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Modeling And Simulation Based Structured Approach For Automated Manufacturing Process

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ABSTRACT

Quality and productivity are the important driving forces in rapidly growing automobile industry. Arc welding is one of the areas in automobile industry where automation has shown the remarkable impact. Optimum use of resources like robots, fixture, and auxiliary devices is the only way to remain competitive by increasing profits and production. Automated welding has improved upon manual welding by increasing speed, quality and throughput. Top-notch weldments are easily repeatable with robots. Robot welding automation is much safer and more cost-effective. Robotic Simulation acts as a powerful tool to evaluate and control welding parameters, optimum path generation and other important areas such as robot placement and layout optimization, cycle time estimation, reachability studies, interference check etc.
The major aim of this paper is to emphasize the role played by robotic simulation in automating arc welding process to achieve improved productivity, safety and design efficiency. The authors have proposed a framework for welding automation and demonstrated its effectiveness through a case study in this paper.

Keywords: Welding Automation, Robotic Simulation, Workcell, Multiple Robot Simulation, Work Balance, Welding Torch, CAD, Reach Analysis.

1. Introduction

Arc welding process was originally designed to be used manually but during the industrial evolution and through the introduction of robots in industry in the 1970s, automatic welding was developed. It is today one of the most common tasks for an industrial robot.
The benefits of robotic arc welding:

- Consistency of quality welds
- Repeatability
- Reduction of production costs
- Fewer scrapped parts
- Increase your return on investment (ROI)
- Faster cycle rates

Layout Design is very vital stage in overall welding automation life cycle .The need for increased efficiency and minimal design lead time has led many companies towards computer simulation to accelerate the overall activity and achieve optimum results reducing iteration form of design related decisions. Robotic simulation is a modeling-based problem solving approach developed for the design, analysis, and offline programming of robotic work cells and it is very effective tool to analyze alternate scenarios to optimize design process that will best suit with requirements. Through robotic simulation tools designers are empowered with interactive and virtual environment to obtain plausible solutions for designs.

Simulation is often the only modeling method available ,which can get close to capturing the important elements in the real system [14].The overall simulation schematic is given in fig.1 which shows how simulation environment enables design engineer to counter real time problem with ease.

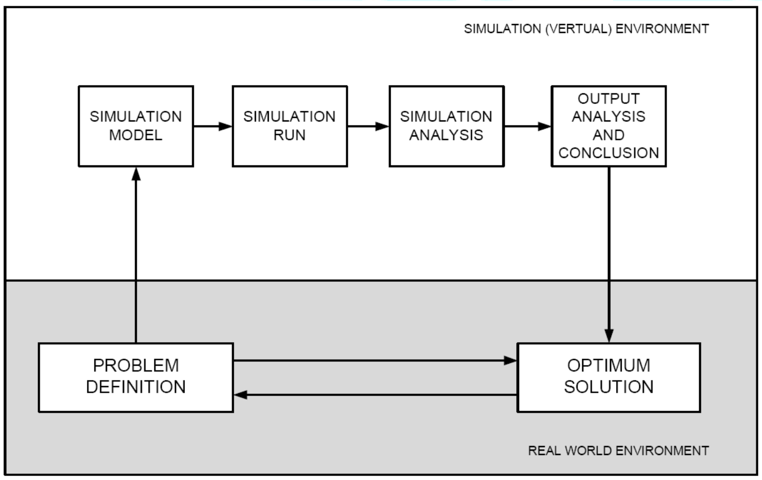

Figure: 1.Typical simulation schematic

In modern trends of engineering solutions following types of simulations are important tools depending upon type as

1) Robotic Simulation
   A) Arc Weld Simulation
   B) Spot Weld Simulation
   C) Paint Simulation
   D) Laser Cutting and Dispensing Simulation
2) Ergonomic Simulation
3) Plant Simulation

In which Ergonomic Simulation deals with ergonomic consideration that is safe working environments that accommodate a wide range of workers and for ergonomic assessment and task analysis .It mainly emphasis on human interface issue with Designed system[21]. Two main software are widely giving solutions in this area are Delmia-ERGO (Dassault Systems) and Jack (Siemens) [4].

