EAI Endorsed Transactions
on Context-aware Systems and Applications Research Article **EAI.EU**

Manipulation of the Multi-Vehicle System for the Industrial Applications

Vincent Lourve[1,*]

[1] INP Institute of Engineering, Grenoble Alpes University, Grenoble, France

Abstract

INTRODUCTION: This approach should indicate some challenges in routing and scheduling for the multi-vehicle system.
OBJECTIVES: The proposed method delivers a novel method to generate the free-collision trajectory as well as optimal route from starting point to destination.
METHODS: The estimated time at one node and the classification of load level support vehicle to decide which proper route is and stable movement is reached.
RESULTS: From these results, it could be observed that the proposed approach is feasible and effective for many applications.
CONCLUSION: The proposed method for routing and scheduling might be useful in the multi-vehicle system. In the large-scale system, some intelligent schemes should be considered to integrate.

Keywords: Robotics, Intelligent System, Motion Control, Complex System

Received on 25 September 2023, accepted on 29 September 2023, published on 02 October 2023

doi: 10.4108/eetcasa.v9i1.3978

1. Introduction

In the rapidly evolving landscape of Industry 4.0, technology's transformative power extends its reach far beyond the confines of traditional manufacturing and production processes. It seeps into every corner of modern life, sparking innovations that reshape how human work, live, and move. One such innovation that has garnered significant attention and holds the potential to revolutionize transportation and logistics is the Multi-Vehicle System (MVS) [1-4]. MVS represents a paradigm shift, a convergence of cutting-edge technologies and strategies that are redefining the way human think about mobility, automation, and connectivity.

Industry 4.0, often referred to as the Fourth Industrial Revolution, is characterized by the fusion of the physical and digital worlds [5-7]. It encompasses a vast array of technologies, including the Internet of Things (IoT) [8], big data analytics [9], artificial intelligence (AI) [10], and autonomous systems [11]. These technologies have been harnessed to drive efficiency, productivity, and sustainability across various industries, and transportation and logistics are no exception.

The core concept of the Multi-Vehicle System lies in its ability to create interconnected networks of vehicles, whether they be drones [12], material handling vehicles [13], delivery robots [14], or even conventional trucks [15] and forklifts [16]. These vehicles operate in concert, leveraging real-time data, advanced algorithms, and automation to optimize their movements and tasks. The result is a transportation and logistics ecosystem that is not only more efficient but also smarter and more adaptable.

One of the fundamental pillars of the MVS is automation. Autonomous vehicles, equipped with sensors, cameras, and sophisticated AI, can navigate their environments without human intervention. They can make decisions in real-time, avoiding obstacles, optimizing routes, and ensuring the safe and efficient delivery of

---

[*] Corresponding author. Email: lourve.vincent@gmail.com

goods. In manufacturing plants and warehouses [17, 18], autonomous forklifts and robots collaborate seamlessly, reducing human labour requirements and improving precision and speed.

Connectivity is another key element of the MVS. In the age of Industry 4.0, vehicles are not isolated entities but rather nodes in a vast network. They communicate with each other, with central control systems, and with external data sources [19]. This enables them to share vital information, such as traffic conditions, weather updates, or inventory levels, allowing for dynamic decision-making. This level of connectivity not only enhances efficiency but also contributes to safety, as vehicles can coordinate movements to avoid collisions and other hazards.

2. Background Works

MVS represent a dynamic and evolving field of study within the realm of autonomous robotics and transportation. These systems involve the coordination and control of multiple vehicles to accomplish various tasks, such as exploration, surveillance, transportation, and search and rescue operations. This literature review aims to provide an overview of the key developments, challenges, and trends in the field of multi-vehicle systems, highlighting both historical and recent research contributions [20, 21].

The concept of multi-vehicle systems has its roots in military applications, where fleets of drones and unmanned aerial vehicles (UAVs) were used for reconnaissance and surveillance purposes [22, 23]. Over time, the scope of MVS expanded to include ground-based vehicles like autonomous cars, underwater vehicles, and even swarms of tiny robots. Early research focused on centralized control algorithms, with a key milestone being the development of the Distributed Architecture for Mobile Robotic Teams (DART) framework in the late 1990s, which laid the foundation for decentralized control in MVS.

