School of Computer Science
Monash University

Research Proposal — Comp Sci Honours, 2017

Improving Autonomous Vehicles in Warehouses

Phillip Wong 25150510

Supervisor: Daniel Harabor

Contents

Abstract

TODO Warehouse Automation is a cooperative multi-agent pathfinding problem where a number of agents are individually moving inventory from shelves to a picking station.

This project will be looking at two aspects which we suspect will decrease complexity of the pathfinding.

First, is the configuration of the warehouse.

Second, is the positioning of the inventory.

Lastly, we will look at improving on existing cooperative pathfinding techniques - specifically Conflict-Oriented Windowed Hierarchical Cooperative A.

1 Introduction

In warehouse automation, there exists an automated method of moving around inventory to picking stations where human workers will be located to pack the inventory. Automation has mostly utilized conveyor belts for moving inventory, the issue with conveyors is its large operational and rigid infrastructure (Wurman et al. (2008)).

AutoStore (2017) is a recent system which utilizes a grid of stacked bins. Robots move around on top of the grid, lifting bins off the grid and delivering them to a human picker. Some benefits include high storage density and expansion capability but similar to conveyor belts has large operational and maintenance costs. While not much is known about the specifics of AutoStore, we suspect some downsides of this system to include: high retrieval cost when a bin is located at the bottom of the grid and items need to be of similar size to fit into the bins.

In this project we look at Kiva Warehouse-management Systems (now known as Amazon Robotics). In Kiva systems, inventory are stored in shelves known as Storage Pods. Robots known as drive units are capable of picking up these storage pods. Lastly there are picking stations located around the warehouse (see Fig 1 and 2).

Figure 1: A worker picking an order from a storage pod. Underneath, in orange is the drive unit carrying the storage pod. (Al Dekin (2014))

The process for a drive unit is as follows:

1. Unit is assigned an order

2. Unit moves to the storage pod containing the order and picks it up
3. Unit carries the pod to a picking station
4. Human worker picks the order from the pod and packs the inventory
5. Unit returns the pod back to where it was picked up
6. Unit is assigned a new inventory

Kiva systems do not require a complex infrastructure to operate hence solving the main issue of maintenance and operational costs. When a unit malfunctions it can be easily accessed and replaced. While malfunction occurs other units can move around it and the system remains operational. They are also very flexible and can be easily scaled as a warehouse needs only storage pods, a picking station and a number of drive units.

1.1 Need for the study

HALF-DONE Finding an optimal solution to multi-agent pathfinding is an NP-hard problem and has been research a low number of agents. Without optimization this is not an option as Warehouse Automation deals with hundreds of agents, the Office Supply company Staples uses at 500 robots in their $30000m^2$ center (Guizzo (2008)).

Existing literature has mainly focused on improving multi-agent pathfinding, in this project we will .

1.2 Research Aims

TODO In this project we aim to reduce the complexity of Cooperative MAPF by adjusting aspects specific the to Warehouse Automation. On top of that we hope to provide a path oracle which

1.3 Review of the literature

HALF-DONE There are a number of problems in Warehouse Automation, some of these we will be looking at in this project include: multi-agent pathfinding, order sequencing and warehouse design.

In multi-agent pathfinding, Cohen and Koenig (2016) uses highways.

Gu et al. (2010) provides a comprehensive review of warehouse design and performance. It covers 5 major aspects, overall structure, sizing and dimensioning, department layout, equipment selection and operation strategy selection.

De Koster et al. (2007) provides a survey on order picking

Wurman et al. (2008) provides an in depth overview of Kiva Systems, describing their benefits, usages and research areas.

Ma and Koenig (2016) presents a Conflict-Based Min-Cost-Flow algorithm which is correct, complete and optimal. It implements it on Kiva Systems looking at hundreds of agents split into dozens of teams.

De Koster et al. (2007) overview of picking

Boysen et al. (2017) looks at the batching and sequencing of inventory orders which are given to units. Their study found that only half the units is needed when orders are optimized optimized picking allows

2 Research Context/Background

2.1 What is Cooperative Multi-Agent pathfinding

I think I am missing a lot here. Not exactly sure what other background to give besides expanding on Coop MAPF

TODO Cooperative multi-agent pathfinding (MAPF) involves a number of agents in an environment moving to individual locations while avoiding collisions with one another.

