Computers in Industry 81 (2016) 152–170

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

Electromagnetic modular Smart Surface architecture and control in a microfactory context

The Anh Tuan Dang *, Magali Bosch-Mauchand, Neha Arora, Christine Prelle, Joanna Daaboul

Sorbonne universités, Université de technologie de Compiègne, CNRS, Laboratoire Roberval, Centre Pierre Guillaumat, CS60319, 60203 Compiègne Cedex, France

ARTICLE INFO

Article history:
Received 30 April 2015
Received in revised form 3 February 2016
Accepted 8 February 2016
Available online 23 February 2016

Keywords:
Microfactory
Smart Surface
Reconfigurable manufacturing system
Flexible manufacturing system
Modular manufacturing system
Routing flexibility
Collision avoidance

ABSTRACT

This paper presents an electromagnetic conveyance system called electromagnetic modular Smart Surface (emSS) permitting to move pallets on a planar surface in a microfactory context. The proposed surface concept allows flexibility in reconfiguring the system layout along with product routing. The possibilities of accurate positioning of the moving pallet and controlling multiple pallets on the surface make the emSS suitable for reconfigurable and flexible manufacturing systems. However, the emSS control needs to be robust and scalable to adapt the changes in manufacturing systems. A framework is therefore defined to monitor and control the emSS by simulation or in-line. It allows to define product routing on the emSS by satisfying numerous requirements such as reduction in energy consumption, collision avoidance, etc., and to minimize the human interventions by changing product routing when emSS component failures occur. A first experiment realized on an emSS prototype, allowed to compare two paths strategies regarding cost function linked to energy consumption and velocities. Two other studies exploit the emSS modeling in terms of pallet path generation and simulation of collision avoidance.

1. Introduction

Nowadays, micro manufacturing systems have been adopted as a new concept to handle numerous challenges linked to sustainability, globalization and increased competition [1–3]. In order to answer the turbulent business environment requirements [4], micro manufacturing systems are designed to be flexible and reconfigurable at both hardware and software levels [5,6]. In such a context, the microfactory concept has emerged and was first defined as a small manufacturing system in which production equipment is miniaturized to match product dimensions in order to reduce energy, material and space consumptions [7]. Furthermore, modular manufacturing systems architectures at machine level are applied for most of the microfactories currently developed. They provide flexible and reconfigurable manufacturing lines [3]. In such modular microfactory systems, each workstation is a modular item that is designed to work as a standalone unit or as a part of a production line [8]. With a standard interface, this workstation can be plugged at multiple locations in the microfactory and connected with others modular items. Thanks to exchangeable workstations, the microfactory can produce a wide range of products. Furthermore, Wang et al. have [9] demonstrated that the design of manufacturing systems based on the six RMS key requirements (customization, convertibility, scalability, modularity, integrability and diagnosability [10]) is more cost-effective and provides a better adaptability to market demands. For instances, the manufacturing capacity can be easily modified by adding, subtracting and/or changing modular items; the manufacturing system can be customized for a single product family.

At the same time, smart surfaces used to manipulate micro-objects have been developed both on the technological point of view and on the control level [11,12]. Smart surfaces can be used as conveying system for microfactory [13,14] and are defined as a set of identical modules, often distributed in a planar matrix layout [13], that can be rearranged in different 2D shapes. The goal of the presented work is to benefit from the Smart Surface concept and the modern modular manufacturing system design to achieve flexibility and reconfigurability requirements in microfactories. This paper focuses on the advantage of using an electromagnetic modular Smart Surface (emSS) to flexibly convey micro-products, located on

* Corresponding author. Tel.: +33 344237357.
E-mail address: the-anh-tuan.dang@utc.fr (T.A.T. Dang).

http://dx.doi.org/10.1016/j.compind.2016.02.003
0166-3615/

pallets, over a planar surface. Hence, if production planning changes or perturbations occurrence implies a product routing modification, the pallet routing can be automatically reconfigured without the need of changing the production line. Therefore, the main research focus of the work presented in this paper is to propose a framework to control and monitor the emSS developed in the Roberval laboratory, and to perform first numerical and experimental tests to validate the physical model and the modules aiming to generate pallet path and simulate collision avoidance of this emSS.

This paper is organized as follows. First, microfactory concept is introduced; research works dealing with modular microfactories and smart surfaces are analyzed; and a synthesis is proposed related to requirements. Then physical principles and characteristics of the proposed emSS are described in Section 3. The proposed monitoring and control framework of the emSS enabling reconfigurability and flexibility is explained in Section 4. Finally, Section 5 describes three validation steps of the proposed framework. In the first step experimental results obtain with the real prototype are compared to simulation results in order to evaluate the coherency of the emSS physical model. The steps 2 and 3 are two numerical use cases, performed with this validated physical model, allowing to evaluate strategies for trajectories refining and for collision avoiding.

