Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 38 (2019) 1683–1690

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

29th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2019), June 24-28, 2019, Limerick, Ireland.

Integration of autonomous intelligent vehicles into manufacturing environments: Challenges

Liam Lynch[ab], Fintan McGuinness[b], John Clifford[b], Muzaffar Rao[ab], Joseph Walsh[c], Daniel Toal[ab], Thomas Newe[ab]

[a]*Lero Research Centre, Centre for Robotics and Intelligent Systems, Department of Electronic and Computer Engineering, University of Limerick, Castletroy, Limerick, Ireland*

[b]*Centre for Robotics and Intelligent Systems, Department of Electronic and Computer Engineering, University of Limerick, Castletroy, Limerick, Ireland*

[c]*Lero Research Centre, Head of school of STEM, Head of IMaR, Institute of Technology Tralee, Tralee, Ireland*

[d]*KOSTAL Ireland GmbH, Abbeyfeale, Co. Limerick, Ireland*

Abstract

As companies begin to move towards Industry 4.0 and implement Smart Manufacturing techniques, flexible manufacturing comes to the fore. This allows a facility to adapt to changing needs and demands, with less impact on production, when compared to rigid production lines.

Traditionally, the introduction of new equipment into a production line is somewhat straightforward, as the equipment is generally static. In recent times however, Autonomous Intelligent Vehicles (AIVs) have become a pivotal component of smart production lines. Given there may be in excess of twenty AIVs working simultaneously, the integration challenge becomes even more complex.

This paper identifies several challenges associated with the integration of an AIV into a manufacturing environment controlled by a Manufacturing Execution System (MES). Further to this a discussion of the solutions being implemented currently on a live project is provided.

Peer-review under responsibility of the scientific committee of the Flexible Automation and Intelligent Manufacturing 2019 (FAIM 2019)

Keywords: Robotics for Manufacturing; Autonomous Intelligent Vehicle; Software Interfacing; Manufacturing Execution Systems.

Peer-review under responsibility of the scientific committee of the Flexible Automation and Intelligent Manufacturing 2019 (FAIM 2019)
10.1016/j.promfg.2020.01.115

1. Introduction

Flexible manufacturing offers a facility greater capability to produce goods as a modular system, rather than the traditional linear one [1][2]. It also provides the ability to select which processes are carried out on a given product, without having to reconfigure the entire assembly line [3]. Therefore, a production line may be used to produce more than one product when the line is modular in nature as it may vary which modules are incorporated in the process.

As current work stations are typically linear in nature, with each connected by a straight conveyor belt, when they are reconfigured to a modular system a replacement is required for the straight conveyor [4]. An Autonomous Intelligent Vehicle (AIV) may be used as an alternative, which requires information such as:

- What payload to collect
- Where to collect the payload
- Where to deliver the payload
- When to deliver the payload

The above information is not required by the traditional linear system, but the AIV requires instruction based around this data due to the lack of physical connectivity. Providing and collecting this data is done via sensors which can be fitted to the input and output stage of each module. These sensors provide the data to the overall Manufacturing Execution System (MES) and allow it to manage the entire processing line, as well as directing AIVs between each module as required.

However, there are several considerations for a fleet of AIVs which may be required to work in conjunction with an MES. Several of the challenges that need to be overcome are as follows: developing an interface between an MES and AIV where both are able to communicate in real time, interfacing two different software platforms, identifying the availability of any AIV at any given time, when and where a product should be, what payload an AIV is carrying or about to collect/deliver, directing AIVs and optimising their routes. These issues are discussed in greater detail below.

2. Overview of MES and AIV

Firstly, it is required to understand what an MES is, as well as how it operates. The same is required of the AIV.

2.1. The Manufacturing Execution System (MES)

The formal definition of an MES is provided by Saenz de Ugarte et al. [5]: “An MES delivers information that enables the optimisation of production activities from order launch to finished goods”. The definition also states that an MES can improve profitability as well as resource management and manufacturing time.

