3D printed Robot Dog Walking on Terrain for STEM education

Project Plan

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1. Project Background

Quadruple robots are defined as four-legged robots. Composed of a main body and control unit, it can not only walk as a quadrupled animal but also do decisions like a human.

In terms of the development history of robotics, the idea of “robot” has been created a century ago. In 1914, the world’s first programmable robot was created by American George Dewall [1]. It was used to replace workers doing welding in cars which was a dangerous job. Workers could have lost their fingers if they had careless mistakes. Therefore, it shows that robots are destined to assist humans in risky jobs.

A lot of inspiring and useful quadruple robots are developed from then on. For example, ANYmal C was developed by ANYbotics [2], and HyQ was produced by the Italian Institute of Technology [3]. These robots have proven that quadruple robots are an alternative or even better solution when traveling through terrains other than wheeled robots. [4]

This project uses Spot, a robot dog released by Boston Dynamics in 2019. Its transformative mobility automates routine inspection tasks more accurately [5]. For example, its junction between legs and bodies has 360° perceptions which stimulate quadrupled animals’ ankles and can provide flexibility when walking on terrains. There are other features that will be discussed in later chapters.

![Fig 1: Spot, a quadruple robot dog released by Boston Dynamics, serves as this project’s robot model](image-url)
2. Motivation to the study

At present, quadruple robots participate in various applications, such as inspection work, e.g., inspecting buildings for gas leakage; and delivery, e.g., transporting goods through paved roads [6]. Therefore, walking on terrains is the fundamental element for almost every application. However, it is still not an easy task. Most algorithms programmed to the robots are set to be adaptive to specific applications, or even a specific “road”. Unpredicted obstacles or miscalculations would cause robots to fall into errors. Therefore, it is an ongoing need to develop more comprehensive algorithms for robots to walk and climb efficiently.

Another importance of this project is related to STEM education development. As every child is a possible future engineer, this project includes mathematics (inverse kinematics calculations), hands-on experience (robot building with hardware tools), and computer programming (Arduino programming). This project would be used as a skeleton for creating related STEM teaching materials. Developing children’s interest in this topic would continue the optimization of robot dogs in the future.

3. Project Objectives

This project aims to improve the performance of 3D-printed robot dogs walking on uneven terrain. By implementing robot dog inverse kinematics, together with walking gait and self-balance algorithm, the robot dogs will be capable of walking across rocks and can climb up and down.

A mobile app will be developed to control the robot dog. And a set of STEM course materials will be constructed for this project.

In other words, the project deliverable includes:
- A fully functional robot dog that can walk on terrain
- Code on robot dog by Arduino programming
- An Android app as a controller for robot dog
- A set of courseware and teaching materials using this robot in STEM education
4. Project Methodology

4.1 Hardware Tools

4.1.1 MCU

MCU (microcontroller unit) can be viewed as a small computer on a single integrated circuit [7]. It contains one or more CPUs, program memory storage, and an input/output interface. It is widely used in embedded systems, for example, automobile control systems, and implantable medical devices.

In this project, MCU is used as the main control system of the robot dog. According to Figure 2, after receiving the input order, it will control the movement of servomotors that are connected to the robot dog legs. Different algorithms can also be stored in it and run with the help of MCU. Since MCU acts as a “brain” of the robot dog, it is the container of Arduino programs and the robot dog’s actions.

![Fig 2: MCU, a small computer which controls the movement of robot dog](image)

4.1.2 IMU

IMU (Inertia Measurement Unit) is a 9-axis sensor that measures velocity, orientation, and gravitational forces [8]. It detects rotational movement of the three-axis: Pitch, Roll, and Yaw, while the Accelerometer, Gyroscope and Magnetometer are inserted into it. The common models of IMU are MPU-9250 and MPU-6650.
In this project, the model used is MPU-9250 (see Figure 3). It can be used to detect the rotational movement of four robot dogs, and the data obtained will be used in inverse kinematics calculations.

![MPU-9250](image)

*Fig 3: MPU-9250, serves as IMU in this project*

4.2 Software Development
4.2.1 Arduino programming
Arduino code is based on C++, on top of that special methods and functions are added [9]. Arduino Integrated Development Environment (IDE) is used to write Arduino programs. It compiles the code and translates them to Arduino executable code.

4.2.2 Android app
An android app will be created for testing and debugging. It controls the start, overall movement of the robot, etc. It will connect to MCU by Bluetooth. The IDE to develop this Android app is Android Studio.

4.3 Inverse kinematics
Inverse kinematics is an opposite algorithm of forward kinematics. The input of it is the target position, then the inverse kinematics algorithm will calculate the pose or action required for the end effector (merely the position at the end of the robot dog’s legs) to arrive that target position [10]. Therefore, the output is the pose. This algorithm is applied to this project as the coordinates of robot logs are measured by servomotors, while the pose of dog’s legs to reach target position are unknown.
5. Project Schedule and Milestones

- September 2022
  - Project planning
  - 3D printing for components of robot dog

- October 2022
  - Deliverables of Phase 1 (2 Oct 2022)
    - Detailed Project Plan
    - Project Web Plan
  - Assemble robot dog
  - Study existing code and be familiar with Arduino programming

- November 2022 – December 2022
  - Implement walking gait and self-balancing algorithms
  - Develop an Android app for testing

- January 2023
  - First presentation (9 Jan 2023)
  - Deliverables of Phase 2 (22 Jan 2023)
    - Preliminary implementation
    - Detailed interim report

- February 2023
  - Implement enhancement: adding camera and perception work

- March 2023
  - Realize STEM education courseware and teaching materials

- April 2023
  - Final presentation (17 Apr 2023)
  - Deliverables of Phase 3 (18 Apr 2023)
    - Finalized tested implementation
    - Final Report

- May 2023
  - Project exhibition (3 May 2023)
6. Reference


