Project Research:

Stair-Climbing Robot

Department of Mechanical Engineering, Systems Division

Advisor: Prof. Tsai, Shyi-Jeng

Author: Chao Po-Ju Lo-Ping

Date: 2024.01.16

I. Abstract

The goal of this semester's project was to design a Bluetooth-controlled vehicle capable of climbing indoor stairs with a step height of **8 cm**. To realize this concept, we applied **3D printing** and **laser cutting** technologies.

The robotic arms were modeled in **Autodesk Inventor**, exported as CAD files, and then sliced in **Cura** before being fabricated using a 3D printer. The chassis was designed in **AutoCAD** as 2D drawings and manufactured using a laser cutter.

The purpose of this project was to integrate **mechanical analysis and control of vehicle dynamics** with **3D printing technology** in order to develop a remote-controlled vehicle capable of stair climbing.

II. System Design

The vehicle consists of **two front arms, two rear arms, and a central idler wheel**. The motion process is illustrated in **Figure 1**. The green components indicate **MG996 servo motors**, while all wheels except the central idler wheel are equipped with **DC TT motors**. In total, the system integrates **five servo motors** and **four DC motors**.

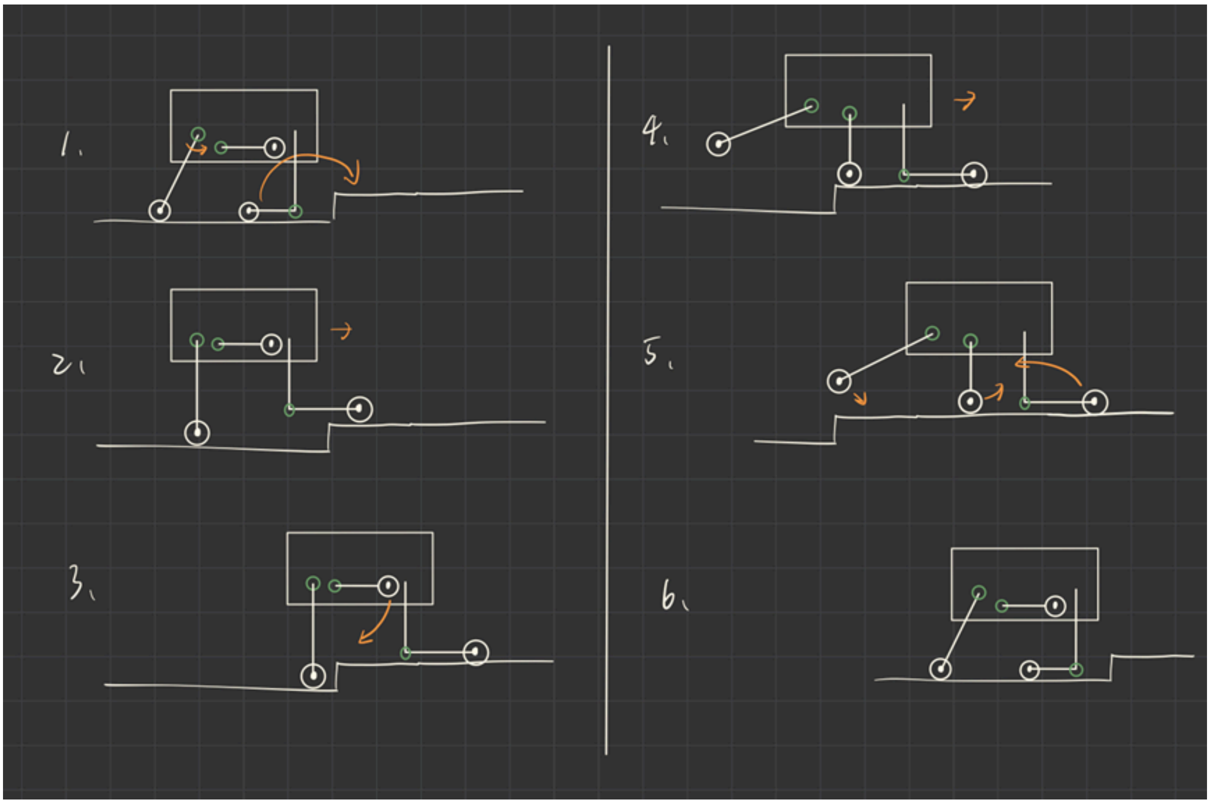


Figure 1. Side View of Vehicle Operation Process

The operation steps are as follows:

1. When the vehicle reaches the stair, the front arms rotate forward by **180°** to climb the step, while the rear arms rotate toward the body until fully extended.

