DEVELOPMENT OF AN AUTOMATED CONFIGURATION SYSTEM FOR ROBOT WORK CELL

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ABSTRACT: Configuration robot work cell has received considerable attention in the last few years due to it is very knowledge-intensive, intricate, and time-consuming process. This paper elaborated the development process of the automated configuration system (ACS) for (re-)configuring robot work cell while satisfying certain requirements of users in an innovative way. The primary purpose of this work was to provide a fast configuration system with less cost and human involvement at little or no further investment. The ACS was constructed based on the variant-shaped configuration concept with its mathematical model. A configuration and programming structure with a graphical user interface (GUI) were the outcomes of this work that were capable of determining the optimal robot work cell according to the user requirements e.g. the number of a robot, Nr and the types of configuration. This work utilized both macro and Visual Basic (VB) editor in CATIA 3D CAD software for creating a completed user interface. The current outcomes of this work will provide a basis for future investigation in determining the optimal layout of robot work cell that is dependable on other requirements.

KEYWORDS: *Robot Work Cell, Automated Configuration System (ACS), CATIA, Graphical User Interface (GUI) and Visual Basic (VB).*

1.0 INTRODUCTION

Configuring the layout of robot work cell is a tough challenge among system design engineers in industry which utilizes the industrial robot as their machine. It is due to the involvement of high cost of investment[1], long commissioning time, high level of expert knowledge and lots of human involvement [2]–[4] in configuring the layout. Moreover, the challenging part is during execution process as it needs to take into account the safety element[5]. An ACS is proposed for fast and easy configuration of robotic work cell in order to minimize the cost, lower down human involvement and also minimize investment cost such as the trial and error adjustment.

Initial works on configuration robot work cell in [5,6] are taken as reference. The illustration of two-dimensional (2D) robot work cell with its safety measure is utilized to model the safety measure for multi-robot work cell. Figure 1 illustrates the 2D robot work cell with its safety clearance.

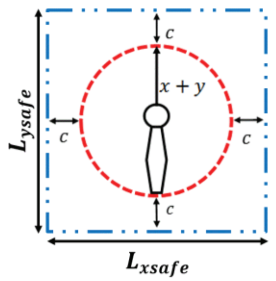


Figure 1: Illustration of 2D Robot Work Cell with safety clearance [6]

$$A_{safe} = L_{xsafe} \times L_{ysafe}$$
$$= 2(X+Y+C) \times 2(X+Y+C) \quad (1)$$

Where,

X: Length of robot arm (mm)

Y: Length of the robot tooling and work piece (mm)

C: Clearance for the worker movement in a work cell taken as 650mm

A variant-shaped configuration is formed by joining one or more equal square/s side by side subject to the quantity of robot used. The configuration is developed by excluding the corner, half facing, diagonal and mix arrangement without considering rigid transformation condition (translation, rotation, reflection or glide reflection). These condition and constraint are taken into consideration due to they may assist in easy modelling the configuration pattern with grouping the identical shape or arrangement of configuration layout as one layout. Table 1 represents the data of possible variant-shaped configuration of the robot work cell where it is the key element to the invention of the ACS [7].

Table 1: Variant-Shaped robot work cell configuration data [7]

Number of Robot, Nr	1	2	3	4	5	6	7	8	9	10
Number of Configuration, Nc	1	1	2	5	12	35	108	369	1285	4655

Recently, CATIA (Computer Aided Three-dimensional Interactive Application) software is utilized rapidly in designing an automatic and intelligent system i.e. in [8 –15]where it has proven that with the system, it is able to reduce the development time, minimize the errors and introduce technologies faster to the market [12], [13], [16]. Therefore, CATIA 3D models, Visual Basic (VB) Interface and macro tools were utilized in developing a completed ACS where it could process the data of user requirements through the developed GUI and also generate the robot work cell configuration layout based on the data through the CATIA CAD drawing.

