Robotized assembly process using Dual arm robot

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Abstract

This paper investigates into the use of a dual arm robot system for performing manual assembly operations. The investigation is based on a case study, originating from the final assembly area of an automotive assembly plant. The motivation as well as the benefits derived from the employment of a dual arm robot are discussed. The station layout, tooling design and robot programming are elaborated. The use of a dual arm robot enables the performance of operations that are carried out by humans, while the comparison of using single arm robots offers a number of advantages, which are discussed in the paper. The assembly of a vehicle dashboard is used as the use case coming from the automotive industry.

Keywords: Assembly process, design, dual arm robot, automotive industry

1. Introduction

Today’s market evolution and continuous competition rise increase the pressure on industry for acquiring a larger market share [1]. The automotive industry cannot be excluded from this competition. Especially, since product variety is increasing, the mass customization paradigm [2][3] dictates the necessity for manufacturing systems to be designed in such a way so as to be responsive to the needs of individuals [4]. The automotive final assembly operations require more flexibility and robustness [5]. For higher automation levels [6] multiple performance aspects have to be investigated into and optimized with respect to metrics such as cost, productivity, quality and flexibility [7].

The automotive assembly lines are divided into automated, such as stamping body shop, paint shop and the human based assembly lines, such as final assembly stations, powertrain etc., as illustrated in Fig. 1. Michalos et al. [8] describe three categories of automotive assembly operations: the manual, flexible, semi-automated and fixed assembly operations.

Especially the human based assembly lines include operations that require dexterity that can only be achieved two-handedly. These operations are also known as bi-manual [9].

Fig. 1 (a) Automated assembly line; (b) Human based assembly line.

The aim of this paper is to examine the increase of automation levels in human based assembly lines, with the introduction of robots that can offer precision, repeatability and increased production rates as well as dexterity being closer to human-like performance [10][11][12][13]. Inspired by human task execution, the introduction of dual arm robots in assembly lines, presents a double novelty [14]. On the one hand, the attempted automation of a traditional manual
assembly cell is a challenge by itself. On the other hand, the choice of a human like robot is essential for addressing tasks that require restricted space and both arms acting in cooperation. The concept of using multiple cooperating robots for assembly operations has been already discussed in numerous research works such as in [15]. The adoption of such robots, in the assembly line, seems promising as it enables multi-tasking, as well as space and cost efficiency by eliminating the fixtures and clamping devices [16]. Last but not least, the fact that dual arm robots resemble the human body structure, [17], made the design and programming of assembly operations easier and more intuitive.

This study primarily investigates the mechanical and programming aspects of using a dual arm robot in operations that are typically performed by humans. The selected case includes the design and programming of a dual arm robot to execute the pre-assembly of a vehicle dashboard traverse, as illustrated in Fig. 2. The first step includes the lifting of the traverse from the loading area and its placement on the assembly bank. Following, the car’s body computer is grasped, positioned and fixed on the traverse. Nearby this station, the installation of cables, air-condition unit etc. takes place.

This paper is structured as follows. Section 2, describes the extraction requirements from the assembly operations analysis. In section 3, the dual arm involvement in robotized assembly lines is discussed. The automotive case study is described in section 4, while sections 5 and 6, present the results, discussion and conclusions respectively.

2. Requirements and assembly operations analysis

The analysis carried out on the existing human based assembly process has resulted in a list of nine important requirements for the designing of a robotized assembly. These requirements involve:

- R1: Improvement in the final product quality. The product quality is important as it is directly associated with customer satisfaction. Issues that can affect the quality are related to assembly errors that in manual assembly lines are common due to human factor.
- R2: Minimum modifications in the current production line. Any attempt towards higher automation should aim at minimal modifications, resulting in cost and changes reduction in the adjacent assembly stations.
- R3: Reduction in the cycle time towards achieving higher production rates. The reduction is desired, but at least, the intention is that the current cycle time be respected.
- R4: Improvement on working conditions and more specifically, on aspects of ergonomics. Lifting heavy parts and repeating monotonous movements by operators are some aspects to be improved in the designed robotized line.
- R5: Overall production cost reduction. This reduction is mainly related to the reduction of reworking hours due to low quality products.
- R6: Safety. The safety issues are complementary to the ergonomic aspects and are mostly related to the avoidance of injuries or work related accidents.
- R7: Ease of use and maintainability. It is important to enable easy ways of training an operator on how to use a system, as well as to his easily maintaining the equipment.
- R8: Improvement on production performance. For the automotive industry, some important examples are technical efficiency, annual production, number of required shifts, number of human operators required etc. Such aspects are aspired to be improved by increasing the automation level. The technical efficiency (T.E.) is calculated as the actual production throughput divided by the planned production throughout.
- R9: Space saving. This requirement is important for saving space for other stations or adding an extension module to the same station.

In Fig. 3, the discussed requirements have been fused into an assembly cell design and also a hierarchical model has been derived in order to accommodate the assembly activities.

