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Motion Planning for Autonomous Grain Carts

Dissertation presented to Texas A&M University, College Station, Texas, USA
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TEXAS A&M UNIVERSITY

1 Introduction

A. MOTIVATIONS

Cooperative Crop Harvesting
- Combine covers entire field nonstop
- Grain cart commutes between combine and semi-trailer

Need for Autonomous Grain Carts
- Labor shortages & growing costs
- Operational imprecision & inefficiency
- Safety hazards

B. CHALLENGES

Key Unloading Timing
- Late: combine full and stopped, harvest interrupted
- Early: grain cart follows combine, more fuel consumption

Dynamic Environment
- Traversable areas for grain cart constantly changing
- Unexpected obstacles or events

Numerous Design Parameters
- Vehicle dimensions, poses, speeds, capacities, etc.
- Field geometry and yield

C. RESEARCH GAPS

Industry
- Semi-autonomy with human supervision/control
- Most harvesting performed without detailed planning

Academia
- Interactions between combine and automated grain carts scarcely investigated

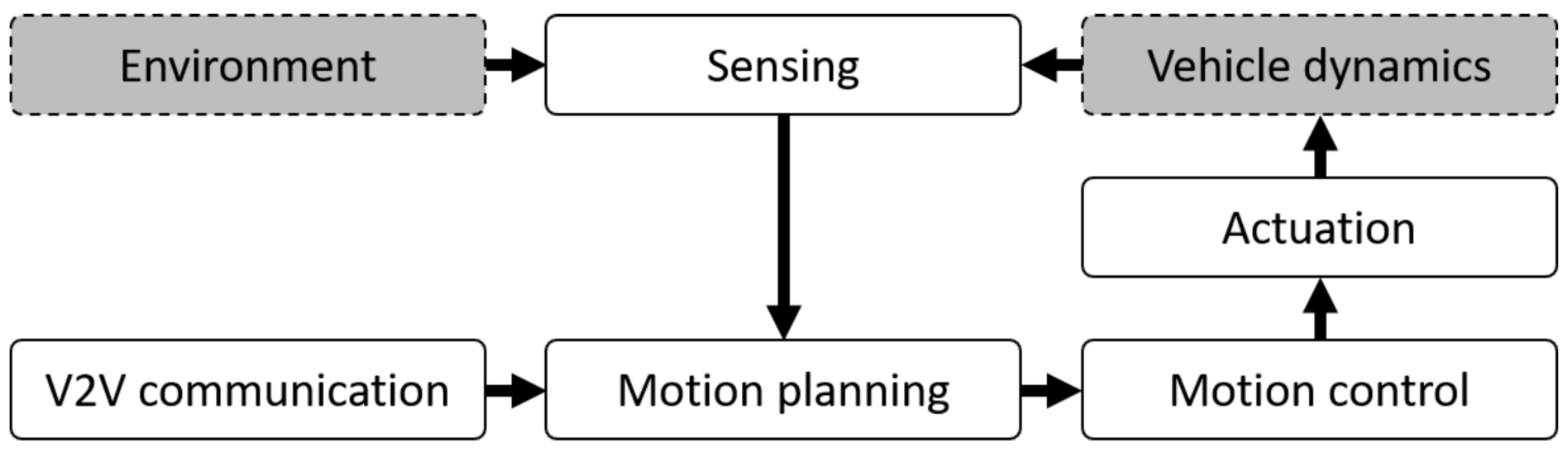
D. OBJECTIVES
- Develop a motion planner for autonomous grain carts
- Provide a high-level software and hardware solution to building navigation systems on autonomous grain carts