The developed system provides the simulation stage of the configuration before the configuration of the real robot work cell. The result of this system will improve the way of configuring the robot work cell later on. It will likewise additionally enhance the human-robot interaction as well as lessen the cost and spare the future investment and additionally decrease the time for developing an advanced configuration system in future.

2.0 REVIEW OF RELEVANT WORK

Several studies have been carried out for the configuration of the robot work cell where a majority of the reports have focused on developing high-quality configuration systems. A high quality of the configuration system would prove to be very advantageous to the design engineers. One of the studies is the ideal robot arrangement for tasks execution [3] where it aimed to optimize the base position of an industrial robot with the goal to achieve all predefined tasks and minimize cycle time. This approach has effectively given a plausible arrangement in enhancing cycle time for a robot station by placing the robot in an ideal position. However, ongoing work needs to focus on optimization of the placements for several robots and on the automatic creation of optimized robot programs.

Another study of configuration in [5] was done where a Framework for the Robotic Work Cell Configuration (FraRWCC) for determining the workspace and safe working area of the robot is proposed. The point of this work is on giving a quick and simple arrangement approach for a safe robot working area. The developed framework is capable of presenting 3D simulation of robot work cell but it only concentrates on the linear (straight) arrangement and for up to four numbers of a robot. Furthermore, a study in [7] exhibits a key approach for easily configuring multiple robots inside the work cell. The works aim to provide quick configuration proposal with less human involvement at zero further investment. A mathematical model has been developed where it is capable of providing the possible number of configuration, N_c for a different number of the robot, Nr. Nevertheless, this work requires further investigation in determining the optimal layout, L_{opt} for configuring multiple robot work cell as well as creating the computer-based configuration.

Other studies involve of configuring robot work cell is carried out by [17] where this work proposed a novel approach for the simultaneous designing of the multi-robot cells of spot welding and generating the associated robot motion. The aims of this work are to:

(a) Minimize time for designing and installing the cell,
(b) Minimize homogeneity of the solutions provided,
(c) Minimize the needs of operator's knowledge or skill,
(d) Provide a better ability in explaining the operational choices to the clients.

This work requires future investigation on the safety measure amongst other robots. On the other hand, a study [18] introduced a work on improvement for laying out multi-robot work cell in a vertical area plane which is utilized to make an external surface of a vast fuselage board. The motivation behind this work is to maximize the overlapped workspace of two robots without collision between robots and work pieces. This approach could accomplish a layout that yields sensible positions for two robots and is applied on a current design. However, this work can only be used for two robots only. In another review [19], a procedure and framework for the improvement of the position of the diverse workstations in the industrial robot work cell are introduced. In this work, a framework and the advancement procedure for the work cell layout including one or many tasks and the industrial robot for carrying out these tasks are done. Their work is expected to enhance the execution of the robot and enhance the efficiency of the automated work cell. However, the study is not applicable in the cases which use more than one robot.

Numerous new configuration techniques have been proposed in the last few years, though there are some persistent issues which exist, like the configuration time [3], human involvement [3, 7] , some other investments like the workspace, costs, or automatic creation [5, 7,18,19] and safety elements [3,17]. Therefore, this work aimed to settle the emerging issue by utilizing the optimized configuration concept where it involves a safety and diverse arrangements for up to ten robots. Besides, this work aims to create an automated system where it assists to minimize the configuration cost, human involvement at low investment as well as satisfy the user requirements.

3.0 METHODOLOGY

Figure 2 shows the flowchart that outlines the overall process development of the ACS. It involved three phases; configuration structure design, programming structure model, and GUI development. The first phase emphasized on the designing of the configuration structure where it comprised the configuration specifications as well as the constraints and conditions. The probable optimal robot layout and its configuration pattern were the outcomes of this phase. Next phase entailed the formation of the selection process flow where the user requirements as the number of robot, N_r and types of configuration were employed. Optimal robot layout was dictated on any selected requirement set by user. Lastly, a GUI of the ACS was generated using both VB and macro editor. The procedure of generating the GUI is presented within this phase.

