ECE 445: Senior Design Laboratory
Project Proposal

Design and Control of a Fetching Quadruped

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Introduction

1.1 Problem Statement

There are various commercially available robotic dog platforms, yet no “fetching” skill is shown. One reason is the lack of integration of a manipulator with the dog. To be compatible with the robot dog, the robot arm needs to be lightweight, accurate, and robust. The integrated system will be able to perform simple tasks such as fetching, with the help of visual feedback. Such a manipulator requires a new design, good coordination of its components, along with a dedicated controller.

1.2 Solution Overview

We aim to create an integrated robotic system by combining a robot dog with a custom-built manipulator arm. This system is designed to enable object fetching through the use of visual recognition algorithms, ensuring precise grasping capability. In addition, we intend to develop a lightweight, accurate, and robust robotic arm that is compatible with existing commercial robot dog platforms, while achieving coordinated control between the robot dog and the mounted arm. This approach will effectively bridge the gap in commercial platforms that currently lack manipulation abilities.

1.3 Hight-level Requirements

To meet these objectives, the system must satisfy several high-level requirements. The robotic arm should be lightweight enough to be mounted on the robot dog without compromising its 6-DoF functionality, while keeping the total cost under 1500 RMB. Moreover, the system must successfully identify and track target objects using visual feedback. Finally, the integrated system must ensure that the movements of both the robot dog and the arm are well coordinated to achieve accurate object grasping.

Design

2.1 Block Diagram

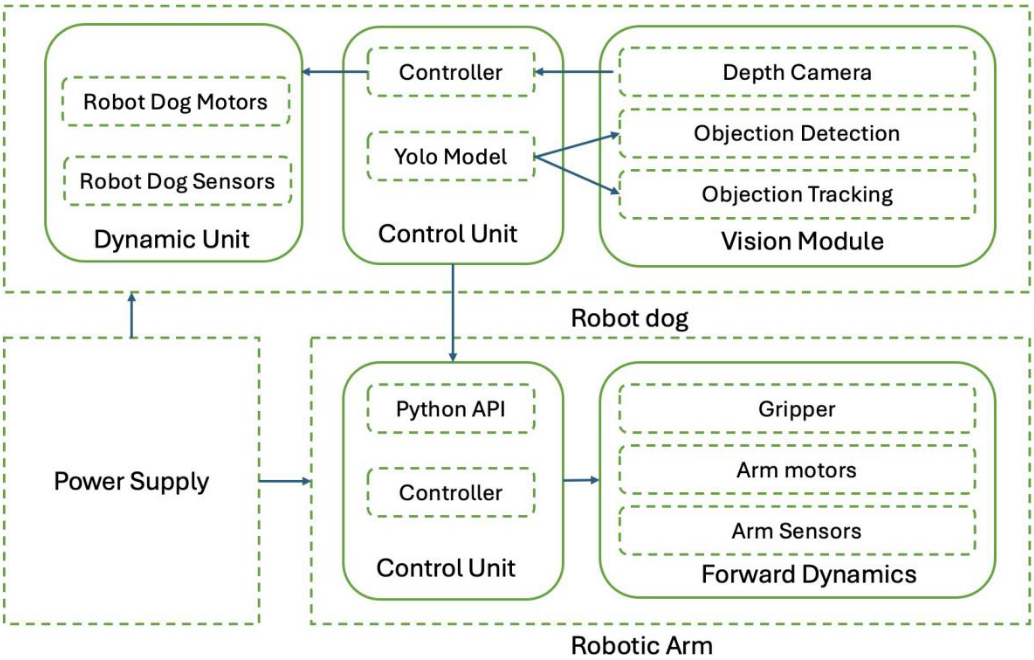

Figure 1. Block Diagram

2.2 Robot Dog

2.2.1 Dynamic Unit

The dynamic unit of the robot dog is provided with the commercial robot dog by Unitree. The robot dog motors drive its legs to enable walking, turning, and other locomotion tasks using brushless motors and dedicated drivers, which must supply sufficient torque and fast response to ensure stable movement on flat ground. Additionally, the robot dog is equipped with sensors—including an Inertial Measurement Unit (IMU), force sensors, and encoders—that gather information on the robot's pose, joint angles, and contact forces. These sensors are required to have high sampling rates and low noise to offer real-time motion control and accurate state estimation.

2.2.2 Control Unit

The Controller serves as the primary control and processing unit for the robot dog, processing data from the Vision Module and built-in sensors before executing motion control algorithms. It requires real-time computing power to perform data processing and maintain high-frequency control. Meanwhile, the Yolo Model acts as the embedded visual AI for object detection, running locally and interfacing with the Vision Module. It must strike a balance between detection accuracy and speed.