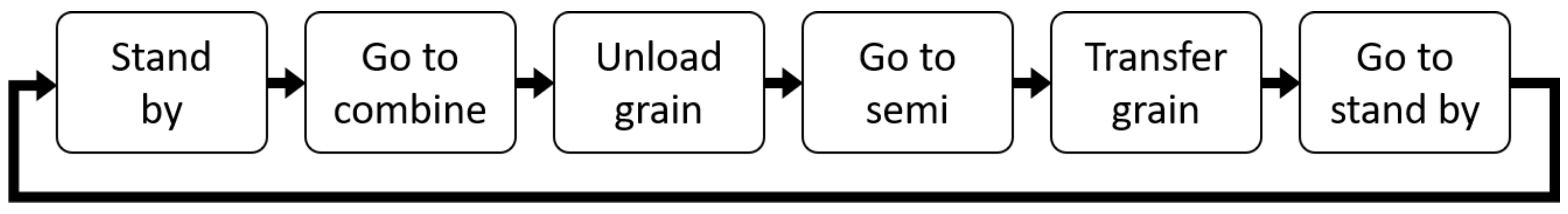
2 Solution Procedure

A. NAVIGATION SOLUTION

Sensors:
- RTK-GPS for global localization
- 2D lidar for local obstacle detection
- IMUs for measurement of states of motion

