Advanced Logistic Systems – Theory and Practice, Vol. 17, No. 2 (2023), pp. 5-13.
https://doi.org/10.32971/als.2023.011

EXAMPLES FOR THE APPLICATION OF RULE-BASED ALGORITHMS IN THE SIMULATION MODELLING OF THE PHYSICAL SEPARATION OF AUTOMATED GUIDED VEHICLES

RÓBERT SKAPINYECZ[1]

Abstract: *Nowadays, in parallel with the rapid spread of modern automation and digitalization solutions, different autonomous systems are playing an increasingly important role in the field of industry and logistics, a classic example of which is the case of automated guided vehicles (AGVs). Although these devices have been in use for a long time in the aforementioned areas, at the same time, in parallel with the progress of automation in the recent period, in many cases they can be seen more and more as autonomous mobile robots (AMRs), which perform the tasks assigned to them with a high degree of independence. At the same time, issues such as the problem of preventing collisions between individual freely moving vehicles in industrial environments naturally come to the fore. The purpose of this publication is to provide an example for the structure of some simpler rule-based algorithms in response to the former question, which may be relevant in terms of avoiding some potential collision situations of lower complexity. The operation of the algorithms was represented using the Siemens Tecnomatix Plant Simulation discrete event simulation software.*

Keywords: *automation, AGVs, collision avoidance, simulation*

1. INTRODUCTION

In the recent period, as a result of the rapid rise of the Industry 4.0 concept, the demand for various automation solutions has increased tremendously both in the industry in general and in the field of logistics. One of the most obvious examples of this is the rapid spread of the use of modern automated guided vehicles (AGVs) [1]. This type of equipment has long been present in the most diverse areas of the industry and the economy, but at the same time, vehicles with a high degree of autonomy, which the literature already defines as autonomous mobile robots (AMR), are becoming increasingly widespread. The possibilities of utilization of such equipment are extremely wide, thanks to their high degree of independence and flexibility, which enables their application ranging from the fulfilment of traditional material handling tasks through performing more complex logistics functions to the specialized use cases in the health sector [2].

At the same time, the rapid spread of the devices in question naturally brings to the fore the challenges related to the development and operation of such systems, as well as the possibilities for future development directions [3]. Among the many development areas, one of the most important is obviously the utilization of advanced navigation algorithms, especially with regard to the proper physical separation of vehicles. The latter naturally represents a complex problem that can only be solved by using sophisticated algorithms, many of which increasingly utilize the potential of machine learning. For example, Hu et al. used a multi-agent reinforcement learning based approach to solve the problem of anti-conflict path planning for AGVs in automated container terminals [4]. Liang et al. applied multi-sensor fusion and deep reinforcement learning for the real time collision avoidance of

[1]associate professor., Institute of Logistics, Miskolc, Hungary
robert.skapinyecz@uni-miskolc.hu

mobile robots in dense crowds [5]. Hu et al. applied a combined approach based on behaviour trees and reinforcement learning for the development of a self-adaptive traffic control model for AGVs in the Industry 4.0 paradigm [6]. As another example, Jeon et al. utilized a Q-learning technique for the routing of automated guided vehicles in container terminals [7].

At the same time, there are many special situations regarding the movement of vehicles in relation to each other, in which case the physical separation between devices could be ensured by using relatively simple algorithms. The purpose of the publication is to present two such simpler, rule-based approaches that can be part of a complex collision avoidance algorithm, even as submodules designed to handle simpler cases. It should be noted, however, that both example algorithms can only be used with complete safety only when the trajectory of the other AGV can be accurately specified in advance and there is no need to count on additional vehicles in the area in question from the point of view of maneuvering.

The operation of the two procedures is also presented in the publication with the help of simulation. The Siemens Tecnomatix Plant Simulation software (version 16.0) was used for this, which is one of the most widely used discrete event simulation environments. These types of software are also important because, within the framework of the Industry 4.0 concept, their role has particularly increased in terms of modelling industrial and logistics processes, especially in relation to the creation of so-called digital twins [8]. That is the reason why it is useful to model the movement and operation of modern automated guided vehicles with the help of such software, as this task may become increasingly important from the perspectives of both the industry and of the area of research and development.

