# Robust Control of Robotic Arms Applied to In-Flight Crop Seeder Refilling

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## Overview

The objectives of this research are to build a framework for cooperative networks of robotic manipulators operating on dynamic platforms, with emphasis on two key applications in precision agriculture:

- Semi-automated seeding operations with in-flight, robotic refilling vehicles;
- High-throughput crop inspection and treatment in uncertain environments.

***Specific Aims***

- Field validation of an adaptive control architecture for a robotic manipulator on a dynamic platform moving across uneven terrain.
- Experimental validation of control strategies for robust performance of networked robotic manipulators in the presence of communication delays.
- Design of a robotic seed-tank refilling system for uninterrupted seeding.

## Field validation of a robust adaptive controller

***Background***

An adaptive controller for a robotic manipulator mounted on a moving platform was proposed in [1] to ensure guaranteed transient performance in uncertain environments. The controller has a low-pass filter in the feedback channel, before the input to the controlled system, enabling fast estimation without loss of robustness [2].

***Results***

Physical experiments (fig. 1) confirm an expected initial decrease in the tracking error as the filter bandwidth increases (fig. 2), as well as an increased sensitivity to discretization errors, actuator time delays, and unmodeled dynamics beyond a critical bandwidth. Tests demonstrate successful control of the end-effector orientation during travel [3].

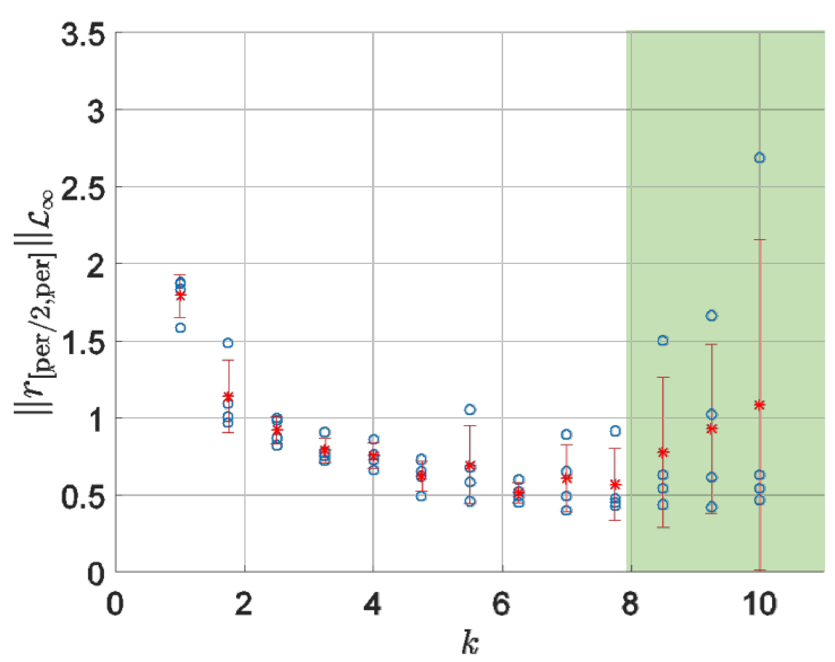

*Fig 2. Maximum tracking error for different values of the filter bandwidth k. Beyond a critical value, discretization error, delays, and other perturbations make the tracking error increase, as shown in the green highlighted area.*