2.2.3 Vision Module

The Depth Camera captures RGBD images of the environment to provide essential 3D information, and it must deliver valid images under varying lighting conditions while ensuring accurate depth measurements within a 3-meter range. In addition, the Object Detection module employs YOLO or similar models to identify objects within the camera feed, requiring high frame rates for real-time operation and maintaining high detection accuracy. Furthermore, the Object Tracking system continuously monitors detected objects by calculating their trajectory, velocity, and position for effective motion planning, and it must remain robust against target loss while ensuring real-time tracking during movement.

2.3 Robotic Arm

2.3.1 Overview

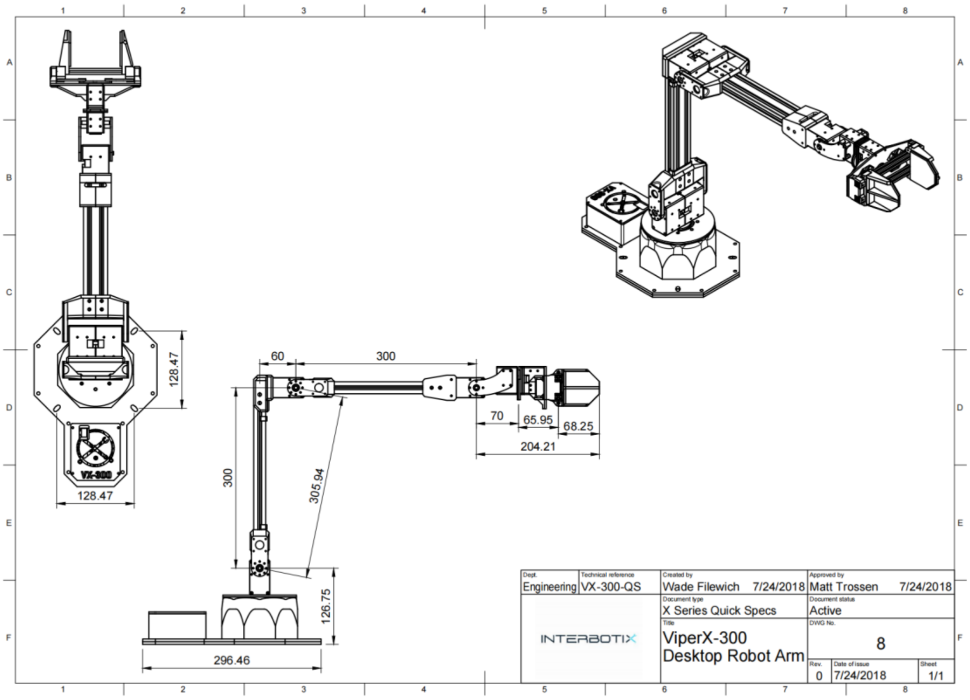

Figure 2. Overview of the Robotic Arm

The design of the robotic arm [4] to ensure that it can hold objects below its own height effectively. We intend to modify the base design of the ViperX-300 from Trossen Robotics and adjust the lengths of each arm accordingly. In the manufacture of arm in the matter, we plan to use 3d printing technology to finish. ABS (styrene acrylonitrile butadiene) will be used as robotic arm manufacturing materials, it is because the ABS material has many advantages, such as high hardness, excellent fatigue resistance, low cost, low density, and ease of processing, which makes the structural design necessary for a robotic arm is relatively fast.

2.3.2 Control Unit

The RoboMaster Development Board Type A [3] serves as the main controller, featuring an STM32F427IIH6 processor and dedicated 16 PWM output interfaces (Label 8) that enable direct motor control without the need for an external motor driver. It outputs three PWM signals per motor for direct three-phase brushless motor control