Talk about:

- NP-hard
- Optimality has only been done with small number of agents. Not possible here.
- Completeness

3 Research Design

3.1 Path oracle

Strasser et al. (2015)

PLACEHOLDER Decentralised MAPF algorithms usually involve search. A typical problem solving process (e.g. FAR (Wang & Botea, ICAPS 2008)) involves each agent finding a path independent from all the rest (i.e. if there are k agents we solve k single-agent problems separately). When all agents have a path they each take turns moving one step at a time towards their goal. Conflicts are resolved locally choosing in favour of one agent over another in some way (e.g. assign a priority to each agent and always favour the agent with highest priority). We aim to improve efficiency by introducing a path oracle which removes entirely the need to search. The oracle is pre-computed up front and reused for every subsequent pathfinding query thereafter. Since the cost of the initial path searches tends to dominate runtime in MAPF we expect this approach will significantly improve performance. **PLACEHOLDER**

3.2 Warehouse layout

In many studies, the picking station is positioned on one side of the warehouse and the pods are laid out in rows (Fig. 2).

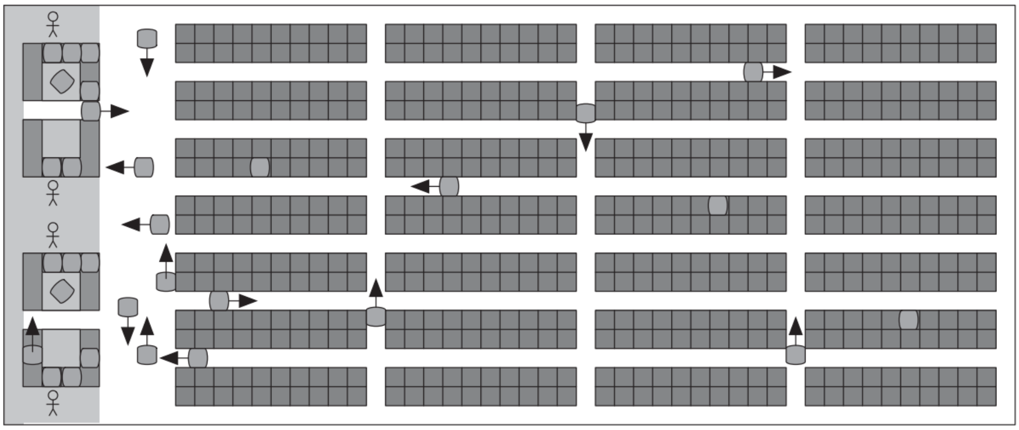

Figure 2: A Small Region of a Kiva Layout (Wurman et al. (2008)). Picking stations located on the left and storage pods laid out in rows.

Wilt and Botea (2014) looked at identifying zones by areas which are bottlenecks and assigning a controller, for that zone which manages any agents who need to travel through the bottleneck. Inspired by this and assuming pickup stations, we plan to split the warehouse into two halves and introduce an intermediate zone (See Fig 3). Delivering pods which are situated in the far zone is a two step process:

1. Units in the far zone move pods to the intermediate zone instead of a pickup station
2. Units in the delivery zone will pickup pods in the intermediate zone

These zones will have their own controller which handles any agents within the zone and tells them what behaviour should occur.

