Design optimization of robotic work cell layout in automotive industries

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Abstract. In today’s world of manufacturing industries especially automotive sectors which expects high productivity, quality and accuracy, dependence on the industrial robots is increasing more than the human labor. A robot cell is a part of manufacturing environment composing of one or more robots with controllers are becoming popular in the automobile industries for many operations like welding, assembling and painting. It is observed that the issues with the design of robotic cell layout play a major role in achieving better production rates and safety aspects. This paper discusses on the critical issues with the robotic cell layout and optimization of the work cell layout after an analysis for elimination of errors.

Keywords: cellular manufacturing, robotic work cell layout, automotive industry.

1. Introduction

Robot cells, referred as work-cells are a part of any automated manufacturing environment and it composes of tailor made robots with a generic controller performing designed functions in any typical manufacturing viz., automotive industry. In the recent year modern industries are more dependent on flexible manufacturing concept for efficient usage of the material handling systems to make the maximum usage of machine time and to reduce the ideal time cost. This increases the productivity and as a revolutionary effect in the industrial sectors robots are replacing human being for repeated tasks and hazardous working environments. In addition to its accuracy applying robots leads to increasing quality of the product that has become mandatory this cutting-edge manufacturing environment. As a factor of that sequence of robots are installed to perform a challenging task which is called as the robot work cell. Two aspects arise in the robot applications in industrial production line. Layout structure and the progression of materials have a huge effect on the execution of assembling framework [1]. These can assist with expanding efficiency, lessening work in procedure and stock. Short creation lead time smoothes out the progression of materials and decreases non esteem exercises from the creation procedure of pausing and transportation, which make the industrial facility meet clients’ necessity rapidly [2].The increase in availability and the dynamic development of industrial robots have led to their implementation in almost every field of industry. Increasingly, systems with high levels of flexibility, automation, and reconfiguration possibility are emerging in place of classic manufacturing systems. The intensive development of industrial robotics is, obviously, a challenge for modern robotic engineers. Appropriate design and modeling of the manufacturing system is essential for the efficient integration of the work cell components and the proper operation maintenance of robotic production systems [3].
1.1 Robot Cell
A robot cell involves multiple robots and its accessories framed in a format for carrying out series of operations in a manufacturing assembly. This is what is meant to be a cellular manufacturing system. The objective of manufacturers is the investment return rate that they gain by automating the operations of a sequence. It is largely determined by the productivity of robotic cell and the leading time of robotic production system. A crisp procedure method to design a robotic cell layout with the maximum throughput for a given task is undeniably a worthy research topic. The proper selection of configuration for task, manual operation skill learning and translation, collaborative design tool-chain, optimization in cell layout and operation scheduling, optimal end-of-arm tooling design, and human–robot collaboration are very significant in the present scenario [4]. The design of a robotic cell layout can be carried out by three mathematical models (i) select and position the resources, (ii) allocate the tasks to the resources and (iii) identify a coordinated robot motion plan. With this proven methodology, a perfect design of cell layout can be achieved for motion planning and for any environment complexity can be devised [5].

1.2 Work-Cell algorithm
A unique spatial representation system is used to model the shapes and orientation of the stations in the work-cell. The representation is very flexible and can closely represent the shapes of many common types of peripheral machine encountered in a robot work-cell. A heuristic algorithm for optimizing the layout of a robot work cell can be used to minimize the total path of travel of a robot arm for a given sequence of operations by determining the relative positions and orientations of the stations in the work cell. The algorithm has been implemented on an IBM compatible PC and the results obtained are promising [6].

1.3 Components of a Robot Work cell
The robot is located approximately at the center of the cell and the equipment are arranged within the reach of robot. The robot services the equipment in a particular sequence of its operation. The service operations are loading and unloading the equipment with the partially finished products. Sometime robot should wait (or idling) till the processing by a machine is completed (eg: CNC machining). Parts are to be supplied to robot to perform a pick and place (loading/unloading) or a processing operation. Conveyors, part feeders, delivery chutes and pallets are the means of accomplishing the supply of parts to robot. Discrete part productions such as die-casting, machining plastic moulding and other similar production operations can be accomplished by this work cell.

1.3.1 Inline Robot Work Cell
Robot is located along a moving conveyor and to perform tasks on the product that is coming on the conveyor. Many in-line robot work cell involve more than one robot. One common example is: Car body assembly. Robots are positioned along the assembly line to spot-weld the car body frames and panels. Synchronous or intermittent Transfer System: Moves the parts with a start and stop motion from one work station along this line to another work station. Here all parts are moved simultaneously and then registered at the next respective locations, and the robots are stationary along the line of transfer (conveyor). A part is registered and kept stationary so that robot finishes the process during the robot work cycle [7].