2. DESCRIPTION OF THE FIRST ALGORITHM

The first algorithm to be presented is based on a relatively simple principle, which can essentially be summarized as if another vehicle comes within a certain safety distance from the given AGV, then the latter stops and remains in this state until the other device does not move far enough to leave the safety zone of the equipment in question.

Fig. 1 on the following page shows how this simple principle works (the safety distance in this case is 8 meters). In this implementation the algorithm was realized in the form of a method that essentially starts parallel to the beginning of the simulation and only stops when it is ended (if the algorithm would had been developed for a real AGV, then by definition it would run from the start of the device as long as the latter is in operation). So in this implementation, it is essentially a self-repeating cycle that is only interrupted by stopping the simulation. The safety distance of eight meters is, of course, significantly greater than that used by the emergency stop algorithms of equipment operating in an actual real environment. However, this latter procedure, which is activated in the event of the emergence of a sudden obstacle in the vicinity of the vehicle, is very similar in principle to the current algorithm. During the run of the simulation, even this simple algorithm could occasionally ensure physical isolation between the two vehicles in some more complex situations, primarily due to the relatively large safety distance (the simulation was limited to the modelling of two vehicles).

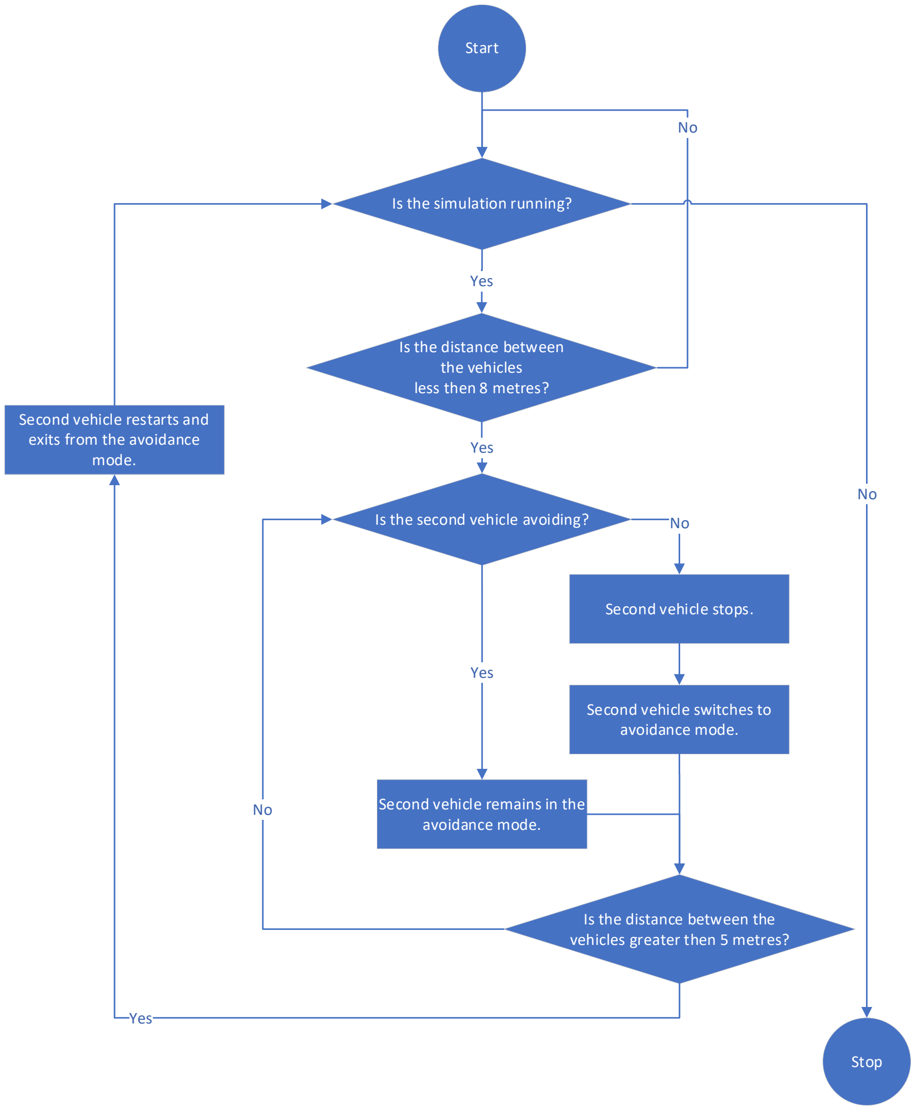

Figure 1. Flowchart of the simpler algorithm based solely on stopping the second vehicle