Therefore, an MES can be considered as the overall control system for a manufacturing facility, managing the material in, the finished products out, the resources, workstations and product flow for the facility. Figure 1 shows a graphical representation of what an MES structure may look like

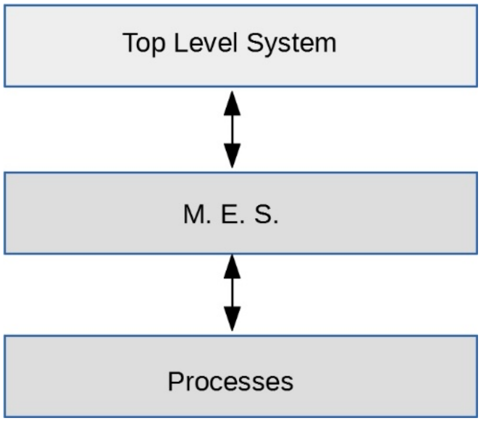

Figure 1. MES Architecture

Figure 2. Unit Load AIV

2.2. The Autonomous Intelligent Vehicle (AIV)

The Autonomous Intelligent Vehicle refers to many robot technologies. By definition: "An Intelligent vehicle consists of four fundamental technologies: environment perception and modelling, localisation and map building, path planning and decision-making, and motion control" [6]. The term AIV refers to vehicles that can navigate without human intervention [7][8][9]. The configuration researched and referred to in this paper is the successor to the Automated Guided Vehicle (AGV), with its intended area of operation being the industrial manufacturing environment.

AIVs come in several forms such as a unit load, towing, pallet truck or forklift style [9]. The version examined in this paper is a unit load AIV. This is the most common version used in assembly lines due to its non-complex configuration and versatility.

Figure 2 shows the typical configuration for such a robot. The unit load AIV has a platform which can be raised and lowered, allowing the vehicle to position itself at the end of a conveyor system and raise its platform to lift its payload and move it to the desired location. Typical models have a payload of between 50 kg and 300 kg, although variations with higher and lower lifting capacities are available [10] [11].

3. Issues associated with Introducing AIVs to Manufacturing Environments

3.1. Software Interfacing

Manufacturing Execution Systems are designed to work in conjunction with workstations, manufacturing lines, conveyor belts and automated processes throughout a manufacturing facility. The MES has its own user interface, which has the capability to be interfaced with new and existing equipment installed in a factory. This is vital as most modern manufacturing equipment will need to be integrated into the automation processes of the facility [1][2].

The software interface varies from each MES, as well as the interface on each piece of equipment. This can pose challenges when integrating new equipment. Interfacing the two software packages, of the MES and the equipment, can be a difficult process and often what is required is development of a software tool which will enable communication between the two. This layer of software is needed to act as a conversion tool and enable successful communication between both software platforms [12].

Figure 5 demonstrates the architecture of how such a system could operate. The interface tool allows for two-way communication between both devices. Two-way communication allows the AIV to update the MES with faults or issues encountered in real time, and the MES is then able to re-route or reassign the AIV to higher priority tasks. This information can also aid the MES in calculating projections for output at any given time.

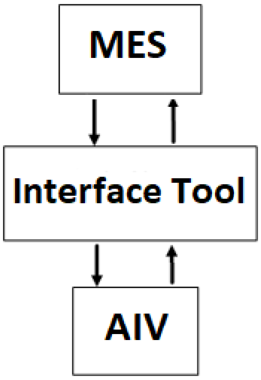

Figure 3. Interfacing Architecture

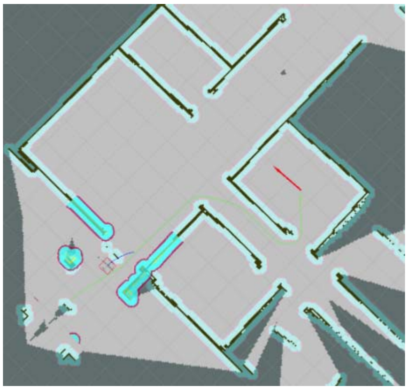

Figure 4 SLAM Navigation map from an AIV

3.2. Communication between AIV and MES

Assuming successful interfacing between the AIV and MES softwares, the next task relates to establishing how the two systems will communicate with each other. Typically, the equipment being installed is static in nature and is physically connected into the network of the facility via Ethernet/LAN or equivalent. However, the AIV is dynamic in nature, and a physical connection to the network is not possible. An alternative wireless connection is required in order to enable communication to take place [12]. The AIV requires information regarding its collection point and delivery point. The MES provides this information to the AIV, from sensors throughout the factory, and through a secure connection.

Communication between both AIV and MES is done wirelessly, with the most common form being through a secure wireless network within a facility. Some MES providers use web services as a form of communication between equipment and Execution system. ROS (robotic operating system) also uses web services, meaning an AIV programmed in ROS can communicate in real time with most MES options currently available [13]. Research prior to selection of AIV operating system can ensure issues with this aspect of the project are kept to a minimum.