This may be categorized as three sub systems. Continuous Transfer System, Moving based line tracking and Stationary based line tracking system. The tracking window is the intersection of work volume of robot with the production line. Sensing the presence of part within the tracking window is required. Robot starts its functioning as the part enters the tracking window.

Problems of stationary based line tracking system: Robot has to continuously manipulate its joints so that it does the required job on the part without interruptions as the part is moving on the conveyor. Real time controlling of robot has to be very effective. The velocity of parts coming along the line has to be known and fixed. Variations in velocity will deter effective robot cell performance.
1.3.2 Non-synchronous Transfer System
This is a mode of system of alignment of specific function robots that moves independently along a conveyor in a stop-and-go fashion. This system is also termed as power and free system. Each part is placed on a cart that moves along the conveyor, at the work station, the cart is brought away from the conveyor nearer to the robot so that robot takes its time for performing a task on the work part. The process is complex and is to be provided with sensors to decide where exactly the cart is. Some time the conveyor may be stopped so that the duration of robot’s task on the part is substantially long.

1.3.3 Mobile Robot Work Cell
Robot is capable of moving to the various equipment within the cell [8] A mobile base is needed. This could be accomplished by having rails either on the floor or overhead so that the robot can reach the equipment easily. Overhead system is expensive but reduces floor space. Another very effective but complex design is to have more than one robot operating in a network of rail system overhead. This can effectively reduce the machine interference and robot idle time.

A realistic approach of robotic cell layout is presented to model problem using the robot joint space. Such method enables the robot control parameters to be considered in the problem formulation. A non-linear optimization model can be presented and solved using the Sequential Quadratic Programming algorithm available in the Mat lab® optimization tool box. By implementing to a real industrial robot, the feasibility of the proposed approach can be examined through several examples. 3D simulation software is used to provide a practical analysis of the developed layout and robot dynamics [9].

Software to compute the time-optimal motions along specified paths, local optimal paths and the global optimal path between given end-points is developed at the Robotics and Automation Laboratory. It considers the full robot dynamics, actuator constraints, on the payload acceleration or the gripping force, and any number of polygonal obstacles of any shape. The graphic displays provide a useful tool for interactive motion planning and work cell design [10].

Robotic work cell simulation is a modeling-based problem-solving approach developed for the design, analysis, and offline programming of robotic work cells. Current industrial practices show that commercial robotic simulation software packages are able to provide designers with an interactive and virtual environment in which credible solutions for robotic work cell designs can be obtained. However, conducting robotic work cell simulation studies via robotic simulation packages require designers to carry out complex processes of modeling, programming, and analysis, which often results in technical challenges and difficulties [11].

A multi objective layout optimization method for the conceptual design of robot cellular manufacturing systems can make designing easier. Robot cellular manufacturing systems utilize one or more flexible robots which can carry out a large number of operations, and can conduct flexible assemble processes. The layout design stage of such manufacturing systems is especially important since fundamental performances of the manufacturing system under consideration are determined at this stage. The design criteria for robot cellular manufacturing system layout designs are clarified, and objective functions are formulated. A multi objective genetic algorithm used to obtain Pareto optimal solutions for the layout optimization problems can be made use of as suggested in literature [12].

The objective of this paper is to identify the key locations in an industrial scenario of robots application and suggest a suitable layout for installation of robotic work cell layout. It is identified in the flexible cellular manufacturing system in the automotive industries that the usage of robotics are dominating and replacing the human labors. It has been observed that the location of the robots and the space occupied by them to carry out the work has been called as the concept of robot workcell layout and it has to be designed for achieving increased productivity. Normally the basic function of the workcell is controlled by sequence of operation, human interface and safety monitoring. The main challenge of this workcell design and control is error detection and recovery (EDR) and robot cycle time analysis. These issues are analyzed and better options are to be studied.
2. Methodology
A virtual environment for a robotic cell is developed and the layout design is validated and implementation planning is conducted to set up the real robotic cell. Such developed semi-immersive environment provides users with a sense of presence in the digital environment, and enables them to work with 1:1 scale digital objects as in the real world [13].

A three dimensional robotic work cell layout designed in CAD package is shown in Fig 1 and 2. The design shown is done with specified objectives like minimal foot-print, shortened path of travel and comfortable space for movement of goods and materials.