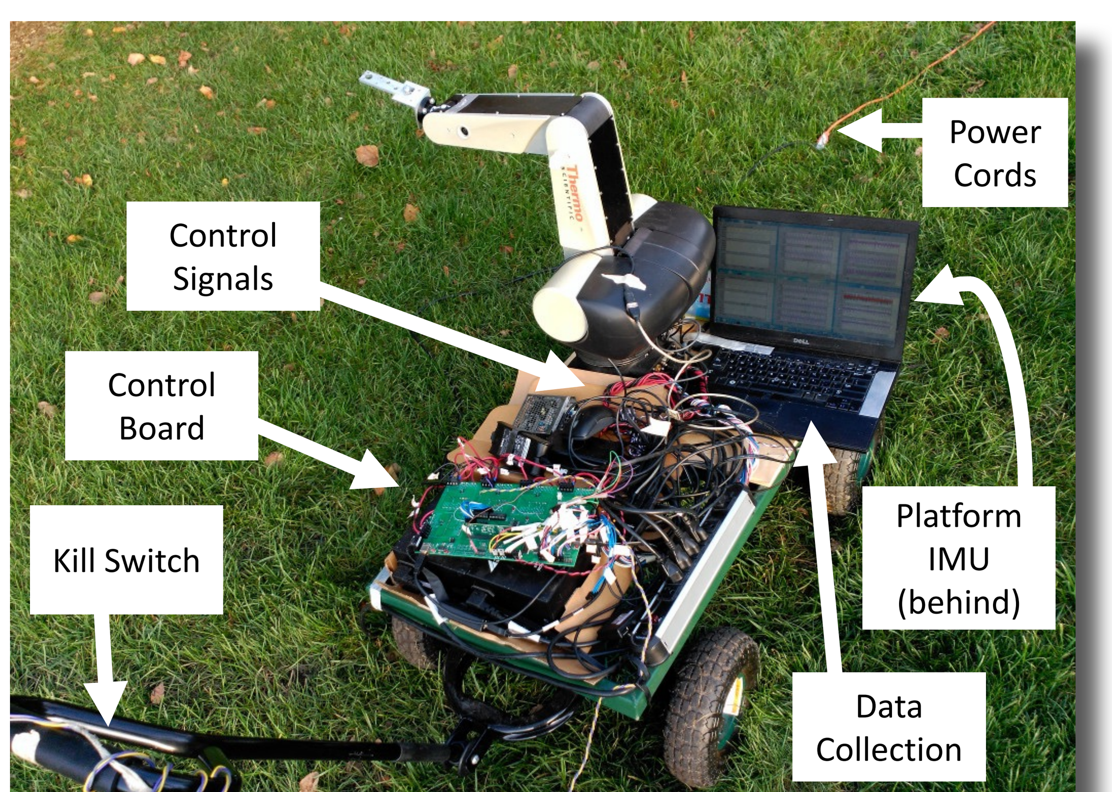


*Fig. 1. The robotic manipulator used in the experiments is mounted on a wheeled platform.*

