



Development of an AGV system using MBSE method and multi-agents' technology

Khalil Aloui, Moncef Hammadi, Amir Guizani, Thierry Soriano, Mohamed Haddar

► To cite this version:

Khalil Aloui, Moncef Hammadi, Amir Guizani, Thierry Soriano, Mohamed Haddar. Development of an AGV system using MBSE method and multi-agents' technology. Design and Modeling of Mechanical Systems - V, Springer International Publishing, pp.103-114, 2023, Lecture Notes in Mechanical Engineering, 10.1007/978-3-031-14615-2_13 . hal-03590002

HAL Id: hal-03590002

<https://hal.science/hal-03590002>

Submitted on 26 Feb 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Development of an AGV system using MBSE method and multi-agents' technology

Khalil Aloui¹, Moncef Hammadi¹, Amir Guizani², Thierry Soriano¹,
Mohamed Haddar²

¹ QUARTZ Lab. EA7393, ISAE-SUPMECA, 3 rue Fernand Hainaut, 93400 Saint-Ouen, France ;

alouika95@gmail.com (K.A.) ; moncef.hammadi@isae-supmeca.fr (M.H.) ;
thierry.soriano@univ-tln.fr (T.S.)

² LA2MP, Ecole Nationale d'Ingénieurs de Sfax, University of Sfax, Sfax 3038, Tunisia ;
amir.guizani@live.fr (A.G.); mohamed.haddar@enis.rnu.tn (M.H.)

Abstract. Today, smart manufacturing is differentiated from many other initiatives by its emphasis on human ingenuity. Human capabilities must be enhanced by intelligently designing a customized solution for a specific domain. For example, Industry 4.0 is based on collaborative robots that digitize and simplify manufacturing processes. In fact, Automatic Guided Vehicles (AGVs) are widely used in intelligent industries due to their productivity, flexibility, and versatility. They are widely considered as one of the most important tools for flexible logistics in workshops. They can move materials and products without a predefined route. Many commercially available AGVs provide a self-guided navigation system to find their way to target workstations. However, many developers and producers of industrial robots face several challenges in designing AGV systems, such as the difficulty of defining a decentralized system decision as well as the discontinuity and complexity of the design process. In this article, we propose a new design approach based on multi-agent technology and the Model-based systems engineering method (MBSE) to meet the challenges of functional, physical, and software integration. It is a top-down approach from requirements specification, functional and structural modeling using the systems modeling language (SysML) to model simulation with the multi-agent tool (Anylogic). Our design approach was applied on an Automated Guided Vehicle (AGV) system to serve items and deliver parts and supplies to stations in a smart factory.

Keywords: automated guided vehicles (AGV), MBSE method, SysML, Multi-agents' technology, Industry 4.0

Table 1. List of abbreviations and acronyms used in this article.

Abbreviation	Explanation
AGV	Automatic Guided Vehicle
BDD	Block definition diagram
IBD	Internal block definition
ROS	Robot operating system
SysML	Systems modeling language
MBSE	Model-based systems engineering

1 Introduction

Productivity in industries is increasing thanks to rapid advancements in manufacturing technologies and applications. Manufacturing companies are becoming more flexible, compatible and scalable (Zhong et al. 2017). Indeed, the complexity of a manufacturing system becomes higher and higher, its size becomes larger and larger. Today, the new manufacture mode requires the application system to have agility and flexibility. Recently, the agent concept has been used in many fields of application, including the field of industrial logistics (Yao et al. 2000). The application of multi-agents' system in the industrial logistics brings new challenges for multi-agents system technique such as the architecture of the multi-agent system and the prediction of the collaborative decision of the agents (Lasi et al. 2014).