2. All four wheels drive forward until the rear wheels reach the base of the stair.

3. The central wheel is deployed.

4. The rear arms are lifted upward beyond the stair height. The front wheels then drive the entire vehicle forward until the rear wheels pass over the stair.

5. The rear wheels are lowered back to the ground, the central wheel is retracted, and the front arms rotate backward by **180°** to return to their original position.

6. The vehicle continues moving forward until it encounters the next stair.

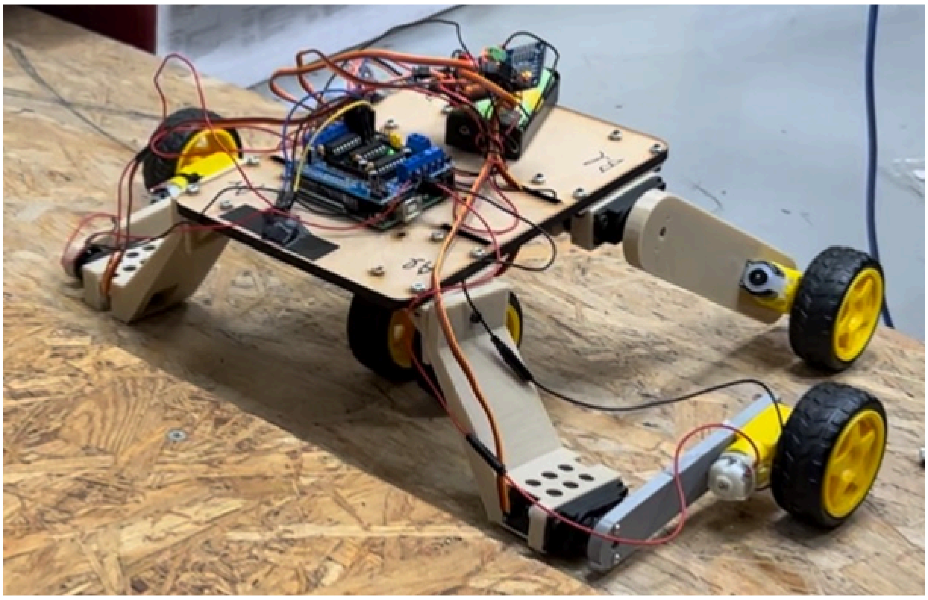


Figure 2. Final Vehicle Prototype

III. Detailed Mechanical Structure

1. Front Arms

The front arms are mounted on both the left and right sides of the vehicle. Each arm consists of three main parts:

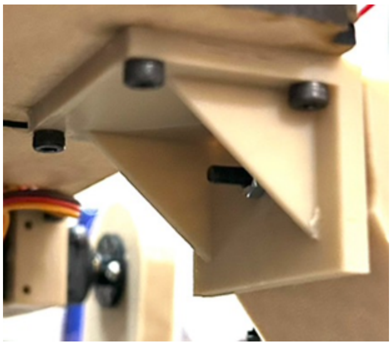
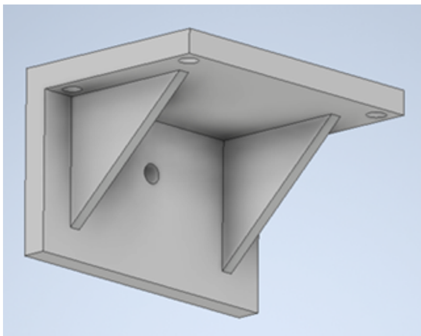
 