Communication: WLAN or ZigBee
Control: PID
Actuation: drive-by-wire powertrains

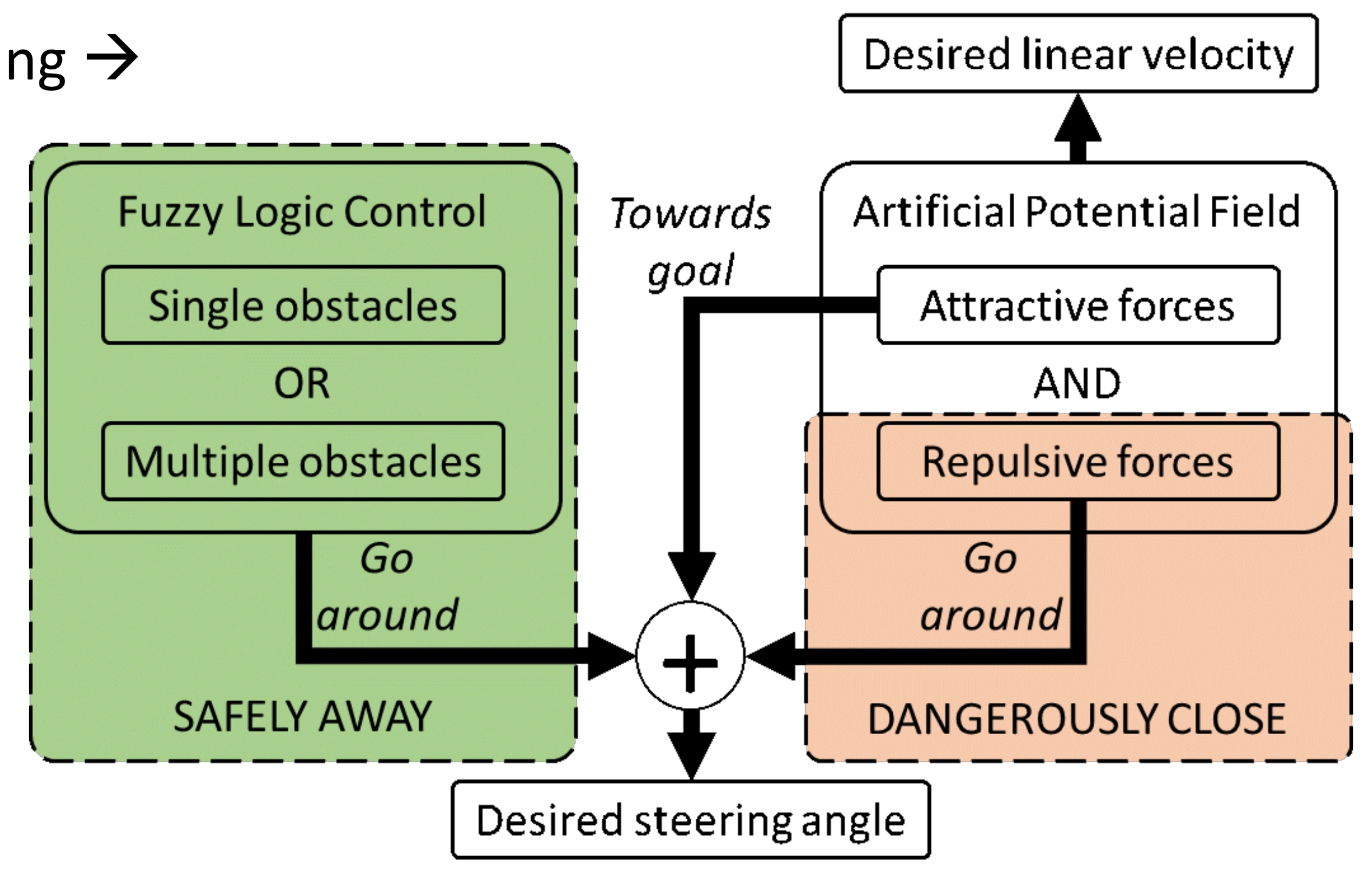


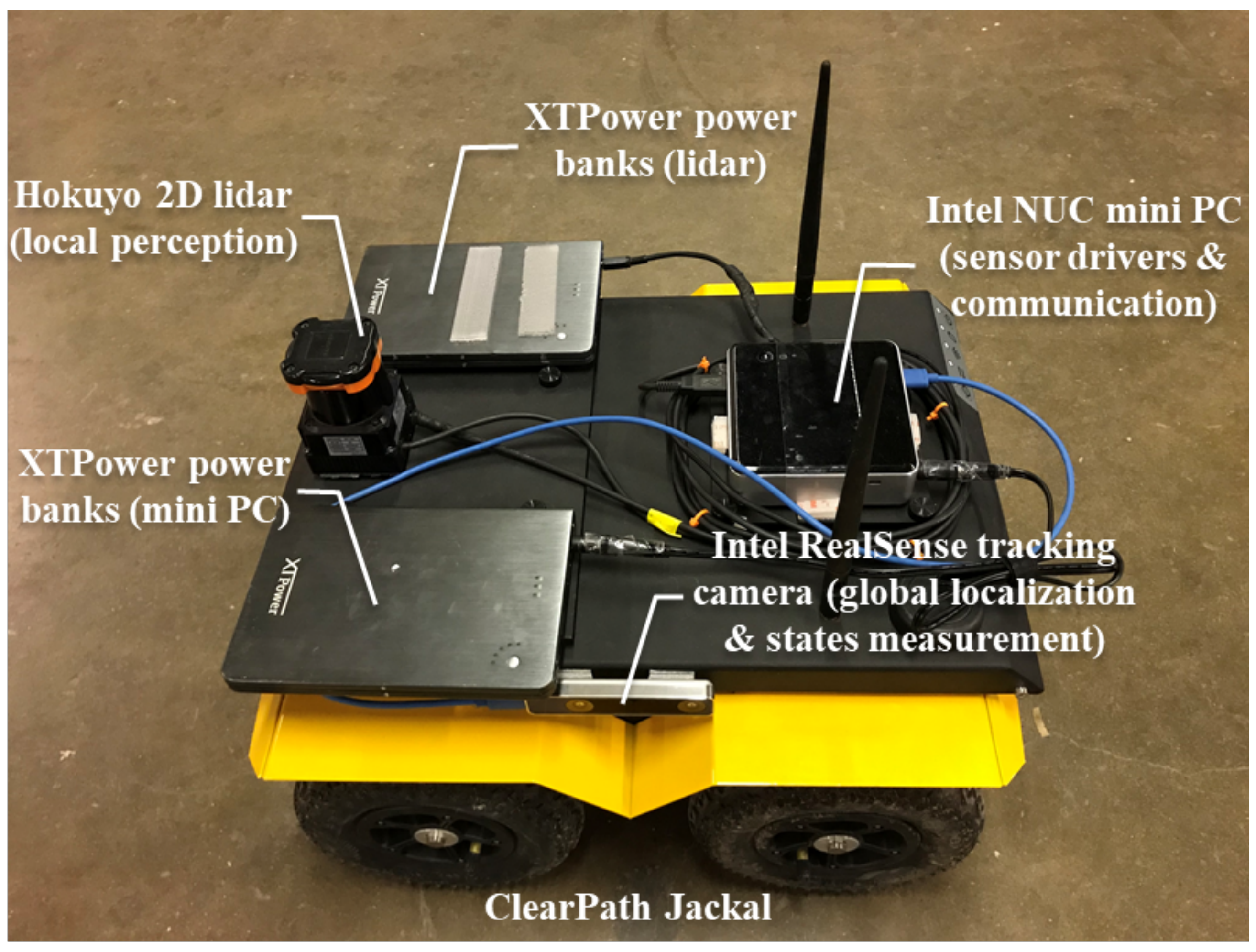


B. PLANNING ALGORITHM

Task Scheduling
- Stand by & calculate timing → go to combine for unloading → unload grain from combine → go to semi-trailer → transfer grain to semi → go to standby point

Collision Avoidance
- Artificial Potential Field (APF)
  Advantages: simple, efficient, real-time fast
  Disadvantages: local minima traps, infeasibility
- Fuzzy Logic Control (FLC)
  Features: simple, efficient, robust, use of human knowledge, experience, intuition
- APF+FLC Rationale
  APF only effective when dangerously close to obstacles to avoid local minima
  Another algorithm takes over when safely far
  Use intelligence of human operator
  Handle environment & model uncertainties





C. TEST DESIGN

Simulation Tests
- APF+FLC v.s. simple APF: no/static/dynamic obstacles other than unharvested crop rows
- APF+FLC v.s. Vector-Field-Histogram (VFH): general collision avoidance tasks

Mobile Robot Tests
- APF+FLC simple harvesting
- APF+FLC v.s. simple APF in general collision avoidance tasks

3 Results and Conclusions

A. SIMULATION TESTS

Effectiveness and Robustness
- Autonomous navigation in field
- Accomplishment of logistical tasks
- No collision with static or dynamic obstacles

Efficiency
- APF+FLC: 15~20% shorter, smoother against obstacles
  Simple APF: oscillations and local minima traps
- APF+FLC: less smooth but shorter by up to 60%
  VFH: missed shortcuts and misled by tricky obstacles

