IMPLEMENTATION TRAFFIC CONTROL ALGORITHM FOR MULTI-AGV SYSTEM

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ABSTRACT
Automated Guided Vehicle (AGV) systems are being used in many industrial warehouses for part transferring process and the major challenge is the management of traffic between multiple AGVs. AGV traffic control system with an anti-collision path planning algorithm which can increase the efficiency of the part transferring process in the warehouse. This paper discussed and compared several path planning algorithms and traffic control algorithms that can be implemented for the warehouse AGV systems that have multiple AGV robots. This also proposed the most efficient traffic control algorithm and path planning algorithm with the implementation of the anti-collision algorithm. The proposed AGV traffic control system can be further improved to implement an anti-collision AGV traffic control system in warehouses in Sri Lanka and will be presented as future work in this paper.

Keywords*:* Anti-collision, Traffic control, Warehouse AGV system, Supply Chain, Material Handling.

1. NOMENCLATURE AGV – Automated Guided Vehicle

2. INTRODUCTION
Due growth of supply chain and globalization, it is an issue that should be addressed in the engineering perspective to reduce the complexity. According to the statistics, the global market of the warehouse for drums and barrels have been growing to dominate the market and accounted for more than 36% of the total market share in terms of revenue[1].

With the shortage of labor and increasing retailers offering and fast delivery options the process in a warehouse is getting more complicated over time. Automating the warehouses would increase the efficiency of the warehouse operations. This would lead to an increment of the robotic warehouses which was 2,500 in the year 2018 up to more than 23,000 by 2025.

In the current industry, most of the task is been automated to increase efficiency in the industry. But to get the maximum efficiency from this automation, this automation needs to be synchronized and communication needs to be established. Industry 4.0 or the Industrial Internet of Things (IoT) has been developed through this era with the growing number of computers and devices interconnected in the autonomous systems to peaks its maximum efficiency. The productivity also improved by enabling flexible manufacturing, analytical and cognitive systems[2, 3].

Due to the increase in supply chain complexity [4-6], warehouse operations need to automate to increase the efficiency of those operations. Automated guided vehicles (AGV) widely used in many fully automated and semi- automated warehouses to automate the object transferring services inside the warehouse[7]. Nevertheless, most of the current warehouses are large in scale, implementing a single AGV is insufficient to complete the task inside the warehouse. Therefore, the implementation of Multi-AGV system is required to reduce complexity and the manual workload of a warehouse. However, managing the AGVs in Multi-AGV system to become conflict-free and collision-free is the most challenging task which needs to be solved while implementing the multi-AGV system in a warehouse.

In the current industry, most warehouses are still developing a fully automated warehouse. Therefore, the AGV system needs to be defined as a semi-automated warehouse that involves human interaction in warehouse operations[8]. But most recent research papers proposed AGV traffic control systems for fully automated warehouses that cannot implement on semi-automated warehouses in developing countries like Vietnam.

Implementing a single AGV isn't enough and Multiple AGVs are required to achieve a considerable efficiency. However, implementing Multiple AGV system in an industrial warehouse is a bit challenging because this multiple AGV system requires to implement with a traffic control algorithm to eliminate collisions between AGVs in a dynamic environment[9]. Traffic control algorithms that can be implemented to a multiple AGV system are proposed in many kinds of research [10-15].

This paper presents the developed traffic control algorithm for multiple AGV system and the results of its implementation for the industrial warehouse. The first section presents the overview of currently proposed traffic control algorithms for multiple AGV systems for industrial warehouses in a few types of research. The second section presents the developed algorithm for multiple AGV systems and the implementation and simulation results of a developed algorithm on a real-life industrial warehouse. Finally, a discussion on the future developments and implementation of the developed traffic control algorithm in the warehouse.

3. SYSTEM REQUIREMENTS

When designing a Multiple AGV system for warehouse operations, the AGV system should satisfy two main requirements.

- The system should manage traffic between AGVs to eliminate collisions between AGV.
- AGV system should detect changes in its environment and manage the collision between AGVs and other obstacles such as a human.

To manage the AGV traffic in a warehouse, it needs to eliminate the collision between AGVs and the collision between AGV and the obstacle in the environment. There are three types of collision can be occurred in a static environment.

- Intersection collisions
- Catching up collisions
- Facing collisions

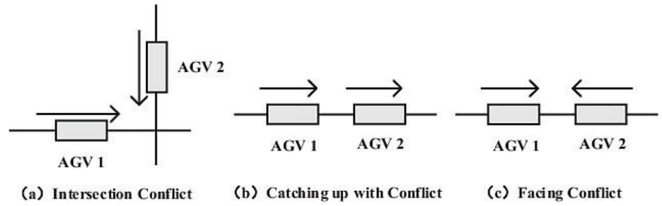

Figure 1: AGV collision types

As seen in Figure 1 Intersection collision occurs at an only node when two AGVs reach the same node at once. And catching up collision occurs when two AGV moving in the same path in the same direction. Facing collisions occurs due to the motion of two AGV on the same path in the opposite direction.

