

Region-based collaborative conflict-free path planning for smart warehouse robots

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➤ Outline

- **Introduction**
- Proposal
- Related Work

Introduction

Warehouse Logistics

- With the rise of e-commerce, the volume of goods in logistics warehouses has significantly increased
- As a result, enhancing the **processing speed** within warehouses has become a crucial aspect that cannot be overlooked



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Logistics Flow

- When goods arrive at the logistics center, they need to be moved to each driver's loading point



Introduction

Common Warehouse Robot Operation

- The commonly seen warehouse robots operate by lifting entire shelves that have goods already placed on them and directly transporting the shelves to the driver's loading point



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Introduction

Current Issues

- As the volume of goods increases, more robots are added to logistics centers to enhance processing speed
- However, the increased number of robots results in delays, as robots must often wait while transporting shelves
- Despite various conflict reduction strategies, the current solution still involves having robots stop and wait to avoid collisions



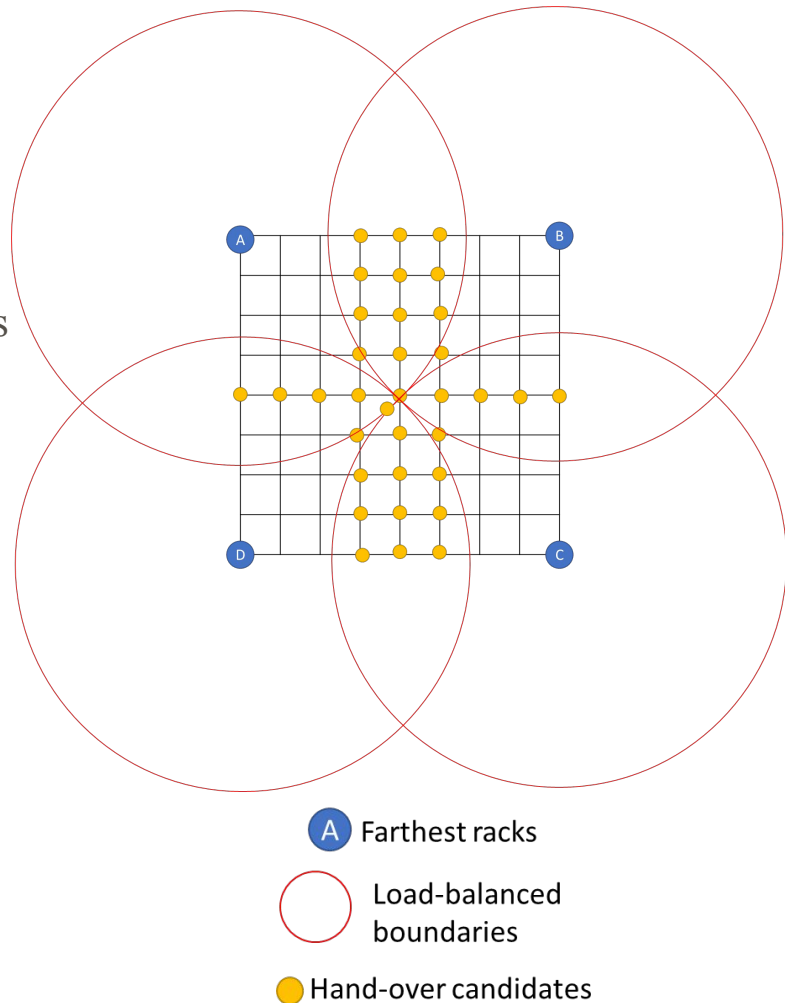
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Proposal