## In-flight seed refilling system

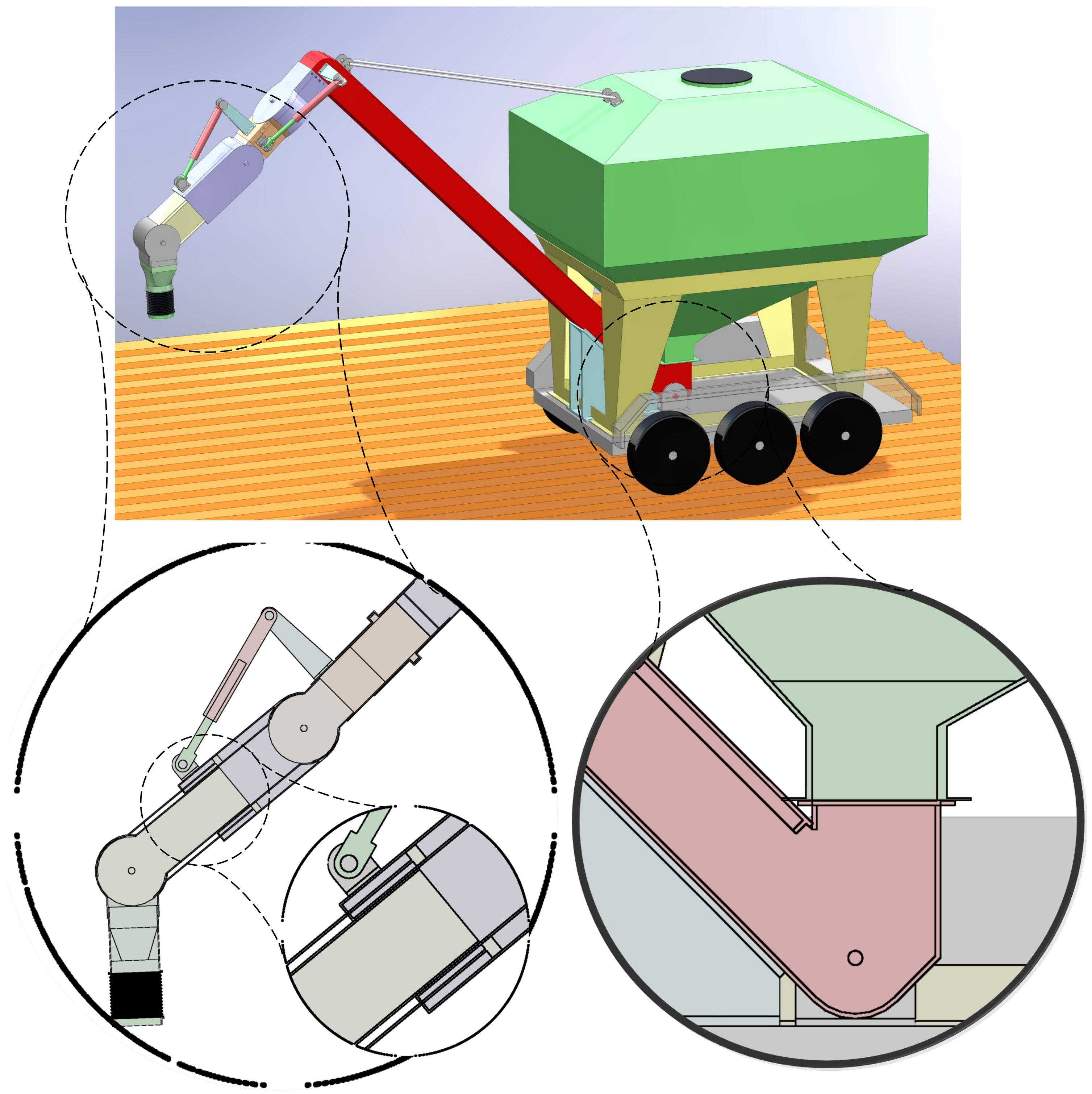

*Fig. 3. Overview of a robotic seed-tank refilling system.*

***Background***

A potential target for robotics in agriculture is seeding of field crops. This task is time-consuming and sensitive to environmental conditions. Opportunities for automation include the development of autonomous vehicles that traverse a field based on predefined seeding patterns, as well as mechanical solutions for planting seeds according to desired depth and spacing.

Our research is motivated by the possible deployment of a robotic seed-tank refilling system (fig. 3) that allows for continuous operation of a planter, without interruption or extraneous travel, in contrast to current practice [4].

***Mechanical Design Goals***

- The seed transfer system accommodates different planter geometries.
- The coupling between the refilling system and the seed tank on the planter is robust to disturbances caused by travel across uneven terrain.
- The coupling between the refilling system and the seed tank on the planter is pressurized to allow uninterrupted seeding during the refilling process.

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## Validation of robust control of networked robots

***Background***

Coupling of networked robotic manipulators may allow for coordinated movement, but introduces potential destabilizing effects of communication delays. Theoretical analysis of the adaptive control architecture in [5] proves robustness to bounded communication delays for simple synchronization strategies provided that the filter bandwidth is sufficiently large.

***Results***

A heterogeneous network consisting of three coupled industrial robots on separate platforms, along with one custom-built robot was constructed. Experiments with consensus, leader-follower, and synchronization control strategies were performed to validate the theoretical predictions and showed that the synchronization of the robots in a circular configuration (fig. 4) is stable given appropriate tuning of the control parameters for each robot.