An agent system is applied in various fields because it has many advantages. The most important thing is in favor of distribution. This is because the agent technique is one of the best choices when the problem area is linked to many different objects that are physically or logically distributed (Guizani et al. 2014). These objects must cooperate with each other for same goal (Guizani 2014). Collaborative robotics has been considered as one of the enabling multi-agents' technologies in the industry 4.0 program (Ferraguti et al. 2019). The use of AGVs in industrial logistics today is not yet widespread in manufacturing plants. Many manufacturers and developers of industrial robots have entered the AGV industry to reduce the problems of transporting of raw materials and final products by manual forklifts (Sabattini et al. 2013) but they have faced many integration challenges.

The first challenge to integrating AGVs into the production industry is related to the restrictions of the operating environment. Indeed, complete flatness and horizontality are imperative for the safe and efficient operation of AGVs, for example floors should not be too uneven, and every transition from one surface to another should be considered (Ferreira and Gorlach 2016). The second challenge is related to the limited flexibility of AGVs compared to driver-controlled vehicles since the human operator can react and change tasks quickly. AGVs are therefore less adapted to unrepertive tasks. Different AGV systems do not really share the same

language. So, the third challenge to AGV integration in the smart factories is the problem of making AGVs built by different manufacturers work together. We will see later in this paper that the right choice of AGV development methodology could facilitate the collaboration of AGV systems from different manufacturers. Another challenge in integrating AGVs into the production industry is the high initial capital cost of the AGV system. However, AGVs are becoming more and more feasible while increasing the number of working hours which increases the overall efficiency and productivity which generates economic benefits (Saputra and Rijanto 2021).

To ensure the effective development of AGVs, all of the above challenges must be overcome by adopting the right development tools and methodology. For example, the complexity and discontinuity of the design process are major issues that slow down the integration of AGVs in smart industries. In other words, to avoid the risk of errors and rework, there must be continuity between the data and the models used throughout the design process. Additionally, the designer should verify physical and software integrations to ensure design consistency.

In this article, we present a design approach to reduce the gap between the different design phases of an AGV system. In particular, our approach reduces the discontinuity between the different design phases and improves traceability between the design specification, behavioral modeling, architectural modeling and validation phases with multi-agent simulation.

Generally, this article will be organized as follows: in the next section, we present the different methods proposed in the literature for the design of AGV systems. In the third section, we will detail our approach to designing AGV systems based on multi-agent concepts. We will also detail the implementation of the proposed design method using the systems modeling language SysML and the multi-agent tool Anylogic. In the fourth section, a case study of an AGV system design in a production industry is considered in order to validate our method. Lastly, we close the article with a conclusion.

2 Related Works

Logistics plays an important role in the smart industry where typical manufacturing operations are conducted. Recent advances in computer processing power and wireless internet technology have opened up new possibilities in the field of automated guided vehicles (AGVs) (Zaheer and Kacprzak 2013). In the context of Industry 4.0, several researchers are faced with several challenges to develop AGVs that meet more specific and personalized needs. (Mahadevan et al. 1990) are focused on the design of a vehicle-based automated guided material handling system for a flexible manufacturing system. (Aloui et al. 2021) proposed a new integrated design methodology based on swarm robotics to meet the challenges of functional, physical and software integration. This methodology comprises two

phases: a top-down phase from specification of requirements to functional and structural modeling using the systems modeling language (SysML); with a bottom-up phase for the integration and implementation of the model in the robot operating system (ROS). In addition, (Stouten et al. 2004) have described the use of AGV systems for the cooperative transport of heavy loads. In another research work, (Luna et al. 2010) have proposed partially decentralized solutions to reduce the complexity of the optimization process and address the problem of planning multi-robot paths through a set of network nodes. Indeed, AGVs must be equipped with an appropriate detection system, to identify obstacles when they have moved in congested environments.