The operation of the algorithm in a simulation model can be seen in the next two figures. The first of these (numbered as Fig. 2.) shows how the second vehicle coming from below stops according to the previously described algorithm, while the first vehicle coming from above starts a left-turning maneuver right in front of the second one (this is not part of the algorithm, the reason of the maneuver is simply that the destination of the first vehicle is the drain located on the right side of the figure, so the vehicle starts to turn towards it exactly in this moment).

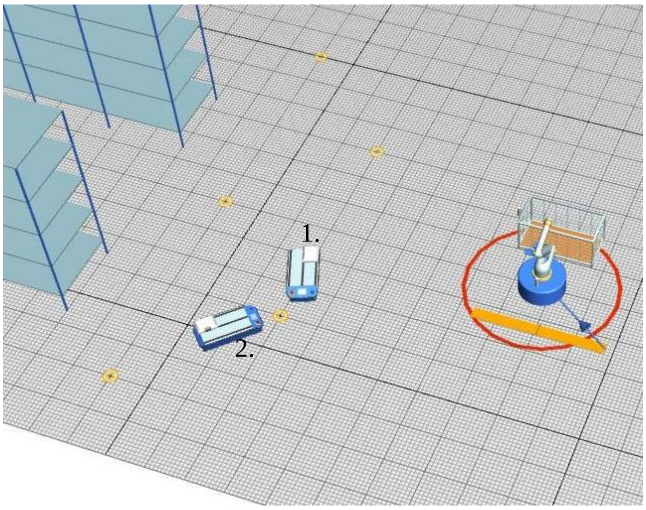

Figure 2. According to the described algorithm, the second vehicle stops in front of the first vehicle approaching from the other direction (from above)

According to the algorithm described in Fig. 1, the second vehicle remains in a stationary position until the first vehicle moves eight meters away from it, which in this case will only happen when the latter has already stopped on the orange-marked track section located in front of the destination station. Of course, in reality, AGVs operate with a much smaller safety distance, however, as mentioned earlier, this simple procedure was used alone in the current simulation model, so the oversized minimum distance was required in order to ensure the physical separation between the vehicles in the described situation. In the following Fig. 3, the first vehicle has already partially turned to the left in front of the second vehicle, which is still stationary.

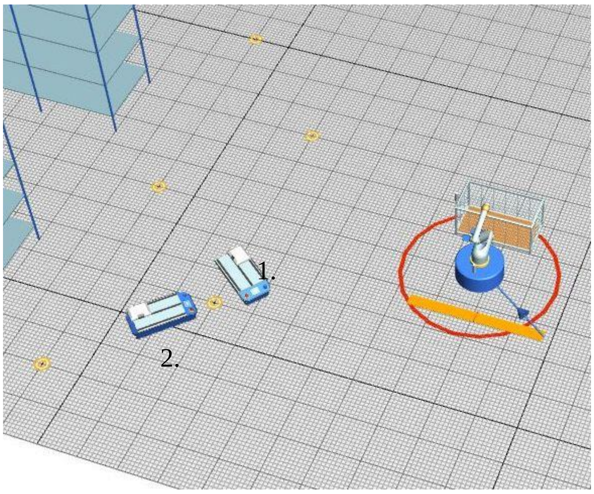

Figure 3. The second vehicle waits in a stationary position, while the vehicle coming from the other direction turns to the left (from its own perspective) and heads toward the destination

