Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 24 (2018) 190–195

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

4th International Conference on System-Integrated Intelligence

Intelligent workpiece carrier for distributed data collection and control in manufacturing environments

Walter Gasparetto[a,*], Georg Egger[a], Andrea Giusti[a], Erwin Rauch[b], Michael Riedl[a], Dominik T. Matt[a,b]

[a]*Fraunhofer IEC, via A.Volta 13 A, Bolzano 39100, Italy*
[b]*Free University of Bolzano, Piazza Università 5, Bozen 39100, Italy*

Abstract

The growing demand for customized products is challenging companies to change their organizational structure towards a flexible organizational model. However, small and medium sized enterprises (SME) do not have the necessary resources to integrate in their production processes new technologies which could help them facing such challenges. We propose a framework in which an intelligent workpiece carrier (IWC) is introduced in a traditional production line. We propose to integrate the knowledge of production steps in the IWC to make it able to take decisions about the process execution. A first prototype was developed and tested to verify the effectiveness of the proposed framework. Through the implementation, it has been shown that the IWC represents a promising component in the realization of flexible production systems.

Keywords: intelligent, workpiece, carrier, mass customization, decentralization, distributed Control, IoT flexibility, industry 4.0 ;

1. Introduction and theoretical background

Along the production chain companies are faced with increasing changes in demand and the need for mass customization [4]. The growing demand for customized products is forcing manufacturing to change its organizational structure, which is traditionally based on mass-production, towards mass-customization. Today, most production sites are mainly structured hierarchically, from the shop floor level up to the enterprise resource planning level. A reference architecture to describe this structure is the information pyramid of automation introduced in [16]. In that paper, the authors also suggest that the information pyramid will evolve and be replaced by a mesh architecture for handling flexibility along the production chain. Information, clients, servers and departments, represent nodes of this mesh to exchange data based on a common information model. According to Brettel et al. in [5], distributed systems provide

* Corresponding author. Tel.: +39 3471662471.
E-mail address: walter.gasparetto@fraunhofer.it

2351-9789
10.1016/j.promfg.2018.06.040

better handling of flexibility, compared to the rigid, centralized hierarchical control of a pyramidal structure. Although a distributed structure cannot be applied in every field, evidence from the aeronautics and automotive industries shows that such systems are highly flexible and able to deal with highest complexity, managing more than 20.000 components and 80 companies in the supply chain [4]. According to a survey conducted by the laboratory for machine tools and production engineering in Aachen (Germany), the incorporation of flexibility into mass production, and in the early stages of product design where 80% of costs of the product are allocated, is one of the main issues for managers in the manufacturing industry [14]. Flexibility in production processes can be used to solve plant downtime caused by abnormal functioning or overloaded working stations. To address these challenges, internal corporate research and development (R&D) need to be subsidized. However, for a small and medium sized enterprise (SME) this is difficult, since they usually do not have enough investments and resources to efficiently integrate new technologies in production [5]. These aspects have been considered also in other works such as [12], where the authors propose a modern methodology to help SMEs facing the above mentioned challenges. Among other approaches a demonstrator that simulates a real production can be seen as a promising approach for knowledge transfer from research to the industrial shop floor.

We propose a framework where an intelligent workpiece carrier (IWC) is introduced, which is able to interact with the production system as well as to give assistance to the workers or other elements of the production environment in order to optimize the processes. An IWC is an intelligent unit that can wisely store and exchange information with the other actors in the production chain, take decisions, and give assistance. Please note that an IWC can also be seen as an implementation of a intelligent product as discussed by authors in [13]. Potentials for an IWC are widely discussed in [2, Chapter 2] and they are, among others: information flow without interruption, availability of data stored in the product, improvement in the logistic tracking (milkrun and kanban see e.g. [2, Chapter 2]), and production parameters that are directly exchanged with the working stations. Even though some examples of implementation can be found in previous work (see e.g.[15][10][9]), a practical study comparing the IWC and its benefits with a traditional production line is missing. We have developed a method to include the product realization plan in an IWC that satisfies logical constraints on the assembly sequence, and that provides assistance to the factory staff by collecting useful data to optimize the production. The framework and its features represent the flexible production environment (Section 2). The IWC prototype and an experimental application are described in Section 3.