System modeling is another big challenge in the design of AGV systems. For example, (Sharma et al. 2017) modeled an AGV system with a nonlinear kinematic model that describes the speed of the robot, its position, the orientation and the angular speed of its links. (Caruntu et al. 2020) present the concept of applying bio-inspired coordination and control techniques to the development of freight transportation and future manufacturing. On the other hand, the optimization and scheduling of tasks is another issue to be considered from the design phases of AGV systems. For this reason, several researchers are working on swarm approaches to develop AGV systems. The study (Aloui et al. 2021) proposes a top-down approach to ensure consistency and continuity from the level of requirement at the behavioral level to the functional and structural levels of a swarm system that can be used for the AGV system. Even though we have complete knowledge of the robot's interior, analyzing and designing self-organizing systems like swarm robotics remains a difficult task (Aloui et al. 2020). For this, (Lategahn et al. 2012) proposed an integrated methodology based on the principles of swarm robotics to design a swarm of automated guided vehicles (AGVs).

To overcome the challenges described above, we propose in this article a new approach based on multi-agent technology combining the possibilities SysML and Anylogic. SysML will be used to specify the system requirements and model the AGV architecture from different points of view (behavioral, functional, and structural). Anylogic, on the other hand, will be used to adapt existing base robots with the SysML information model and to validate the design with multi-agent simulation. In the next section, we detail the different SysML diagrams used to model the AGVs system which can then be simulated on Anylogic to ensure compliance with system requirements.

3 Top-down approach for designing an AGVs system

The current need for AGV development is a closer integration that encompasses various factors related to design methods, design practices and tools, design team members, and their interactions. this study is to develop a design approach

allowing specialists from different engineering fields to combine their expertise to ensure functional, physical, and software integration using SysML and Anylogic.

The AGV design approach proposed in this article is a top-down approach from the specification of requirements to functional and structural modeling using SysML to the integration of models on the multi-agent tool (Anylogic) and their implementation on real robots (Prototype).

The designer of the AGVs system begins by specifying design requirements using SysML diagrams to describe the various system needs. From these requirements, the designer identifies the different functions that build the collective behavior of AGVs. SysML activity diagrams and state machine diagrams are therefore used to model swarm behavior. Indeed, the designer uses the allocation matrices (Requirement-Behavior, Behavior-Function) to ensure high-level traceability between requirements, behaviors, and functions. These matrices plot the specified requirements with the functions that the AGV system must perform while respecting the collective behavior. Once the collective behaviors of the AGVs are modeled, the designer details the structure of the AGV by specifying the components capable of performing the previously modeled functions that the AGV must perform using the block definition diagram (BDD) and the internal block diagram (IBD). To ensure software integration, the designer uses the SysML model developed in the previous steps to implement the collective behavior of AGVs on Anylogic. The final simulation of the behavior of AGVs is performed with Anylogic to meet the requirements described with the SysML requirements diagrams. Figure 1 shows the steps in the proposed top-down design approach.

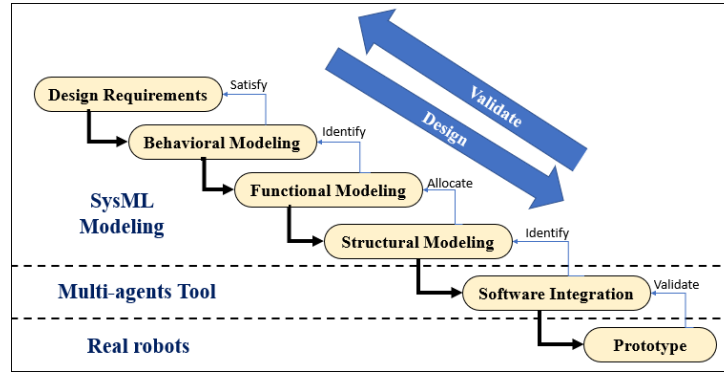


Fig. 1 Top-down approach for designing an AGV system

3.1 Design Requirements of AGVs

The design requirements are the necessities, the needs, and expectations that the developed AGVs system must meet, or the constraints that it must satisfy (Schranz et al. 2018). AGVs are deployed in many different application areas.