Central to the success of multi-vehicle systems is the development of effective control and coordination algorithms. Research has explored various strategies, including centralized [24], decentralized [25], and hybrid approaches [26]. Centralized control relies on a central controller that computes the trajectories for all vehicles, while decentralized control enables vehicles to make local decisions based on their surroundings and the information they share with nearby peers. Hybrid approaches combine elements of both to optimize performance and scalability.

Communication among vehicles is essential for information sharing and coordination in MVS. Wireless communication protocols, such as Wi-Fi [27], Zigbee [28], and Bluetooth [29], have been used to establish communication links among vehicles. However, challenges like network connectivity, data latency, and security remain important research areas. Sensing technologies, including GPS [30], LiDAR [31], cameras [32], and other sensors, play a crucial role in perception and decision-making for MVS. Advances in sensor miniaturization and cost reduction have contributed to the growth of multi-vehicle systems.

Multi-vehicle systems find applications in a wide range of fields. In agriculture, fleets of autonomous tractors can optimize farming operations [33]. In environmental monitoring, autonomous drones and underwater vehicles are used for data collection [34]. Autonomous transportation systems, including self-driving cars and delivery drones, aim to revolutionize urban mobility [35]. Search and rescue missions leverage MVS to access hard-to-reach locations during disasters. These diverse applications demonstrate the versatility and potential impact of multi-vehicle systems on society.

Despite significant progress, several challenges remain in the field of multi-vehicle systems. Scalability is a critical concern, as managing large numbers of vehicles efficiently is non-trivial. Safety and reliability issues must be addressed to ensure the safe integration of MVS into real-world environments. Furthermore, ethical considerations and legal frameworks need to be developed to govern the behaviour of autonomous vehicles [36-39]. Research into robust coordination algorithms, adaptive control strategies, and fault tolerance mechanisms is ongoing.

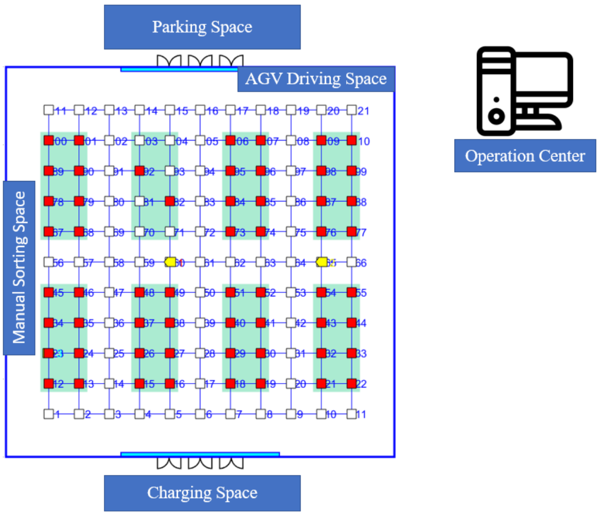

Figure 1. Description of the whole map for this design.

3. Preliminaries

3.1 Overview of system

A cross-docking warehouse represents a specialized facility meticulously designed to streamline the movement of goods within the supply chain. Its primary function revolves around acting as a pivotal distribution centre, where incoming products from suppliers are swiftly received, meticulously organized, and promptly transferred to outbound vehicles for immediate dispatch to customers or other distribution hubs. The layout of a cross-docking warehouse, as depicted in Figure 1, is a well-thought-out configuration comprising several crucial areas [40]:

Receiving Area: This designated zone is where shipments from suppliers are initially received. It is equipped with loading docks and often includes a staging area for temporary storage of incoming merchandise. To expedite the process, efficient unloading methods such as forklifts or conveyor systems are employed to swiftly move items from incoming vehicles to the staging area.

Sorting Area: Once the products have been unloaded and verified for accuracy, they progress to the sorting area. Within this space, goods are meticulously arranged based on their respective destinations or specific criteria, such as product type, size, or customer orders. The sorting process may involve the use of conveyor belts, automated sorting systems, or manual sorting stations, tailored to accommodate the volume and complexity of the operations.

