Mounting an arm on a Dogbot

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November 2024

Abstract: Quadrupedal animals have the ability to perform agile while accurate tasks: a trained dog can chase and catch a flying frisbee before it touches the ground; a cat alone at home can jump and grab the door handle accurately. However, agility and precision are usually a trade-off in robotics problems. Recent works in quadruped robots either focus on agile but not-so-accurate tasks, such as locomotion in challenging terrain, or accurate but not-so-fast tasks, such as using an additional manipulator to interact with objects. In this work, our goal is to design a robot dog capable of standing upright, freeing its front legs. We will mount a robotic arm on its front legs, enabling the robot dog to have grasping capabilities.

1 Introduction

Quadrupedal robots have gained significant attention in robotics research due to their ability to mimic the agility and mobility of animals such as dogs and cats. These robots have been used in various applications, including search and rescue, exploration, and tasks requiring high mobility on uneven terrains. However, traditional quadrupedal designs often prioritize either agility or precision, rarely achieving both simultaneously.

Inspired by the natural versatility of quadrupedal animals, this project aims to push the boundaries of what a quadrupedal robot can achieve. Specifically, we propose to design a robot dog capable of standing upright, thereby freeing its front legs for additional functionalities. By mounting a robotic arm on its front legs, the robot will be able to perform grasping and manipulation tasks, bridging the gap between agility and precision.

The motivation for this research stems from the increasing demand for multifunctional robots that can adapt to dynamic and unpredictable environments. A robot dog with the ability to switch between locomotion and manipulation tasks could play a crucial role in scenarios such as disaster recovery, where the robot needs both high mobility and the ability to interact with objects. Given the high cost and relatively cumbersome mobility of humanoid robots, this project explores the integration of robotic arms with quadrupedal systems to enhance the robot's capabilities and broaden its potential applications.

2 System Description

In this section, we provide a detailed description of the design and components of the robot dog system, with a focus on its mobility and grasping capabilities. The robot is built around a quadrupedal platform, which provides high agility and stability for locomotion. To enable the robot to perform both locomotion and manipulation tasks, we integrate a robotic arm onto its front legs. The system consists of several key components, including the robot's body structure, the actuators that control its movement, the robotic arm, and the sensors required for task execution. Each component is carefully designed to ensure seamless integration and optimal performance.

2.1 Robot Body and Mobility

Figure 1: Go2

The robot's body is designed to be lightweight yet robust, ensuring both mobility and durability. It features four actuated legs, each equipped with multiple degrees of freedom (DOF), enabling the robot to perform complex movements such as walking, running, and jumping. The legs are powered by high-torque actuators, which provide the necessary force for dynamic locomotion across various terrains, including uneven surfaces and small obstacles.

To maintain balance and stability during movement, the robot is equipped with a suite of sensors, including accelerometers, gyroscopes, and force sensors. These sensors provide real-time feedback to the control system, allowing the robot to adjust its posture and maintain equilibrium, even during dynamic actions such as jumping or standing upright. The integration of these sensors ensures that the robot can navigate challenging environments while remaining stable and agile.

2.2 Control System

The control system of the robot dog is divided into two main subsystems: locomotion and manipulation. Each subsystem is designed to operate independently while maintaining seamless communication to ensure coordinated task execution.