3.3. Identifying AIV availability

Identifying the correct AIV to send to a pick-up point is crucial to the smooth running of the process as misidentification or non-optimal identification, could result in substantial delays in the manufacturing process and ultimately, a reduction in output. Such delays would have negative consequences on the output of a facility and inevitably affect profitability. This issue is primarily a software issue and will require an algorithm capable of identifying the most suitable AIV to send to the correct location at any given instance. The selection of the programming language to address this issue will be down to the resources, expertise and processing power available.

3.4. Navigation

Accurate planning and preparation are required to assess the optimal location to install the new equipment. Considerations to layout and access routes are also important, as well as the safety of those who already occupy the space.
As an AIV is required to navigate these surroundings, the hardware and software requirements must too be assessed in detail [6]. An AIV must be fit for purpose and not endanger the other occupants of the area of operation, or the other equipment it will work in conjunction with or, finally, the payload for which it is responsible.
The sensors and navigation system to be employed by the system must be suitable for the environment in which it is

intended to operate. It should be able to identify objects and individuals and avoid contact with them, while navigating through its area of operation in an optimum fashion. Considerations should be made for its planned paths and waypoints, as well as the routes it will share with others.

The AIV navigation systems are very well developed at this moment in time. Technology used in various applications has been focused specifically for the industrial setting. Advancements in Lidar, Object recognition, SLAM technology and operating systems have made the introduction of AIVs significantly more time and cost efficient than their predecessors, the AGV [14] [15]. Figure 4 demonstrates a map created using SLAM Technology on an AIV.

3.5. Route Optimisation

Once an AIV navigation system and sensors have been selected, the optimisation of its route planning comes into consideration. The most efficient route between collection and drop off points is ever changing, especially in a system that has multiple locations for both. An AIV must be able to decipher how best to navigate between both locations in an ever-changing environment. Unplanned obstacles and blocked routes need to be accounted for, as the live factory setting is shared with other users [16]. A failure to achieve the optimum route will invariably lead to a slow-down of production as the system will not be operating at full capacity. The effect that a delay in payload delivery can have from one line to another is a potential issue which would have a large knock-on effect to the overall system.

3.6. Identifying the correct payload to be collected/delivered

When the MES sends a command to an AIV to collect/deliver a payload, it is of vital importance that the vehicle identifies the correct payload to be moved. The knock-on effects from misidentification can lead to reduction in productivity in a facility. Wrong material placement could at the very minimum slow production, and at its most extreme shut down a process entirely. On this basis, prevention is the best cure, and correct identification can be ensured by using one of two methods.

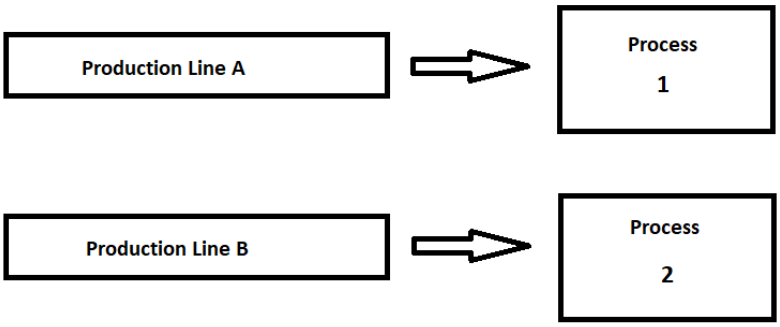

Figure 5 . Sample Process Flow

For example, as demonstrated in Figure 5, two production lines are feeding two separate processes. Line A feeds process 1, and line B feeds process 2. If material from A gets accidentally delivered to 2 or vice versa, the entire process will be shut down, especially if the error is not detected before entering the processing station. Wrong material entering a processing station may do a level of damage to the workstation that would cause it to be inoperable for potentially hours or days.

Barcodes are used on the material to help identify and distinguish parts [17], while RFID tags are also considered to be a viable option on higher end goods [18] [19].

3.6.1 Barcode Scanning

Barcodes are often used in processing plants to identify and distinguish different products. The MES can take advantage of this system, and the movements of product through the facility can be recorded. By retrofitting older equipment, or ensuring newer equipment has laser scanners fitted, the MES can be kept up to date on the movements of the product. The scanners can be placed in vital parts of the production line and can give a step by step update of the current location and process being carried out on the product. Similarly, end of line and start of line scanners can identify when a product has arrived at the end of a processing line to be moved to its next destination.