AGV Operating Area: Within the layout of a cross-docking warehouse, there are designated spaces to support various functions essential for its smooth operation. These areas encompass administrative offices, quality control stations, maintenance zones, break rooms, restroom facilities, and spaces for employees. These support areas are strategically situated to ensure convenient access and comprehensive oversight of the warehouse's overall operations.

Furthermore, at the core of the cross-docking warehouse lies the cross-docking zone. This critical section is where incoming products are matched with outgoing orders or consolidated for further distribution. It involves activities such as amalgamating shipments from multiple suppliers, breaking down large shipments into smaller ones, or combining smaller shipments into larger units. The overarching goal is to optimize delivery routes and reduce transportation costs. Additionally, for sustained operation, a charging station is provided to replenish the energy of AGVs when their batteries are running low. The entire system is managed and controlled from an operation centre.

In this system, our model incorporates a configuration comprising two active wheels, two passive wheels, a vision module, and a lifting platform. The active wheels are directly linked to two driving motors, while the passive wheels remain unpowered. When the AGV alters its course, the active wheels adjust their speeds in accordance with forward kinematics and the number of pulses generated. Within the AGV driving space, the area is structured as a grid, with each grid cell referred to as a workstation or node, pinpointed by a QR code, as depicted in Figure 2. This grid-based layout enables the AGV to precisely determine its location, position, and direction of movement. Subsequently, it communicates this positional information to the central system. The cargo area is designated for package storage, while the remaining spaces serve as aisles.

Figure 2. Example of target vehicle.

3.2 Theoretical model

The AGV's structure is illustrated in Figure 3. Key parameters of this vehicle include Ox_Iy_I, which denotes the coordinate system fixed to the ground, Ox_ry_r the coordinate system affixed to the AGV, and θ which signifies the angular deviation between these two coordinate systems. A represents the midpoint of the road connecting the two drive wheels, C marks the AGV's center of mass, R indicates the radius of each wheel, and L signifies the separation distance between the centers of the two wheels.

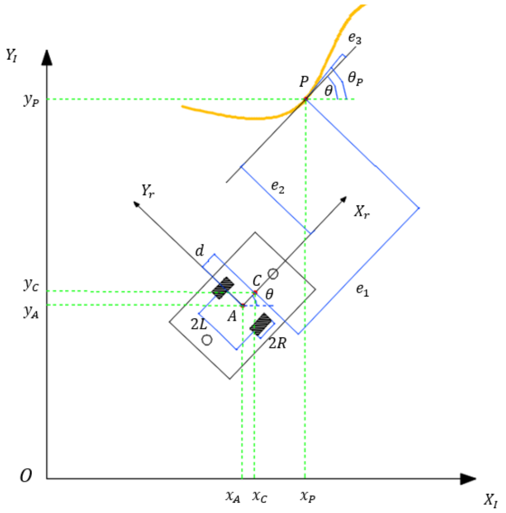

Figure 3. Demonstration of mathematical model.

The velocity equation for the center of mass C of the AGV in the ground-attached coordinate system is expressed as follows:

$$\begin{cases} \dot{x}_c^I = R\dfrac{(\dot{\varphi}_R + \dot{\varphi}_L)}{2} cos\theta - dR\dfrac{(\dot{\varphi}_R - \dot{\varphi}_L}{2L} \\ \dot{y}_c^I = R\dfrac{(\dot{\varphi}_R + \dot{\varphi}_L)}{2} sin\theta + dR\dfrac{(\dot{\varphi}_R - \dot{\varphi}_L}{2L} \\ \dot{\theta}_c = R\dfrac{(\dot{\varphi}_R - \dot{\varphi}_L)}{2L} \end{cases} \qquad (1)$$

In accordance with Figure 3, we must determine three error parameters pertaining to the AGV and the reference point P. Specifically, we define $\mathrm{e}_1, \mathrm{e}_2, \mathrm{e}_3$ as the errors in the X, Y, and Z axes, respectively. Additionally, θ_P represents the angle between the direction of movement and the reference point. In the relative coordinate system affixed to the tracking point C, the following relationships apply:

$$\begin{bmatrix} e_1 \\ e_2 \\ e_3 \end{bmatrix} = \begin{bmatrix} \cos\varphi & \sin\varphi & 0 \\ -\sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_R - x_C \\ y_R - y_C \\ \varphi_R - \varphi_C \end{bmatrix}$$

(Error! No text of specified style in document.)