Zone Division

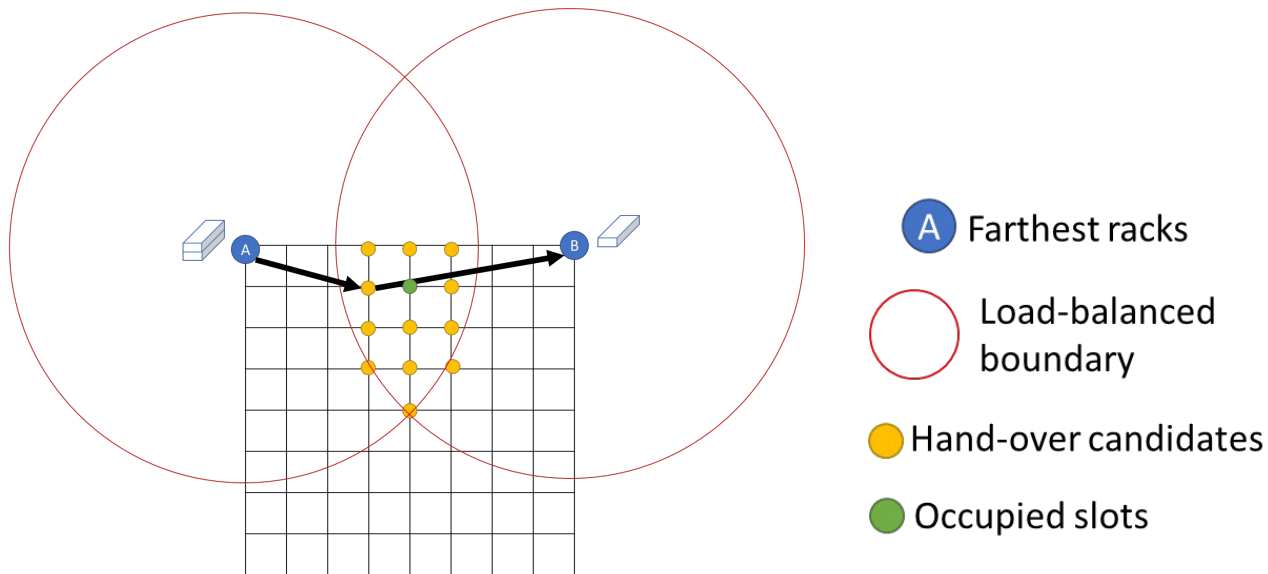
- Divide the warehouse into designated areas
- Robots can only operate within their assigned zones
- Control the number of robots within each zone
- Reduce congestion caused by an excess of robots



Proposal

Goods Handover

- Set up multiple handover points
- When goods need to cross zones, select a handover point
- Place the goods at the handover point
- Goods will wait at the handover point for the next zone's robot to arrive



Proposal

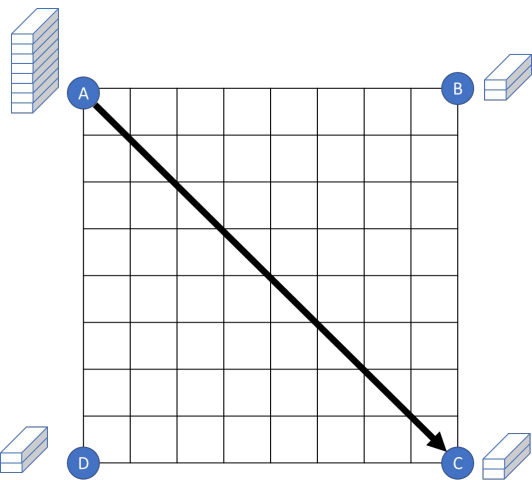
Advantage of Zone Division and Goods Handover