They are used in the manufacturing, warehousing, automotive, food, and healthcare industries. This variety of applications specifies general system requirements. The requirements diagram shown in Figure 2 is used to specify the design requirements for an AGVs system. As illustrated in this figure, a traceability relation "satisfy" is added to ensure traceability between the different design views.

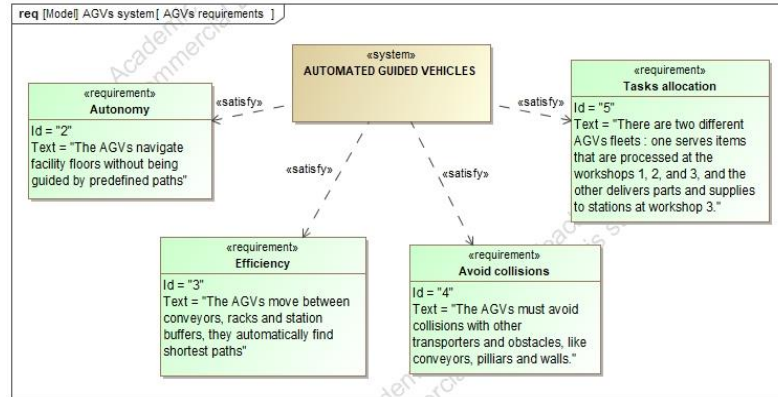


Fig. 2 Requirement diagram of automated guided vehicles (AGV) in SysML

The AGVs navigate facility floors without being guided by predefined paths. There are two different AGVs fleets in this model: one serves items that are processed at the workshops 1, 2, and 3, and the other delivers parts and supplies to stations at workshop 3. The AGVs move between conveyors, racks and station buffers, they automatically find shortest paths and avoid collisions with other transporters and obstacles, like conveyors, pillars and walls.

3.2 Behavioral Modeling of AGVs

An AGV usually transfers a pallet from an automated production line. The pallet must be brought to the shipping area. Sometimes pallets have to be stored in a warehouse that is composed of a set of block storage areas. There are two different AGVs fleets in this model: one serves items that are processed at workshops 1, 2, and 3, and the other delivers parts and supplies to stations at workshop 3. Figure 3 shows the distribution of this two AGV fleets.

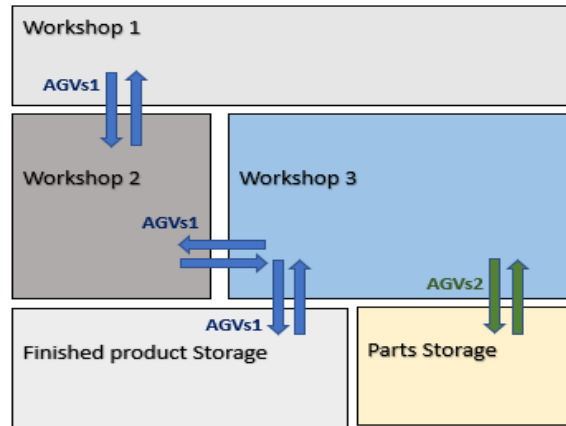


Fig. 3 Different behaviors of two AGV fleets

3.3 Functional Modeling of AGVs

For the AGVs system, the functions offered by the system are the functions performed by each AGV. A set of functions forms a collective behavior of AGVs. On the other hand, this behavior satisfies a requirement of the system. To apply the collective aspect, each AGV performs its functions in parallel with the other AGVs (that is, throughout the mission, each AGV performs a set of individual functions). The state machine diagram shown in Figure 4 represents all the functions of the first fleets of AGVs serving the items processed in workshops 1, 2 and 3.