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closely connected with the robotized assembly operations. For this reason, the hierarchical approach that was described in [14] has been adopted. The hierarchical model is the structure of the assembly operations in different steps and levels. This structure helps the designer to identify the possibility of automating all the steps, the problems that may arise, possible redesigns of the station etc.

In the dashboard assembly case a number of parts have to be assembled step by step. The vehicle traverse is the first part as shown in Fig. 4. A Body computer is depicted in Fig. 5, from two different viewpoints with the screws that are used in order to be fixed on the traverse.

3. Dual arm robot use for robotized assembly operations

The analysis of human operations focuses on analyzing the lowest level arm motions. These motions can be divided into single arm actions, as well as bi-manual actions, according to the classification described in [14]. The bi-manual operations can be considered both as the coordinated motion of the two arms, referred to as “COOP” in this work, as well as synchronized motion when both arms are moving independently and synchronized which are denoted as “SYNC” motions.

The dual arm robot motion capabilities can cover most of the human motions, both single and bi-manual actions. In the automotive case study, examined in this paper, both types of motions have been encountered and are presented in [14]. Between them, there are 22 bimanual operations, 16 of which are SYNC and 6 are COOP arm operations. On the other hand, there are only 8 single arm operations used. This is also a reason for directing the robotizing of the dashboard assembly cell towards using a dual arm robot.

<table>
<thead>
<tr>
<th>Dual arm robot tasks</th>
<th>Number of SINGLE arm operations</th>
<th>Number of SYNC arm operations</th>
<th>Number of COOP arm operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lift traverse</td>
<td>0</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Place traverse</td>
<td>0</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Lift body computer</td>
<td>0</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Place body computer</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Lift screw driver</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Screwing process</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Place screw driver</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

The analysis of tasks in SINGLE, SYNC and COOP motions has an important role in the design and selection of tools and grasping devices, as well as in the workstation layout. A dual arm robot enables the exploitation of the maximum workspace around it, opposed to other solutions dealing with single arm robots. This is further analysed in the comparison presented in section 5, including the comparison of one or multiple single arms and a dual arm robot for the specific case.

4. Automotive industry- A case study

4.1. Layout design & implementation

In the selected assembly scenario, the tasks are currently performed by a human operator using his/her hands or tools such as screw drivers. This investigation presents the potential of setting up a dual arm robot cell for the assembling of a vehicle’s dashboard traverse. For this purpose, a COMAU Smart Dual arm robot has been selected as the robot platform. The selection was based on the handling of heavy and complex geometry parts, as well as flexible parts from different materials such as metal and plastic.

Loading and assembly areas are visualized in Fig. 6(b), while in Fig. 6(a) the overall designed cell is presented. On the left side, the traverse is standing on the loading area. The basic concept is that, due to its greater accessibility, the loading area is ideal for the human operator to load a traverse. The robot can transfer the traverse to the assembly bank by using both arms in a cooperation mode. The base, where the body computer is placed, can be found on the left side of the cell. Both arms of the robot hold the body computer and place it onto the left side of the traverse. The next step is to be fixed in place using three screws. In order to guarantee that the body computer will be fixed correctly, one arm holds the body computer in place and the other picks up the screw driver from its base.

Fig. 4 Vehicle traverse.

Fig. 5 (a) Body computer view 1; (b) Body computer with screws.

Fig. 6 (a) Layout overview; (b) Traverse bases design.
The grippers used in these tasks are visualized in Fig. 7 and are designed in such a way, so as to allow the handling of more than one objects. In Fig. 7 (a) for example, a specially designed adaptor on one side of the gripper is used for lifting the traverse by being inserted into one of its holes. On the other side, there is a commercial gripper that is integrated into the robot and can be used for picking up the body computer as well as the screw driver. The same concept is also adopted by the second gripper. One side is designed in order to be inserted into the traverse and the other one has a commercial gripper used for lifting the body computer.

With this concept, not only can heavy parts such as the traverse with weight about 11kg be lifted, but also smaller parts such as a body computer with a weight about 0.5kg. Another option would be the use of two different grippers for each arm to be fitted with an automatic tool changer (ATC) system. The cost in this case would be much higher, and the cycle time of the process would be increased due to the time required for the changing of grippers.

The design of the screwing process was based on the use of a simple commercial screw driver (Fig. 8 (b)) that supported the torque control and the construction of a simple adaptor (Fig. 8 (a)). The idea is that the screw driver is placed in the adaptor, which is then fixed on the assembly bank. The left arm of the robot can lift the screw driver using the fingers, which are attached to the commercial gripper. Once again, the alternative option would be to use an ATC system that would cost more and require extra time for changing tools.

The steps that are followed in this workstation are summarized as follows:

1. Traverse placement:
   - Picking up the traverse from the loading area, as shown in Fig. 10 (a). The smart dual arm robot approaches the traverse in the loading area and both arms in the SYNC mode, insert the grippers into the traverse. The lifting of the traverse is carried out using the COOP mode of the robot arms, and finally, the rotary axis which is ARM3 of the robot, brings the traverse in front of the assembly bank.
   - The placement of the traverse onto the assembly bank is shown in Fig. 10(b). The placement is implemented in the COOP mode and when it is finished, both grippers are extracted from the part in the SYNC mode.