- Load balance
- Reduce the idle time of goods

A Farthest racks

○ Load-balanced boundary

● Hand-over candidates



Proposal

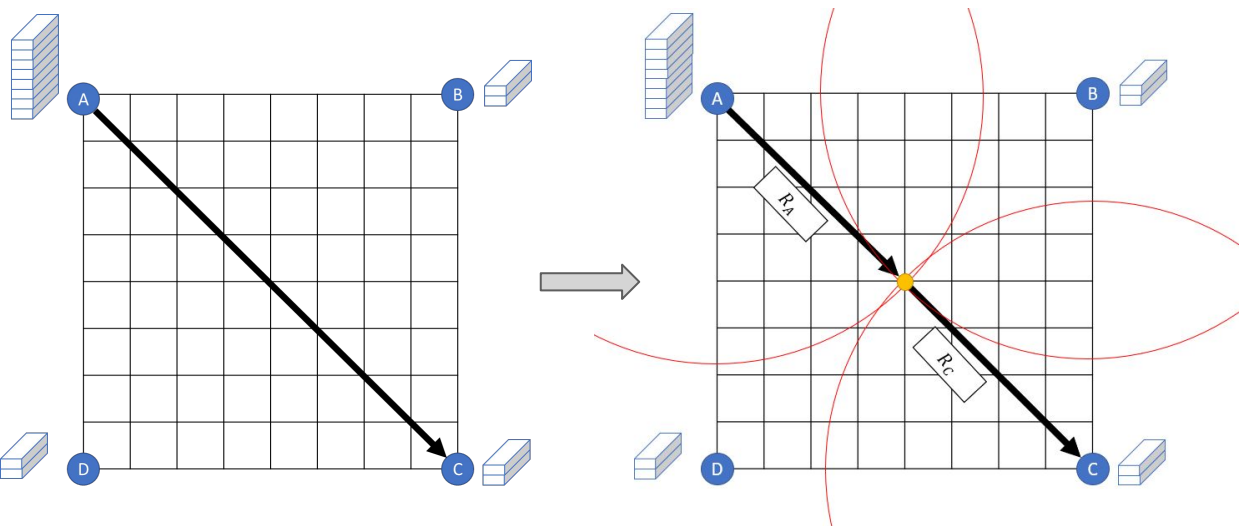
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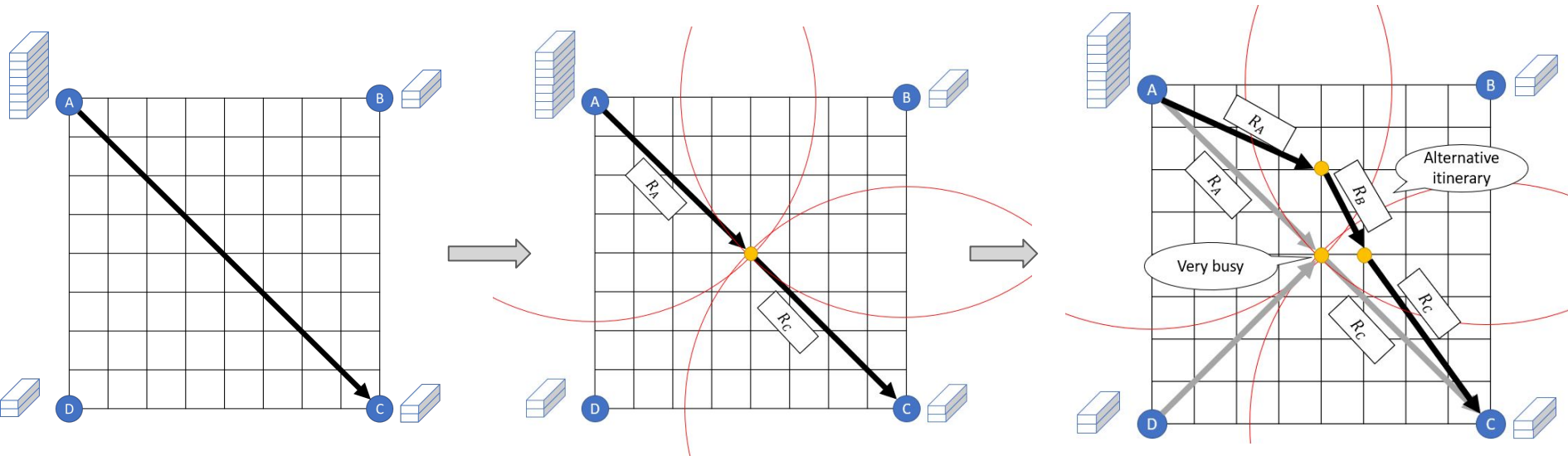
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Proposal

