nonlinear oscillator. With special actuators that enable it to resist collisions and achieve smooth, compliant motion. The oscillator produces rhythmic commands for the arm joints, and feedback from joint motion is used to modify the behavior of the oscillator. The oscillator is able to exploit the resonance properties of the arm to perform a variety of rhythmic and discrete tasks.

In production applications, some people have made attempts in the design and development of mechanical arms in agricultural applications [7]. The manipulator is controlled using a depth sensor, and an inverse kinematics algorithm was used to define the motion of the manipulator. With the appropriate microcontroller board, the robotic arm end actuator moves to the desired position and can be used for picking fruit or pruning branches, etc.

In this context, by studying the integration of mechanical and electrical components, we understand the key factors affecting the performance, reliability and versatility of robotic arm systems, and in this paper we develop a kinematic model of 6 degrees of freedom. The model attempts to complete the task of watering in the designated area by installing the motor at each joint, plus the Arduino system already designed. That is, use the mechanical arm to complete the repeated work in industrial production, and explore the challenges of the mechanical arm in terms of human-computer interaction, safety and cost. The experimental results show that the manipulator system has good motor performance and stability, and can complete the watering task well.

2. Method

This article will describe the design of the robotic arm and how the control can be realized by Arduino, including Circuit Design and PCB Layout, in order to achieve the purpose of watering the flower in the fixed area, including the degree of freedom of the robotic arm, the materials, and the selection of the components. It is very important to determine the size of the mechanical arm and the size of the range of motion, which is a very important data when setting up the Arduino program, which can help us to complete the goal of sending the nozzle to the designated position through the mechanical arm.

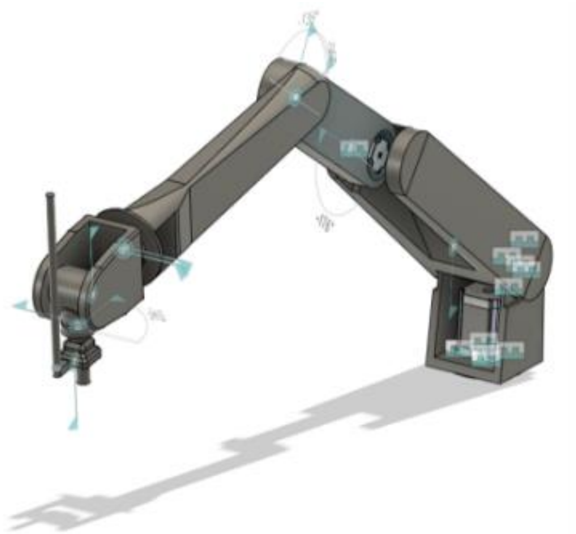

Fig. 2 Design of robotic arm (Photo credited: Original)

2.1. Working Principle of the Robot

The soil moisture sensors which are inserted in the pots will send the signal requiring watering to the Arduino board in the base of the robot. Then the plant-watering robot equipped with an infrared distance measurement sensor will determine the pots' position. Then the robotic arm will gradually extend until reaches the pot. Upon completion of a watering process, the robot will return to its original position.

2.2. Overall Design

The overall design of the manipulator arm in this article is shown in Figure 2. This diagram shows the way where the mechanical arm joint and the motor are located and all the mechanical components are connected. The design consists of six stepping motors, which means it has six degrees of freedom (DOF). Each motor was independently controlled by the Arduino. The design of mechanical parts of robotic arms is an important and important process. The design of the mechanical parts of the mechanical arm requires the Fusion360 to complete the modeling.

To shape robotic arms, mechanical components must be based on how the motors carry their own weight and the weight of the objects involved. And to determine which material to choose to make the robot, how much and which motor to use, a rough calculation of the entire robot mass is needed. The volume of each part of the robotic arm, the volume of the elements connecting the

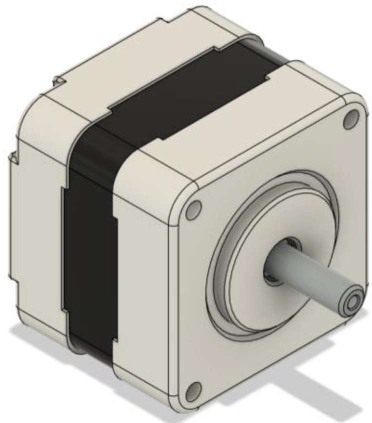

Fig. 3 NEMA 17 (Photo credited: Original)

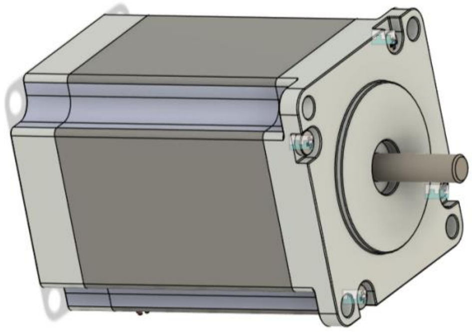

Fig. 4 NEMA 23 (Photo credited: Original)

robotic arm to the base. The weight of the sensors, the electronic dashboard, the motor, and other small components were ignored. In order to reduce the weight, we choose engineering plastics as the main material of the robot. Some specific engineering plastics, such as polyamide (PA, nylon), polycarbonate (PC), polystyrene (PS), etc., have good wear resistance, impact resistance and processing performance, suitable for the manufacture of mechanical arm components. Fully unfolded lengths is between 1.1 and 1.2m, When there is no task it will folding automatically in order to reduce occupancy.