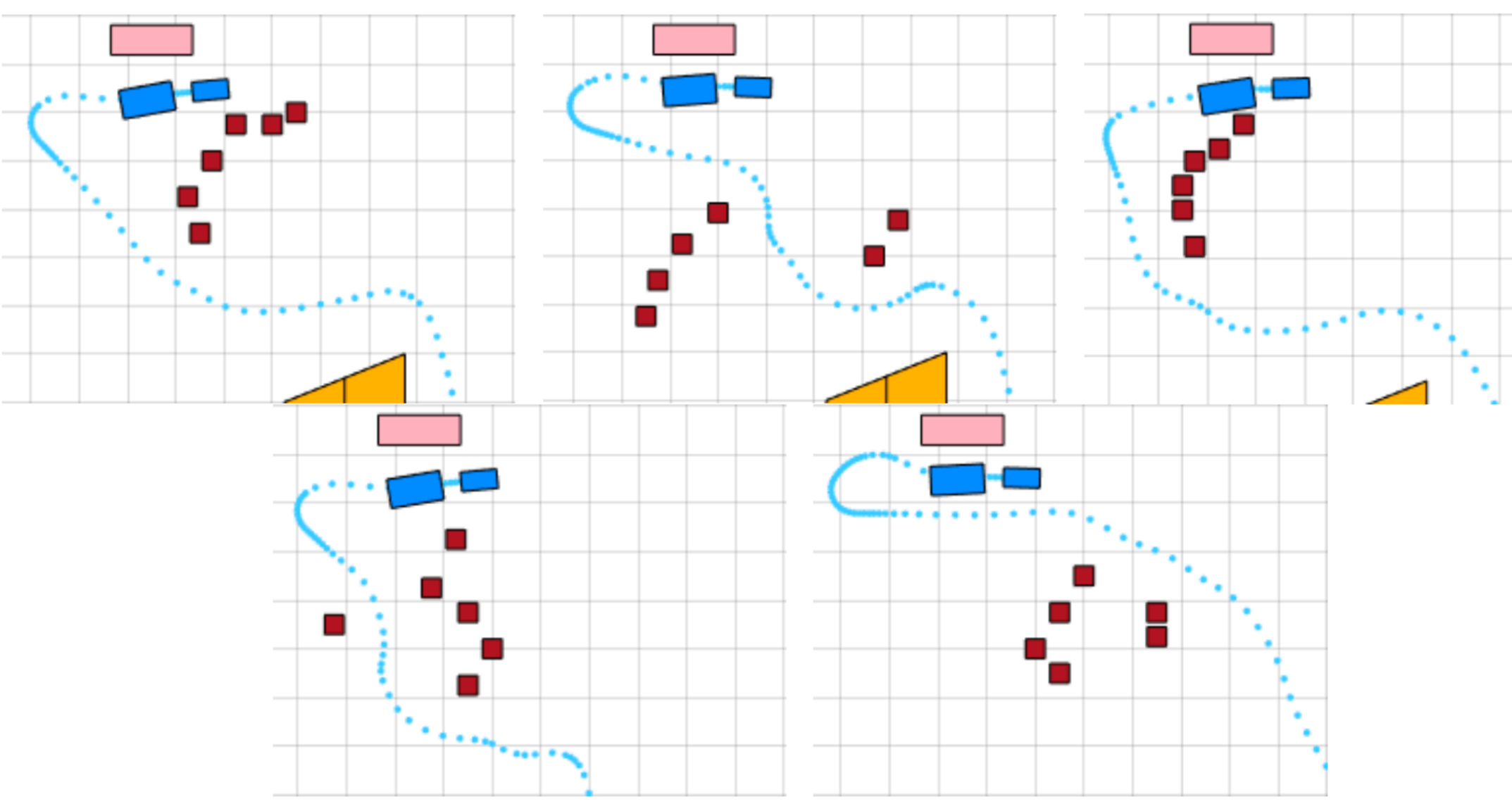
Computational Ease
- 0.74 ms each computation cycle on average
- Ordinary laptop CPU: Intel Core i7-8650U
- Fast enough for real-time applications

B. MOBILE ROBOT TESTS

Effectiveness and Practicality of Navigation Solution
- Autonomous navigation in field (cardboard sheets as crops)
- Accomplishment of logistical tasks in harvesting operations