When considering a dynamic environment, the obstacles of the environment keep changing with time. An AGV system should detect these environmental changes and manage collision between AGVs and the obstacles.

4. IMPLEMENTED ALGORITHM

To overcome the implementation problems metioned in the above, a developed AGV traffic control algorithm was proposed in this paper.

A. Environment Modeling

To manage AGVs using the automated system a model of the map is required to the system to plan the task assignment for each AGV. There are several methods of modeling maps for automated systems and in this case topological map was created using the graph theory. More specifically, the graph of the map is presented as $G = (N, E)$, where N is set of nodes and E a set of edges, and each edge in E connects two nodes in N. The weight of edges in E are presented as W_{ij}, where $i \neq j$ and i,j = 1,2, ….., k and k is the number of nodes in the map. When there is no edge between given two nodes, the value of weight is set to zero.

B. Path Planning

Next, the path for each AGV needs to be plan depends on the task demand in the warehouse. For this path planning process, there are many algorithms that can be used, such as the Dijkstra algorithm, A* algorithm, Breath first search, Depth-first search, ant colony algorithm, genetic algorithm, artificial potential field, and fuzzy path planning algorithm[12]. But in this proposed algorithm A* and the Dijkstra path planning algorithms were used due to its efficiency when comparing to the path planning algorithms mentioned before. The planned paths can be represented as P_i, where i = 1,2,….,n and n is the number of AGVs that operate in the warehouse. And P_i is a set of nodes that a specific AGV needs to pass while completing its task.

C. AGV Velocity profile calculation

After planning the path for each AGV according to its task collisions may occurs in a node or in edge after executing the AGVs to complete its tasks. To avoid these collisions between AGVs, AGVs can drive in different velocities along its path. For this, a Velocity profile can be defined for each AGV which includes the velocities that need to be moved along each edge of its planned path. To be more specific velocity profile can present as V_i, where i = 1,2,….,n and n is the number of AGVs that operate in the warehouse. And V_i is a set of velocities that a specific AGV needs travel through each edge.

Velocity profile calculation procedure:

- First, the maximum speed for AGVs should be defined in the system. Because of limited maximum speed, the catch-up conflict between AGVs can be avoided.
- When tasks are assigned to AGVs in the warehouse, a priority level must be assigned to each AGV depends on the length of the path that AGV needs to travel to complete the given task. More specifically if an AGV assigned a task with the longest path, this AGV should have the highest priority.
- Then a simulation must be done before executing AGVs for completing its tasks to calculate the velocity profile and to verify there no collision between AGV when executing the task.
- In the simulation, the location of each AGV was calculated over time. The pre-defined maximum velocity was used to calculate, the first iteration of each AGV's location over the time is stored. Then the calculated locations of all AGVs are used to find any conflicts between each AGV while completing their tasks. When comparing locations of two AGVs, a conflict can be found in these two AGVs that got the same location on a specific time. At this point, the only conflict that can happen was the intersection conflict which occurred in a node. To avoid this type of collision, the velocity of AGV with the lowest priority is needed to be reduced, only for the edge before the node in which collision happens. In this way, velocities need to be reduced to eliminate the collisions. After velocities were changed for the all AGVs, the location estimation overtime for all AGVs must be recalculated and re-compared to find any conflicts. This loop must be done until there are no conflicts between each AGV in the simulation.

D. AGV Collision management on a dynamic environment

Driving AGVs under different velocities on its path using a velocity profile is a strategy that only can eliminate collisions between AGVs. In the implementation process of the AGV system in a semi-automated warehouse, the AGV system should include a strategy to manage the collision between AGV and obstacles in the environment because in a semi-automated warehouse environment keeps change with time due to the human activities.

To detect the environmental changes, all the AGVs should be equipped with environmental scanning sensors such as LIDARs. When any of AGV detects an obstacle while move along its path the AGV should immediately stop to avoid collision and send data about the obstacle location to the control panel. Then the AGVs which path is blocked by obstacle should follow an alternative path which planned using a traffic control algorithm. If these AGVs don't have an alternative path to complete its task, then those AGVs should stop and notify to remove the obstacle.

5. VALIDATION OF THE IMPLEMENTED ALGORITHM

The proposed algorithm is simulated using MATLAB software to check its validity and performances under a real- life situation.