Or,

$$\begin{bmatrix} \dot{e}_1 \\ \dot{e}_2 \\ \dot{e}_3 \end{bmatrix} = \begin{bmatrix} v_R \cos e_3 \\ v_R \sin e_3 \\ w_R \end{bmatrix} = \begin{bmatrix} -1 & e_2 \\ 0 & -d - e_1 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} v \\ w \end{bmatrix} \qquad (3)$$

4. The Proposed Approach

Motion planning results in determining the precise timing for AGV (Automated Guided Vehicle) movements as they navigate to various workstations. This timing is critical for preventing collisions and avoiding deadlocks. The accuracy of the algorithm plays a significant role in achieving this goal. In the context of cross-docking, AGVs follow routes composed of combinations of straight path segments, with acceleration from 0 m/s and deceleration to 0 m/s occurring at turns, as depicted in Figure 5. The enhanced motion planning algorithm for AGVs can be broken down into four distinct stages:

Step 1: Calculation of the travel time (Δ_{time}) between two nodes within the same route.

Step 2: Integration of these individual travel times (Δ_{time}) to create a comprehensive schedule.

Step 3: Once the schedule is determined, the system can identify potential collisions between this AGV and others, categorizing them based on collision types.

Step 4: The predefined strategies for handling these potential collisions are then implemented on a case-by-case basis.

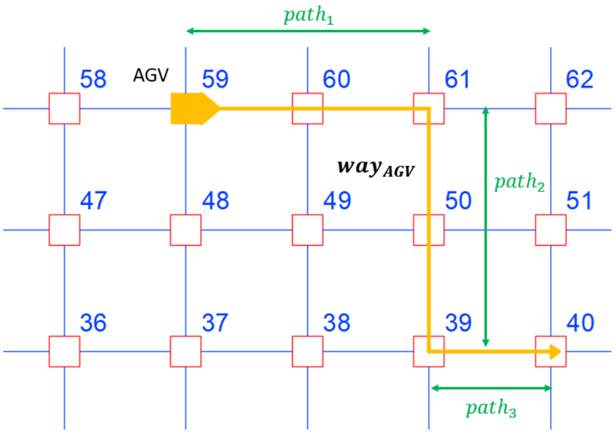

Figure 4. Example to generate the traveling route from several sub-path.

5. Experiment of Study

In this section, our research conducts simulations of this system on a personal computer equipped with highly computational performance, including an Intel Core i7 processor running at 3,300Hz, 8GB of RAM, and the Windows 10 operating system. These simulations take place within the MATLAB software environment and focus on the cross-docking scenario illustrated in Figure 5, featuring several key parameters.

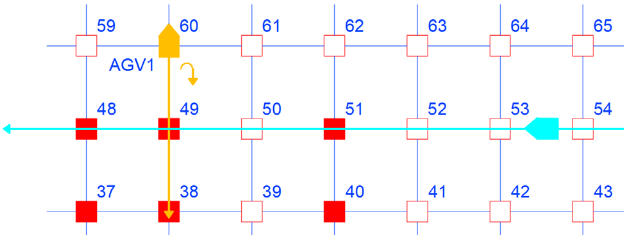

Figure 5. Demonstration of working map for potential collision.

Workstation Separation: The distance between two workstations is set at $\boldsymbol{d_{node} = 4.5\ m}$.

AGV Target Velocity: The desired velocity for the AGV (Automated Guided Vehicle) is defined as $\boldsymbol{v_{TH}}$ = **1.2** $\boldsymbol{(m/s^2)}$.