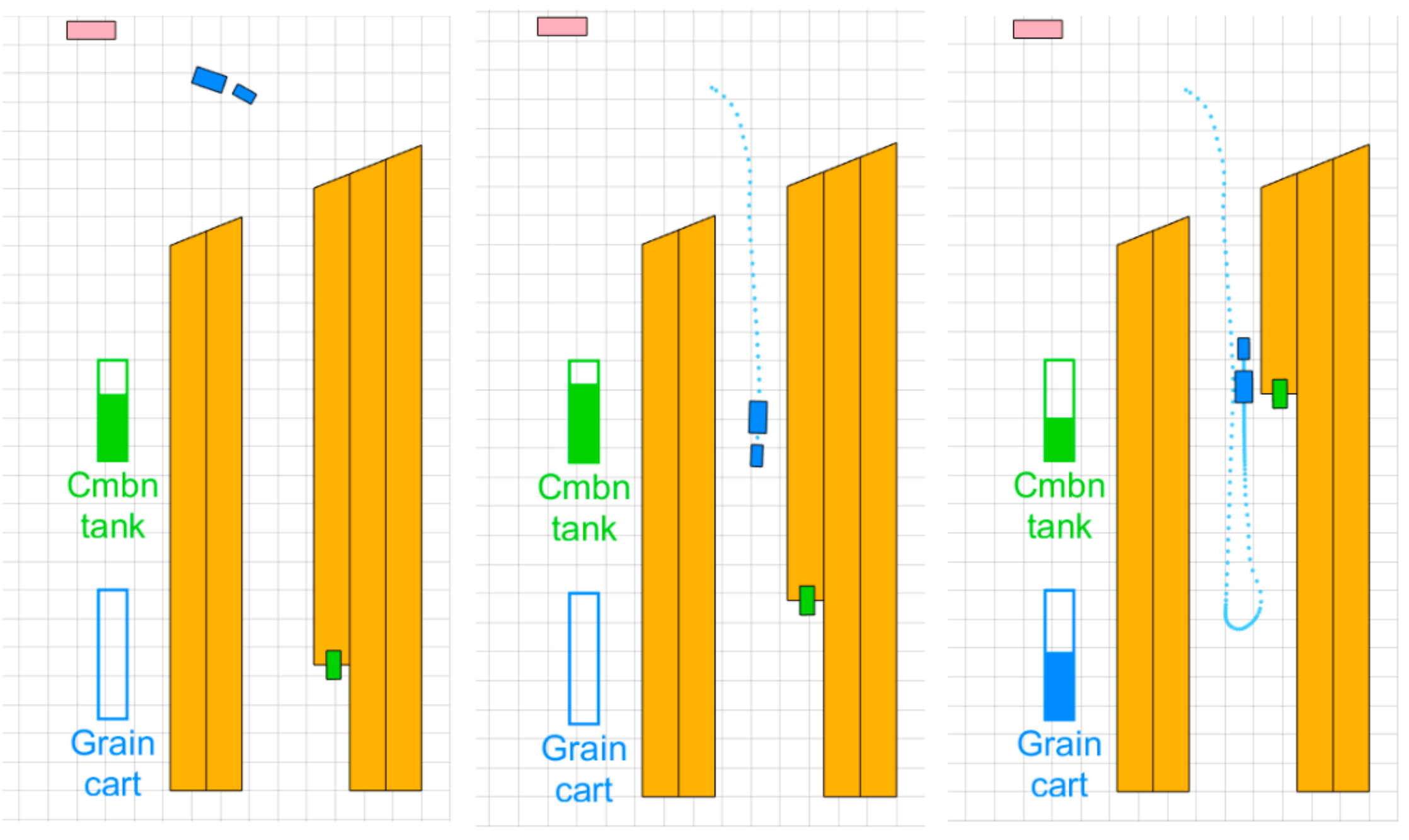
Effectiveness and Robustness of APF+FLC Planner
- Accomplishment of various general collision avoidance tasks

Efficiency
- APF+FLC: up to 25% shorter & 3 times smoother
- Simple APF: occasional oscillations and local minima traps