Advantage of Zone Division and Goods Handover

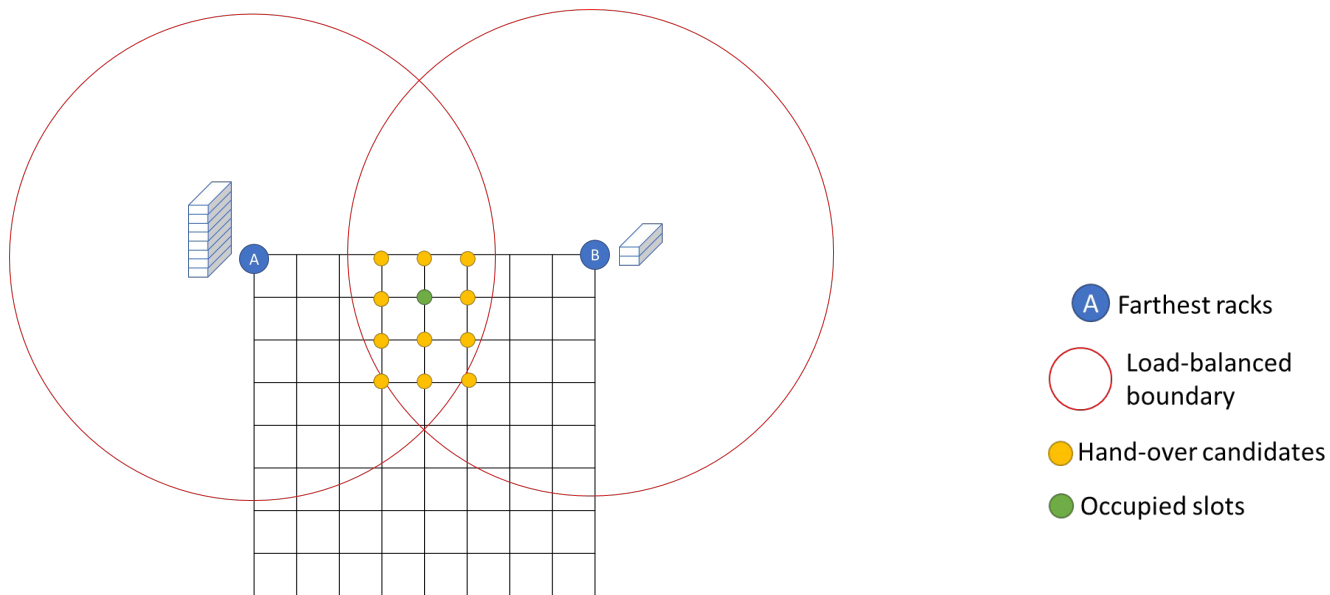
- Load balance
- Reduce the idle time of goods



Proposal

Disadvantages of Fixed Zones

- Imbalanced workloads across different zones
- Robots in zones with fewer goods may remain idle
- Zones with more goods will experience a growing backlog of unprocessed items



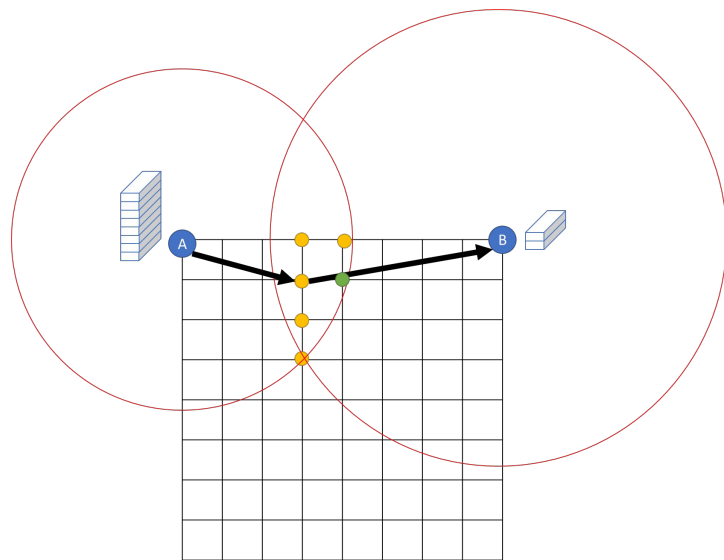
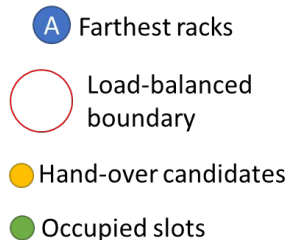
Proposal

Disadvantages of Fixed Zones

- Imbalanced workloads across different zones
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Dynamic Zone Adjustment

- Divide zones based on the destination of goods
- Prevent imbalanced workloads across different zones



► Proposal

Goals

- **Plan collision-free routes for multiple robots**
 - Deliver all goods to the driver's loading point before departure
 - Optimize for shorter and more energy-efficient paths
- **Increase the handling capacity of the logistics center**
- **Balance the workload of robots within each zone**
 - Divide the logistics center into zones
 - Control the number of robots within each zone to reduce congestion
 - Set up handover points for cross-zone deliveries