2. Proposed framework

The study proposed by Agiplan [1] has grouped modern disruptive technologies in five functional areas allowing praticitioners to deal better with the complexity of the subject. As discussed in [4], and successfully shown in [15], an IWC can be used to make the product more intelligent, and to test the technologies reported by Agiplan in [1]. IWCs can also be implemented in an autonomous vehicle as presented by the authors in [6] or using the Robotinos® from Festo [8]. We consider a shop floor in which a product is built in subsequent steps. The machines used are neither connected to each other nor with the production planning department through LAN connection. They communicate with IWCs through a short distance communication system. As in [1], five functional areas representing a typical framework in the manufacturing sector can be identified: (i) data collection and processing, (ii) assistance systems, (iii) network integration, (iv) self-organization and autonomy, (v) decentralization/service orientation. The components of the proposed framework are detailed in the following subsections.

We describe how in this framework a production cycle can occur. First, the customer can choose among a series of product variants: once the customer has chosen one variant, he can place an order for that specific product. At this point, we integrate the knowledge of the production process in the IWC. The IWC is able to take decisions about the process execution as long as it respects some constraints. After the set of the production parameters for the working stations is generated, the logic in the IWC is tested on a off-line simulation of the production cycle. The data are uploaded in the IWC by a special station called base station and the IWC starts visiting the different working stations. If a working station is busy, an alternative will be generated. The IWC recognizes that the next station is busy when the Near Field Communication (NFC) with the machine takes place. When it has visited all the stations, the IWC heads to the base station to upload all the parameters that have been collected during production. This data can be used successively to analyse the production process and implement some improvements.

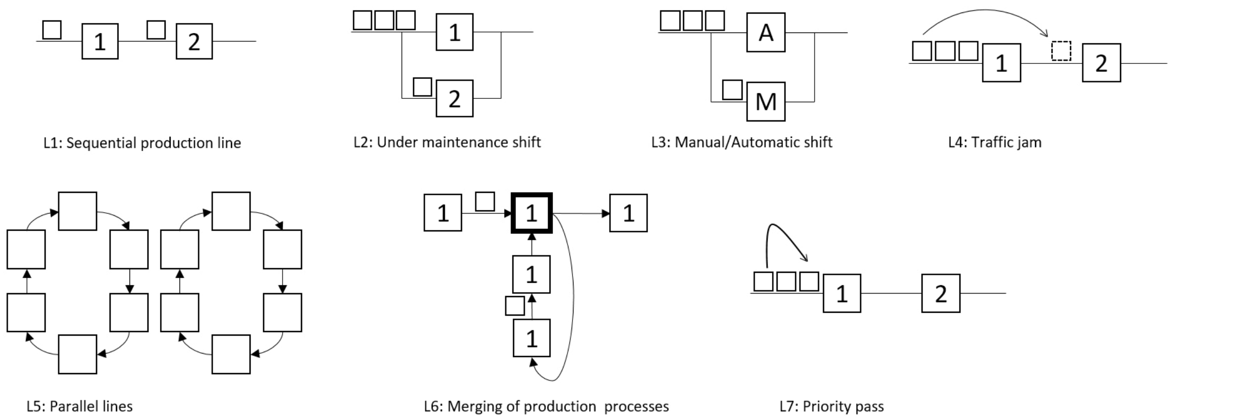

Fig. 1. Basic instances of process variants considered in the proposed framework. The large rectangles represent the working stations and the small ones the product that must be processed.

2.1. *Flexibility*

To solve the challenges of mass customization [16] [17] and efficient automation with batch size one, the product configuration allows more freedom depending on the product itself like, for example, personalized engraving, colours and size [15]. This implies that the product variance is high compared to a classical production line. The proposed framework can manage high product variability, and it enables us to prove the algorithms and systems that add flexibility in the production. A stop when a production step is temporally unavailable can limit the output of a company. Instead, if an alternative production route can be used, flexibility is improved. A flexible process does not stop when a production step is temporally unavailable and it can choose among other process variants e.g. to end the production of a product within the scheduled time. In the framework, we present an algorithm that decides among a list of working stations which one to visit. This differs from classical production lines, where the production process is not able to react autonomously to unforeseen changes and only one option is possible at every production step. The possibility of choice implies that the product does not have to follow a specific sequence but, given a certain degree of constraints, can randomly undergo a set of processes, choosing different variants. Figure 1 shows basic instances of process variants that can occur in production lines. With the exemption of case L1 (sequential production line), these situations lead to some changes in the production process that have to be addressed through process variants. The large rectangles in Figure 1 represent the working stations and the small ones the product that must be processed. The number of process variants is determined by the product configuration, the modularization and the technology used. In particular, Figure 1 illustrates the following instances:

- L1) sequential production line, where the product undergoes every process in a row;
- L2) under maintenance shift, where the product finds that the working station 1 is under maintenance or similar and, consequently, it switches to a redundant working station;
- L3) manual automatic shift, where the production is balanced between an automatic and a manual working station;
- L4) traffic jam, when the product encounters a traffic jam (workstation 1), it jumps that station and undergoes the process of station 2 (this solves bottlenecks during the production process);
- L5) parallel lines, which produce the same product independently (when a station is out of service, the production is shifted to the functioning line);
- L6) merging of production processes in production line, where a main product is assembled with a secondary product from a different production line (in this case, there is a merging of two different workpiece carriers);
- L7) priority pass, when the priority of a product is higher than others, the product can overtake the others.

2.2. Data

The data related to the production environment are stored in the IWC and can be divided in two categories: (i) parameters stored before the production, and (ii) parameters gathered during the production. The former are process parameters for each working station, product ID and boolean logic to let the IWC take decisions about the next step. Parameters such as tolerances, are integrated before the production cycle and directly uploaded to the working stations in a decentralized way. The parameters gathered during production are instead times measured in the production process, number of times a busy station was encountered and the measured work-flow. Measured times and production sequence are used in the production analysis to trace the product route and to optimize the resources usage. These data fall under the five data categories proposed from the authors in [3]. In this framework, we use a small dataset but, as this depends on the product, this dataset can be expanded for example with environmental data and quality measures.

2.3. Sensors, Actuators, Energy, and Communication

The workpiece in the proposed framework needs to undergo a working process. A set of on board sensors of the IWC can be used to trace the quality of the related process as shown in [3]. Onboard sensors can measure geometric tolerances and vibrations, among others parameters. Even though there were previous efforts in building an IWC composed of a set of actuators, the target application must always be analyzed (see e.g. [10]). Regarding the power management in [9], a mix of both efficient low energy components and a solar panel are used, yet in our application we use accumulators.

In our framework, instead of using a set of specific sensors, we include a series of virtual sensors that can be chosen from a defined list. Therefore, the IWC collects data from virtual sensors placed in the working station to simulate the gathering and the exchange of information. When the IWC reaches a workstation it connects to the machines through a wireless communication interface. Potential communication technologies include Bluetooth Low Energy, WiFi (wireless local area networking based on the IEEE802.11 standard), RFID (Radio Frequency Identification), NFC (Near Field Communication), and other proprietary radio frequency solutions. Among the mentioned techniques, NFC has some benefits such as the intrinsic security due to magnetic coupling which allows connectivity only in a limited range of space [15], [3].

2.4. Human Machine Interface

IWC, machines and operators need to communicate effectively. This means that not only interaction needs to be transparent and effective, but also the data used in the communication need to be easily interpreted. We propose the use of JSON (JavaScript Object Notation), a unified lightweight text like XML (Extensible Mark-up Language). JSON encodes common computer data types in a readable form and enables a universal communication between different machines as well as between machines and humans.

The IWC can communicate with an operator, and depending on the type of information, a screen or a set of operational light emitting diodes (LEDs) can be used. The information that we show to an operator in the proposed framework and that we implement in the set-up are both the process status and the next scheduled step. These are the minimum information needed to test the process variant algorithm developed.

3. Prototype and experimental application

The prototype is an implementation of the IWC in the framework we propose, and it is composed of technologies divided in the five functional areas that are described in the previous section as the most challenging for mass customization (see [11] [1]). For this set-up (see Figure 2a), we focus on one variant of the product as we want to have a fixed example to test the logic we embed in our IWC. To represent the process variants, we use an easy 2D example built with LEGO bricks (see Figure 2b). A, B, C, D, represent four process steps in the setup. The sequence A, B, C, D would represent the sequence of production steps in a traditional non-flexible production line. In our setup, we add the possibility to choose between different sequences, or respectively process variants (for example, A, C, B, D or A, B, D, C). A is the first step of the production process as well as the prerequisite for all subsequent processes.