- The robotic work cell primarily is expected to minimize wasted space in the center of cell.
- The robots position could be elevated in the z – direction as much as possible.
- The width of conveyors could be reduced to match the product or pallet size rather than the standard widths.
- Only providing the level of automation needed to accomplish the goals of the project.
- Modify the control options of robot that could allow for safety fencing for the robot to reach points closer.
- To provide only the required amount of product or load accumulation to accomplish the goals of the project.
- Use lift gates or embed components into the floor slab to allow additional accessibility.

![Figure 1](image1.png)

**Figure 1** A sample 2D industrial robot work cell layout

The requirements of typical robotic work cell take the form of the following:
- Product in feed locations
- Raw material delivery locations
- Forklift travel aisle ways
- Obstructions that are part of the industrial building
- Tie-in points of existing machineries
- Electrical and pneumatic tap locations
A robotic cell scheduling problem with m machines under the assumption of process and operational flexibility is formulated. This new cycle dominates all classical robot move cycles considered in the literature for m = 2. It could also be proven that changing the layout from an in-line robotic cell to a robot-centered cell reduces the cycle time of the proposed cycle even further, whereas the cycle times of all other cycles remain the same. For the m-machine case, it is found that the regions where the proposed cycle dominates the classical robot move cycles, and for the remaining regions it presents a worst case performance with respect to classical robot move cycles. Considering the number of machines as a decision variable, optimal number of machines that minimizes the cycle time of the proposed cycle is determined [14 - 15].

3. Result and Discussion

3.1 Work-cell layout attributes

Attribute 1: Workflow must be simple and hassle free.

The most important attribute of a work-cell layout is free movement of semi-finished goods within the cell or between the cells that perform consecutive operations. The operator’s movement is also taken into consideration for a easy and quicker movement between workstations.

Attribute 2: Transit time of goods is to be maintained minimal.

Time taken for the goods to move around the cell or between the cells for the specified sequence of operations is a very significant attribute for the design of a cell layout. The cycle time of each operation on the various machines, the time of travel between the machines are very crucial and an accurately positioning them with the movement of robot manipulator becomes essential.

Attribute 3: Avoid unwanted harming objects

The positioning of machines is to be in such a manner that the operators should not be inhibited by sharp and tight corners and comfortable movement of materials is also to be ensured. If automated conveyors are used instead of manual transport sufficient space availability and easy manoeuvrings necessary in such an environment.
The sample robot manipulator assembly has been shown in Fig.3 that is been used in the robot cell work layout. This robot manipulator can be employed to most common work cell layouts in an automotive industry. The way machines are assembled with the robot manipulator form a layout and this provides smooth flow of work delivered by the robot manipulator. The shapes by which the robot manipulator and the machines assembled are in the shape of some alphabets and are similar to conventional material flow arrangements in traditional assembly lines. They form the letter shapes like Z, S, T and U. Streamlined flow of unfinished goods and finished work is the utmost expected function out of these layouts. In industries where construction pillars or huge machineries are assembled Z and S layouts are recommended. The robot manipulator works by moving around the pillars, machineries or any construction.

In a typical automotive industry, the robot manipulator stations are aligned with the other machines midst the space available. The robots incur electric motor power during their operations, and for an economical cost effective production, transit time of robots, semi-finished and finished goods are made minimum by constructing stations closer and in a linear manner.

Even though automated stations in assembly lines with robot manipulators are becoming a common scene in any manufacturing assembly of the time, so is the requirement of skilled manpower to support the complete assembly, where-in more accuracy is expected. Layout in the shape of alphabet U is specifically low work and energy consuming machine. The specific features of a U shaped Layout will be minimum travel distance for more work conversion rather than the conventional assembly lines.

- The entry and exit are not far apart and this permits complete visual control and management of operations. The complete task can be handling by one skilled person that would result in more economical approach.
- As the travelling distance is further reduced it leads to reduction of transportation waste and sharing of work.
- The entire operations are performed inside the U shaped layout and the materials are all housed outside the layout for faster operation in minimum time possible.
- Walk distances are reduced as all components are closer to layout and thus the objective of reducing operation time with maximum robot time utility is achieved.
The Major types of the robot cell layout that is selected based on the three factors like the workflow, functionality and the transient time. Robot cell layouts of automotive industries are designed for operations like spot welding, painting and assembly of the components. These layouts are in the above forms. The model of the sample robot manipulator along with the image of the layout was created using CAD software CATIA-V5 that provided a better visualization of the layout and as per the simulation of the work-flow layout process (Figure 4) U shape is good that gives a normal input and output. The functionality is also good in which the required function is accomplished. The important desired outcome, the transient time of the process is also good compared to Table.1. The other types of the layout such that T, S and Z shape (Figure 5, Figure 6 and Figure 7). It has been observed from the working condition that the U and Z shapes are comparatively better in connection with increased productivity and safety aspects. For the performance comparison of different layouts refer table 1.