As it is mentioned before, it is important to see that, in essence, this simple procedure is the one that AGVs use in reality to avoid collisions with suddenly arising obstacles (this could even be the case with persons stepping in front of the vehicle). In this sense, the procedure actually works in practice like a submodule that stops the equipment in the event of an emergency, overwriting all other movement programs. A common solution for detecting sudden obstacles is, for example, the use of ultrasonic sensors along the entire outline of the vehicle. At the same time, it is very important to point out that in reality this procedure cannot be used for anything else, only and exclusively for this, so to solve cases such as those shown in Fig. 2 and 3, a significantly more complex approach is needed in order to completely eliminate possible collisions.

3. DESCRIPTION OF THE SECOND ALGORITHM

The second described algorithm differs from the previous one primarily in that in this case the second vehicle does not merely stop, but also deviates in a specific direction and extent. After that, in a manner similar to that described in the case of the previous algorithm, it remains stationary until the first vehicle moves away beyond the safety distance (6 meters in this case). After that, the second vehicle first executes a maneuver returning to its original route, and then continues its journey.

It is clear that the algorithm described above works well mainly if the two vehicles approach each other basically face-to-face or with a relatively small angular deviation. The following 4 consecutive figures show an example of this. Fig. 4, the first of these, shows how the second vehicle coming from the right is just starting the evasive maneuver, as the distance between vehicle 1 and 2 has decreased to less than 6 meters.

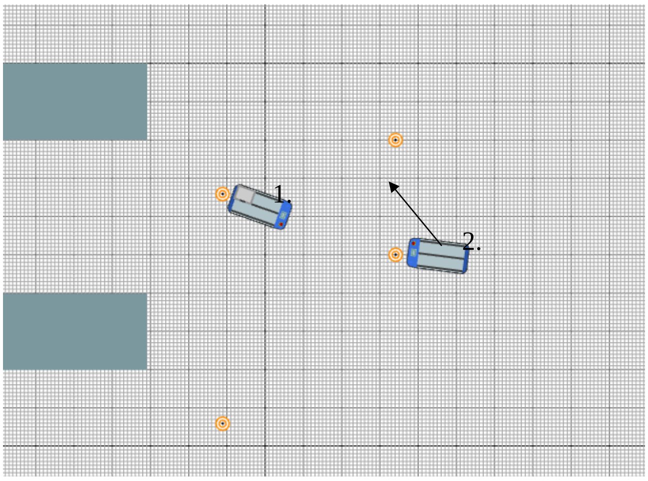

Figure 4. The second (unloaded) vehicle coming from the right starts to swerve to the right at a 45 degree angle to the direction of travel at the beginning of the evasive movement

The following Fig. 5 shows how the second vehicle largely performed the evasive maneuver. while the first vehicle continues straight along its original route.

