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Multi-robot spot-welding cells for car-body assembly: Design and motion planning

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ABSTRACT

Multi-robot cells for spot welding use coordinated robots to assemble metal panels via spot welding by coordinated robots, for instance in the construction of car doors. The design of multi-robot cells for spot welding required both cell design and off-line motion planning. Cell design involves resource selection (such as robots and welding guns) and resource configuration, while considering cell productivity, costs, flexibility and reconfigurability. Motion planning involves allocating welding points to each resource and calculating collision-free motion plan for each robot. Currently, cell design and motion planning are sequential and manual activities, managed by different and separate industrial functional units. This results in several cycles before the design converges to a feasible final solution. The proposed approach introduces a unified methodology, aiming at optimizing the holistic cell design and motion planning, that reduces design time and errors. The feasibility of the proposed approach has been demonstrated in several ad-hoc basic replicable cases and in one industrial case. The outcome of this research improves state of the art, reducing design and motion planning time over current technology. Moreover, the method has been integrated into a computerized approach which has the potential to accelerate the whole cell design and motion planning processes and to reduce human efforts.

1. Introduction

Over the past 20 years, the automotive industry has moved towards the assembly of different vehicle models on the same assembly line through flexible and reconfigurable multi-robot cells [1,2]. This shift reflects two major drivers in automotive production: the saturation of the production capacity to reduce the production costs; the increase of product flexibility in terms of new vehicle models, and customization [3,4].[1]

Vehicle body-in-white is obtained through the assembly of ~300 – 500 metal panels and sheet components. These panels, produced through different processes such as stamping and machining, are generally provided in ‘white’, i.e., unprimed and unpainted. They are assembled into sub-assemblies necessary for the definition of the vehicle upper body or lower body, e.g., front and rear doors, front and rear trails, and the body-in-white, i.e., the assembly of the upper and lower body. The assembly of metal panels and sub-assemblies requires dedicated lines. The number of multi-robot welding cells can vary among the lines (generally between 55 and 75 cells per line) and depends on the total number of needed welding points, possible precedence constraints in the execution sequence of the welding points and in the desired takt time (average unit production time needed to meet customer demand) [6]. Each spot-welding assembly cell is an environment constituted, as in depicted in Fig. 1, by body-in-white transportation device so that the body-in-white can enter and exit the cell; body-in-white fixture to hold the body-in-white during the welding process; industrial robots; welding guns to be mounted on the robots; robot support structure to fix the robot in the space. The robot support structure influences the possible robot position and orientation in the cells. These selectable devices determine the cell cycle time that has to be minor or equal to the line takt time.

In the current industrial practice, automotive companies, proving all the necessary specifications such as the required cycle time (RCT) and consequently the talk time, commission turnkey systems to original equipment manufacturers (OEMs) that act as

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[1] In US, the number of vehicle models doubled from 1980 to 1999 (1050 models in 2000); in China, the number of vehicle models increased from 278 in 2010 to 474 in 2014 [5].

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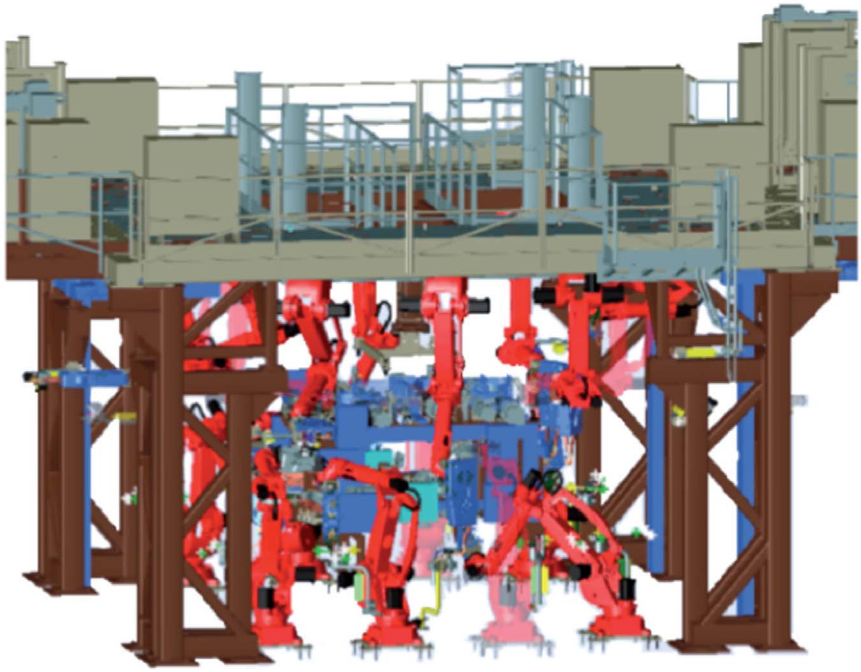