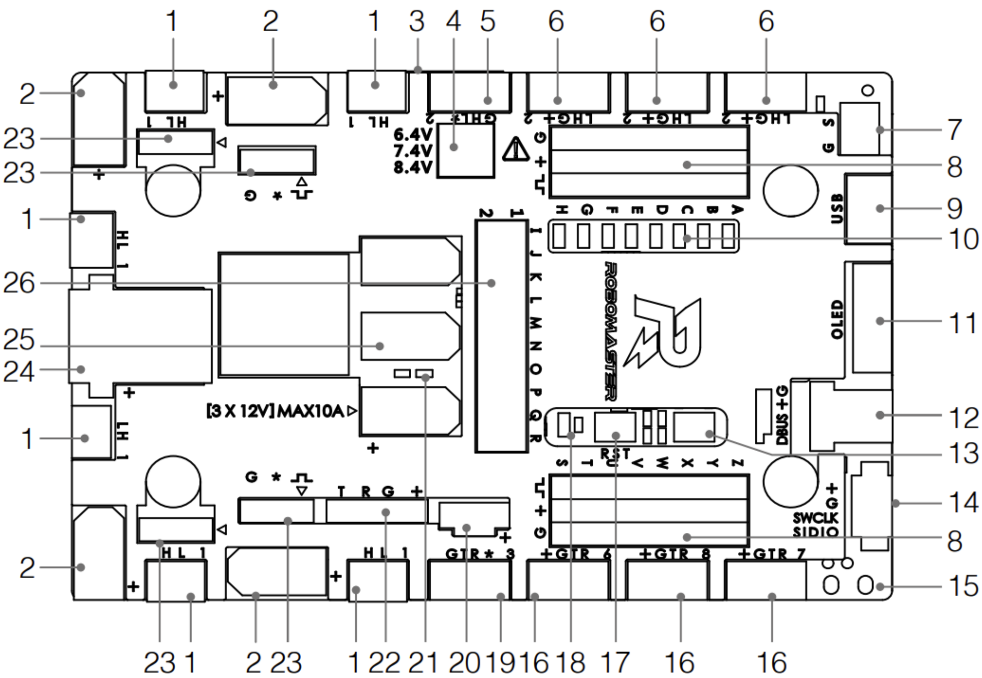

Figure 2. Development Board Type A Pin assignment

2.3.3 Python API

The Python API is a high-level interface that developers use to program in Python and test robotic arms. The requirements for the Python API are that it needs to be compatible with mainstream Python versions and provide stable communication, for example, Communication can be achieved with ROS, RPC, or similar protocols.

2.3.4 Forward Dynamics

The forward dynamics model is essential for calculating the end-effector's position and orientation based on the input joint torques. The robotic arm follows a kinematic structure described using Denavit-Hartenberg (D-H) parameters, which define the transformations between different joints. The motion of each link is determined by homogeneous transformation matrices that consider rotation and translation along various axes. The board's built-in computational capabilities process these transformations in real time, enabling smooth and accurate movement of the robotic arm.

Each joint is driven by a directly controlled three-phase brushless DC motor, utilizing the PWM output from the development board, which provides the following control parameters:

- Rotor Angle: Measured through external or integrated encoders.
- Motor Speed: Controlled by adjusting the PWM duty cycle.
- Output Torque: Controlled by modulating the PWM signal width and adjusting the motor’s current draw.

2.3.5 Clamp

The end effector of the mechanical arm is primarily responsible for grasping and manipulating objects. It is designed with a clamp that must feature an adjustable clamping force and be capable of adapting to various sizes and shapes of objects.

2.3.6 Arm Motor

The Brushless RM M2006 P36 DC motor [2] operates under a direct PWM control mode, utilizing direct three-phase PWM signals from the RoboMaster Development Board Type A at a frequency between 10 kHz and 20 kHz to ensure smooth motor operation.

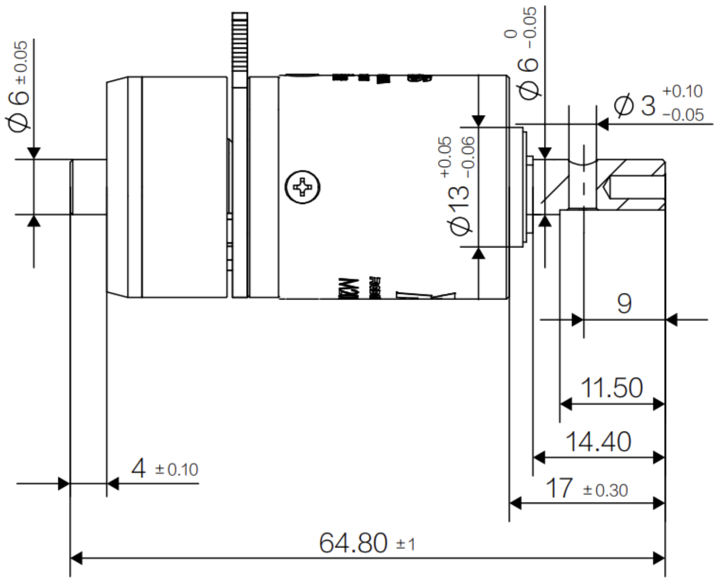

Figure 3. RM M2006 DC Motor

2.3.7 Arm Sensors

The robotic arm incorporates a 4-pin encoder that build in M2006 motor for precise motor position feedback, which is directly connected to the RoboMaster Development Board Type A. This encoder provides real-time rotor angle measurements, allowing for precise motor control.