Figure 3. Joint between Front Arm and Chassis & CAD Model

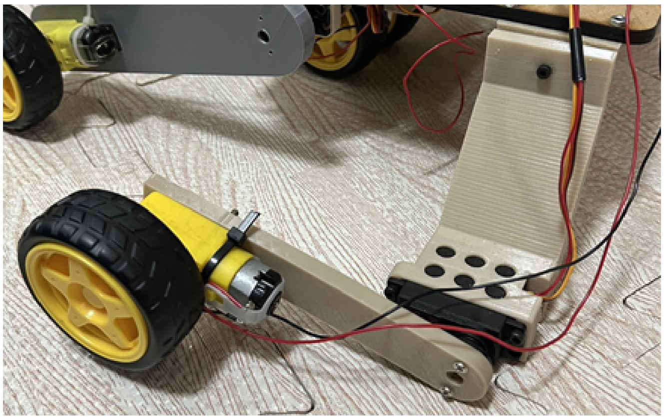


Figure 4. Front Arm 1 and Front Arm 2

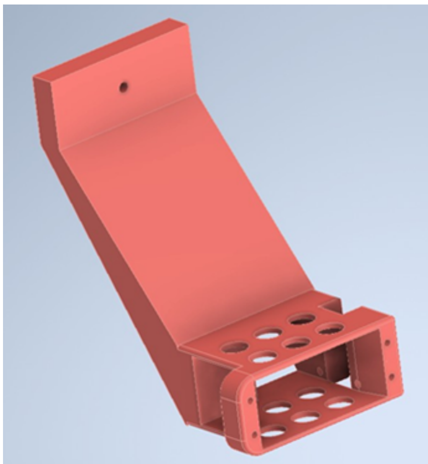
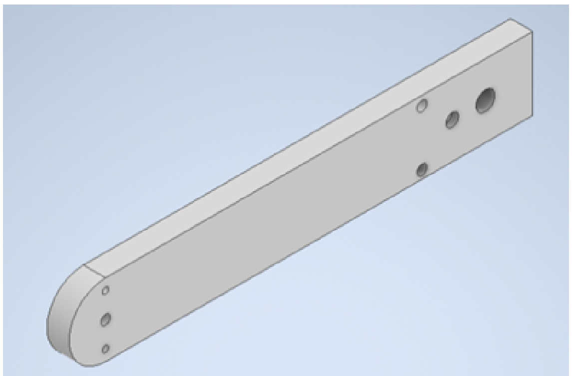
 

Figure 5. CAD Model of Joint between Front Arm and Chassis

2. Rear Arms

The rear arms are also mounted symmetrically on both sides of the vehicle. Each rear arm includes two parts:

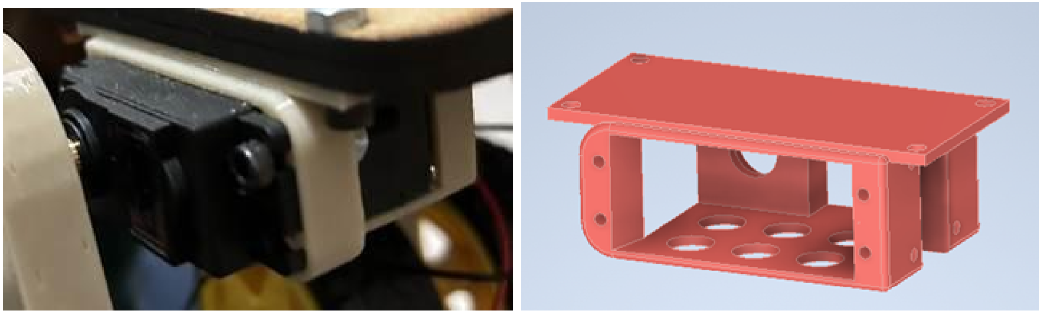


Figure 6. Servo Motor Mount & CAD Model

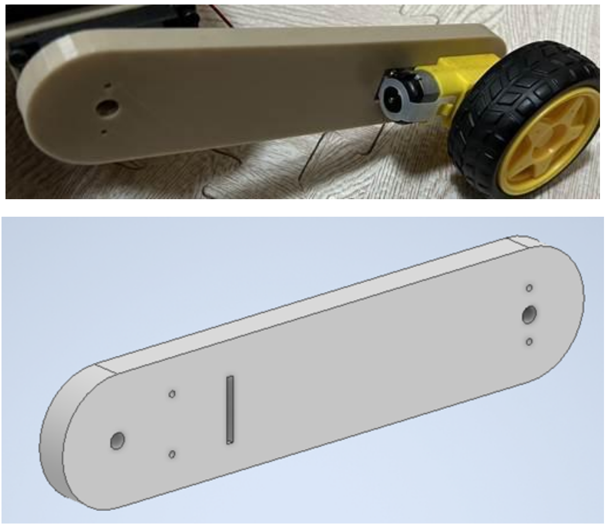


Figure 7. Rear Arm & CAD Model

3. Middle Arm

The middle arm assembly includes two parts:

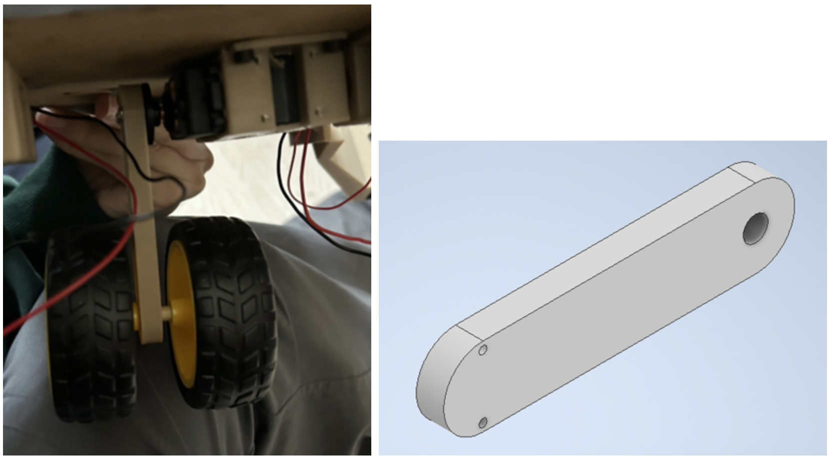
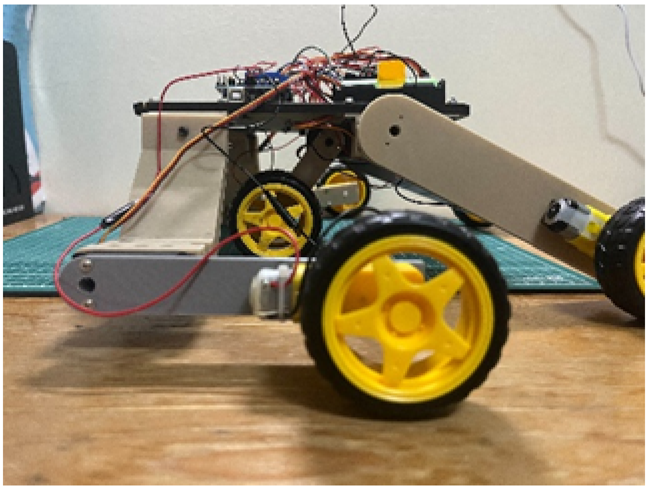


Figure 8. Middle Arm Assembly

4. Design Issues and Discussion

In the initial design of the front arms, the joint shown in *Figure 3* was designed as a **free-moving hinge**. However, testing revealed that this caused the vehicle's center of mass to be concentrated on the front-arm servo motors. This generated excessive normal force against the ground, resulting in high friction and making it difficult for the wheels to drive the vehicle forward.



To resolve this issue, the hinge joint was replaced with a **fixed screw connection**, which improved stability. However, for a more complete redesign, **Front Arm 1 should be directly integrated into the chassis** as a fixed component to eliminate unnecessary load on the servo motor.

IV. Vehicle Control

1. Control Board and Motor Drivers

For this project, an **Arduino UNO board** was used as the primary controller for managing I/O operations across the system. Two types of motors were utilized:

- **TT dual-shaft DC motors**, which drove the rubber wheels of the chassis.
- **MG996 servo motors**, which controlled the lifting and lowering of the robot arms.

Motor drivers included:

- A **16-channel PWM Servo Driver Board** for controlling the servo motors.
- An **L293D DC Motor Driver Expansion Board** for driving the TT DC motors.

2. Bluetooth Module and APP Inventor Application

Wireless communication was established using the **HC-05 Bluetooth module**, which connected to a smartphone. The control interface was developed using **MIT App Inventor**, enabling remote operation of the vehicle.