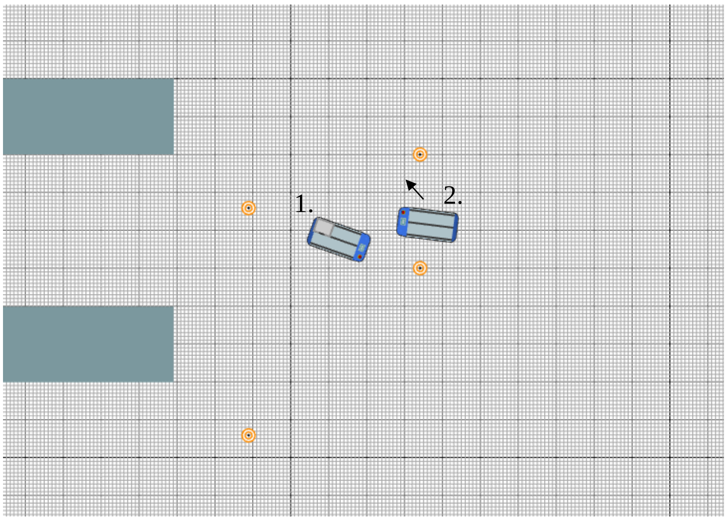

Figure 5. The second vehicle coming from the right obviously evaded significantly in front of the first vehicle coming directly from the left side

In the following Fig. 6, the second vehicle can be seen already in a stationary position while waiting for the first vehicle to pass by and for the distance between the two AGVs to increase again to more than 6 meters.

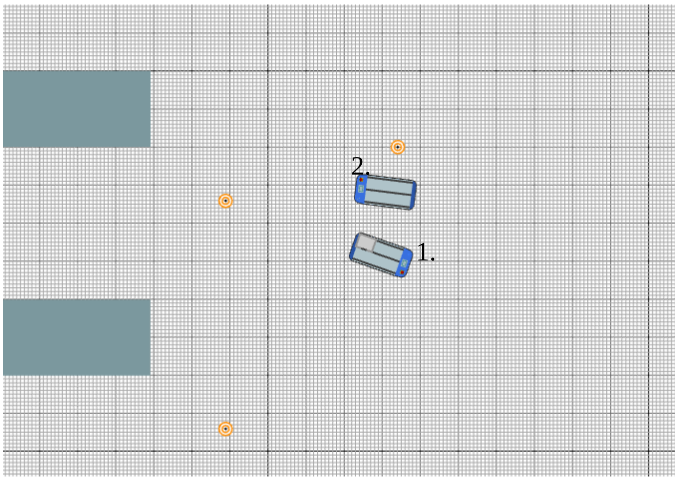

Figure 6. The two vehicles pass each other while the second vehicle (top AGV in the picture) waits in a stationary position after executing the evasion

Finally, it can be seen in Fig. 7, as soon as the required minimum distance value between the two vehicles is reached, the second vehicle restarts, first starting with the return maneuver (it moves 2.5 meters at an angle of 45 degrees to the left in relation to the original direction of travel), after which it continues the original route.

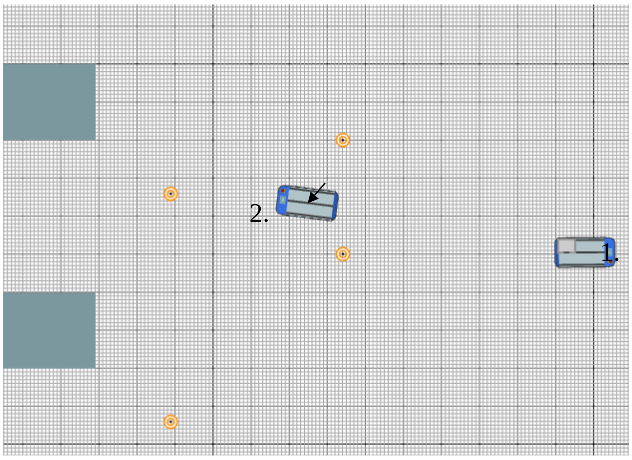

Figure 7. After the vehicle that originally came from the left has moved away considerably, the second vehicle starts again, first performing a "return" maneuver

Although the algorithm described above is already able to handle a significantly larger set of cases compared to the first described procedure, it is still only a limited applicable solution. The reasons for this are obvious:

- since the vehicle in question always deviates in the same direction and to the same extent, situations can easily occur where this is not a solution, for example, if the other vehicle is coming from such an angle that the two devices would also meet each other in this case as well, or if some other object would prevent the implementation of the pre-defined evasive maneuver,
- there may also be cases where the trajectories of the two vehicles differ to such an extent that there is no risk of a collision between them, but due to the rigidly defined algorithm, the vehicle in question will also perform the evasive maneuver in this case, thereby unnecessarily slowing down the material handling process,
- under certain circumstances, a collision between the two devices could be avoided if the vehicle in question simply continued straight on or stopped, but the evasive maneuver performed according to the rigid rule just causes a physical encounter.