Fig. 1. Multi-robot spot-welding cell - COMAU Robogate. Courtesy of COMAU Robotics™.

system integrators. On the basis of the received specifications, the OEM initially solves the multi-robot cell design problem and subsequently provides a feasible robot motion plan, making cell design and motion planning two sequential activities generally managed from different industrial functional units. Firstly, taking into account position of welding points required by the automotive company, the OEM designs the body-in-white fixture (*BF*) that will influence the final quality of the body-in-white and the transportation device (*BTD*). Secondly, the OEM preliminary selects the resources in term of "which", "where", "how many" robots and tools are needed. Specifically, they select the robot model (*RM*), the robot support structure model (*RSM*), the robot positions and orientations (*RPOs*) on the robot support structure, and a welding gun model (*WGM*) for each robot in the cell. This activity is mainly based on tabular information coming from the OEM's experience and expertize. Finally, the OEM allocates the welding points to the robots, defines a motion plan for each robot and solves coordination issues among the robots. However, the mutual-influence of the multi-robot cell design and motion planning cannot be ignored: the decoupling of design and planning activities could lead to infeasible motion plans, imposing changes to the cell design. Thus, mutual interactions and cycles could be needed to obtain a feasible final solution. Each cycle causes delays and accumulated errors in a process that generally requires up to 14 weeks of works. This separation of the activities is partially justified by (i) the complexity of the two steps that represents a barrier for a straightforward optimal solution, and (ii) the multi-disciplinary activities and research fields required. The separation of multi-robot cell design and off-line motion planning that characterizes the industrial practice can also be identified in literature, where the integration between the two activities has not been adequately investigated so far.

2. Overview

This section focuses on the state of the art with respect to the following topics: design of multi-robot systems with a focus on multi-robots in assembly spot-welding cells; robot motion planning; and simultaneous design and motion planning of robotic cells. The innovative aspects of the proposed approach will be compared to these state of the art methods in Section 3.

2.1. Multi-robot cell design for spot-welding assembly

Several papers deal with the problem of designing spot welding cells, where each paper focuses only on partial aspects of the problem. A computer-aided process planning (CAPP) platform for integrating robot systems in small and medium enterprises is presented in [7]. However, the paper only defines the framework for cell design without addressing problems related to the design process.

On the contrary, an approach to optimally identify the gun model and the robot installation position for a single robot is described in [8], taking into account the flexibility of the production system and the versatility of the equipment. A similar approach is introduced by [9], where a single robot is optimally placed in order to execute some predefined tasks. Task reachability is checked for several possible discrete positions of the robot, taking into account collisions with objects in the environment. Other approaches focusing on the optimization of the robot position in the cell or the robot selection are described in [10,11].

Michalos et al. [12] marks a step forward in the state of the art, analyzing the design of multi-robot cells. Specifically, the paper proposes a more comprehensive approach for the design of multi-robot assembly cells to derive assembly line design alternatives. Given the product specifications and a set of possible technologies, layouts, resources and operations, alternative solutions are generated. Investment costs, cell availability, resource reutilization, flexibility and mean annual production volume are calculated for each solution. Although the presented methodology was applied to an automotive case, the allocation of the tasks to the robots is not considered for optimization.

The problem of the production tooling structure for multi-robot spot-welding assembly cells is considered in [13–16]. This approach focuses on the identification of the flexible elements of vehicle body-in-white and their interaction with the production tooling structure. The aim is to provide a reconfigurable and