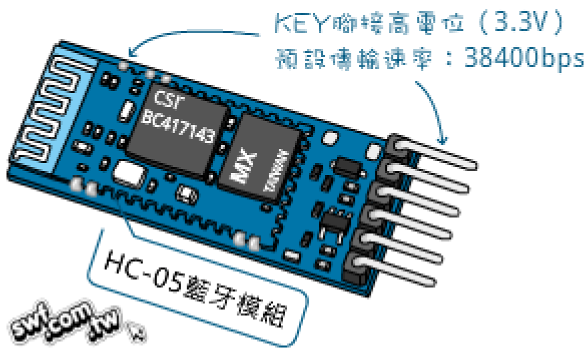


Figure9. HC-05 Bluetooth Module

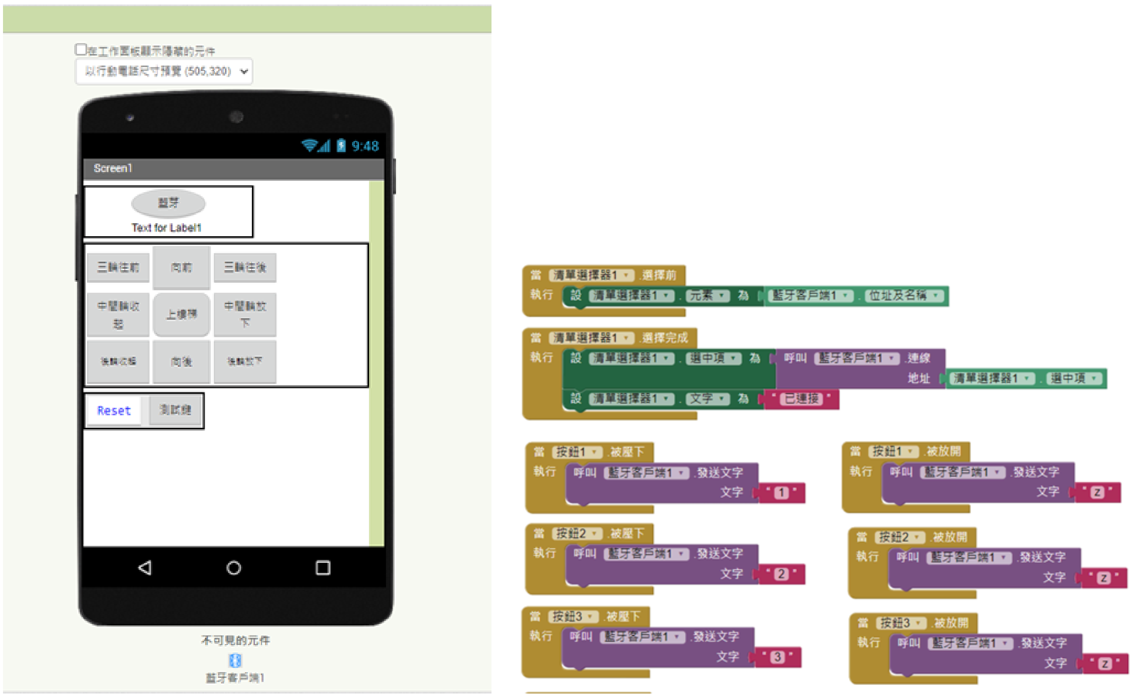


Figure10. APP Inventor Interface & Program

3. Program Control

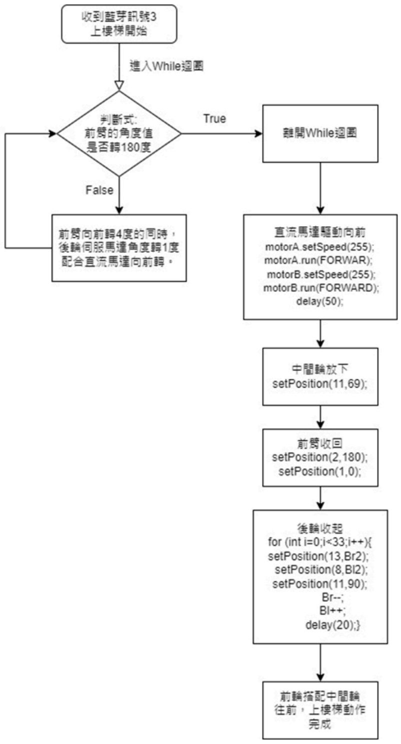
The overall control logic for stair-climbing was implemented as shown in the **flowchart**.

- The main logic executes different program blocks depending on the **signal (val)** received from the **BTSerial (Bluetooth) module**.

```
void loop() {
  if (BTSerial.available())
  {
    val = BTSerial.read();
    Serial.print(val);
    if (val == '1')//前進
    {
      motorA.setSpeed(255);
      motorA.run(FORWARD);
      motorB.setSpeed(255);
      motorB.run(FORWARD);
      BTSerial.print('1');
    }

    else if (val =='2')//後退
    {
      motorA.setSpeed(255);
      motorA.run(BACKWARD);
      motorB.setSpeed(255);
      motorB.run(BACKWARD);
      BTSerial.print('2');
    }

    else if(val == '3')//上樓梯
    {
      while(1){
         setPosition(2,Ar);
         setPosition(1,Al);
         motorB.setSpeed(150);
         motorB.run(FORWARD);
         setPosition(13,Br);
```



4. Issues and Discussion

No major problems were encountered in the programming process. However, a critical issue arose during motor driver testing. The **16-channel servo driver board** was inadvertently supplied with a voltage exceeding its specification. As a result, one of the servo motors overheated, **caught fire, and burned out**. Fortunately, no injuries occurred.

This incident highlighted the importance of carefully consulting the **datasheet** of any component before operation, as overlooking specifications can lead to dangerous outcomes.