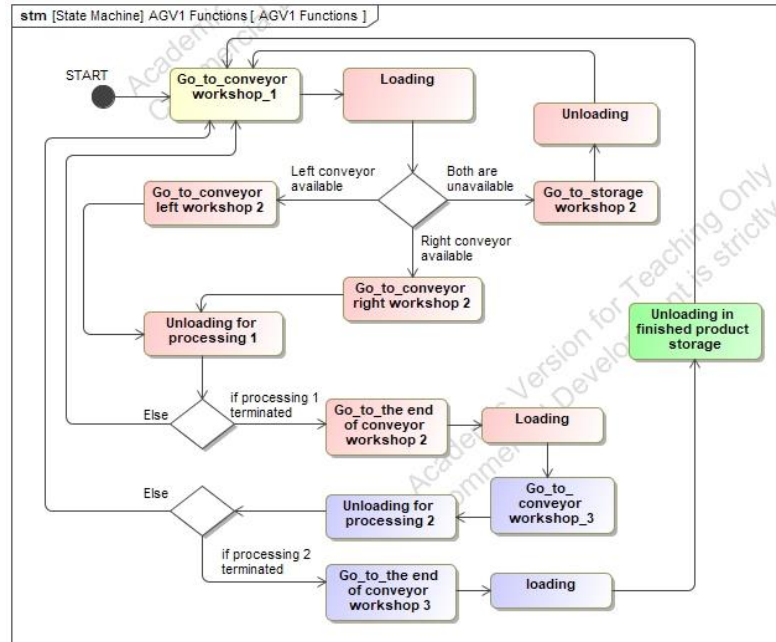


Fig. 4 Functional modeling of the first AGV fleets in workshops 1, 2 and 3

Additionally, the functional modeling of the other AGV fleets that deliver parts and supplies to workshop 3 stations is shown in the state machine diagram shown in Figure 5.

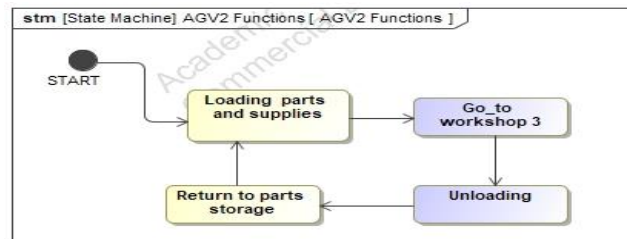


Fig. 5 Functional modeling of the AGV fleets in workshops 3

3.4 Structural Modeling of AGVs

In this step, the general structure of the AGV system should be defined. The AGV swarm consists of a group of AGV individuals. So, the block definition diagram shown in Figure 6 describe the general AGV structure.

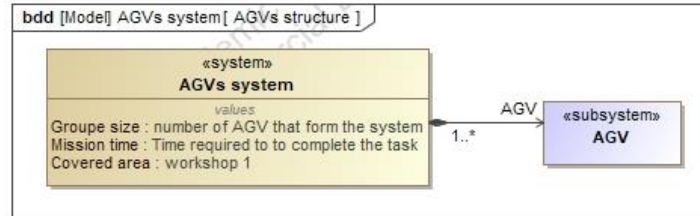


Fig. 6 General architecture of AGVs system in SysML

The next step is to identify the different alternative solutions that can meet the functional architecture of the AGV system. In fact, the final structure of the AGV is broken down into subsystems and components. Figure 7 represents the different elements of an AGV.