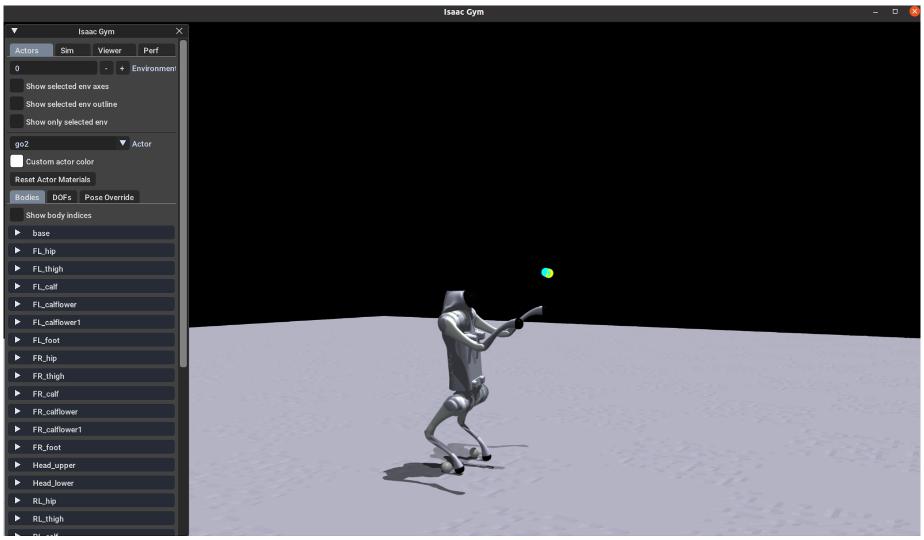


Figure 2: Gym

1. **Locomotion Control:** The locomotion subsystem is managed by a built-in computer that coordinates the movement of the robot's legs. This computer processes data from the onboard sensors and generates control signals for the actuators, enabling the robot to perform complex movements such as walking, running, and jumping. The locomotion control system also incorporates advanced algorithms for path planning and obstacle avoidance, ensuring smooth and efficient navigation in dynamic environments.
2. **Manipulation Control:** The manipulation subsystem is responsible for controlling the robotic arm. It consists of a microcontroller unit (MCU), which receives commands from the robot's main computer and translates them into precise control signals for the arm's servos. The MCU, an Arduino Nano, is responsible for parsing incoming signals and generating the pulse-width modulation (PWM) signals required to control the servos. Additionally, the system employs reinforcement learning algorithms to optimize the arm's movements, improving the accuracy and efficiency of manipulation tasks. The rotation sequence, angles, and timing of the robotic arm's joints are determined by these algorithms, ensuring precise and repeatable performance.

The integration of these two subsystems allows the robot to perform both locomotion and manipulation tasks simultaneously, making it a versatile platform for a wide range of applications.

```c
void ServoPwmDutyCompare(void)//脉宽变化比较及速度控制
{
    uint8 i;

    static uint16 ServoPwmDutyIncTimes; //需要递增的次数
    static bool ServoRunning = FALSE;   //舵机正在以指定速度运动到指定的脉宽对应的位置
    if(ServoPwmDutyHaveChange)//停止运动并且脉宽发生变化时才进行计算      ServoRunning == FALSE &&
    {
        ServoPwmDutyHaveChange = FALSE;
        ServoPwmDutyIncTimes = ServoTime/20;    //当每20ms调用一次ServoPwmDutyCompare()函数时用此句
        for(i=0;i<8;i++)
        {
            //if(ServoPwmDuty[i] != ServoPwmDutySet[i])
            {
                if(ServoPwmDutySet[i] > ServoPwmDuty[i])
                {
                    ServoPwmDutyInc[i] = ServoPwmDutySet[i] - ServoPwmDuty[i];
                    ServoPwmDutyInc[i] = -ServoPwmDutyInc[i];
                }
                else
                {
                    ServoPwmDutyInc[i] = ServoPwmDuty[i] - ServoPwmDutySet[i];

                }
                ServoPwmDutyInc[i] /= ServoPwmDutyIncTimes;//每次递增的脉宽
            }
        }
        ServoRunning = TRUE;    //舵机开始动作
    }
    if(ServoRunning)
    {
        ServoPwmDutyIncTimes--;
        for(i=0;i<8;i++)
        {
            if(ServoPwmDutyIncTimes == 0)
            {       //最后一次递增就直接将设定值赋给当前值

                ServoPwmDuty[i] = ServoPwmDutySet[i];

                ServoRunning = FALSE;   //到达设定位置，舵机停止运动
            }
            else
            {

                ServoPwmDuty[i] = ServoPwmDutySet[i] +
                    (signed short int)(ServoPwmDutyInc[i] * ServoPwmDutyIncTimes);

            }
        }

    }
}
```

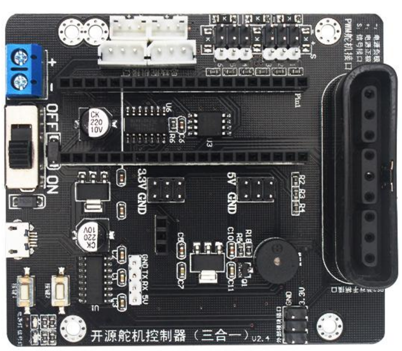
Figure 3: The primary control method for the robotic arm's servos.

2.3 Robotic Integration

Figure 4: Arm

A key feature of our design is the integration of a robotic arm onto the front legs of the robot dog. The arm is mounted in such a way that it can be used for grasping and manipulation without hindering the robot's ability to move. The arm consists of multiple joints and actuators, providing it with sufficient flexibility and dexterity to perform precise tasks, such as picking up small objects or interacting with tools. Each joint is powered by high-precision servos, which allow for fine-grained control over the arm's movements.

The arm is designed to be lightweight and compact, ensuring that it does not compromise the robot's overall agility. Despite its small size, the arm is capable of varying its orientation to accommodate different objects, enabling the robot to perform complex grasping and manipulation tasks in a variety of environments. The arm's design also includes a modular end-effector system, allowing for the attachment of different tools or grippers depending on the task at hand.



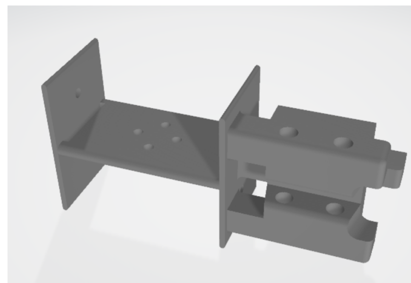
(a) Control Board

(b) MCU

Figure 5: Components of the Robotic Arm Control System

The servo control section of the robotic arm is composed of an MCU and a control board. The MCU, an Arduino Nano, is responsible for parsing signals and sending the PWM signals required to control the servos. The control board, on the other hand, is tasked with stabilizing the voltage and driving the servos. This dual-component design ensures reliable and precise control over the arm's movements, even during high-speed or high-precision tasks.