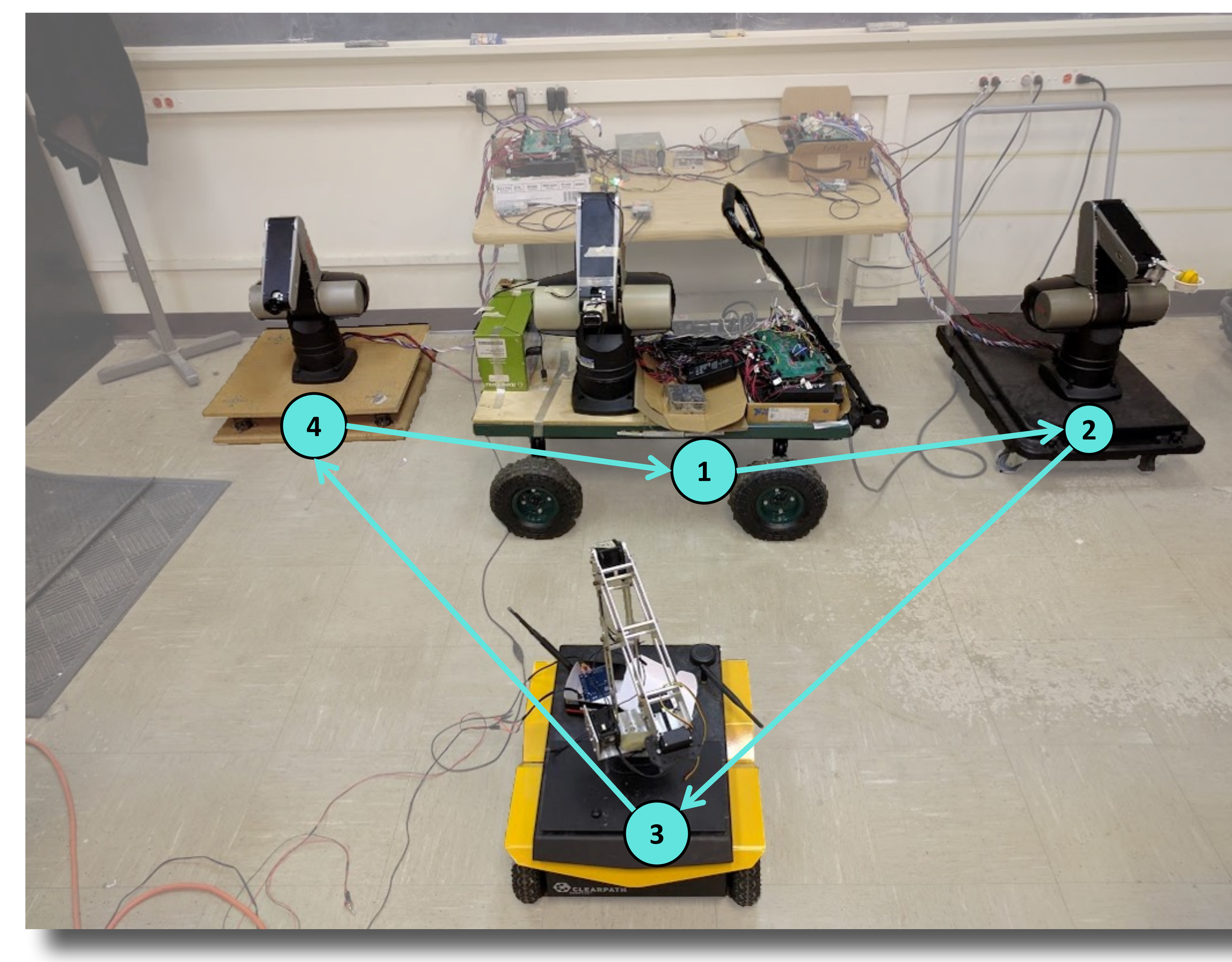


*Fig. 4. A heterogeneous network of robotic manipulators on mobile platforms.*

## Summary

Experimental validation of theoretical predictions for candidate adaptive control strategies applied to single or networked manipulators on mobile platforms provides insight into the use of automation in agricultural applications, specifically, the design of a robotic seed-tank refilling system that ensures uninterrupted seeding and is robust to travel across uneven terrain, communication time delays, and unmodeled actuator dynamics.

## References

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