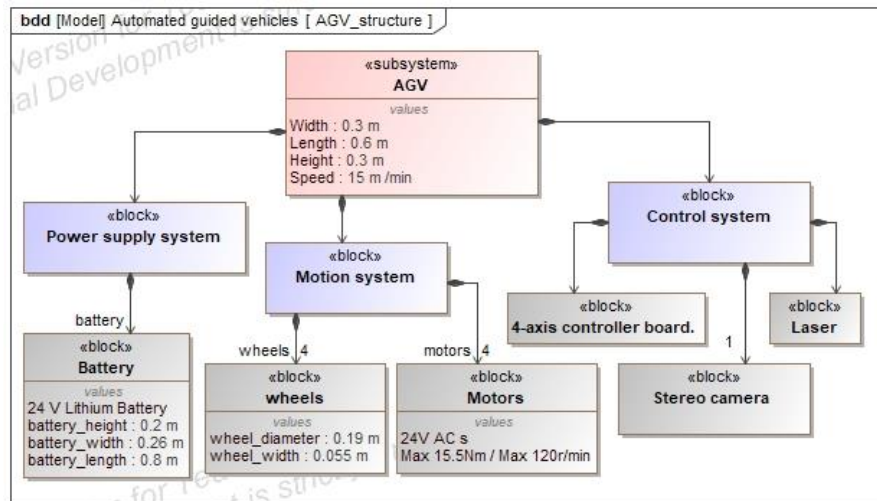


Fig. 7 The AGV structure modeled with the SysML BDD diagram

The structure of the automatic guided vehicle depends on the functions required. In fact, AGV consist of a motion system such as motors to operate and wheels to provide movement. In addition, the AGV contain batteries to provide energy. Other components are specified according to the appropriate behavior such as position sensors to provide localization and laser sensors to explore the environment.

Finally, an allocation matrix is created to link the hardware components of the AGVs system with the individual functions provided by each AGV to ensure the design continuity and consistency of this approach. Figure 8 represents a component function allocation matrix.

Legend															
Allocate															
AGV's components		Individual functions													
		Go_to workshop 3	Go_to conveyor workshop_3	Go_to conveyor left workshop 2	Go_to conveyor right workshop 2	Go_to conveyor workshop_1	Go_to storage workshop 2	Go_to the end of conveyor workshop 2	Go_to the end of conveyor workshop 3	Loading	Loading parts and supplies	Return to parts storage	Unloading	Unloading for processing 1	Unloading for processing 2
		4-axis controller board	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Battery	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		laser	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Motors	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		stereo camera	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		wheels	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Unloading in finished product storage	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Fig. 8 Components-Functions allocations

3.5 Multi-agents Simulation

In this step, a multi-agent software tool called AnyLogic is used to implement the AGV simulation model (AnyLogic Simulation Software 2016).

Generally, the AGVs move on the floors of the installations without being guided by predefined paths. In fact, our model is made up of two different AGV fleets. Using the models developed with the MBSE method above, the simulation presented in figure 9 shows that the AGVs move between conveyors, racks, and station buffers, they automatically find the shortest paths and avoid collisions with other carriers and obstacles.

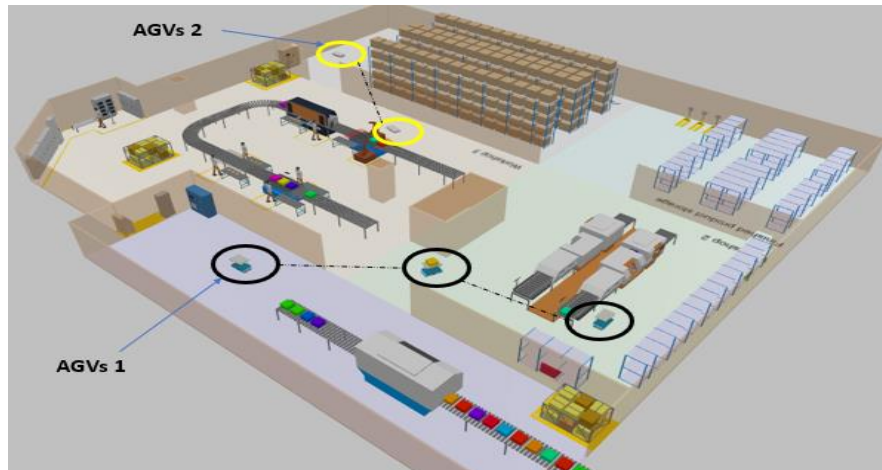


Fig. 9 Simulated model of AGVs system in smart factory

In this simulated model, the following two performance criteria are evaluated: Item wait time for AGV and Number of items moved. Figure 10 shows the evolution of these two criteria over time.

