Design and Experimental Evaluation of an Actively Stabilized Payload Platform for High-Speed Mobile Robots

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August 14, 2026

Abstract

This thesis proposes the development of an actively stabilized payload platform mounted on a high-speed mobile robot. Unlike conventional self-balancing systems, the objective is to maintain a payload near a desired inertial pose while the robot undergoes aggressive translational and rotational maneuvers. The stabilization mechanism will be realized as a compact parallel robotic platform that performs counter-movements relative to the robot body. Plate attitude will be estimated using both an onboard inertial measurement unit (IMU) and an external Vicon motion-capture system, enabling a quantitative comparison of estimation accuracy, latency, and robustness. The work will include mechanical design, embedded implementation, control-system development, and experimental validation. Performance will be evaluated using metrics such as plate attitude error, angular acceleration, payload displacement, and settling time during high-speed trajectories.

1 Introduction

Mobile robots operating at high speed are increasingly used in logistics, service robotics, inspection, and autonomous transportation. During rapid acceleration, braking, and turning maneuvers, significant inertial disturbances are transmitted to payloads mounted on the robot. Passive mounting solutions are often insufficient when sensitive equipment, liquids, or freely moving objects must remain stable. This motivates the development of an active stabilization system capable of compensating for base motion in real time.

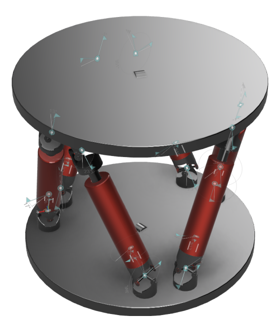

Figure 1: A 6DOF Stewart platform.

The proposed system consists of a mobile robotic base carrying an actuated stabilization platform that supports a flat plate. A freely moving object placed on the plate serves as the primary disturbance-sensitive payload. The stabilization platform will generate counteracting motions to reduce plate tilt and object displacement as the robot moves.

The stabilization stage is envisioned as a compact Stewart platform (see Fig. 1) mounted on top of the mobile robot. By commanding coordinated actuator motions, the platform can generate compensatory roll, pitch, and yaw motions that counteract disturbances originating from the robot base. This configuration allows the payload plate to remain closer to a desired inertial orientation even during aggressive maneuvers such as rapid acceleration, braking, or turning.

The central research question is:

> *To what extent can an actively actuated parallel-platform stabilizer reduce payload motion on a high-speed mobile robot, and how do IMU-based and Vicon-based attitude estimation methods affect stabilization performance?*

2 Objectives

The thesis will pursue the following objectives:

1. Design and construct a compact actuated stabilization platform for a mobile robot.
2. Develop attitude estimation methods using:
   - an onboard IMU,
   - a Vicon motion-capture system,
   - and, optionally, sensor fusion.
3. Implement and evaluate feedback control algorithms for disturbance rejection during aggressive robot maneuvers.
4. Quantitatively compare stabilization performance under different sensing configurations.

3 Methodology

The work will proceed in four stages:

1. **Mechanical and electrical design:** CAD modeling, actuator selection, power electronics, and embedded integration.
2. **System modeling:** Derivation of the platform kinematics and simplified dynamics of the robot-platform-payload system.
3. **Estimation and control:** Implementation of IMU-based attitude estimation and a baseline stabilization controller (PID with feedforward compensation), with Vicon measurements used as ground truth.
4. **Experimental validation:** High-speed trajectory experiments including straight-line acceleration, slalom motion, circular motion, and emergency stopping.

These metrics provide a direct measure of stabilization quality and disturbance rejection capability.

4 Expected Contributions

The expected contributions of the thesis are:

- a complete mechatronic implementation of an active payload stabilizer,
- a comparative study of IMU and Vicon attitude estimation,
- experimentally validated stabilization strategies for mobile robots,
- and a reusable experimental platform for future research on dynamic payload stabilization.

5 Conclusion

This thesis addresses the problem of dynamic payload stabilization on high-speed mobile robots through the design of an actively actuated parallel-platform stabilizer. By combining onboard inertial sensing with external motion-capture measurements and experimentally evaluating the resulting control strategies, the work aims to provide practical insights into maintaining payload stability under aggressive robotic motion. The proposed research integrates hardware development, state estimation, control design, and experimental validation within a focused and feasible master-thesis scope.