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Full length Article

Configuration and inspection of multi-fixturing pallets in flexible manufacturing systems

Evolution of the Network Part Program approach

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ABSTRACT

During last decade, flexible manufacturing systems (FMSs) have moved toward the development of computer aided process planning techniques able to cover the gap among process planning, production planning and scheduling. Among these techniques, the Network Part Program (NPP) approach was able to support the on-line automatic generation of the part programs for multi-fixturing pallets, i.e. fixturing hosting several workpieces. In this context, the proposed approach presents an extension of the NPP in two directions: (i) a pallet configuration module for the automatic generation of alternative pallet configurations, when the workpiece setups are given and different part types are considered; (ii) a pallet inspection module based on laser scanner technology for the automatic identification of possible mounting errors and the automatic evolution of potential resulting errors. The provided extensions increase the flexibility at the shop-floor level in terms of pallet configuration to be machined and the reduction of possible mounting errors due to the increased variability in pallet configurations. The developed approach has been validated on a real case.

1. Introduction

Manufacturing market has been characterized during last years by high fluctuations in the product demand, rapid evolution of the part types and significant decrease in the batch size [1–3]. Computer aided process planning (CAPP) systems have tried to answer these market trends increasing their level of flexibility and partially filling the existing gap among process planning, production planning and scheduling [4–7]. Among the existing process planning approaches, the Network Part Program approach (NPP) [8] has moved in the direction of multi-fixturing pallets, i.e. fixturing hosting several workpieces, and specifically of the continuous reconfiguration of the pallet in terms of part mix and quantity.

Even if the advantages related to such a solution are demonstrated [9], continuous pallet reconfiguration has aroused two main issues which current NPP is not able to manage: (i) the manufacturing of different part types on the same pallet in order to better absorb demand fluctuations; (ii) the possibility to quickly generate new and alternative pallet solutions coping with the constraints of already defined workpiece setups (workpiece orientations during machining). Moreover, a rapid and efficient pallet inspection is extremely important in order to automatically detect possible errors during the pallet mounting in terms of incorrectly closed fixtures, incorrect mounted part type, unmounted workpiece etc. The aim of this paper is to propose an evolution of the NPP approach coping with the here described issues.

The paper is structured as follows: Section 2 presents a short review on CAPP and NPP systems; Section 3 describes the goals and novelties of the proposed NPP evolution as well as the new NPP framework; Section 4 is dedicated to the description of the new pallet configuration module; Section 5 depicts the pallet inspection procedure; in Section 6, the application of the developed new NPP modules is presented on a real case; finally, Sections 7 and 8 derive conclusions and future work, respectively.

2. Literary review

During the last decades, great importance has been given to the development and industrialization of computer aided process planning methodologies (CAPP). Recently, CAPP systems have evolved trying to better answer the increasing dynamism of a market characterized by

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continuous fluctuations of the demand, rapid evolutions of the products, reduction of the product life cycle, large variety of products, small batch size. In this context, an effective non-linear [10,11], dynamic [12] and distributed [13,14] CAPP approach is the Network Part Program (NPP).

In comparison to all the previous CAPP systems, the NPP approach has four main advantages: (i) the manufacturing of one part type on multi-fixturing systems (pallet) typical for flexible manufacturing system; (ii) the possibility to efficiently and rapidly adjust the part and/or the operation assignment policies to the system resources as a result of an unforeseen event such as machine failure or the lack of a cutting tool; (iii) the real-time regeneration of the pallet part programs according to the changes in assignment policies; (iv) the compliance to the standard ISO 14649 [15], while granting the applicability of the method in real industrial contexts.

The idea of the NPP is first introduced in [16] and subsequently developed in [8]. The complete approach is based on 4 main steps: workpiece analysis, setup planning and pallet configuration, operation sequencing and, pallet part program generation. Workpiece analysis consists in the identification of the machining features (geometrical information), machining operations (technological information such as required tools, tool access direction, spindle speed and feed rate) and machining workingsteps (MWSs—association between geometrical and technological information) according to the standard ISO 14649 [15] and in the definition of the precedence constraints among the defined MWSs [17]. The number of orientations of the workpiece in the 3D space in order to allow its complete machining [18] is defined by setup planning. Indeed, the accessibility to the workpiece operations, i.e. the visibility of the operation tool access direction (TAD), depends on the workpiece orientation on the pallet [19,20]. Pallet configuration [21,22] consists in the identification of the number and position (pattern) of workpieces on the pallet, so that the operation and setup accessibility are granted. Once the number of the machine tool axes is selected, the accessibility to the workpiece MWSs depends on both workpiece setups and pattern [8,23]. Operation sequencing and pallet part program generation [24–26], that are managed at the shop-floor level where all of the information about the machine and tool availability is known, consists in the identification of the operation sequence that minimizes the non-contact time and the generation of the program of the pallet according to the standard ISO 6983 [27].