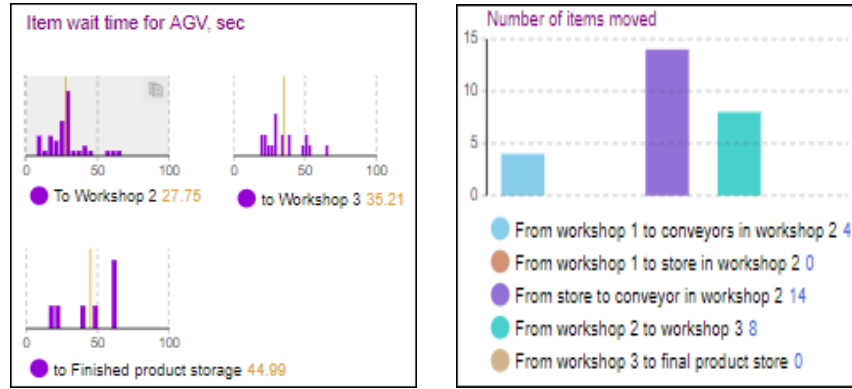


Fig. 10 Evolution of the Item wait time for AGV and the number of items moved

3.6 Prototype: Real robots' implementation

In this phase, manufacturers and developers of industrial robots design the final AGVs system. Indeed, using the models developed and the simulation performed, manufacturers and developers of industrial robots can use already found robots or create new robots to perform given tasks. In this paper, we have not yet implemented real robots. This task is undergoing and it could be a subject of a future paper.

4 Conclusion

Differently from bottom-up approaches, our top-down design approach, which is based on the MBSE method and multi-agents' technology, offers a systematic methodology towards the development of AGVs systems. With our approach, we can specify the AGV requirements to avoid the risk of developing the "wrong" system, that is, a system that does not satisfy the requirements. Our approach facilitates also the development of a set of simulation and hardware-independent models that can be easily reused in future applications.

In the future, we plan to validate our approach with a real implementation of an AGVs system. After that we can apply our design approach to more complex applications.