Table.1 Performance comparison of different layouts

| Type of Layout | Workflow | Functionality | Transient time |
|----------------|----------|---------------|----------------|
| U              | Good     | Good          | Good           |
| T              | Average  | Good          | Average        |
| S              | Better   | Good          | Better         |
| Z              | Better   | Good          | Best           |

4. Conclusion

Robotic cell layouts are designed based on the required criteria and modeled in CATIA and the placement of robotic manipulator is studied. The layouts of robotic manipulators and their operations along U, T, S and Z paths reveals the methods by which optimization can be carried out for effective utilization of space for material and semi-finished product moves. The significant factors like work-flow, functionality and transient time are compared.
In a U - layout, the work flow is simple and does not involve cross-paths with either the raw materials or the semi-finished products.

- U - Layout thus does the operations in a shorter path leading to much reduction in transient time of the robotic arms. The arms are not made to wait for the next operation.
- U – layout shall thus lead to increase in the productivity
- U – layout also provides the ease of receiving the semi-finished products adjacent to the same entry point
- Z – Layout also provides a comfortable movement of the products as here too work flow of raw materials is linear.
- Z – Layout provides a step ahead of receiving the semi-finished products at the opposite end, thus avoiding the confusion with raw materials.
- Z – Layout, on the other end has a longer path than the U – layout.
- U and Z – layout provide a better workflow environment with low transient time comparatively.

Reference

[1] T. Yang and C. Kuo, May 2003, A hierarchical AHP/DEA methodology for the facilities layout design problem, European Journal of Operational Research, Vol. 147, pp. 128-136.
[2] H. Kaebernick, M. Bazargan-Lari, and G. Arndt, 1996, An Integrated Approach to the Design of Cellular Manufacturing, CIRP Annals - Manufacturing Technology, Vol. 45, pp. 421-425,
[3] A Sekala et.al, 2017, Modelling and Simulation of a Robotic Work Cell, IOP Conf. Series: Materials Science and Engineering, 227, p.1-8.
[4] Jiafan Zhang and Xinyu Fang, 2017, Challenges and Key Technologies in Robotic Cell layout design and optimization, J Mechanical Engineering Science, Vol. 231(15), 2912–2924.
[5] https://ottomotors.com/blog/manufacturing-work-cell-design-layout.
[6] Tay.M.L. & Ngoi.B.K.A Optimising Robot Workcell Layout, The International Journal of Advanced Manufacturing Technology Vol.12, pages 377–385(1996).
[7] HAKAN GULTEKIN et.al, April 2008, Scheduling in robotic cells: process flexibility and cell layout, International Journal of Production Research, Vol. 46, No. 8, 2105–2121.
[8] Allan S. Tubaileh, 2014, Layout of robot cells based on kinematic constraints, International Journal of Computer Integrated Manufacturing, 1-13.
[9] Allan S. Tubaileh, 2015, Layout of Robot Cells based on Kinematic constraints, International Journal of Computer Integrated Manufacturing, Vol. 28, No. 11, 1142–1154
[10] Zvi Shiller, Optimal Robot Motion Planning and Work-Cell Layout Design, Cambridge University Press Robotics (1997) Vol.15, pp 31 – 40.
[11] Frank S. Cheng, A methodology for developing robotic workcell simulation models, Proceedings of the 2000 Winter Simulation Conference, 1265-1271.
[12] Kazuhiro Iizui et al, 2013, Multiobjective layout optimization of robotic cellular manufacturing systems, ElsevierComputers & Industrial Engineering, Vol 64, S37–S44.
[13] Saber DARMoul et al, Mrch 3-5,2015, Virtual Reality for Manufacturing: A Robotic Cell Case Study, Proceedings of the 2015 International Conference on Industrial Engineering and Operations Management Dubai, United Arab Emirates (UAE). 
[14] HAKAN GULTEKIN et al, 15 April 2008, Scheduling in robotic cells: process flexibility and cell layout, International Journal of Production Research, Vol. 46, No. 8, 2105–2121.
[15] http://chohmann.free.fr/lean/cell_u.htm