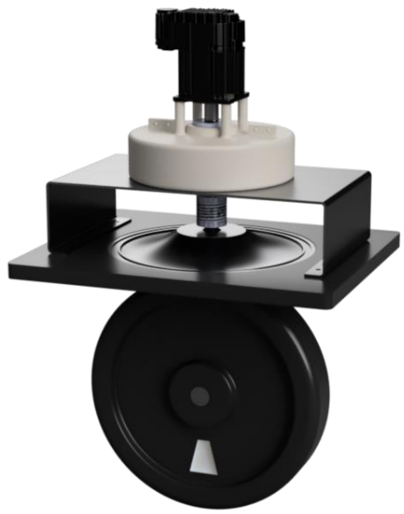
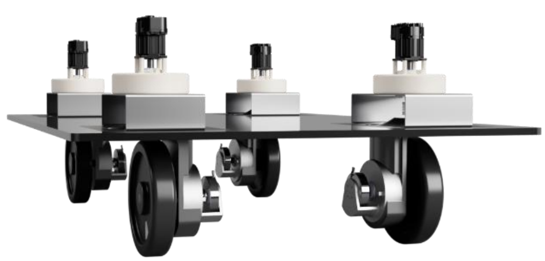
Swerve Drive Module Design





Project Title: Swerve Drive Module Design and Simulation

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Abstract

The swerve drive module is a highly maneuverable and efficient drivetrain used in robotics applications. This project focuses on designing a unique swerve drive module with a custom planetary gear system. The module consists of one wheel, two motors, and a supporting plate, providing independent control of wheel rotation and steering.

Introduction

Swerve drive systems provide independent control of each wheel's speed and direction, allowing omnidirectional movement with high agility. Unlike traditional differential or mecanum drivetrains, swerve drive enhances maneuverability and efficiency, making it a preferred choice in robotics competitions, industrial automation, and autonomous robots.

This project aims to develop a novel swerve drive module featuring:

- A custom planetary gear system for optimized torque and speed.
- T-Motor U8 Pro and ClearPath Servo for drive and steering respectively.
- Precise control algorithms for smooth and stable movement.

The uniqueness of this project lies in the custom mechanical design, efficient control algorithms, and simulation-based validation.

System Design

Concept Overview

The swerve drive module consists of:

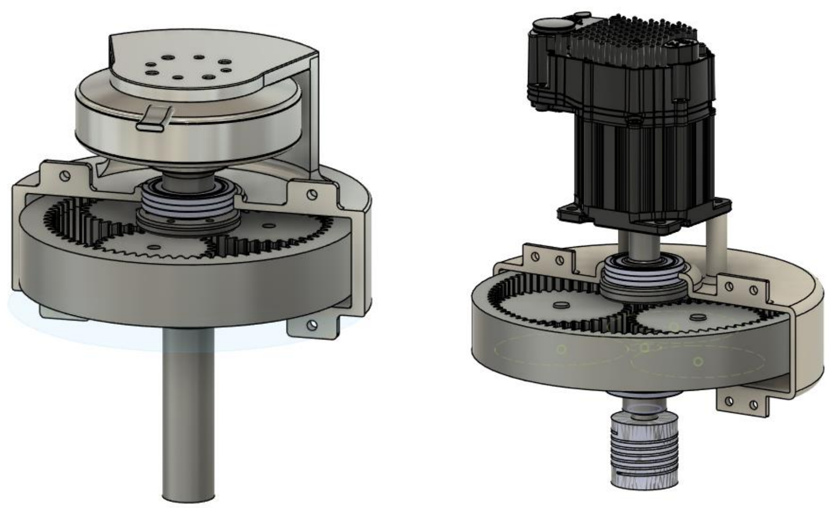
- One wheel (diameter: 245 mm) housed in a 140mm planetary system casing.
- Two motors:
  - T-Motor U8 Pro for wheel propulsion.
  - ClearPath Servo for steering control.
- Custom planetary gear system for steering and wheel propulsion for torque and speed optimization.

- Clamp for wheel propulsion or wheel drive assembly and steering assembly
- Standard Bearings for smooth functioning

Component Selection

- Motors:
    - Drive Motor: T-Motor U8 Pro (170KV, high efficiency, low noise)
    - Steering Motor: ClearPath Servo (precise and high torque)
- Gear Ratios:
    - Drive: 1:7 (planetary gearbox for optimal speed-torque balance)
    - Steering: 1:10 (for precision control)
- Wheel Size: 245mm
- Bearing:
    - Big one
    - Small one

Mechanical Design:



<u>Gear Specifications:</u>

Sun Gear:

Planetary Gear:

In the planetary gearbox configuration where the sun gear is the input and the planetary gears (via their carrier) serve as the output, with the sun gear being smaller than the planetary gears, the system will exhibit specific behavior based on the gear ratio and component interactions:

Application	Gear Ratio	T_s	T_r	T_p	r_s	r_r	r_p
Drive	1:7	12	72	30	18	1081	45
Steer	1:10	10	90	40	15	135	60

<u>Key Characteristics of This Configuration:</u>

1. Speed Reduction & Torque Multiplication
   - The smaller sun gear driving larger planetary gears creates a high gear reduction ratio.
   - The reduction ratio depends on the number of teeth:

$$\boldsymbol{Gear\ Ratio = 1 + \frac{number\ of\ ring\ gear\ teeth}{number\ of sun\ gear\ teeth}}$$

A smaller sun gear (fewer teeth) increases the ratio, leading to greater speed reduction and torque amplification.

2. Fixed Ring Gear
   - If the ring gear is held stationary (common in this setup), the planetary gears orbit the sun gear while rotating on their own axes.
   - The carrier, which holds the planetary gears, becomes the output, translating the combined motion into slower rotation with higher torque.
3. Compact Power Transmission
   - Torque is distributed across multiple planetary gears, balancing loads and reducing stress on individual components.
   - This design is efficient for applications requiring high torque in a confined space, such as robotics or electric vehicles.
4. Supporting the Gearboxes

- The wheel drive gearbox along with motor has been supported by custom 3d printed part that is press fitted in the bearing which is further press fitted on the thick plate
- The steering gearbox assembly along with motor is supported on the plate by a custom sheet metal part

Practical Implications

- High Torque: Ideal for heavy-load applications like industrial machinery or vehicle transmissions.
- Efficiency: Power loss is minimized due to load distribution across multiple planetary gears.
- Design Constraints: Precision is critical to avoid imbalances caused by uneven gear meshing.

If the sun gear is smaller than the planetary gears, the reduction ratio increases further, amplifying torque while sacrificing speed. This configuration is common in applications requiring precise control over high torque, such as conveyor systems or wind turbines.

The planetary gear system is custom-designed, with:

- Three planetary gears connected to a custom housing and sun gear.
- Motor driving the sun gear, transferring torque to the planetary gears.
- The wheel connected to the planetary carrier to ensure torque multiplication.

Control

The control system of the swerve drive module ensures precise and independent manipulation of both wheel propulsion and steering. This section details the control architecture, motor actuation strategy, and motion algorithms used to achieve efficient and stable maneuverability.

Control Architecture

The control system consists of:

- **Microcontroller/Embedded Computer**: Responsible for processing movement commands and executing control algorithms. A real-time capable microcontroller such as an STM32 or an embedded system like the Raspberry Pi will be used.
- **Motor Controllers**:

- T-Motor U8 Pro Drive Motor – Controlled via a BLDC motor driver supporting PWM and closed-loop control for speed regulation.
- ClearPath Servo Steering Motor – Operates with built-in feedback for high-precision steering control.

- Feedback Sensors:
  - Encoders: Measure wheel speed and steering angle to enable closed-loop feedback.
  - IMU (Inertial Measurement Unit): Provides orientation data for maintaining stability and aiding in odometry calculations.
- Communication Protocol:
  - CAN (Controller Area Network) or UART for motor control, ensuring minimal latency and reliable command transmission.

Control Algorithms

To achieve smooth and accurate movement, the control system employs the following algorithms:

1. PID Control for Speed and Steering:
   - The wheel drive motor is regulated using a Proportional-Integral-Derivative (PID) controller to maintain desired speed based on command inputs.
   - The steering motor uses a separate PID loop for precise angular positioning.
2. Kinematic Model-Based Control:
   - Given the desired velocity vector, inverse kinematics calculations determine individual wheel speeds and angles.
   - Each swerve module receives independent commands for wheel propulsion and steering based on these calculations.
3. Trajectory Following and Path Planning:
   - The module integrates with trajectory generation algorithms for smooth path execution in dynamic environments.
   - Potential future enhancements include AI-based path optimization for real-time decision-making.

4. **Fault Tolerance & Safety Measures**:
    - The system monitors motor health, encoder feedback, and IMU data to detect anomalies.
    - Safety features include emergency stop functionality and automatic recalibration mechanisms to prevent drift.

Script

*attached

Conclusion & Future Scope

This project successfully demonstrates the design and simulation of a unique swerve drive module using a custom planetary system. By leveraging high-efficiency motors, optimized gear ratios, and simulation-based validation, this system provides a robust and precise movement mechanism.

Future Scope:

- Physical implementation with real-world testing.
- Integration of sensors for feedback control.
- Autonomous path planning using AI-driven optimization algorithms.
- Exploration of advanced materials for lightweight and high-strength performance.

This project serves as a strong portfolio piece, highlighting expertise in mechanical design, control algorithms, and simulation-driven development.