References

- Aloui, K., Hammadi, M., Soriano, T., Guizani, A., & Haddar, M. (2020, November). On the continuity of the swarm robot design using MBSE method and simulation. In 13ème CONFERENCE INTERNATIONALE DE MODELISATION, OPTIMISATION ET SIMULATION (MOSIM2020), 12-14 Nov 2020, AGADIR, Maroc.
- Aloui, K., Guizani, A., Hammadi, M., Haddar, M., & Soriano, T. (2021, March). A Top-Down Approach to Ensure the Continuity of the Different Design Levels of Swarm Robots. In 2021 18th International Multi-Conference on Systems, Signals & Devices (SSD) (pp. 1438-1445). IEEE.
- Aloui, K., Guizani, A., Hammadi, M., Soriano, T., & Haddar, M. (2021). Integrated Design Methodology of Automated Guided Vehicles Based on Swarm Robotics. *Applied Sciences*, 11(13), 6187.
- Caruntu, C. F., Pascal, C. M., Maxim, A., & Pauca, O. (2020). Bio-inspired Coordination and Control of Autonomous Vehicles in Future Manufacturing and Goods Transportation. *IFAC-PapersOnLine*, 53(2), 10861-10866.
- Editions Comparison — AnyLogic Simulation Software » in www.anylogic.com (consulté le 8 juin 2016).
- Ferreira, T., & Grolach, I. A. (2016). Development of an automated guided vehicle controller using a model-based systems engineering approach. *South African journal of industrial engineering*, 27(2), 206-217.
- Ferraguti, F., Pertosa, A., Secchi, C., Fantuzzi, C., & Bonfè, M. (2019, March). A methodology for comparative analysis of collaborative robots for industry 4.0. In 2019 Design, Automation & Test in Europe Conference & Exhibition (DATE) (pp. 1070-1075). IEEE.
- Guizani, A., Hammadi, M., Choley, J. Y., Soriano, T., Abbes, M. S., & Haddar, M. (2014, July). Multidisciplinary approach for optimizing mechatronic systems: Application to the optimal design of an electric vehicle. In 2014 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (pp. 56-61). IEEE.
- Guizani, A., Hammadi, M., Choley, J. Y., Soriano, T., Abbes, M. S., & Haddar, M. (2014, November). Agent-based approach for collaborative distributed mechatronic design. In 2014 10th France-Japan/8th Europe-Asia Congress on Mechatronics (MECATRONICS2014-Tokyo) (pp. 156-161). IEEE.
- Guizani, A. (2016). Approche multi-agents pour la conception optimale des systèmes mécatroniques (Doctoral dissertation, Université Paris-Saclay; Laboratoire de recherche de Mécanique, Modélisation et Production (Sfax, Tunisie)).
- Lategahn, J., Müller, M., & Röhrig, C. (2012, September). Global localization of automated guided vehicles in wireless networks. In 2012 IEEE 1st International Symposium on Wireless Systems (IDAACS-SWS) (pp. 7-12). IEEE.
- Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business & information systems engineering*, 6(4), 239-242.
- Luna, R., & Bekris, K. E. (2010, October). Network-guided multi-robot path planning in discrete representations. In 2010 IEEE/RSJ International Conference on Intelligent Robots and Systems (pp. 4596-4602). IEEE.
- Mahadevan, B., & Narendran, T. T. (1990). Design of an automated guided vehicle-based material handling system for a flexible manufacturing system. *The International Journal of Production Research*, 28(9), 1611-1622.
- Sabattini, L., Digani, V., Secchi, C., Cotena, G., Ronzoni, D., Foppoli, M., & Oleari, F. (2013, September). Technological roadmap to boost the introduction of agvs in industri-

- al applications. In 2013 IEEE 9th International Conference on Intelligent Computer Communication and Processing (ICCP) (pp. 203-208). IEEE.
- Saputra, R. P., & Rijanto, E. (2021). Automatic Guided Vehicles System and Its Coordination Control for Containers Terminal Logistics Application. arXiv preprint arXiv:2104.08331.
- Schranz, M., Bagnato, A., Brosse, E., & Elmenreich, W. (2018, January). Modelling a CPS Swarm System: A Simple Case Study. In MODELSWARD (pp. 615-624).
- Sharma, B., Vanualailai, J., & Prasad, A. (2017). A d ϕ -Strategy: Facilitating Dual-Formation Control of a Virtually Connected Team. *Journal of Advanced Transportation*.
- Stouten, B., & de Graaf, A. J. (2004, April). Cooperative transportation of a large object-development of an industrial application. In *IEEE International Conference on Robotics and Automation, 2004. Proceedings. ICRA'04. 2004 (Vol. 3, pp. 2450-2455)*. IEEE.
- Yao, S., Geng, S., & Liu, Y. (2000, October). Application of development method based on multi-agents. In *Proceedings 36th International Conference on Technology of Object-Oriented Languages and Systems. TOOLS-Asia 2000 (pp. 158-161)*. IEEE.
- Zaheer, A., Covic, G. A., & Kacprzak, D. (2013). A bipolar pad in a 10-kHz 300-W distributed IPT system for AGV applications. *IEEE Transactions on Industrial Electronics*, 61(7), 3288-3301.
- Zhong, R. Y., Xu, C., Chen, C., & Huang, G. Q. (2017). Big data analytics for physical internet-based intelligent manufacturing shop floors. *International journal of production research*, 55(9), 2610-2621.