A. Sample Problem Explanation

For the simulation of the proposed algorithm, a real-life map of a warehouse is used.

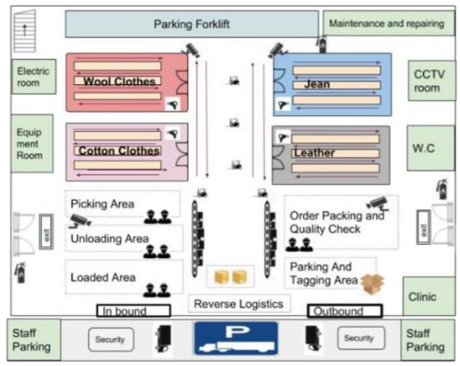

Figure 2: Plan of the sample warehouse

A floorplan of a manually operated warehouse was shown in Figure 2. In this sample warehouse, a package is transferred from picking area to storage and after that, it needs to be transferred to the packing area. This process needs to automate using Multiple AGV systems.

B. Map modeling from Real-life map

The map of the warehouse needs to model as defined for the simulation process. This modeling process starting with recreating a binary image of the floor plan. When creating this binary image, it only included the areas that AGVs needs to move while complete its tasks. In this scenario, the AGV parking area, storage units, picking area, and Packing area were illustrated the binary image of the map.

After the illustration map needs to represented using graph theory (Figure 3). For this, all the data about the node and edges need to define in MATLAB software. After defining data of the map, these nodes and edges can show in the illustrated map

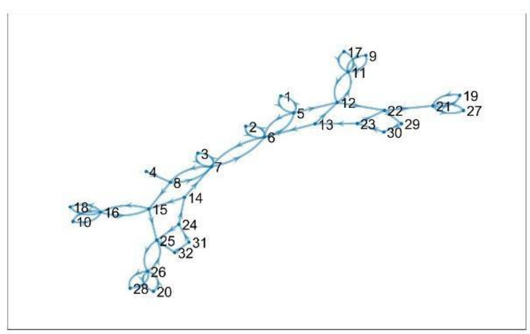

Figure 3: Graph theory representation of the map

C. Path Planning

After representing the map using the graph theory, this model map in MATLAB can be used for the path planning process. For this path planning process, several path planning algorithms can be used such as the Dijkstra algorithm, A* algorithm, Breath first search, Depth-first search, ant colony algorithm, genetic algorithm, artificial potential field, and fuzzy path planning algorithm. But in this simulation Dijkstra algorithm was used due to its ease of implementation. In Figure 4 show the planned path in the MATLAB simulation from starting point to an endpoint.

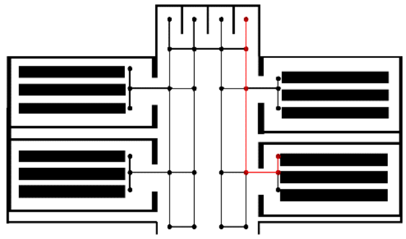

Figure 4: Planned path in simulation

D. Calculation and Simulation of Velocity Profile

After the path planning process velocity profile for each AGV needs to be calculated according to their task assignment. The velocity profile calculation process was done according to the developed velocity profile calculation process. The motion of AGVs with the calculated velocity profile was simulated and the location of the AGVs was plotted with respect to the time domain as seen in Figure 5. The Figure 5 warehouse floor is illustrated from the X and Y axis and the time domain is showed from the Z-axis. According to Figure 5, the plot of the motion of two AGV doesn't interest at any point until the AGVs reaches its goal location. From this plot, a conclusion can be made that developed velocity calculation algorithms calculate velocities for multiple AGV system to eliminate the collisions between AGVs.

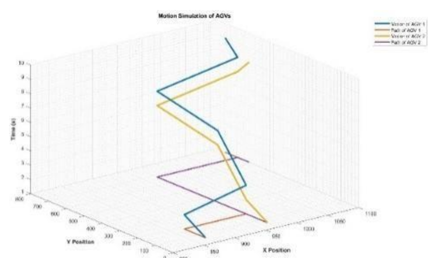

Figure 5: AGV motion simulation in the time domain

6. CONCLUSION AND FUTUREWORKS

Currently, most industrial warehouses need automation for their warehouse operations due to the increase of the supply chain. And the implementation of multiple AGV system is required for this automation. But the major challenge in the implementation process of multiple AGV systems is the managing traffic between AGVs inside the warehouse. As a solution for these, many types of research proposed several traffic control algorithms and most algorithms are defined for the static environment in which human activities are not involved.

In conclusion, this paper presents a traffic control algorithm for multiple AGV system in a dynamic environment, which uses graph theory for map modeling and A* path planning algorithm for the path planning process. Then the time-based method used to simulate and calculate the optimized velocity profile for each AGV to eliminate the collision between AGVs.