Plant simulation is typically for schematic representation of plant activities and processes in order to get vital information regarding its efficiency ,reliability and to overcome bottlenecks .In this type of simulation some software also gives 3D representation over conventional 2D .Delmia QUEST (Dassault Systems) and Factory CAD (Siemens) are used for the same purpose [4].

Robotic simulation concerns simulation and programming of a robot task using a virtual model of the workcell and the part to be welded. Examples of research in this area are the integration and development of virtual assembly and the optimization of welding sequences and torch trajectories to avoid collisions and to increase productivity [3, 4].Use of robotic simulation is also for Conception, Design and Validation .There are plenty commercial software available in this context still key players are Igrip (Dassault Systems) and RobCAD (Siemens). Cycle time calculation and validation and layout related decisions which can be effectively encountered with the help of robotic simulation .In general Robotic simulation is a great tool to use at almost any point in the automation life cycle .The robotic simulation industry has responded to above said need by producing products that are more customizable, compatible, accurate and automated [1]. These underlying trends can be seen in the new and innovative functionality that has been incorporated throughout the industry within the different software packages. These systems have been developed to meet the specific requirements of the production industry and can accomplish an amazing array of tasks.

2. State-of-the-art in welding automation

The authors have review following areas:

1) Robotic welding

2) Robotic simulation

2.1 Robotic welding

The use of industrial robots for welding automation is a major and expanding applications area. [19]. Welding is used extensively in the manufacture of automobiles, farm equipment, home appliances, computer components, mining equipment and earth moving etc. Hundreds of products we use in our daily life are also joined together by some type of welding processes [6]. During recent years the automation of production processes in small and medium enterprises has been a subject of growing interest. By selecting appropriate strategy for the automation these industries can achieve quality as well as throughput. Processes like arc welding can be automated by using robots to achieve the same. The automation systems are as a rule complex and their implementation is resource consuming [18]. Robots have replaced humans in performing a wide range of tasks which would otherwise be time-consuming and/or dangerous. Industrial robots have long been used to increase productivity and efficiency through the automation of manufacturing processes, such as welding and assembly [11]

Various authors have analyzed the implementation of robots focusing on several important areas like welding, selection criteria, programming etc. Some authors have covered areas like general trends in the industries, field of use [15]. Different programming techniques like on line and offline programming [9]. General trends in welding processes like MIG welding etc. [13]. Workload study and management [28]. Suitability of robot and their selection criteria [3].These papers indicates the usefulness of robots in automating the processes like arc welding. While the world is rapidly advancing towards globalization, in order to remain competitive, automating these robotic processes is single most significant means and to achieve this robotic simulation is the key.

2.2 Robotic simulation

Robotic simulation is a powerful tool which is extensively useful industry in order to save money and end users time while designing a robotic welding workcell. User can predict the behavior of workcell prior setting up actual process and thus can save both time and money. Robotic simulation allows smoother transition from concept to reality giving user a freedom to make mistakes, study and analyze them while designing the workcell. Robotic work cell simulation is considered as a significant tool that off line programming (OLP) software packages bring to the robotic programming. Simulation enables the program to get verified without the use of an existing physical robot, which reduces the downtime of a robotic system [29]. Many industries are now recognizing simulation as a viable tool as it provides better manufacturing designs and also offers cost benefits in engineering and installation benefits [23].

Robotic simulation is an integral part of a digital factory concept. Simulation is a key technology for improving the manufacturing processes in digital factory environments. Digital manufacturing and simulation of robotic workcells focuses on the design, simulation, optimization, analysis and offline programming of robotic workcells and automated manufacturing processes. Depending on actual demand virtual models can be defined on different levels of details [26]. In digital factory environment robotic simulation addresses common problems such as Data translating interface, motion and process simulation, collision detection and calibration [25]. In other welding areas such as BIW (body in white), some authors have stated that robotic simulation is a feasible means to improve efficiency and reliability of body-in-white welding line by virtual simulation technology [27] and also it provides the ability to visualize robot motion can quickly answer questions regarding path planning, workspace constraints and coordination issues with other systems [22].