AGV Acceleration Levels: The AGV's acceleration profile is categorized into four levels based on the load it carries:

Heavy Carry: **a = 0.12** $\boldsymbol{m/s^2}$

Middle Carry: **a = 0.28** $\boldsymbol{m/s^2}$

Small Load: **a = 0.82** $\boldsymbol{m/s^2}$

Without Carry: **a = 1.1** $\boldsymbol{m/s^2}$

Rotation Times: When the AGV undergoes a 90° rotation, it takes $\boldsymbol{t_{90}}$= **6 (s)** to complete the maneuver. Similarly, a 180° rotation is achieved in $\boldsymbol{t_{180}}$= **8 (s)**.

System Safety Thresholds: The system is designed with safety thresholds in mind. The safe operational limits are defined as follows: $\boldsymbol{\mu_1 = 12.6\ (s)}$ and $\boldsymbol{\mu_1 = 10.2\ (s)}$.

In these experiments, it has been observed that the previous planner [41] exhibits certain limitations when estimating travel times for AGVs as they traverse towards their target nodes. Particularly, for complex routes or when transporting larger payloads, these limitations can lead to issues in collision avoidance and, in some cases, unfortunate collisions. However, this study introduces a novel approach that effectively mitigates these shortcomings. To elaborate, let's consider the scenario in which AGV2 initiates its movement from workstation 54, as illustrated in Figure 5. Approximately 4.1 seconds after AGV2 begins its movement, another vehicle, AGV1, is tasked with moving from workstation 60 to workstation 38. During this phase, our system takes on the responsibility of scheduling AGV1's movements. For our experiment, we designate the starting moment of AGV1's motion as the reference time point.

5. Conclusion

Our study introduces a method for detecting potential collisions within a large-scale system that incorporates multiple AGVs. The layout of our workspace consists of both vertical and horizontal lines serving as reference trajectories for vehicle movements. Additionally, we have integrated a digital camera on the underside of each AGV to identify lane boundaries and relay this information to the main microprocessor. Our proposed method involves a four-step mechanism to identify possible collisions and offers a novel strategy for collision avoidance. To showcase the effectiveness and practicality of our approach, we conducted a comparative analysis between our proposed method and a prior approach, providing a detailed explanation of the results. Looking ahead, our future endeavours involve establishing a hardware platform for multi-vehicle systems to implement our algorithm successfully. Furthermore, we intend to enhance the system's performance by integrating intelligent algorithms such as machine learning or reinforcement learning into our approach.

References

[1] Nirmale, S., Sharma, A., & Pinjari, A. R. (2023). Multi-vehicle anticipation-based driver behavior models: a synthesis of existing research and future research directions. *Transportation Letters*, 1-20.

[2] Montoya-Torres, J. R., Franco, J. L., Isaza, S. N., Jiménez, H. F., & Herazo-Padilla, N. (2015). A literature review on the vehicle routing problem with multiple depots. *Computers & Industrial Engineering*, *79*, 115-129.

[3] Braekers, K., Ramaekers, K., & Van Nieuwenhuyse, I. (2016). The vehicle routing problem: State of the art classification and review. *Computers & industrial engineering*, *99*, 300-313.

[4] Huang, S., Teo, R. S. H., & Tan, K. K. (2019). Collision avoidance of multi unmanned aerial vehicles: A review. *Annual Reviews in Control*, *48*, 147-164.

[5] Pereira, A. C., & Romero, F. (2017). A review of the meanings and the implications of the Industry 4.0 concept. *Procedia manufacturing*, *13*, 1206-1214.

[6] Peres, R. S., Jia, X., Lee, J., Sun, K., Colombo, A. W., & Barata, J. (2020). Industrial artificial intelligence in industry 4.0-systematic review, challenges and outlook. *IEEE Access*, *8*, 220121-220139.

[7] Oztemel, E., & Gursev, S. (2020). Literature review of Industry 4.0 and related technologies. *Journal of intelligent manufacturing*, *31*, 127-182.

[8] Ngo, H. Q. T., Nguyen, T. P., & Nguyen, H. (2019, November). Hardware Design for Intelligent IoT Approach to Optimize Parking Slots. In *2019 International Conference on Advanced Computing and Applications (ACOMP)* (pp. 171-175). IEEE.