Due to the shortcomings listed above, of course, the present method cannot be used by itself, and its possibilities of use are also considerably limited. At the same time, in addition to the use of additional safety procedures, its application can be useful in cases where the other vehicle predictably arrives strictly from the front and the space available to perform the evasive maneuver is guaranteed, for example in the case of well-defined, longer and sufficiently wide straight road sections. A simple safety solution, essentially based on the previous example, could be for both vehicles to stop if they get too close to each other, adding that this could lead to a deadlock condition (both vehicles remain stationary), which would also need to be resolved somehow. It can therefore be seen from this that the examined problem area covers a very complex set of questions, the answer to which, in addition to the combination of simple rule-based approaches, also requires the use of higher-level procedures, with special emphasis here on the field of machine learning, which has shown extraordinary development in the recent period. At the same time, simpler algorithms such as the procedure presented in the current example can also be used as part of a complex solution in certain simpler situations, and with due consideration of the known limitations. The diagram for the current algorithm is shown in the following Fig. 8.

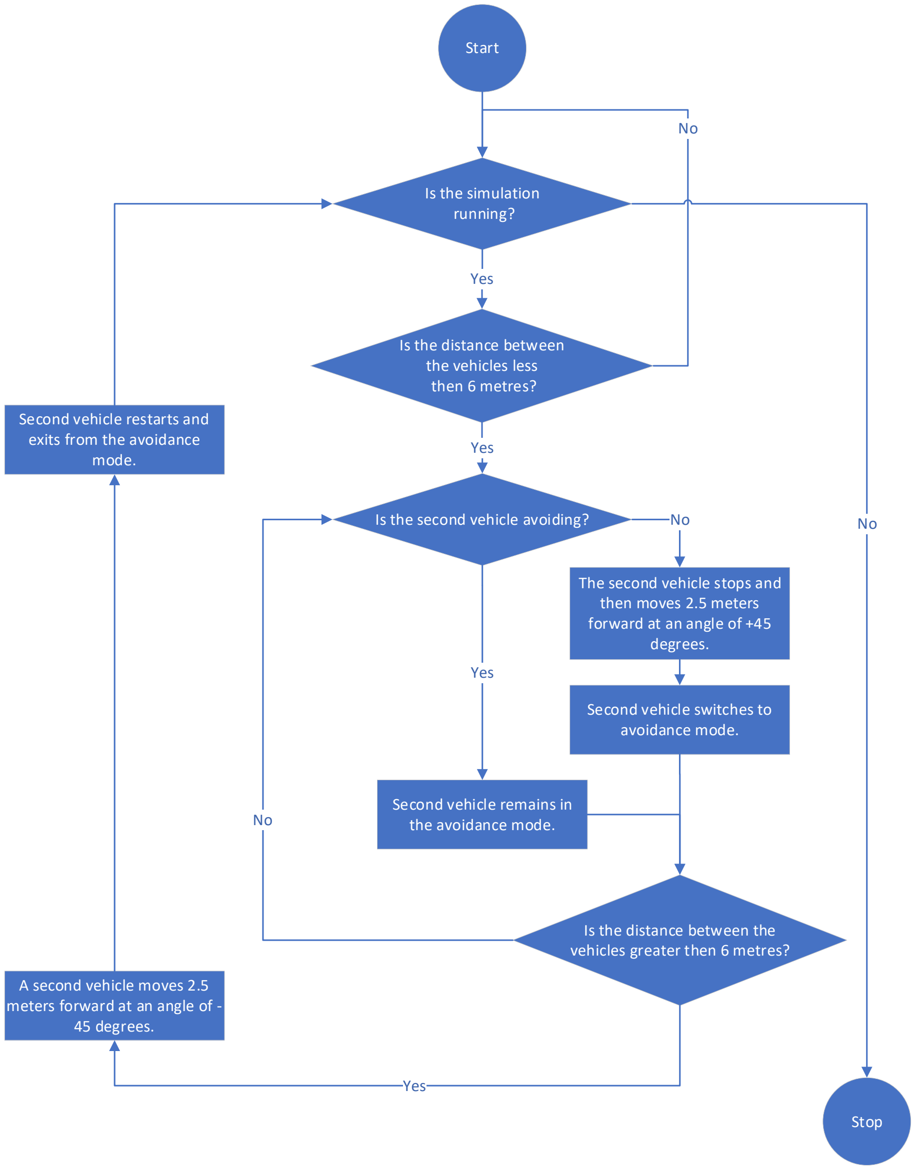

Figure 8. Flowchart of the algorithm for avoiding collisions using an evasive maneuver

4. SUMMARY

Two simpler, rule-based algorithms were presented in the publication, which can be used in certain well-defined cases in the simulation modelling of the physical separation of modern AGVs. Of course, none of the procedures can be used by themselves, which should be particularly emphasized in case the possibility of implementation in an actual physical system arises. At the same time, as additional elements of a complex navigation module increasingly based on machine learning, the described algorithms can also be useful for the fast and efficient solution of some special, simpler situations. The latter is especially true in relation to the first procedure, which is essentially used in a similar form in practice for the purpose of emergency stop to prevent collisions with obstacles that suddenly appear in front of the vehicle.