A lot of other authors have analyzed the robotic simulation. Their approaches include several subjects and focuses on certain areas like offline programming, digital factory, workcell design etc. The areas covered are the following:

- Comparison of various robot programming methods and advantages of generic offline programming method, different steps in OLP[29]
- Different types of simulation like FEM simulation, motion simulation, discrete event simulation[26]
- simulations used in the design of real-time control for automated welding[8]
- Low cost simulation based robot path simulation to predict and pre-evaluate performance of robot programs generated off-line [22]

- Role played by robotic simulation to detect crash situations and verify design changes[10]
- Motion planning for multi-robot assembly systems[17]
- Tuning of a complex robotic workcell of eight joints devoted to specific tasks like milling process[12]

2.3 Critique

Use of robotic simulation in manufacturing process like welding is endorsed by many authors. Some authors have explained different robotic simulation aspects like Off Line Programming OLP, equipment libraries, modeling of complex kinematics of robots and other mechanisms, robot calibration for improving accuracy, automatic path planning, collision detection, sequence of operations (SOP) etc. Particularly while discussing robotic simulation, lot of emphasize is given on off line programming (OLP) by various authors. A structured approach to carryout robotic simulation activity for process like welding is missing.

To fill this gap in this paper authors have proposed a framework and demonstrated its effectiveness through a case study. In workcell design for efficient transformation of concept to final layout a systematic workflow has been stated and explained.

3. A Framework for welding automation

This paper describes role and advantages of robotic simulation in automobile chassis welding for optimizing welding process, layout design, as well as some other parameters. A Problem definition includes automating automobile chassis welding process by using multiple robots to achieve

- Reduction in production cost through a consistency and repeatability of robotic welding systems s in various ways. For example, the precise movement of the robot arm and torch may result in fewer scrapped parts or parts that need rework.
- Reduction in consumables usage because of consistent welding parameters, such as wire feed speed and travel speed, by eliminating the speed variation inherent in manual welding. This consistency reduces the amount of filler wire, electricity, and shielding gas used for each welded part.
- Improved product quality as repeatable travel speeds and torch angles generate a more consistent weld penetration and weld strength. The perfect movements of the robot and torch also generally produce a superior cosmetic appearance of the welded part.
- Productivity improvement because an automated system achieves more throughput than a manual system, and robotically made welds is more consistent than those produced manually.

Formerly it was manual operation involved human intervention for loading and unloading component which is crank shaft. For automating the process robots are incorporated for this critical material handling. In order to give complete solution designer has to conceptualize the process and he has to validate the same. Through robotic simulation one can achieve following task.

- Robot selection
- Robot reach and equipment placement
- Process cycle time validation
- Welding torch design with respect to component being welded
- Welding torch mounting configuration with respect to robot mounting flange
- Tooling/ fixture clearances with robot operations
- Cycle time optimization using actual robot controller software (RCS)
- Safety envelopes with fencing and light screen placements
- Optimized facilities layout and system configuration
- Off line programming

By studying general application requirements one has to kickoff the process with preliminary designs then with the help of data available he has to do analysis and synthesis activity which is under influence of results evaluated and throughput of simulation activity.

Considering above factors one can easily understand that this typical workcell optimization activity involves critical system inputs and need to carryout iterative design procedure. Without robotic simulation designer cannot get actual inputs and he would end up the activity based on hypothetical assumption causing design and hence project failure in final proving phase. That means any unrealistic assumptions or overlooked factors can produce inaccurate, inefficient, or unfeasible robotic motions and actions, greatly affecting the overall performance of the workcell.

In order to optimize and validation of robotic welding process in its early design phase Robotic Simulation is going to give real time inputs on basis of which the entire process could be completed in less time with better accuracy and efficiency. Figure 2 represents the automating welding activity with robotic simulation.