[9] Qi, Q., & Tao, F. (2018). Digital twin and big data towards smart manufacturing and industry 4.0: 360 degree comparison. *Ieee Access*, *6*, 3585-3593.

[10] Ngo, H. Q. T. (2023). Design of automated system for online inspection using the convolutional neural network (CNN) technique in the image processing approach. *Results in Engineering*, 101346.

[11] Faisal, A., Kamruzzaman, M., Yigitcanlar, T., & Currie, G. (2019). Understanding autonomous vehicles. *Journal of transport and land use*, *12*(1), 45-72.

[12] Tran, H. A. M., Ngo, H. Q. T., Nguyen, T. P., & Nguyen, H. (2018, November). Research on aerial vehicle for robust navigation system under natural disaster. In *2018 4th International Conference on Green Technology and Sustainable Development (GTSD)* (pp. 306-311). IEEE.

[13] Ngo, H. Q. T., Nguyen, H., & Nguyen, T. P. (2022). Approaching to the stable transportation based on motion profile phases for material handling system. *Journal of Cleaner Production*, *371*, 133257.

[14] Figliozzi, M., & Jennings, D. (2020). Autonomous delivery robots and their potential impacts on urban freight energy consumption and emissions. *Transportation research procedia*, *46*, 21-28.

[15] Khalaji, A. K., & Moosavian, S. A. A. (2016). Stabilization of a tractor-trailer wheeled robot. *Journal of Mechanical Science and Technology*, *30*, 421-428.

[16] Milanowicz, M., Budziszewski, P., & Kędzior, K. (2018). Numerical analysis of passive safety systems in forklift trucks. *Safety science*, *101*, 98-107.

[17] Huynh, V. N. S., Ngo, H. Q. T., Nguyen, T. P., & Nguyen, H. (2020). High performance of an adaptive sliding mode controller under varying loads for lifting-type autonomous grounded robot. *Applied sciences*, *10*(17), 5858.

[18] Ngo, H. Q. T., Nguyen, T. P., & Nguyen, H. (2019). Research and develop of AGV platform for the logistics warehouse environment. In *Proceedings of the Future Technologies Conference (FTC) 2018: Volume 2* (pp. 455-465). Springer International Publishing.

[19] Abdirad, M., Krishnan, K. K., & Gupta, D. (2023). Dynamic multi-depot vehicle routing problem in the era of Industry 4.0. *International Journal of Procurement Management*, *18*(1), 68-81.

[20] Yao, Q., Tian, Y., Wang, Q., & Wang, S. (2020). Control strategies on path tracking for autonomous vehicle: State of

the art and future challenges. *IEEE Access*, *8*, 161211-161222.

[21] Phuc, T. T., & Ha, P. T. M. (2022, November). A Proposed Model for DDMRP Implementation and Application in a Plastic Manufacturing Company. In *International Conference on Material, Machines and Methods for Sustainable Development* (pp. 221-228). Cham: Springer Nature Switzerland.

[22] Mohsan, S. A. H., Khan, M. A., Noor, F., Ullah, I., & Alsharif, M. H. (2022). Towards the unmanned aerial vehicles (UAVs): A comprehensive review. *Drones*, *6*(6), 147.

[23] Tran, A. S., Vo, A. H., Tu, D. C. T., & Ngo, H. Q. T. (2021). Dynamical analysis and validation of motion control by filtering performance for aerial robotic system. *Journal of Vibroengineering*, *23*(6), 1456-1475.

[24] Li, S. E., Zheng, Y., Li, K., Wu, Y., Hedrick, J. K., Gao, F., & Zhang, H. (2017). Dynamical modeling and distributed control of connected and automated vehicles: Challenges and opportunities. *IEEE Intelligent Transportation Systems Magazine*, *9*(3), 46-58.

[25] Le, T. S., Nguyen, T. P., Nguyen, H., & Ngo, H. Q. T. (2023). Integrating Both Routing and Scheduling Into Motion Planner for Multivehicle System. *IEEE Canadian Journal of Electrical and Computer Engineering*, *46*(1), 56-68.