By improving the visibility of the product cycle, misidentification can be reduced. The MES can store the details of each product, thus more accurately determining their position in the processing cycle. The transition to a more modular system would require these changes, as at present, the straight-line conveyor belt prevents product from being placed in the wrong location.

A negative aspect of barcode scanning is direct line of sight is required for the scanner to pick up the barcode [17]. This can cause issues with sensor mounting and the costs associated. It also can be an issue when there are multiple types of products in a system as the barcode location may be different for each product. Developing a universal location would be required in this type of production.

3.6.2. RFID

Where possible, Radio Frequency Identification tags could be a viable option. These are sacrificial magnetic strips that are attached to each product during assembly. As with the barcode scanning, the magnetic strips can contain information regarding process carried out, as well as future processes required. The main advantage over barcode scanning is there is no direct line of sight required to read the RFID and proximity from scanner to tag can be larger [18] [19].

However, RFID may not be suitable for certain processes as it may generate interfering magnetic signals on the product, which could be harmful to certain electronic components within [18] [19]. Also, the cost of RFID is more than barcode printing and it may only be suitable for products where there is a higher return on investment. For example, RFID would be viable on parts that are selling for values for hundreds of euro, but not as sensible for product being sold for tens of euro.

3.7. When and where a product should go

A major software challenge to be addressed in this dynamic system is developing an algorithm around where and when a product should go. Such an algorithm will have to be able to address AIV availability, product levels, and product priority, while also identifying free space within the processing line to move the material to. A great deal of planning and trial work would be required to implement such an algorithm.

3.8. Managing and directing a fleet of AIV’s

The introduction of just a single AIV is an unlikely scenario, as they represent a large investment and a move towards increased automation. It is also unlikely that a single AIV could cater for the requirements of multiple modules. The most likely scenario is that multiple vehicles will be introduced to work as a fleet carrying out tasks together or operating in parallel. Regardless of the duties the AIV must carry out, a system capable of controlling a fleet is required.

3.9. Adaptation of equipment with sensors

More sensor technology may be required to be installed to the existing and newly installed equipment, at both the input and output stages of the processing line. There are multiple reasons to carry out this work:

1. Provide MES with more accurate data at input and output stage of processing equipment which enables greater visibility as to overall process flow.
2. Help MES identify material with greater accuracy.
3. The more checks carried out on material flow, the less the chance of misplacement or errors being created in the system.
4. Greater visibility is also given into processing time and weak points or bottle necks in the production process.
5. The sensors could ensure smoother pickup and delivery by identifying if an AIV has docked correctly.
6. Also used to detect when material is present to be picked up.

The more sensors in the system, the more information the MES has in order to make decisions and direct AIVs. There is however a trade-off between cost and the amount of information that can be obtained. The correct level of investment will be dictated by the processes in place and the margins the facility can operate within.

4. Conclusion

In conclusion, the paper has examined and outlined various integration tasks and challenges associated with Autonomous Intelligent Vehicles in Manufacturing Environments controlled by a Manufacturing Execution System.

- There are integration tasks which must be planned for and addressed.
- The AIV must have the ability to communicate in real time with an MES in order to maximise the benefits of moving towards this modular system.
- There may be a requirement for modifications to existing and new equipment to provide the MES with enough data to direct a fleet of AIVs.
- The introduction of additional sensors will increase the accuracy and productivity of the production line.
- This increase in sensor technology should provide greater accuracy for the MES to monitor and predict output levels as well as identify bottlenecks in the production process.

The introduction of AIVs can be very beneficial to a facility looking to increase their range of product output which share similar processes, without having to carry out extensive re-modelling on existing production lines. AIVs can play a vital role in facilitating the movement towards flexible manufacturing in a modular production line.

Acknowledgements

This work was supported, in part, by Science Foundation Ireland grant 13/RC/2094 and co-funded under the European Regional Development Fund through the Southern & Eastern Regional Operational Programme to Lero - the Irish Software Research Centre (www.lero.ie).

References

[1] Mehdi Kaighobadi, Kurapati Venkatesh, (1994) "Flexible Manufacturing Systems: An Overview", International Journal of Operations & Production Management, Vol. 14 Issue: 4, pp.26-49
[2] Y. Liao, F. Deschamps, E. Loures and L. Ramos, "Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal", International Journal of Production Research, vol. 55, no. 12, pp. 3609-3629, 2017. Available: 10.1080/00207543.2017.1308576 [Accessed 23 January 2019].
[3] U. Tetzlaff and U. Tetzlaff, Optimal design of flexible manufacturing systems. Heidelberg: Physica, 1990.

