G Model
CIRP-1655; No. of Pages 4
ARTICLE IN PRESS
CIRP Annals - Manufacturing Technology xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
CIRP Annals - Manufacturing Technology
journal homepage: http://ees.elsevier.com/cirp/default.asp

Dual arm robot in cooperation with humans for flexible assembly

Sotiris Makris (2)*, Panagiota Tsarouchi, Aleksandros-Stereos Matthaiakis, Athanasios Athanasatos, Xenofon Chatzigeorgiou, Michael Stefos, Konstantinos Giavridis, Sotiris Aivaliotis

Laboratory for Manufacturing Systems and Automation, University of Patras, Greece

ARTICLE INFO

Keywords:
Robot
Integration
Human robot interaction

ABSTRACT

This paper discusses a flexible assembly cell, including a dual arm robot in cooperation with humans for assembly tasks typically performed by operators. The robot performs these tasks both in isolation and cooperation with the human. Sensor data are used for programming the robot's motion and controlling the program's execution in a fenceless setup. Safety is ensured with the use of 3D sensing devices, while the tasks' coordination is managed by the so-called station controller. The programming approach combines both offline and on-line methods, in an intuitive manner. The proposed assembly cell is demonstrated in an automotive industry case.

1. Introduction

The human-like dual arm robot capabilities for synchronised and coordinated motions are expected to increase flexibility in manufacturing, due to their higher dexterity compared to those of conventional single arm robots [1,2]. They can be used in order to perform tasks in the same way that humans do them with both hands, therefore, the introduction of dual arm robots into human based assembly lines is a promising concept [3].

Both academia and industry have shown significant interest in dual arm robots, due to their advantages such as dexterity, flexibility, space saving, decreased complexity of tools and gripping devices [3–7]. The concept cooperating robots for assembly operations is an ongoing research topic [8,9].

Despite the extent of research on dual arm robot control, research on the advances that can be achieved in a manufacturing environment, has been rather limited. The main focus of this paper, is to investigate the technology that would allow dual arm robots to be used in industrial cases, involving human operators, aiming to advance the industrial practice and enhance shop floor flexibility. The research was performed in cooperation with industrial companies involving robot manufacturers, automobile manufacturers and simulation software providers, where the main research areas where identified following a series of onsite interviews. In order to achieve the introduction of dual arm robots, there are two main research aspects to be addressed. On the one hand, such a system should run safely and should allow for the human to work together with the robot in the same area; thus a safe fenceless cell setup is needed. Research efforts have focused on enabling human robot collaboration, investigating interaction and safety aspects [10–14]. Safety related standards, such as ISO 10218-1 and ISO 10218-2, are considered for robots safety requirements along with the ISO/TS 15066, regarding the collaborative workspaces' requirements. However, case studies involving industrial assembly tasks are rather limited. On the other hand, the introduction of such robots in industrial use, should offer a number of functionalities that would allow to simplify its programming. Dual arm robots are typically more complex to program compared to single arm ones, since there are more arms to program for achieving a cooperative operation. In addition, taking into account the presence of the human, programming of such a robot cell becomes rather complex [3,15,16].

The structure of this paper comprises the overview of the proposed flexible cell, along with programming methods and a fenceless safety approach, as shown in Section 2. The implementation follows in Section 3, while the automotive case study is described in Section 4. Results and discussion follow.

2. Approach

2.1. Flexible assembly cell overview

The proposed flexible cell for human–robot collaboration, namely HRC, includes an industrial size dual arm robot, working in shared or separate workspaces with the human, as shown in Fig. 1. This cell offers increased flexibility for the following reasons. At first, the dual arm robot involves two arms and this allows for more dexterous manipulation, space saving, increased workspace, reduction in the tools and fixtures' complexity compared with that of single arm robots [17]. Secondly, involving a human for performing the assembly of more complex parts, such as the

* Corresponding author.
E-mail address: makris@lms.mech.upatras.gr (S. Makris).

http://dx.doi.org/10.1016/j.cirp.2017.04.097

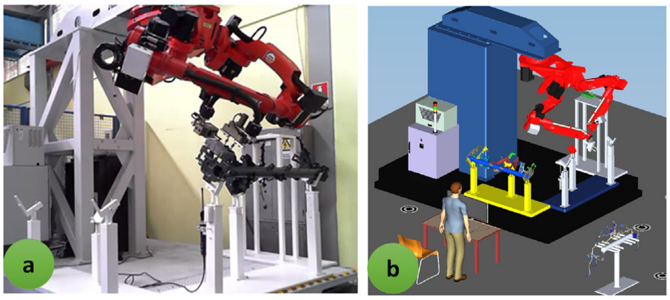

Fig. 1. (a) Flexible cell; (b) flexible cell in simulation environment.

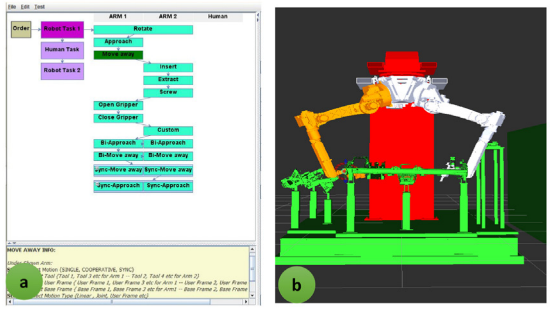

Fig. 3. (a) Graphical interfaces for programming and hierarchical model, (b) CAD based robot programming.

assembly of cables and wire harness, requires intelligence and dexterity that extend further the cell's flexibility.