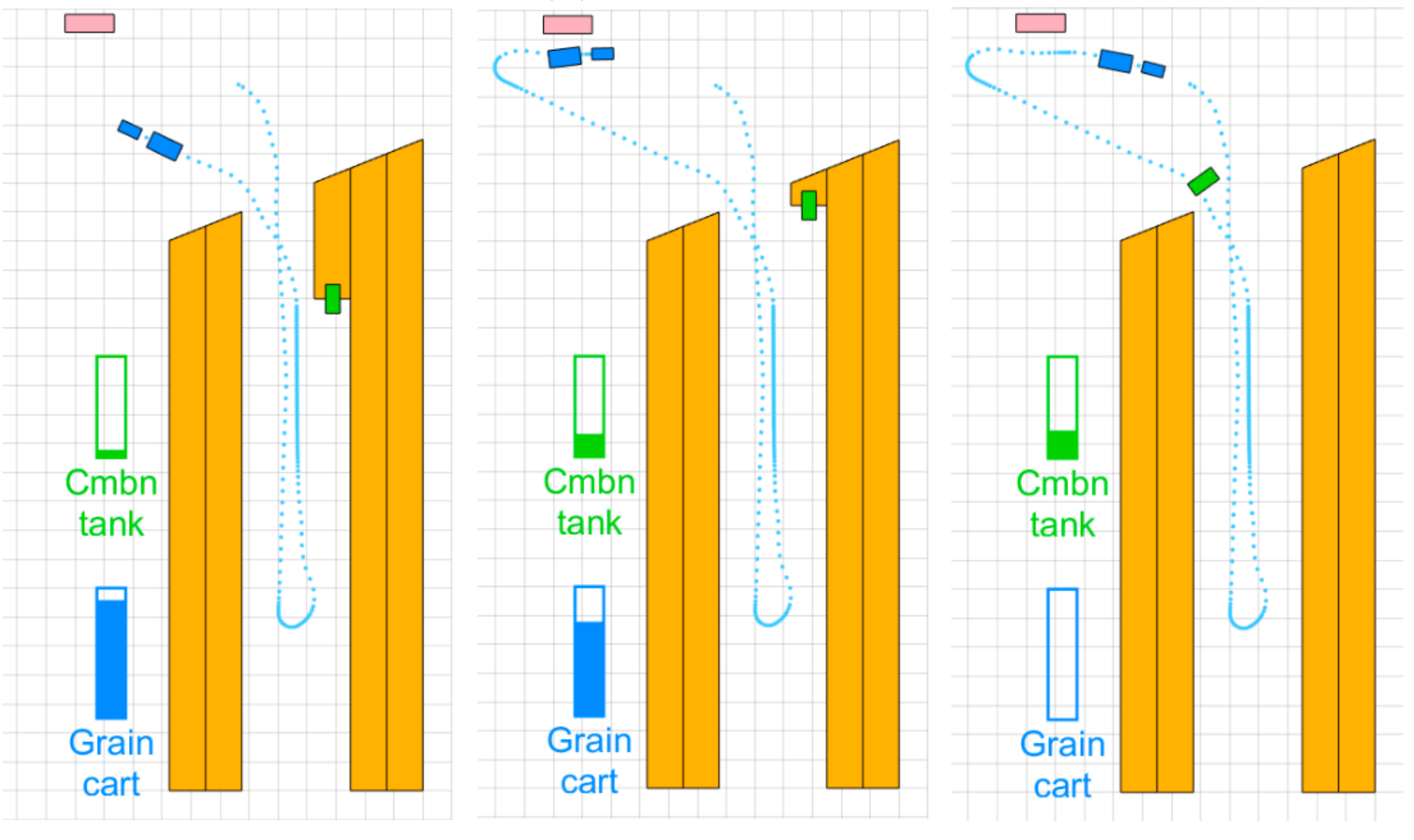


(a) Standby (b) To combine

(c) Unload (d) To semi



(a) Standby (b) To combine (c) Unload



(d) To semi (e) Transfer (f) To standby

4 Final Remark(s)

This study proposed a novel motion planning algorithm and an associated navigation solution to achieve full automation of grain carts, which no study has previously attempted. Experimental results from both simulations and actual mobile robot tests verified that the planner and navigation solution are effective, robust, efficient, and practical for potential adoption in actual autonomous grain carts, addressing the shortages and growing costs of labor while improving harvest productivity.