As the future works of this research, the AGV traffic control algorithm is further improved for the dynamic environment and proceed simulation for the high number of AGVs and implement this traffic control algorithm on the warehouse in Sri Lanka.

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8. REFERENCES

[1] C. Kasemset and J. Sudphan, "Warehouse storage assignment: The case study of a plastic bag manufacturer," in *2014 IEEE International Conference on Industrial Engineering and Engineering Management*, 9-12 Dec. 2014 2014, pp. 219-222, doi: 10.1109/IEEM.2014.7058632.

[2] S. Park, N. Crespi, H. Park, and S. Kim, "IoT routing architecture with autonomous systems of things," in *2014 IEEE World Forum on Internet of Things (WF-IoT)*, 6-8 March 2014 2014, pp. 442- 445, doi: 10.1109/WF-IoT.2014.6803207.

[3] N. Jazdi, "Dynamic calculation of the reliability of factory automation applications: Industry 4.0 applications," in *2016 IEEE International Conference on Automation, Quality and Testing, Robotics (AQTR)*, 19-21 May 2016 2016, pp. 1-6, doi: 10.1109/AQTR.2016.7501286.

[4] M. Akbari and J. Hopkins, "The changing business landscape in Iran: establishing outsourcing best practices," *Operations and Supply Chain Management: An International Journal*, vol. 9, no. 3, pp. 184-198, 2016.

[5] M. Akbari, "Logistics outsourcing: a structured literature review," *Benchmarking: An International Journal*, vol. 25, no. 5, pp. 1548-1580, 2018.

[6] M. Akbari and J. L. Hopkins, "An investigation into anywhere working as a system for accelerating the transition of Ho Chi Minh city into a more livable city," *Journal of cleaner production*, vol. 209, pp. 665-679, 2019.

[7] S.-n. Liu, "Optimization problem for AGV in automated warehouse system," in *2008 IEEE International Conference on Service Operations and Logistics, and Informatics*, 12-15 Oct. 2008 2008, vol. 2, pp. 1640-1642, doi: 10.1109/SOLI.2008.4682790.

[8] F. Oleari, M. Magnani, D. Ronzoni, and L. Sabattini, "Industrial AGVs: Toward a pervasive diffusion in modern factory warehouses," in *2014 IEEE 10th International Conference on Intelligent Computer Communication and Processing (ICCP)*, 4-6 Sept. 2014 2014, pp. 233-238, doi: 10.1109/ICCP.2014.6937002.

[9] Z. Zhang, Q. Guo, J. Chen, and P. Yuan, "Collision-Free Route Planning for Multiple AGVs in an Automated Warehouse Based on Collision Classification," *IEEE Access*, vol. 6, pp. 26022-26035, 2018, doi: 10.1109/ACCESS.2018.2819199.

[10] C. Secchi, R. Olmi, F. Rocchi, and C. Fantuzzi, "A dynamic routing strategy for the traffic control of AGVs in automatic warehouses," in *2015 IEEE International Conference on Robotics and Automation (ICRA)*, 26-30 May 2015 2015, pp. 3292-3297, doi: 10.1109/ICRA.2015.7139653.

[11] Y. Noh and Y. Yoon, "Tactical traffic control for multiple AGV systems based on three dimensional space," in *AIP Conference Proceedings*, 2016, vol. 1790, no. 1: AIP Publishing, p. 150027.

[12] C. Liu, J. Tan, H. Zhao, Y. Li, and X. Bai, "Path planning and intelligent scheduling of multi-AGV systems in workshop," in *2017 36th Chinese Control Conference (CCC)*, 2017: IEEE, pp. 2735-2739.

[13] Y. Zhang, Z. Zhu, and J. Lv, "CPS-based smart control model for shopfloor material handling," *IEEE Transactions on Industrial Informatics*, vol. 14, no. 4, pp. 1764-1775, 2017.

[14] J. Fang, L. Xiaolong, W. Jichao, S. Yunde, X. Fengyu, and Z. Zhang, "Research on Multi-AGV Autonomous Obstacle Avoidance Strategy Based on Improved A* Algorithm," in *2018 25th International Conference on Mechatronics and Machine Vision in Practice (M2VIP)*, 2018: IEEE, pp. 1-6.

[15] W. Zhang, Y. Peng, W. Wei, and L. Kou, "Real- Time Conflict-Free Task Assignment and Path Planning of Multi-AGV System in Intelligent Warehousing," in *2018 37th Chinese Control Conference (CCC)*, 2018: IEEE, pp. 5311-5316.