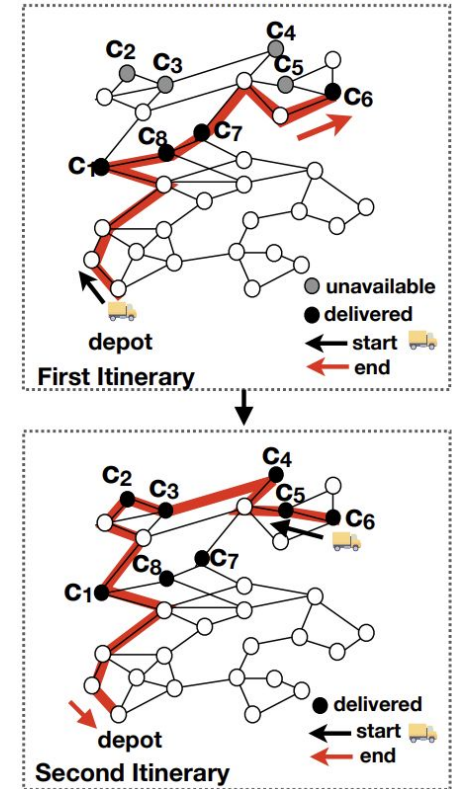
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Related Work

Revisit-free Parcel Delivery [1]

- a driver, a depot
- Hierarchical framework
 - Divide the area into subgraphs
 - Find the child-optimal subgraph itinerary
 - Use KRN (k Rewarded Neighbor) to evaluate and adjust in real-time
 - Apply RL with Q-learning to learn the optimal route



[1] Ting, L.PY., Teng, SY., Wu, SC. *et al.* Interactive planning of revisiting-free itinerary for signed-for delivery. *Int J Data Sci Anal* **14**, 439–456 (2022).
<https://doi.org/10.1007/s41060-022-00333-0>

Related Work

Multi-agent Planning

- Target Assignment^[2]
- Path Finding^{[2][3]}
- Pickup and Delivery^{[3][4][5]}
- Power management^[5]

Region-aware Planning

- Feasible regions^{[6][7]}
- Maximum region coverage^{[6][7]}

[2] Kou, N. M., Peng, C., Ma, H., Kumar, T. K. S., & Koenig, S. (2020). Proceedings of the AAAI Conference on Artificial Intelligence. The Thirty-Fourth AAAI Conference on Artificial Intelligence (AAAI-20)

[3] Antonello Contini, Alessandro Farinelli, Coordination approaches for multi-item pickup and delivery in logistic scenarios, Robotics and Autonomous Systems, Volume 146, 2021, 103871, ISSN 0921-8890, <https://doi.org/10.1016/j.robot.2021.103871>.

[4] Mo, Ni-Lei & Zhang, Wencong. (2024). Capacitated Vehicle Routing Problem With Pickup and Delivery in Robotic Mobile Fulfillment Systems. IEEE Access. PP. 1-1. 10.1109/ACCESS.2024.3442815.

[5] C. Yang, B. Yuan and P. Zhai, "Actor-Hybrid-Attention-Critic for Multi-Logistic Robots Path Planning," in IEEE Robotics and Automation Letters, vol. 9, no. 6, pp. 5559-5566, June 2024, doi: 10.1109/LRA.2024.3396023.

[6] Marina Torres, David A. Pelta, José L. Verdegay, Juan C. Torres, Coverage path planning with unmanned aerial vehicles for 3D terrain reconstruction, Expert Systems with Applications, Volume 55, 2016

[7] E. Viridiana Vazquez-Carmona, Juan Irving Vasquez-Gomez, Juan Carlos Herrera-Lozada, Mayra Antonio-Cruz, Coverage path planning for spraying drones, Computers & Industrial Engineering, Volume 168, 2022

Related Work

	Robots carry and deliver racks	Routing and scheduling			Smart region partition
		Collision-free	On-time delivery	Collaboration of multi-agents	Dynamic boundaries for load balance
[2]	V	V			
[3]	V	V	V		
[4]	V	V	V		
[5]	V	V	V		
RBCCP	V	V	V	V	V

➤ Proposal

Goal: plan collision-free routes for multiple robots

Given

- Robot Position
- Starting point and destination of goods
- Deadline for goods to reach their destination

Constraints

- Goods must reach their destination before the deadline
- Robots must avoid collisions on their routes
- Robots cannot cross dynamically assigned zones

► Additional Features

- **Stackable and separatable racks**
- **Real-time requests**
- **New requests and request removals**
- **Premium process**
- **Dynamic task-aware virtual station assignment**
- **Power-efficient planning**

Additional Features

- **Dynamic task-aware virtual station assignment**