This paper proposes an evolution of the NPP approach in two different directions. First, the pallet configuration module proposed in this paper overtakes the limitations of the current approaches, while being compliant to the NPP concept. A process planning approach involving multi-fixturing but disregarding the possibility to have different workpiece setups on the same pallet system was proposed in [28]. In [29], a NPP-compliant process planning approach able to select the workpieces setups and to define the number and position of the workpieces on the pallet was presented. Extensions of these pallet configuration methodologies where introduced by [30]. This papers proposed a method for the identification of setup planning and pallet configurations that maximize the number of machined workpieces per pallet. The approach relied on the following restrictive hypotheses: (i) the pallet can host only one part type; (ii) the virtual face (VF) of the pallet, i.e. a zone of the physical face (PF) of the pallet hosting workpiece in the same setup, fits the physical face. These two limitations are here overcome, allowing the simultaneously machining of several workpiece types. Thus, differently from the NPP-compliant approaches known in the literature, the proposed approach reuses the information contained in already defined and executed working cycles: existing and tested workpiece setups can be easily allocated to pallets with various shapes and dimensions.

Second, a pallet inspection module based on indirect comparison is introduced within the NPP framework to automatically identify at the shopfloor level possible errors in the pallet mounting. Literature approaches present limitations in the registration process, i.e. the alignment of the measured data—generally a point cloud—to the ideal 3D shape [31–35]: (i) the procedure is only partially automated; (ii) the use of special software (e.g. Geomagic, MeshLab etc.) is required; (iii) qualified operators, able to use programs for handling points clouds correctly, are required; (iv) low reliability of point clouds registration with such software systems. The here proposed module for pallet inspection is able to overcome these limitations, developing a laser scanner system for the acquisition of the pallet point cloud, an autonomous calibration procedure for the laser scanner and a Iterative Closest Point approach for the registration.

3. The methodology

As stated, the goal of this paper is to provide an extension of the NPP approach in the direction of incrementing its industrial applicability. The new developed NPP framework is presented in Fig. 1. In comparison to the existing NPP approach presented in [8], two modules have been added (gray blocks in Fig. 1): the “multi-part-type pallet configuration” and the “pallet inspection”. The role of these modules in the general framework and their novelties are hereafter described.

The user can analyze new workpieces through the “workpiece analysis & precedence constraints” module. This module is based on a specifically developed software tool interacting with a commercial CAM software tool, employed for the identification of the machining features and the generation of the machining operations and MWSs. The results are stored in the workpiece database. The “setup planning & pallet configuration” module is responsible for the generation of alternative pallet configurations and setup plans. The module is connected to the workpiece, cutting tool, machine tool and fixture databases, from which the necessary information is derived. The results are stored in the workpiece setup and pallet configuration databases. If the workpiece setups have already been defined and stored in the workpiece setup database, the user can simply execute the “multi-part-type pallet configuration” module. It extracts the necessary information from the workpiece, cutting tool, machine tool, fixture and workpiece setup databases, storing the results in the pallet configuration database. In comparison to the “Setup planning & pallet configuration” module described in [8,23], the following novelties arise:

- overtaking of the hypothesis characterizing [8,23] according to which only one workpiece setup can be mounted on each physical face (PF) of the pallet. The concept of virtual faces (VFs) as sub-zones of the physical face hosting one workpiece setup is introduced. As depicted in Fig. 2, different decompositions of a physical face can be considered, thus increasing process plan flexibility;
- overtaking of the hypothesis on which [8,23] stands, related to the mounting of only one part type per pallet;
- allowing the generation of alternative pallet configurations exploiting the technological knowledge of already defined workpiece setups, i.e. separation of setup planning and pallet configuration activities.

The use of the here developed extended approach grants the resolution of the industrial cases as the one provided in this paper that would have been not possible through [8,23].

The information related to the pallet configuration is employed at the shop-floor level to assemble the pallet and to verify the pallet consistency through the “pallet inspection” module. This new module extends [8] with the ability to identify possible source of errors in the pallet, so that the worker can fix it. Specifically, the pallet inspection module is able to detect possible errors due to an incorrect mounting of the pallet. The automatic check will reduce the probability to obtain non-conform parts or to cause damages to the fixture or to the machine tools.

Once the pallet is correctly mounted, it can enter the manufacturing system. The operation sequence and the pallet part program are automatically generated in real-time (“operation sequence” and “pallet part program” modules). All the data memorized in the database are accessible from both the shop-floor level and the planning level. Hereafter, the new modules are described in details.