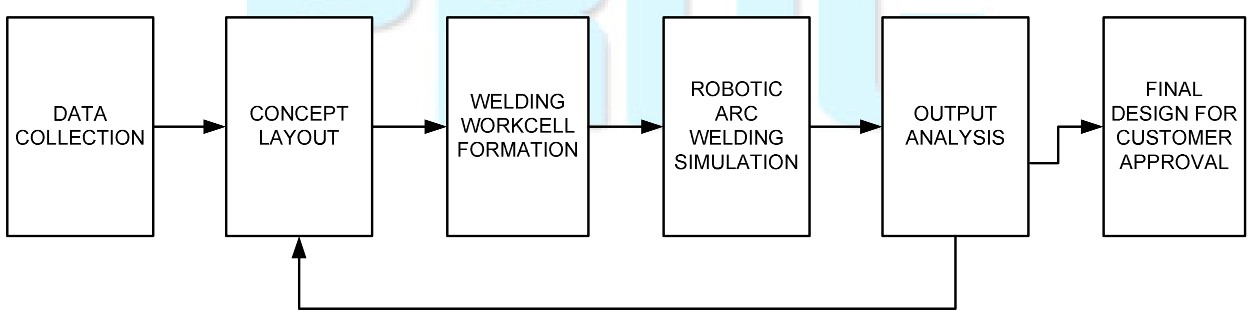

Figure: 2. Workflow with robotic simulation

4. Data Collection

At this stage designer collects and modifies the data for his use which include

- 2D layout data regarding the entire welding activity its fixture components
- 3D CAD modes of component i.e. chassis model, fixture etc.
- Application data like sequence of operation , required cycle time etc. which is supplied by the customer or which application or marketing person have recorded like pictures during application study
- Miscellaneous data regarding bought out components etc.
- 3D CAD data translation in proper format

In data collection and processing stage CAD translation is very important activity the data collected by you may be in the format which your current commercial 2D or 3D software supports but for robotic simulation you need in built CAD integrator in your simulation package which support existing data format as it is or you need to translate it in neutral formats like JT or IGES and then convert it in your simulation software compatible format i.e. here in this case designer need to convert the data in the .co format . Figure 3 shows schematically CAD data translation process.

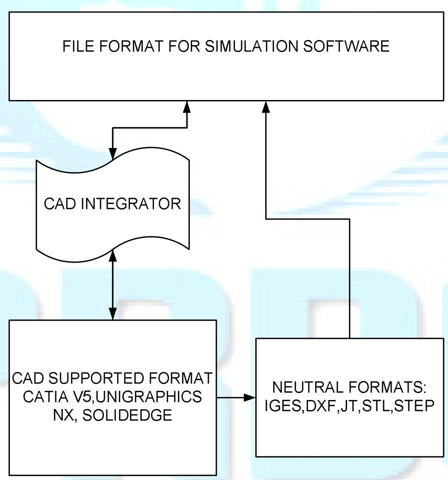

Figure: 3. Data flow between CAD and simulation system

5. Concept Layout

Next stage is concept layout which is an important step in entire automation solution. Actual design initialization starts at this step, after analyzing and synthesizing the application data collected and with the help of 2D as well as 3D CAD data that is taking valuable inputs from data collected designer has to chalk out the conceptual parameters and has to propose preliminary layout. This stage is explained well with the figure 4