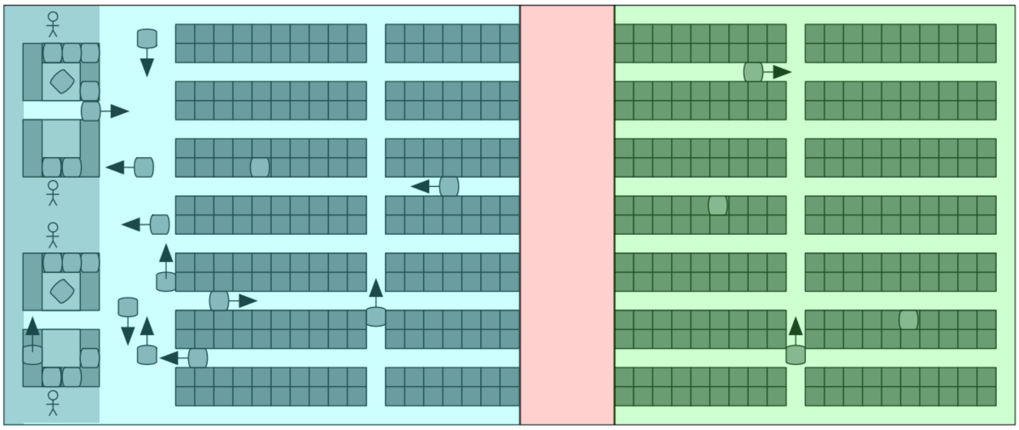

Figure 3: Intermediate zone in red, delivery zone in blue and far zone in green

3.3 Order picking

As pods can be dynamically move around the warehouse, the layout pods can be changed to suit incoming orders. Storage pods containing popular orders may be placed next to a picking station so a drive unit can readily access it and unpopular orders will be placed further away. Vice-versa the distribution of orders can be re-ordered to suit the current layout of the warehouse. Here we may take inspiration from Robin-hood hashing and apply it to sorting the inventory pods. Boysen et al. (2017) covered both of these aspects in detail and revealed that after optimizing orders, the total number of drive units can be cut by half and retain the same supply to picking stations.

3.4 Allowing for movement underneath storage pods

As drive units are capable of moving underneath pods when carrying them, this means that with small adjustments to the dimensions of storage pods it is possible to allow drive units to maneuver underneath the pods. With this the only obstacles in the environment are other drive units.

3.5 Timetable/plan

HALF DONE

Semester 1

Week(s)	Plan
7	Model warehouse and simple A* pathfinding
8	Add multiple agents with A* assigned random pods (no picking station) arsasarsa
9	Implement Cooperative A*
11	Add simple scheduler which assigns agents a location to fetch a random pod and return to the picking station
12	Focus on Interim Presentation
13	Focus on Literature Review
14	Focus on Examinations
Holidays	Implement Path Oracle with Compressed Path Databases

Semester 2

Week(s)	Plan
1	Add more complex scheduler, distributing requested inventory and allow agents dynamically sort pods according to popularity. Agents dynamically sort pods according to popularity. Decide on the focus for the rest of the project.
2-4	Implement Path Oracle with Compressed Path Databases
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	Finish Final Thesis
13	Additional tasks
14	Focus on Final Presentation
15	Focus on Final Thesis

4 Significance / Expected Outcomes of the study

TODO

Contributions

- A Warehouse Automation simulation
- A better understanding of the effects of Warehouse Configurations
- An improved MAPF solution utilizing a path oracle

We should have a better understanding of how the aspects described in Section 3 affect the performance of Warehouse Automation.

Increased inventory supply for the picking stations. Decreasing speed for MAPF calculations.

References

Al Dekin, A. V. (2014). Kiva systems warehouse automation at quiet logistics. **URL:** *https://youtu.be/3UxZDJ1HiPE?t=2m2s*

AutoStore (2017). Autostore introduction. **URL:** *http://autostoresystem.com/thesystem*

Boysen, N., Briskorn, D. and Emde, S. (2017). Parts-to-picker based order processing in a rack-moving mobile robots environment, *European Journal of Operational Research* .

Cohen, L. and Koenig, S. (2016). Bounded suboptimal multi-agent path finding using highways, *Proceedings of the Twenty-Fifth International Joint Conference on Artificial Intelligence*, AAAI Press, pp. 3978–3979.

De Koster, R., Le-Duc, T. and Roodbergen, K. J. (2007). Design and control of warehouse order picking: A literature review, *European Journal of Operational Research* **182**(2): 481–501.

Gu, J., Goetschalckx, M. and McGinnis, L. F. (2010). Research on warehouse design and performance evaluation: A comprehensive review, *European Journal of Operational Research* **203**(3): 539–549.

Guizzo, E. (2008). Three engineers, hundreds of robots, one warehouse, *IEEE spectrum* **45**(7): 26–34.

Ma, H. and Koenig, S. (2016). Optimal target assignment and path finding for teams of agents, *Proceedings of the 2016 International Conference on Autonomous Agents & Multiagent Systems*, International Foundation for Autonomous Agents and Multiagent Systems, pp. 1144–1152.

Strasser, B., Botea, A. and Harabor, D. (2015). Compressing optimal paths with run length encoding, *Journal of Artificial Intelligence Research* **54**: 593–629.

Wilt, C. M. and Botea, A. (2014). Spatially distributed multiagent path planning., *ICAPS*.

Wurman, P. R., D'Andrea, R. and Mountz, M. (2008). Coordinating hundreds of cooperative, autonomous vehicles in warehouses, *AI magazine* **29**(1): 9.