[26] Ho, S. C., & Szeto, W. Y. (2017). A hybrid large neighborhood search for the static multi-vehicle bike-repositioning problem. *Transportation Research Part B: Methodological*, *95*, 340-363.

[27] Kim, M., Do, Y., & Jeon, J. (2022, January). Wireless ECU reprogramming for multiple vehicles in factories and service centers via WiFi. In *2022 16th International Conference on Ubiquitous Information Management and Communication (IMCOM)* (pp. 1-5). IEEE.

[28] Pereira, D. S., De Morais, M. R., Nascimento, L. B., Alsina, P. J., Santos, V. G., Fernandes, D. H., & Silva, M. R. (2020). Zigbee protocol-based communication network for multi-unmanned aerial vehicle networks. *IEEE Access*, *8*, 57762-57771.

[29] Yuan, G., Ze, Z., Changcheng, H., Chuanqi, H., & Li, C. (2020). In-vehicle localization based on multi-channel Bluetooth Low Energy received signal strength indicator. *International Journal of Distributed Sensor Networks*, *16*(1), 1550147719900093.

[30] Ngo, H. Q. T., Cao Tri, H., Tu, N. T., Bao, D. N. T., Anh Duy, P. L., Phat, K. M., ... & Tin, N. T. (2022). Design of reconfigurable mechanism for underactuated robot in the grounded applications. *Cogent Engineering*, *9*(1), 2095882.

[31] Ngo, H. Q. T. (2021). Recent Researches on Human-Aware Navigation for Autonomous System in the Dynamic Environment: An International Survey. In *Context-Aware Systems and Applications: 10th EAI International Conference, ICCASA 2021, Virtual Event, October 28–29, 2021, Proceedings 10* (pp. 267-282). Springer International Publishing.

[32] Nguyen, T. P., Nguyen, H., & Ngo, H. Q. T. (2023). Visual application of navigation framework in cyber-physical system for mobile robot to prevent disease. *International Journal of Advanced Robotic Systems*, *20*(2), 17298806231162202.

[33] Ngo, H. Q. T., Huynh, V. N. S., Nguyen, T. P., & Nguyen, H. (2020). Sustainable agriculture: stable robust control in presence of uncertainties for multi-functional indoor transportation of farm products. *Agriculture*, *10*(11), 523.

[34] Duy, N. V. A., & Hà, P. T. M. Điều độ hoạt động của cần cẩu bờ cảng hàng hỗn hợp tại Việt Nam. *Science and Technology Development Journal*, *20*(K6-2017).

[35] Thien, N. H., Phat, N. T., Dung, N. T. A., & Ha, P. T. M. (2022). Designing a warehouse management system in Vietnam.

[36] Yang, Q., Fu, S., Wang, H., & Fang, H. (2021). Machine-learning-enabled cooperative perception for connected autonomous vehicles: Challenges and opportunities. *IEEE Network*, *35*(3), 96-101.

[37] Eskandarian, A., Wu, C., & Sun, C. (2019). Research advances and challenges of autonomous and connected ground vehicles. *IEEE Transactions on Intelligent Transportation Systems*, *22*(2), 683-711.

[38] Niu, Z., Shen, X. S., Zhang, Q., & Tang, Y. (2020). Space-air-ground integrated vehicular network for connected and automated vehicles: Challenges and solutions. *Intelligent and Converged Networks*, *1*(2), 142-169.

[39] Guanetti, J., Kim, Y., & Borrelli, F. (2018). Control of connected and automated vehicles: State of the art and future challenges. *Annual reviews in control*, *45*, 18-40.

[40] Phan, M. H., Thinh, N. H. Q., Kieu, T. T., & Thai, L. Y. (2020). Redesigning Finished Product Warehouse Layout-A Case Study. *Applied Mechanics and Materials*, *902*, 103-113.

[41] Chen, J., Zhang, X., Peng, X., Xu, D., & Peng, J. (2022). Efficient routing for multi-AGV based on optimized Ant-agent. *Computers & Industrial Engineering*, *167*, 108042.