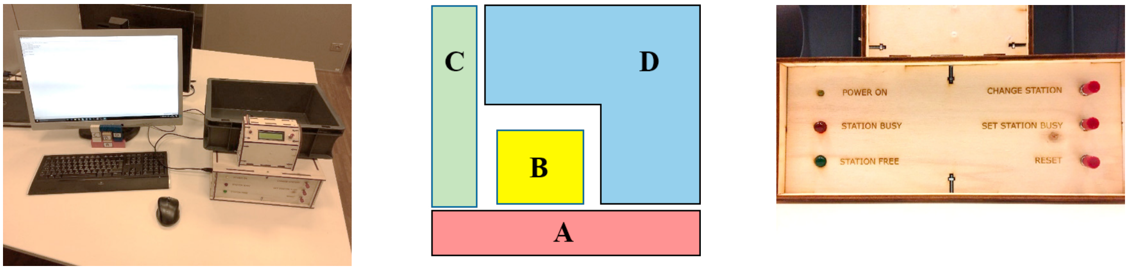

Fig. 2. (a) ; Workpiece carrier over the station simulator. (b) LEGO bricks. (c) Front panel of the Station Simulator;

After the first step, the product can choose one of the other three processes without any constraint. The production process could, for example, occur in the following way: after A, the product chooses B. Once B is carried out, the product chooses C. Once C is carried out, D is the only one option. If we try with another sequence, we can identify some physical constraints in the production process. If the product chooses C (or D) as the second step, then B must be carried out before D (or C) (otherwise B cannot be carried out). To control the process variants mechanism, we propose a model that can also be applied to larger production lines. The minimal data structure is composed of two fields that set the rules: "prerequisite" and "successor" (see Table 1).

Table 1. Process variant model. A, B, C, D, are production steps to realize a product. These steps cannot be executed in arbitrary order.

A	B	C	D
Prerequisite:	Prerequisite:	Prerequisite:	Prerequisite:
/	A	A & (B | !D)	A & (B | !C)
Successor:	Successor:	Successor:	Successor:
B C D	C D	B D	B C

The prerequisite refers to a necessary condition for a specific process step. The successor refers to all allowed successive process steps. As shown in Table 1, process A does not have prerequisites and B has only A as prerequisite. Process C has the following prerequisite. Process A is executed AND one of the following is true: process B is executed OR process D is not executed. The same logic applies to the prerequisite for process D. To validate this logic, we test the algorithm in a hypothetical production run, considering four working stations. A "base station" is introduced which is a unit that can upload the parameters related to a specific product variant before the production starts and also download the data collected by the IWC. To build a first compact prototype, all the five working stations are simulated with a box (here referred to as station simulator, see Figure 2c). The selection of the working stations to be simulated by the station simulator occurs by pressing the button "change station" and can be visualized on a computer screen connected to the station simulator. Pressing the button "set station busy" the working station can be set to be busy or free. The station simulator communicates through an NFC pad, placed below the top of the box. When a station is simulated, the bidirectional communication with the IWC occurs using JSON.

As shown in Figure 2a, the IWC is an independent unit fixed to an industrial plastic turnover box. The NFC pad is placed on the bottom of the box and communicates with the NFC pad of the station simulator. A battery box provides energy to an Arduino microcontroller (placed in the IWC), to the NFC pad and to a LCD display. The display is used to visualize the options provided by the logic to an employee: whether the station is busy, whether the station is the wrong one, as well as the station that must be visited next. The IWC can measure the amount of time a working station needs to process the product, the time the product needs to move between two stations, and the number of times that a station is found to be busy. Moreover, the IWC stores the sequence of the production steps as well as the parameters that the stations have measured themselves, so that the quality of the product can be successively assessed and feedbacks can be given to the persons in charge of the production planning. In case the next station is temporarily busy, the IWC also has the responsibility to find an alternative station using the algorithm described above. Two libraries have been written in C/C++: a boolean parser to parse the data logic and a NFC library for the NFC communication.

4. Conclusion and future research

A framework to test a process variant algorithm towards a flexible production system was presented. Furthermore, a first prototype of an IWC was developed and tested in a laboratory case study. The results show that the IWC could be beneficial for order picking and process optimization of a SME with a low level of automation. Possible application sectors are: stock management, large pharmacies, low automated companies with high complexity in processes. A limitation of this framework is that the customer's order linked to the respective IWC can not be changed once it is being produced. Future research will focus on addressing this limitation. Furthermore, we acknowledge that further research is needed to compare the traditional production line with the proposed one, and to develop a full working industrial prototype to test the framework in a larger and more complex environment. In order to integrate the framework in a real company, the existing workpiece carriers need to be upgraded. The machines of the company also need an NFC interface to be able to communicate with the IWC. In addition, the software must be integrated with the one currently used for production planning. An interesting idea for future works is to consider how a stigmergic cooperation system [7] can be used between the various actors in the production process to achieve optimization in the production.