REFERENCES

[1] Cservenak, Á., Tamás, P., Landschützer, C., & Illés, B. (2022). Application of AMR-type material handling in logistics. *AJME-Academic Journal of Manufacturing Engineering*, **20**(4), 19-25.

[2] Bányai, T., Maral, I., Illés, B., Bányai, Á., & Tamás, P. (2020). Optimization of Operation Strategy for Collection Systems of Biohazard Wastes in Hospitals Based on Autonomous Robots: A Heuristic Approach. *Asian Journal of Research in Computer Science*, **5**(4), 33-43, https://doi.org/10.9734/ajrcos/2020/v5i430142

[3] Alatise, M. B., & Hancke, G. P. (2020). A review on challenges of autonomous mobile robot and sensor fusion methods. *IEEE Access*, **8**, 39830-39846, https://doi.org/10.1109/ACCESS.2020.2975643

[4] Hu, H., Yang, X., Xiao, S., & Wang, F. (2023). Anti-conflict AGV path planning in automated container terminals based on multi-agent reinforcement learning. *International Journal of Production Research*, **61**(1), 65-80, https://doi.org/10.1080/00207543.2021.1998695

[5] Liang, J., Patel, U., Sathyamoorthy, A. J., & Manocha, D. (2020). *Realtime collision avoidance for mobile robots in dense crowds using implicit multi-sensor fusion and deep reinforcement learning*. arXiv preprint arXiv:2004.03089.

[6] Hu, H., Jia, X., Liu, K., & Sun, B. (2021). Self-adaptive traffic control model with Behavior Trees and Reinforcement Learning for AGV in Industry 4.0. *IEEE Transactions on Industrial Informatics*, **17**(12), 7968-7979, https://doi.org/10.1109/TII.2021.3059676

[7] Jeon, S. M., Kim, K. H., & Kopfer, H. (2011). Routing automated guided vehicles in container terminals through the Q-learning technique. *Logistics Research*, **3**, 19-27. https://doi.org/10.1007/s12159-010-0042-5

[8] Skapinyecz, R., Illés, B., & Bányai, Á. (2018). Logistic aspects of Industry 4.0. *In IOP Conference Series: Materials Science and Engineering* **448**(1), 012014, IOP Publishing. https://doi.org/10.1088/1757-899X/448/1/012014