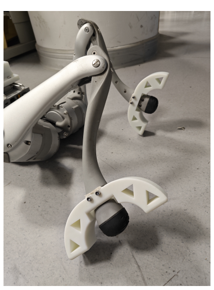
(a) foot-supporter



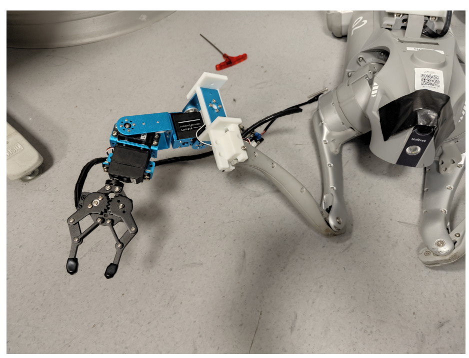
(b) arm-connector

Figure 6: The integration parts of foot and arm.

We have also designed a foot support for the robot dog to enable standing. This support is fabricated using 3D-printed components. The design of the foot support focuses on providing stability and balance while the robot is in an upright position. The 3D-printed structure is lightweight yet durable, ensuring that it does not add significant weight to the robot, which could otherwise hinder its mobility. The foot support is carefully integrated with the robot's legs to ensure seamless transition between locomotion and standing modes. This design allows the robot to maintain an upright posture, freeing its front legs for manipulation tasks while ensuring overall stability.



(a) The foot and supporters for robot dog.



(b) arm-on-robot

Figure 7: The robotic arm installed on the robot dog.

2.4 Power and Communication Systems

To support the robot's mobility and manipulation capabilities, the system is equipped with a robust power and communication infrastructure. The robot is powered by a high-capacity lithium-polymer (LiPo) battery, which provides sufficient energy for extended operation. The battery is connected to a power management system that distributes power to the actuators, sensors, and control electronics, ensuring stable and efficient operation.

Communication between the robot's subsystems is facilitated by a combination of wired and wireless interfaces. The built-in computer communicates with the MCU and sensors via a high-speed serial interface, while wireless communication is used for remote control and data transmission. This dual-communication approach ensures real-time responsiveness and flexibility in controlling the robot.

3 Conclusions

In this project, we aim to design and build a robot dog capable of both agile locomotion and precise manipulation by integrating a robotic arm onto its front legs. We have outlined the key components of the system, including the robot's mobility platform, the arm's functionality, and the control system that integrates both capabilities. Through simple evaluation methods, we will test the robot's performance in locomotion, grasping, and task execution, both in simulation and real-world environments.

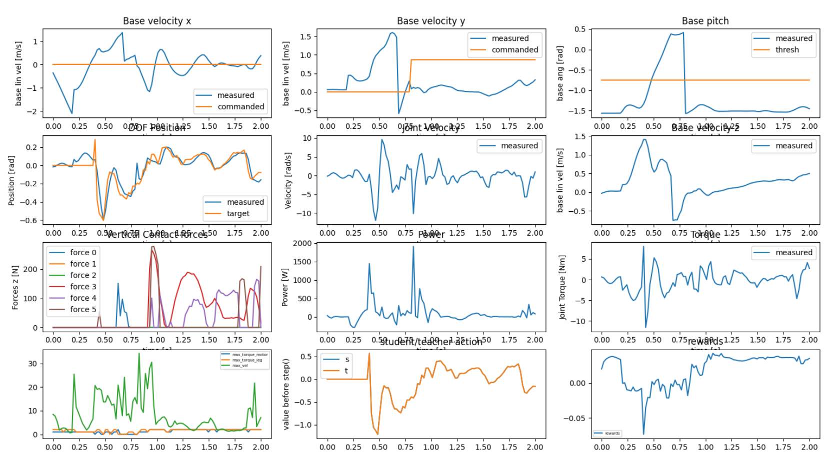


Figure 8: Training Results in Simulation Environment

As shown in Figure 8, we present the training results of the robot dog in a simulated environment. The Figure 8 illustrates the base velocity, joint velocities, forces experienced, and the rewards obtained during training. These metrics provide insights into the robot's performance while walking upright.

The results indicate that while the robot dog has successfully achieved upright walking, there are several areas for improvement. Specifically, the robot struggles to control its velocity effectively, as evidenced by the irregular fluctuations in the base velocity. Additionally, the forces acting on the robot exhibit non-smooth variations, suggesting that the current control strategy is not yet optimized for stable and efficient movement. Furthermore, the policy learned during training is insufficient to consistently guide the robot toward the target point, indicating a need for further refinement.

Our next steps will focus on optimizing the robot's control strategy to address these issues. Key areas of improvement include enhancing the smoothness of force transitions, improving velocity control, and refining the policy to ensure stable and precise movement toward the target. By addressing these challenges, we aim to achieve more robust and reliable performance in both simulated and real-world environments.