About the choose of the motor, this prototype robotic arm has 6 degrees of freedom. For the 6 joints, the waist, the shoulder, and the elbow, there were four NEMA 17 have been used for drive the robotic arm and two NEMA 23 at the support unit. Figure 3 and Table 1 clarify the characteristics of NEMA 17 stepper motors. Figure 4 and Table 1 clarify the characteristics of NEMA 23 stepper motors.

Table 1. NEMA 17 stepper motor and NEMA 23 stepper motor

NEMA 17		NEMA 23	
Weight	200-400g	Weight	600-1200g
Step Angle	1.8 degree 200steps/revolution	Step Angle	1.8 degree 200steps/revolution
Continuous Current	0.5 to 1.5 Amps	Continuous Current	1.5 to 3 Amps
Torque	30 - 70 N*cm		50-200 N*cm

The reason why we select the motors were chosen for their torque capabilities and precision control, ideal for manipulating the robotic arm. Sensor interface circuits incorporated analog-to-digital conversion and signal conditioning to translate sensor outputs into readable digital data for the Arduino micro controller. Motor control circuits were designed to regulate the speed and direction of NEMA motors, facilitating precise movement of the robotic arm.

2.3. PCB Layout

Figure 5 shows an optimized PCB layout to minimize signal interference, enhance signal integrity, and improve thermal management. Component placement was strategically planned to reduce signal path lengths and minimize electromagnetic interference. Ground and power planes were utilized to ensure stable power distribution and mitigate voltage fluctuations. Traces were carefully routed to minimize crosstalk and ensure efficient signal transmission between components.