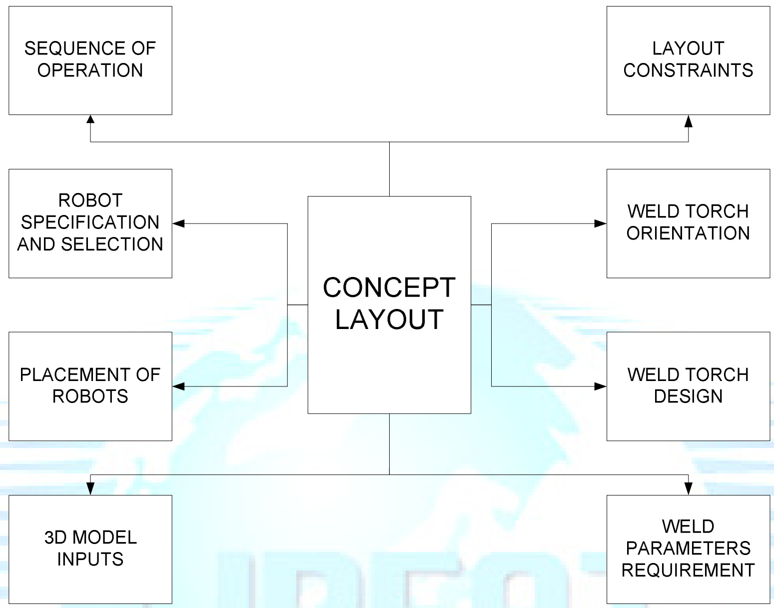

Figure: 4. Concept layout workflow

- In concept layout stage itself robot specifications, total robot quantity required are proposed based on supplier data, engineer's judgment. Further it would get refined using robotic simulation.
- Welding torch design: Welding torch is very important object in entire robotic welding initially proposed welding torch parameters can be further altered considering simulation output.
- Mounting arrangement on robot flange: depending on the exact path which the robot has to follow, torch mounting configuration is important issue .Without actual robotic motion one cannot conclude the mounting details so here robotic simulation plays a key role.
- Self weight, inertia etc should be considered initially with calculation which can be modified further based on real time simulation sequence of operation
- Layout constraints, sequence of operation (SOP) Robot specification are the important considerations in the process.
- Decision related to robots home position to reach maximum required points in its work envelope is to be taken base on the feedback of the simulation.

With a conventional design method, the designer often must rely on guesswork and best assumptions of design parameters and considerations. Correctness and effectiveness of the output solution cannot be evaluated without actual robot performance. But in robotic simulation by visual impact as well as through data recorded in robotic simulation stage he can alter the concept as well as modify the critical parameters without relying his gut feeling. In current case study engineer got vital inputs regarding the robot position, torch position etc.

6. Workcell formation

A robotic workcell is an automated system that uses industrial robots to perform specific process operation [6]. Workcell formation is nothing but creating virtual environment of intended process by calling CAD models of actual robots which we are going to use in the operation in simulation environment, placing them at desired optimum position. It provides methods of transferring and positioning items like robot through peripheral devices such as grippers, tools, fixtures, conveyors, and pallets etc. Position and orientation of all objects can be changed as per users requirement .Typical workcell variables include the functions, positions, motions, and operations of each workcell component. These variables possess characteristics of complexity and dependency, in which changing one or some variables may significantly affect the workcell layout solution and robotic program development. Through workcell Designers can also optimize design solutions by using the software to evaluate layout alternatives.

6.1. Building Workcell Layout Models

Workcell layout models are built by first retrieving the device models from the ROBCAD device library and then positioning them in the ROBCAD layout workspace; the position of the device's base coordinate system defines the position of the device in the layout workspace. The device manipulation functions in the ROBCAD Layout context were used to build the geometry of the simulated workcell shown in figure 5. The robot, table, fixture models were positioned using the software's Translation and Rotation functions, then by using put and place command other peripheral components were placed on respective units. The torches are attached on robot flange by two ways and robot tcpf (tool center point frame) is defined appropriately.Figure.5 shows typical workcell layout for current case study.