2. Body computer placement:
   - Picking up the body computer from the loading area, as shown in Fig. 11(a).
     - The rotary axis approaches the base of the body computer, while both arms in the SYNC mode approach in order to grasp, with both electrical grippers, the body computer. In COOP mode, the robot moves away from the base and approaches the assembly bank using the rotary axis.
   - Placement of the body computer onto the traverse is shown in Fig. 11(b).
     - In COOP mode, the robot approaches the assembly bank and leaves the body computer. One robot arm is moving away to grasp the screw driver.
3. Fixing of the body computer with the screw driver as illustrated in Fig. 12

While the first arm is lifting the screw driver, the second arm holds the body computer in order to complete the screwing process. This is essential for two main reasons. At first, the body computer is not well-fitted in the traverse slot due to its high tolerances, so it has to be held in a specific position. Secondly, there is a need to grip the body computer so that it will stay put during the screwing process. The holes, where the screws will be inserted, are approached by a 6.5Nm torque to be applied to the screw. The final step includes the placement of the screw driver to its initial position.

5. Results & Discussion

The motivation of the proposed assembly cell design is that the automation level be increased in traditionally manual assembly workstations, such as in the automotive final assembly. The first results of this study are promising for directing future research. At the beginning, a simple workstation layout design was carried out.

On the basis of the classification between single and bi-manual actions, the use of dual arm robots has been evaluated. The results show that this kind of robot is suitable for these tasks, as it has control capabilities for the execution of both single and bi-manual tasks. The final product quality—in this case the car—improvement in comparison to the manual assembly line is also an important issue that can be achieved through this workstation, as a human is more susceptible to making assembly errors. Additionally, the working conditions and improvement in ergonomics can be achieved through the proposed concept, since the weight of the traverse is rather high for a human operator in the line.

In case that a dual arm robot is used, better exploitation of the workspace, greater levels of robot reachability as well as easier programming and coordination of arms are allowed. This is compatible with the development of algorithms in the robot’s control system, which can easily perform bi-manual actions. Additionally, the robot workspace can be extended as the robot is equipped with an external rotary axis that allows the robot to rotate 180° around its base, as shown in Fig. 13. In this case, the workspace for cooperative, synchronized and single arm motions is visualized in Fig. 13 (b), covering the larger area of the robot cell.

Fig. 12 (a) Pick up screw driver; (b) Body computer screwing.

An alternative approach to designing this cell, was the use of two single arm robots, as illustrated in Fig. 14 (a). The area where the two separate robots can work, in cooperation, is visualized in the same figure. The cooperative working space is the purple spherical shape and is evidently restricted in comparison to the dual arm robot, as shown in Fig. 13 (b). The limited reachability is visualized in Fig. 15, where the two robots are trying to cooperate in the workspace for placing the traverse. In the same figure, the workspace of Robot 1 can be shown by a red dotted line as well as the non-reachable areas in red color. The areas that have to be reached for the completion of the dashboard assembly scenario are areas 1-3. Area 1, can be reached by both robots, while area 2, cannot be reached by robot 1. It is also evident that in this case, the two robots collide when trying to transfer the traverse from area 1 to area 2. In area 3, both robots have limited reachability, so there is no possibility to complete the dashboard assembly tasks with this alternative solution.

The use of a one single arm robot, with a product specific gripper for lifting the traverse, was another possibility. In this approach, the gripper would be rather heavy and complex for handling the traverse as shown in Fig. 14(b), and it may not be used for grasping a different part. The cost would be considerably increased in this case and an ATC system would be required. Compared to this solution, the dual arm robot has provided the prospect of rather complex parts being handled in a dexterous way and with the use of lower complexity tooling.

Fig. 14 (a) Two arm robots cooperative workspace ; (b) Single arm robot with complex gripper

Additionally, it is worth-mentioning that the design of simple and cost effective grasping devices can enable the handling of different parts such as the traverse or the body computer. This can be accommodated with the limited robot payload, namely 20kg, more easily and without using an ATC system.
environments.

The next step includes the investigation into ways of adopting and integrating this type of workstations, in industrial environments.

**6. Conclusions**

This paper has presented an investigation on the ways of designing, setting up and programming a workstation, encountered in manual assembly lines of the automotive industry. The main innovation is the introduction of a medium payload dual arm robot. The identified advantages of this study can be summarized as follows:

- Increase automation level in manual assembly stations.
- Decrease the cost of setting up a cell by selecting a dual arm robot, instead of single arm robots that would require more complex and expensive grasping devices.
- Increase the robot workspace that can be exploited in the cell and provide more space to be used as storage or another station.
- Simplify programming, as dual arm has already got control functions for bi-manual actions, in contrast to single arm robots that should be synchronized.

The proposed setup is a complete design, which can support the execution of the specific assembly operation. The next step includes the investigation into ways of adopting and integrating this type of workstations, in industrial environments.

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**References**