The dual arm robot, in the proposed flexible cell, was enhanced with sensors for perceiving human's presence, simple gripping devices that enables the handling of parts of a variety of sizes and complexity. Examples of such shapes are the dashboard traverse and the fuse box, as this is discussed in Section 4. Fixtures are placed around the robot for the loading of parts to be assembled, while a screw driver can be used both by humans and robots for relevant operations.

While a wide range of programming techniques have been proposed in the literature, the effort of employing them in a flexible cell integrating a dual arm robot and a human for performing a series of assembly operations is rather limited. Such integration is beyond the individual research achievements that are already at hand for simplifying robot programing and controlling the execution of a program. Additional aspects need to be addressed, for example the integrated consideration of assembly tasks and manufacturing resources, in this case the arms of the dual arm robot and the human. To this effect, a four-level hierarchical approach has been adopted, structuring the assembly tasks in an integrated hierarchy of programme-job-task-operation. This hierarchical structure has been introduced in Ref. [18], combining both human and robot activities in a unique model. Programming, safety related challenges and coordination of the HRC tasks are discussed in the following sections.

2.2. Robot program generation

Programming the dual arm robot for cooperation with the human extends beyond the single robot programming; it should address two aspects. On the one hand the program should handle the sequence of tasks and ensure interlocks among robot and human operations. Nowadays, this level of programming is addressed by the means of PLC programming supervising the robot cell. In case of need to change the sequence, then the PLC needs to be reprogrammed and this requires to involve a programming specialist. On the other hand, the robot needs to be taught a number of positions for reaching the parts to be assembled and also avoid collisions with the human and the environment. Nowadays, this approach is managed in the industry by the use of teach pendants which are used to store the positions in the robot controller accordingly.

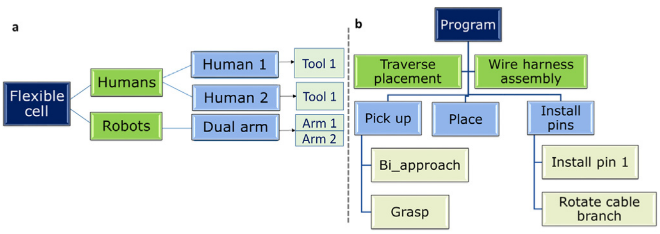

Fig. 2. (a) Resources model, (b) program structure.

In order to address these challenges, this study proposes the structuring of a robotic program, around the introduced hierarchical model, as illustrated in Fig. 2.

The use of the hierarchical representation of tasks in this paper, eliminates the need for code writing for sequencing robot and human tasks. The hierarchy of tasks, along with the definition of their pre-conditions, allows the simple modelling of their sequence. The reconfiguration of the sequence as well as the allocation of tasks, enables the human to restructure the hierarchical HRC program and add new tasks if required.

In terms of the second aspect, of defining the robot motion, the proposed approach permits the automatic generation of robot motions, requesting a small number of key positions, for example the position to grasp the part, avoiding to instruct intermediate positions for avoiding collisions with the fixtures. Such key positions are stored in the operation level according to the four level hierarchy using collision free motion generation algorithms [16], utilising information from sensors along with CAD data, as shown in Fig. 3b.

Two different graphical environments have been implemented for facilitating the cell programming. The first one includes the building of the hierarchy of tasks and operations, as shown in Fig. 3a and it is used onsite.

The second graphical interface is based on the same principle of hierarchically structuring a program, but the robot and human operations are generated by an offline simulation-programming tool, as presented in Fig. 4. This approach is described in Ref. [19] and is based on the use of an XML format file for the generation of the program structure from the offline tool. This file is loaded through the first graphical interface and the program structure is generated automatically. The user can interact in the same way, even in the case of the data being generated from the offline tool.

The main execution system, coordinating and monitoring the human and robot tasks, is called station controller. Interaction during the execution of a program is made via gestures and voice commands. For example, there are gestures available for signalling the start and the end of a human task. All of these processes are controlled through the ROS middleware.

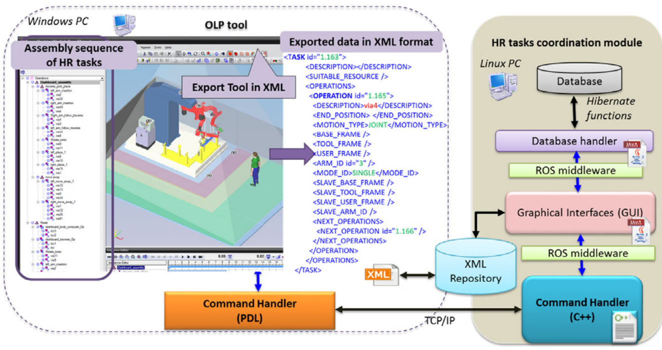

Fig. 4. Graphical interfaces for offline robot programming [17].

Please cite this article in press as: Makris S, et al. Dual arm robot in cooperation with humans for flexible assembly. CIRP Annals - Manufacturing Technology (2017), http://dx.doi.org/10.1016/j.cirp.2017.04.097