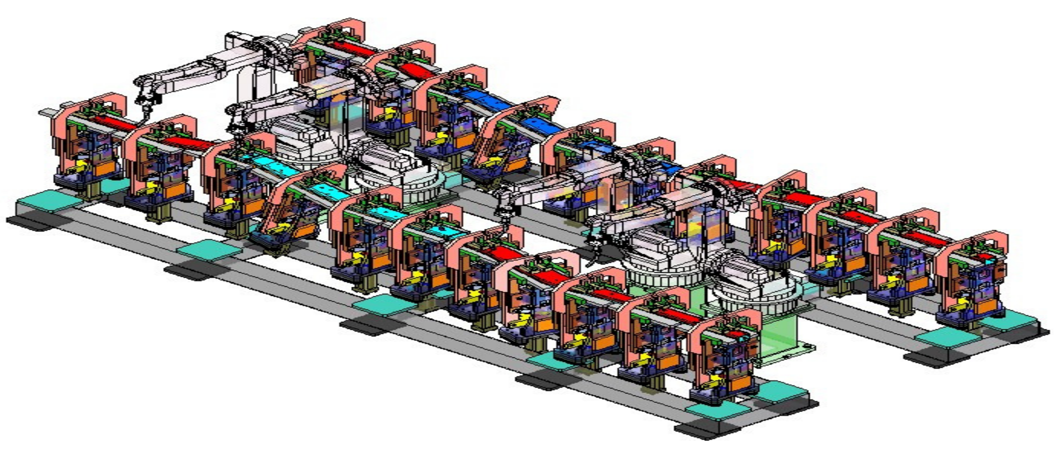

Figure: 5. Workcell layout for robotic chassis welding

7. Robotic Simulation

Before simulation designer has to define robot as active mechanism which is built in mechanism having standard defined kinematics, joint constraints provided by the robot manufacturer. After defining the mechanism one can jog robot virtually in workcell same as jogging robot actually. Figure 6 shows steps involved in robotic simulation.

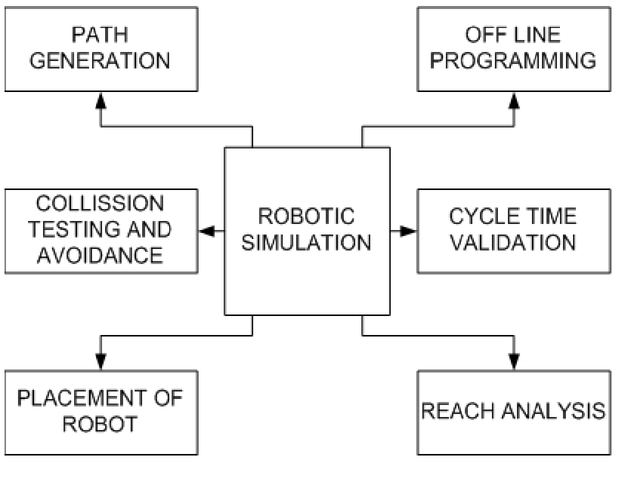

Figure: 6. Steps involved in robotic simulation

7.1. Placement of the robot in workcell

According to layout constraints designer has to place robot in standard workcell properly to do this activity software has provided motion command through which one can do the desired movement of robot or any intended component in position as well as in orientation. Figure 7 shows corrected placement of robots in workcell.

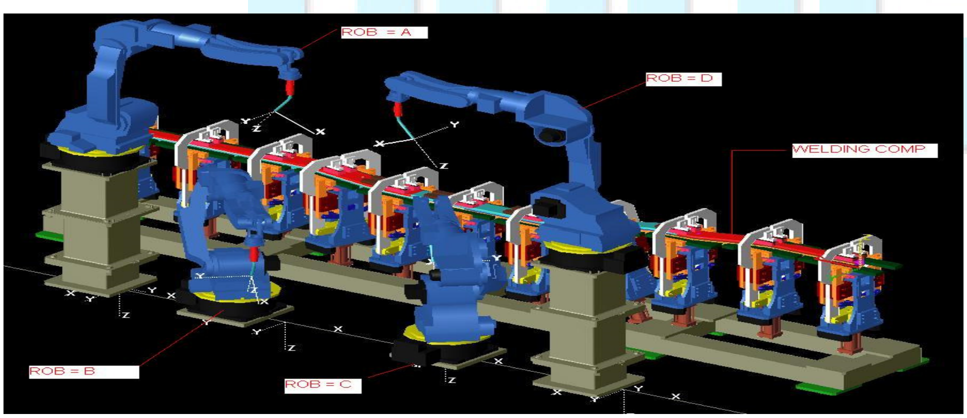

Figure: 7. Optimum placement of robots in workcell

7.2. Reach Analysis

Reach analysis gives proper inputs for placement of robot in given workcell which uses its own unique feature of showing its own robot envelop and user has to make sure that the component to be reached is within robot envelop or not. While designing workcell the placement of the robot and its work pieces are not known, also it very hard to predict. A reach ability analysis option is very important aid in determining the placement locations for the parts and the robot. With this option robot reach ability can be easily obtained allowing user the ability to ensure robots have the correct dimensions and specification.