On the RoboMaster Development Board Type A, the encoder connects via the UART6

(PG14 for TX, PG9 for RX) or UART7 (PE7 for RX, PE8 for TX) interface. Alternatively, if the encoder operates using a quadrature signal, it can be connected to the GPIO pins with external interrupt support. The power (VCC) and ground (GND) pins of the encoder are connected to the 5V or 3.3V power output and GND on the development board. The signal pins (A/B channels for quadrature encoders or TX/RX for serial encoders) are mapped to the respective UART or GPIO input pins of the controller.

2.4 Power Supply

The main role of the power supply part is to provide stable and reliable power support for the robot dog, robot arm, vision module and other types of electronic equipment. The general power supply generally covers the battery (can also be an external power supply), charging circuit and voltage regulation, etc. The requirements for power supply are: To meet the peak power requirements of the two subsystems in the operation process, it is also necessary to have the function of overcurrent protection and overvoltage protection, so as to ensure the safety of the entire system.

2.5 Tolerance Analysis

To ensure robust performance under real-world conditions, we conducted a tolerance analysis addressing key uncertainties in the mechanical, motor, and sensor subsystems. For example, the 3D-printed ABS components may exhibit dimensional variations of ±0.1 mm to ±0.2 mm. The impact on the end-effector's position can be approximated using the error propagation formula:

$$\delta p = \sqrt{\sum_{i=1}^{n} \left(\frac{\partial f}{\partial \theta_i} \delta\theta_i\right)^2}$$

where δp represents the end-effector position error, ∂f is the forward kinematics function, $\partial \theta_i$ denotes the joint angles, and $\delta \theta_i$ is the error in each joint measurement. Motor and sensor tolerances further contribute to the overall error. For instance, the encoder-based measurement error of ±0.2° in each joint can accumulate across multiple joints. We model the total angular error as:

$$\delta\Theta = \sqrt{\sum_{i=1}^{n} (\delta\theta_i)^2}$$

This combined error is then integrated into the forward kinematics model to assess its effect on the end-effector's accuracy.

In addition, we consider taking YOLO model for our visual module, and its performance is often evaluated by a variety of metrics, of which mAP50 [5] is a key metric. This metric is calculated based on the IoU (intersection ratio), which measures the degree of overlap between the bounding box predicted by the model and the real bounding box. We want this value to go as much as we can, while in fact, a YOLO model is usually considered good when mAP50 is above 0.85.

Ethics and Safety

3.1 Ethics

We are committed to upholding the highest ethical standards and ensuring the integrity of our project by strictly adhering to the IEEE Code of Ethics [1]. In doing so, we clearly specify the intended application and operational constraints of our system (IEEE Code 2) and accurately describe workspace and payload capabilities (IEEE Code 5). We also recognize and promptly address any technical deficiencies, while properly crediting all team members for their contributions (IEEE Code 6). To protect personal privacy, our vision system avoids collecting unnecessary information (IEEE Code 1), and we consider the environmental footprint of our design and production processes—particularly in relation to 3D printing (IEEE Code 1). Furthermore, we establish open communication channels for reporting concerns and issues (IEEE Code 7). Throughout our work, we prioritize public safety and well-being, remain vigilant about potential negative social or environmental impacts, and maintain honesty and integrity in all professional activities, thus avoiding unethical conduct such as bribery or illegal actions.

3.2 Safety

To ensure the safety of both team members and equipment, we implement high-voltage protection when working with motor drivers and power systems and conduct regular checks of all power cables and connections. We provide clear instructions for operating the robot dog and manipulator arm, along with an emergency stop mechanism that can immediately halt operation if necessary. This is further supported by torque limiters and mechanical stops to prevent overload and over-extension. Regular maintenance of all mechanical components and a limit on the end effector's maximum grip force ensure safe handling of objects. Dedicated testing areas in the lab, along with adequate ventilation—particularly during 3D printing—help maintain a secure working environment. We also prohibit team members from working alone in the laboratory, enforce strict guidelines for handling and charging batteries or other potentially hazardous materials, and document these measures in standard operating procedures to ensure consistent safety protocols throughout the project.

References:

[1] IEEE, IEEE Code of Ethics, Online, Available: https://www.ieee.org/about/corporate/ governance/p7-8.html, 2020.

[2] DJI RoboMaster. *RM C610 Brushless Motor Driver User Manual*. Shenzhen, China: DJI, 2018.

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[4] ViperX-300 — InterBotix X-Series Arms Documentation. (n.d.). https://docs.trossenrobotics.com/interbotix_xsarms_docs/specifications/vx300.html#:~:text=The%20ViperX-300%20Robot%20Arm%20belongs%20to%20the%20Interbotix,a%20smaller%20form%20factor%20over%20previous%20DYNAMIXEL%20servos.

[5] Ultralytics. (2025, March 16). Home. Ultralytics YOLO Docs. https://docs.ultralytics.com/