2. Microfactory concept and conveying system trends

2.1. Microfactory context

Earlier research works in microfactories have focused, on one hand, on downscaling manufacturing system components [7,15,16] (e.g.: miniaturized machine units and/or micro-press, small-size manipulator, transfer arm or conveyor system to transport the components, and small-size assembly unit or micro-manipulator to assemble the components) and, on the other hand, on integrating the microfactory components into a single portable box [17]. Then, the research interests related to microfactory have evolved to respond to flexibility requirements by developing modular concepts in order to organize the hardware part of the microfactory [5,8,18]. Now, the majority of the microfactories are designed at the outset for rapid change of the structure in terms of hardware as well as software components such as TUT microfactory [5,37]. The existing microfactories have demonstrated some benefits in saving investments, space, energy and resources. The next step is to enhance the performance of micro manufacturing systems such as the design of a fully automated systems with limited human tasks, as well as managing the emerging modular microfactories in order to insure flexibility in both routing and production [3,16,19].

Simultaneously, organization systems for data and information control have been developed to manage the microfactory according to different approaches found in the literature. For example, Fatikow et al. [20] and Gendreau et al. [21] have proposed a methodology to design modular control architecture adapted to micro modular manufacturing systems. In addition, Descourvières et al. [22] and Mauchand et al. [23] have defined data models to manage the reconfiguration of modular manufacturing layout. This means that in case of reorganization and reconfiguration, support functions such as product/process modeling, process planning, production and capacity planning, control of processes and production, and logistics have also to be adaptable and changeable [24,25].

In the current context of mass-customization, where products have to be personalized to answer customer needs, modular manufacturing systems are a mean to improve industrial system flexibility by enabling a rapid change of production. Thus, in such a context of production change, material handling and product transfer processes have to be adapted (reconfigurable), and the product trajectories within the microfactory must be flexible to produce multiple variants of one product.

2.2. New trend for flexible and reconfigurable conveying systems: Modular microfactory and Smart Surface (SS) concept

2.2.1. Modular microfactories

Existing modular microfactories can be classified into two categories based on their architecture for aggregating modules. In the first category, the modular microfactory is made of modular blocks including workstations and part of the transfer system as illustrated in Fig. 1. In the second category, machines and/or components can be plugged or removed near a flexible, but fixed, transfer system (planar surface) as shown in Fig. 2.

For product conveyance, the first category uses conventional downscaled linear transfer line split into independent elementary units that can be combined inside a module in order to setup the desired layout. The modular microfactory operating system is then composed of a set of several modules arranged side by side. The interfaces and setup as well as the geometry of such modules are standardized in order to guarantee smooth integration or exchange without costly time-intensive ramp-up. Thus, the modules can be freely and easily setup on different line layouts and the control of transfer units is relatively simple since it is predefined and linear. Furthermore, the linear transfer line allows high throughputs and accuracy of pallet positioning. However, in case of machine breakdown or full capacity, the entire production process is blocked. Therefore, in this type of modular microfactory, flexible and efficient production can by realized with "bypassing" conveyor that can be added to allow the carriers/pallets alternative routes [26]. Besides, in case of reconfiguration of the layout for a new process or a new product, manual intervention is required to adapt the layout, taking into account the predefined shape and orientation of each elementary transfer unit (in line, with corner, etc.).

The second category of modular microfactory is "flexible transfer line". In this case, the conveyance system is a planar surface on which a number of carriers or pallets can move independently and freely as shown in Fig. 2.

The carrier or pallet is defined as "active" when it is energized to power its own actuators and "passive" in the other cases. For this type of modular microfactories, modularity is due to the ability to plug or remove machines/stations anywhere around the conveyance systems according to the production need. This is achieved by using standardized interfaces. In this case, a base unit or table acts as a service module that supplies power, network connection, pressured air... to other connected modules. This concept provides routing flexibility and reduces time of layout reconfiguration. Nevertheless, this type of modular manufacturing system is limited to the dimension of the planar surface that is not adjustable such as AMMS [8] and Miniprod [27]. Moreover, in this type of system, the wired power supply of the carriers limits the area of displacement. Contrary to AMMS and Miniprod systems, the AAA system is built from a collection of modular base units, platen tiles, and bridges. The workstation modules are setup on the bridges at any locations. The aim of this system is to enable rapid deployment.

This second category responds to the flexibility requirements, nevertheless, the reconfigurability could be enhanced by increasing modularity of the planar surface.

2.2.2. Smart Surface concept

Up to our knowledge, there is no consensus in the literature on the concept of "Smart Surface" (SS) [13,28–30]. In the present