7.3. Path generation

Considering its joint constraints one has to jog the robot in different modes and has to create and store locations. Location is a unique entity storing information about robots position and orientation. Path is generated by connecting typical locations.figure.8 shows path for robots which are welding chassis components clamped together.

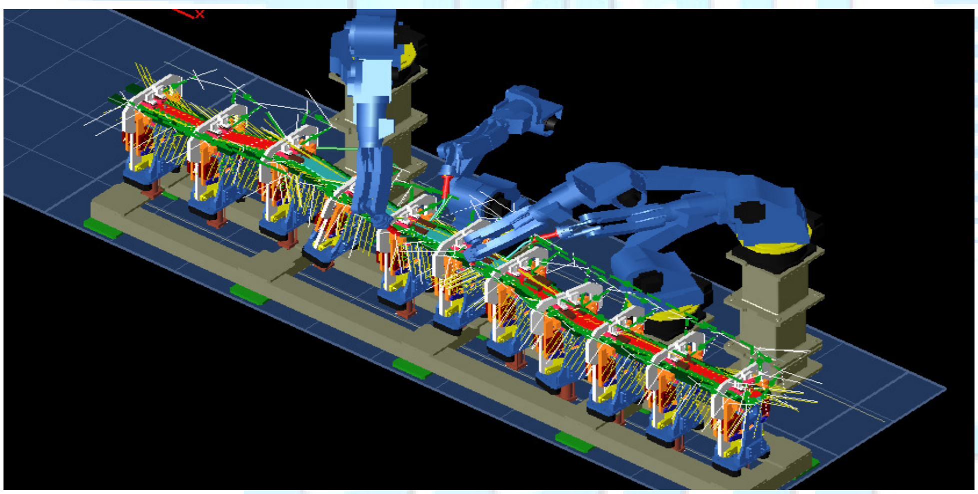

Figure: 8.Path generation component welding

7.4. Collision Testing and Avoidance

This is again excellent feature which simulation software provides and it gives clear-cut understanding regarding fouling of robot with auxiliary subsystems .After generating proper path designer will run the robot and while in motion it will give alarm signal with visual effects for the exact parts which are interfering with each other. Obviously one has to define the pair between which collusion avoidance should be detected.

7.5. Work Balance

Simulation help balance the work load among multiple robots within a work cell. This is very vital and unique feature any simulation software can give .Through work balance stage one can verify the occupancy of all robots while undertaking welding activity to ensure all robots are equally loaded for task and thus it helps to improve productivity.

8. Output Evaluation

After taking some trial runs on system generated paths designer can derive conclusions based on it. HOME position for robot can be decided easily, design modification in case of torches which are colliding with fixture component can be easily executed, and same way mounting arrangement specifications can be concluded.

9. Conclusion

This paper has presented and discussed the framework for robotic simulation to automate the arc welding process. The authors have explained the workflow in detail that begins with gathering data for constructing the design of the workcell and ends with an optimised workcell for the end user. The framework makes use of a simulation methodology that would offer the users with a very useful tool for predicting the performance of systems and alleviate tedious requirements for use of physical models. The authors have demonstrated advantages of the framework in terms of increased efficiency for workcell designers. These users can easily acclimatize and employ infinite iterations of design changes in order to fine-tune the output without having to waste considerable time and effort.

The authors conclude that the proposed framework would offer the most benefits to workcell designers in the aerospace and high end automotive industries. These industries often require an optimised workcell that could be developed now very efficiently and economically using the proposed framework.

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