[4] W. Grzechca, "Manufacturing in Flow Shop and Assembly Line Structure", International Journal of Materials, Mechanics and Manufacturing, vol. 4, no. 1, pp. 25-30, 2015.
[5] B. Saenz de Ugarte, A. Artiba and R. Pellerin, "Manufacturing execution system – a literature review", Production Planning & Control, vol. 20, no. 6, pp. 525-539, 2009. Available: 10.1080/09537280902938613 [Accessed 15 January 2019].
[6] H. Cheng, Autonomous Intelligent Vehicles. London: Springer-Verlag London Limited, 2011.
[7] C. Ilas, "Electronic sensing technologies for autonomous ground vehicles: A review," 2013 8TH INTERNATIONAL SYMPOSIUM ON ADVANCED TOPICS IN ELECTRICAL ENGINEERING (ATEE), Bucharest, 2013, pp. 1-6.
[8] T. Luettel, M. Himmelshach, H-J Wuensche, "Autonomous Ground Vehicles - Concepts and a path to the future ", Proceedings of the IEEE, Centennial Issue, May 2012.
[9] R. Dominguez, E. Onieva et al., "LIDAR based perception solution for autonomous vehicles ", Proceedings of 11th Intl. Conf. on Intelligent Systems Design and Applications, pp. 790-795, Spain, Nov. 2011.
[10] A. Vehicle Manufacturers, I. Savant Automation, A. Motion, A. Inc., J. Corporation, A. Eckhart and I. Ward Systems, "AGV Manufacturers | AGV Suppliers", Automaticguidedvehicles.com, 2018. [Online]. Available: https://www.automaticguidedvehicles.com/. [Accessed: 29 Jun 2018].
[11] G. Fedorko, S. Honus and R. Salai, "Comparison of the Traditional and Autonomous AGV Systems", MATEC Web of Conferences, vol. 134, p. 00013, 2017.
[12] P. Farahvash and T. Boucher, "A multi-agent architecture for control of AGV systems", Robotics and Computer-Integrated Manufacturing, vol. 20, no. 6, pp. 473-483, 2004. Available: 10.1016/j.rcim.2004.07.005 [Accessed 23 January 2019].
[13] A. Jalil, "ROBOT OPERATING SYSTEM (ROS) DAN GAZEBO SEBAGAI MEDIA PEMBELAJARAN ROBOT INTERAKTIF", ILKOM Jurnal Ilmiah, vol. 10, no. 3, p. 284, 2018. Available: 10.33096/ilkom.v10i3.365.284-289 [Accessed 23 January 2019].
[14] T. Corporation, "Guidance and Navigation for AGV and AGC automatic guided vehicle manufacturer", Transbotics.com, 2018. [Online]. Available: https://www.transbotics.com/learning-center/guidance-navigation. [Accessed: 29- Jun- 2018].
[15] G. Dissanayake, S. Huang, Z. Wang and R. Ranasinghe, "A review of recent developments in Simultaneous Localization and Mapping", 2011 6th International Conference on Industrial and Information Systems, 2011. Available: 10.1109/iciinfs.2011.6038117 [Accessed 23 January 2019].
[16] V. Pillac, M. Gendreau, C. Guéret and A. Medaglia, "A review of dynamic vehicle routing problems", European Journal of Operational Research, vol. 225, no. 1, pp. 1-11, 2013. Available: 10.1016/j.ejor.2012.08.015 [Accessed 23 January 2019].
[17] P. Suresh, J. Daniel, V. Parthasarathy and R. Aswathy, "A state of the art review on the Internet of Things (IoT) history, technology and fields of deployment", 2014 International Conference on Science Engineering and Management Research (ICSEMR), 2014. Available: 10.1109/icsemr.2014.7043637 [Accessed 23 January 2019].
[18] M. Wang, T. Qu, R. Zhong, Q. Dai, X. Zhang and J. He, "A radio frequency identification-enabled real-time manufacturing execution system for one-of-a-kind production manufacturing: a case study in mould industry", International Journal of Computer Integrated Manufacturing, vol. 25, no. 1, pp. 20-34, 2012. Available: 10.1080/0951192x.2011.575183 [Accessed 23 January 2019].
[19] J. Hua, T. Liang and Z. Lei, "Study and Design Real-Time Manufacturing Execution System Based on RFID", 2008 Second International Symposium on Intelligent Information Technology Application, 2008. Available: 10.1109/iita.2008.460 [Accessed 23 January 2019].