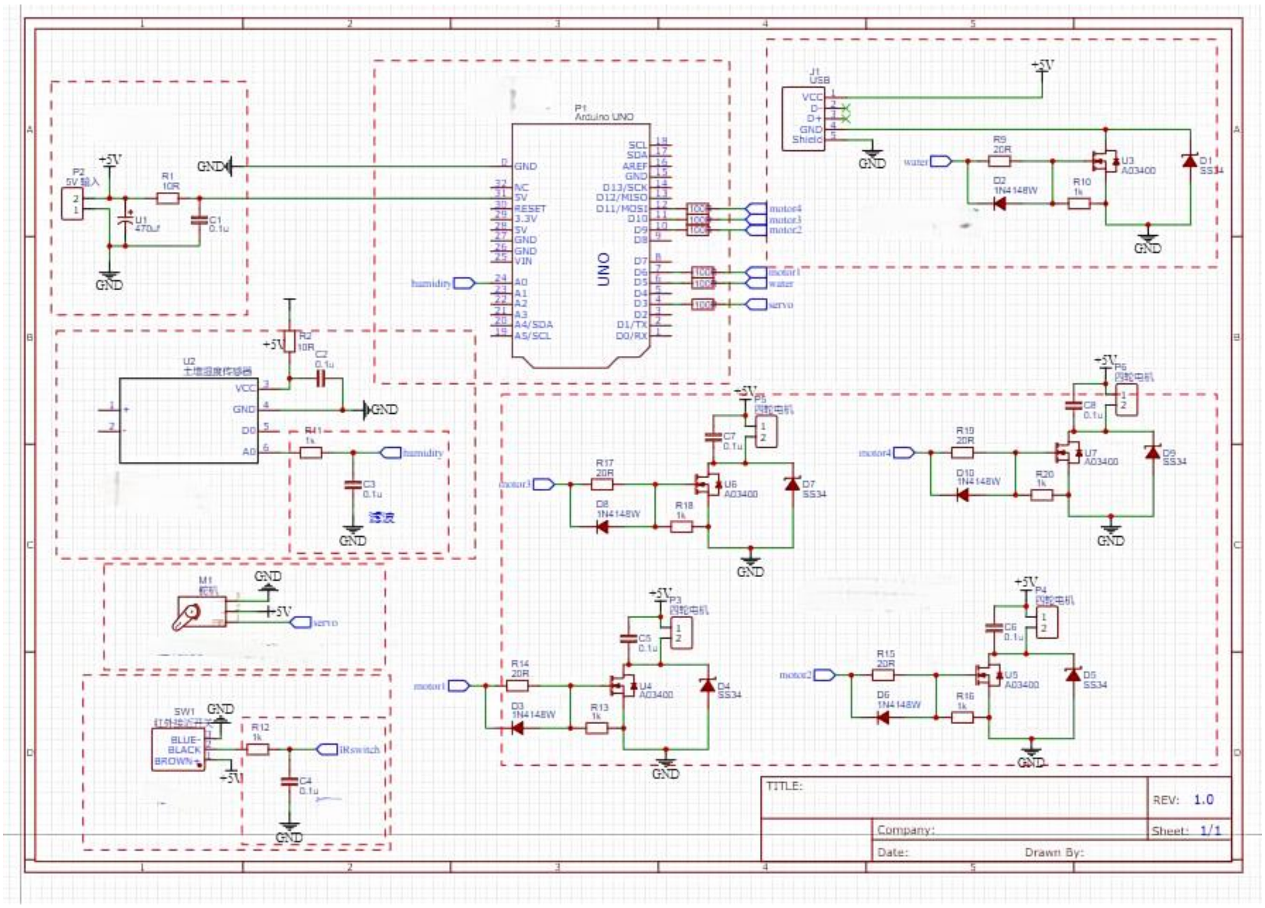

Fig. 5 The layout of the PCB part (Photo credited: Original)

The integration of specific motors, sensors, and Arduino microcontroller, along with the tailored circuit design and optimized PCB layout, culminated in the successful implementation of the automatic watering robot. This comprehensive approach not only ensured the functionality and reliability of the system but also laid the foundation for scalability and adaptability.

2.4. Arduino Microcontroller

The Arduino microcontroller served as the central processing unit for the automatic watering robot, facilitating sensor data acquisition and motor control. Its versatility allowed for seamless integration with various sensors and peripherals, enabling customization of watering schedules and response mechanisms based on real-time data inputs. The designed manipulator will be completely controlled by the Arduino system, so it is important to understand the programming aspects of the Arduino microcontroller and its workflow. The mechanical parts are the assembly parts of the mechanical arm, and the electronic parts are the configuration of the motor to manage the connection of the motor wire. The mechanical arm consists of six stepping motors, four of which are NEMA17 stepping motors, and the other two stepping motors are NEMA23, which connected to the body parts of the mechanical arm.

In this study, the Arduino system used the motor of the robotic arm to generate the corresponding movements. To make the configuration possible, it must be programmed. The programming of the robot needs to be precise to control each stepping motor and its associated motion. The successful implementation of automatic watering robots is finally achieved through the integration of specific motors, sensors and Arduino microcontrollers, as well as the customized circuit design and optimized PCB layout. According to the motor standard used in the system, all motors are directly connected to a 6.5V external power supply with a current rating of 2.5 Amps.

3. Discussion

First, we investigated the key factors and challenges in the robotic arm system design. The design of the robotic arm system involves many aspects, including the mechanical structure, transmission system, sensing device and control system. In the design process, various factors such

as range of motion, load capacity, accuracy requirements, and cost-effectiveness are weighed. These factors have helped us to complete the selection of mechanical arm materials and joint motors. In addition, the design of the circuit board and its control system of the robotic arm is also crucial, which determines the accuracy, speed and reaction time of the robotic arm, and needs to consider the stability and reliability. Second, our results highlight the importance of practical applications for robotic arm design. Although useful experience can be provided in simulation testing, challenges in the real environment may cause the actual effect of the design to not match expectations. Therefore, future studies will focus more on field testing and field validation to ensure the reliability and stability of the design.

On the other hand, our study identified several technical and economic challenges in robotic arm design. For example, some materials may be limited by weight, cost, or durability, and the selection and integration of electronic components may also be affected by the supply chain and costs. The development of robotic arm technology requires the joint efforts of many disciplines such as mechanical engineering, electrical engineering and computer science. Through interdisciplinary cooperation, we can better understand and solve the challenges facing the robotic arm technology, driving its wide application and sustainable development in various fields. Therefore, trade-offs need to be made in the design process, and the best solution is sought.

Furthermore, our study provides some ideas for future research directions. Future studies can further explore the autonomous learning and intelligent control of the robotic arm system to improve the adaptability and intelligence level of the system. Furthermore, the collaboration and interaction between the robotic arm system and the human operators or other robots can also be considered to expand the application of the robotic arm in complex environments. In conclusion, by providing an in-depth discussion of the significance, limitations and future directions of the findings, we can better understand the challenges and potential of robotic arm technology.

4. Conclusion

Overall, our research on robotic arm design and its associated circuit control provides some insight into the complexity of modern robotics. Through a comprehensive exploration of design principles, technological innovations and practical applications, we reveal the key factors affecting the performance, reliability and versatility of the robotic arm system.

Secondly, Our study highlights the importance of interdisciplinary collaboration in driving the development of robotic arm technology. the design of the arm system and circuit control design are the key to realize the function and performance of the arm. Innovation and integration of mechanical design, sensor technology, control algorithm and other aspects are crucial to improve the movement accuracy, stability and adaptability of the robotic arm system. In the design process, various factors, such as mechanical structure, electrical circuit, sensor configuration and control strategy, are needed to ensure that the robotic arm system can meet the requirements of various application scenarios. By integrating knowledge in the fields of mechanical engineering, electrical engineering, and computer science, we can develop robust, efficient, and adaptable robotic arm systems that can meet the needs of various applications.

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