Acknowledgements

This research is part of the project DeConPro (Decentralized control of production processes in the factory of the future) and has received funding from the European Regional Development Fund ERDF 2014-2020 under the grant agreement with project code FESR1017 (CUP B56J16001730001).

References

[1] Agiplan, FraunhoferIML, ZENIT, 2015. Erschließen der potenziale der anwendung von industrie 4.0 im mittelstand. mülheim an der ruhr. http://www.zenit.de/fileadmin/Downloads/Studie_im_Auftrag_des_BMWi_Industrie_4.0_2015_agiplan_fraunhofer_iml_zenit_Langfassung.pdf. Accessed: 2018-03-02.

[2] Bauernhansl, T., Ten Hompel, M., Vogel-Heuser, B., 2014. Industrie 4.0 in Produktion, Automatisierung und Logistik: Anwendung, Technologien und Migration. Springer.

[3] Bertelsmeier, F., Schone, S., Trächtler, A., 2016. Development and design of intelligent product carriers for flexible networked control of distributed manufacturing processes, in: Control and Automation (MED), 2016 24th Mediterranean Conference on, IEEE. pp. 755–760.

[4] Brettel, M., Friederichsen, N., Keller, M., Rosenberg, M., 2014. How virtualization, decentralization and network building change the manufacturing landscape: An industry 4.0 perspective. International Journal of Mechanical, Industrial Science and Engineering 8, 37–44.

[5] Dickson, P.H., Weaver, K.M., Hoy, F., 2006. Opportunism in the r&d alliances of smes: The roles of the institutional environment and sme size. Journal of Business Venturing 21, 487–513.

[6] Egger, G., Rauch, E., Matt, D.T., Brown, C.A., 2017. (re-) design of a demonstration model for a flexible and decentralized cyber-physical production system (cpps), in: MATEC Web of Conferences, EDP Sciences. p. 01016.

[7] Elliot, M., 2006. Stigmergic collaboration: The evolution of group work. m/c journal 9.

[8] Festo, 2018. Robotino. http://www.festo-didactic.com/int-en/services/robotino/. Accessed: 2018-03-02.

[9] FraunhoferIML, 2015. Inbin intelligent bin. https://www.iml.fraunhofer.de/en/fields_of_activity/automation_embedded_systems/Products/InBin.html. Accessed: 2018-03-02.

[10] FraunhoferIPA, 2015. Werkstückträger als cyberphysisches system smartwt. https://www.ipa.fraunhofer.de/content/dam/ipa/de/documents/Presse/Presseinformationen/2015/November/2015_11_05_PM_Productronica.pdf. Accessed: 2018-03-02.

[11] Kang, H.S., Lee, J.Y., Choi, S., Kim, H., Park, J.H., Son, J.Y., Kim, B.H., Do Noh, S., 2016. Smart manufacturing: Past research, present findings, and future directions. International Journal of Precision Engineering and Manufacturing-Green Technology 3, 111–128.

[12] Matt, D.T., Rauch, E., Riedl, M., 2017. Knowledge transfer and introduction of industry 4.0 in smes: A five-step methodology to facilitate the introduction of industry 4.0 principles to smes. Analyzing the Impacts of Industry 4.0 in Modern Business Environments .

[13] Meyer, G.G., Frmling, K., Holmstrm, J., 2009. Intelligent products: A survey. Computers in Industry 60, 137 – 148. doi:https://doi.org/10.1016/j.compind.2008.12.005. intelliget products.

[14] Schuh, G., Arnoscht, J., Rudolf, S., 2010. Integrated development of modular product platforms, in: Technology Management for Global Economic Growth (PICMET), 2010 Proceedings of PICMET'10:, IEEE. pp. 1–13.

[15] SmartFactoryKL, 2015. Smartfactorykl. http://dfki-3036.dfki.de/EN/industrie40_e.php. Accessed: 2018-03-02.

[16] Spath, D., Ganschar, O., Gerlach, S., Hämmerle, M., Krause, T., Schlund, S., . Produktionsarbeit der zukunft industrie 4.0. https://www.iao.fraunhofer.de/images/iao-news/produktionsarbeit-der-zukunft.pdf. Accessed: 2018-03-02.

[17] Stich, V., Kompa, S., Meier, C., Cuber, S., 2011. Produktion am standort deutschland. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb 106, 731–735.