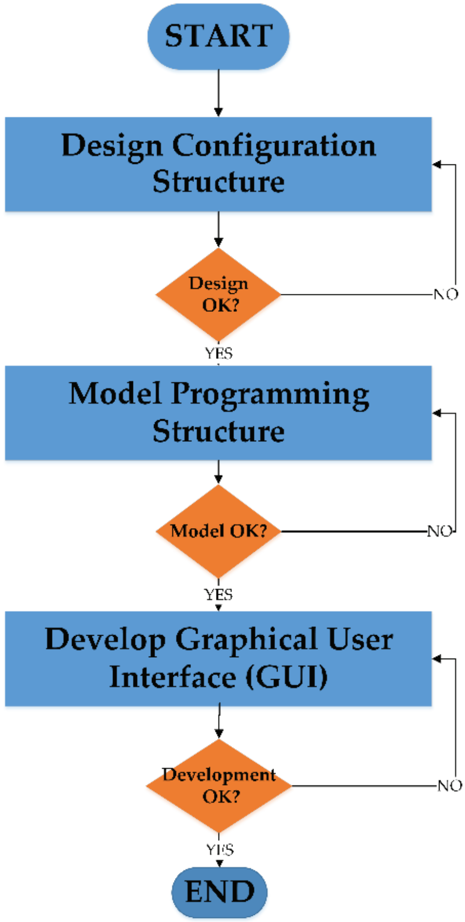


Figure 2: Overall ACS development

4.0 RESULTS AND DISCUSSION

4.1 Configuration Structure

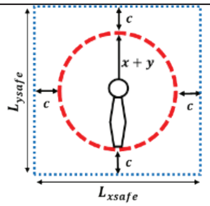
The earlier configuration concept (variant-shaped configuration) [7, 20] was optimized by grouping the number of configuration into the columns configuration. It was grouped according to the same total number of robot in the reference line at the horizontal plane [7]. The columns configuration data are tabulated in Table 2.

Table 2: Columns configuration data [7]

Number of Robot, Nr	1	2	3	4	5	6	7	8	9	10
Number of Columns Configuration, Nc.c	1	2	3	4	5	6	7	8	9	10

Columns configuration must satisfy the following constraints such as avoiding the rigid transformation and the diversity position. Diversity position refers to the robot work cells which have the same number of robot in every horizontal line but diverse in position where they are considered as one optimal layout. As the results, the probable optimal robot work cell layout was finalized and tabulated as shown in Table 3.

Table 3: Probable optimal robot work cell layout

<table>
<tr><th>Number of Robot, N_r</th><th>Probable Optimal Robot Work Cell Configuration, $N_{p.o.c}$</th></tr>
<tr><td>1</td><td>
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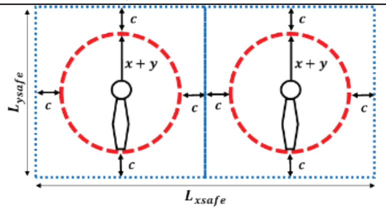
<tr><td>2</td><td>
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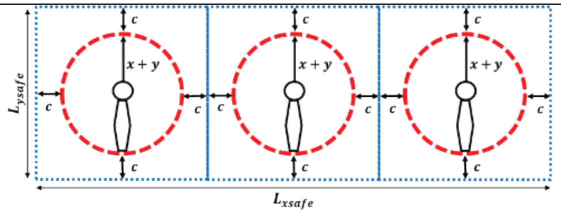
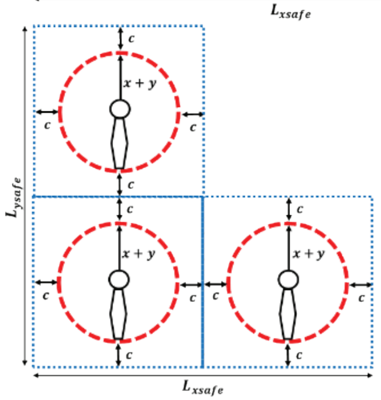
<tr><td>3</td><td>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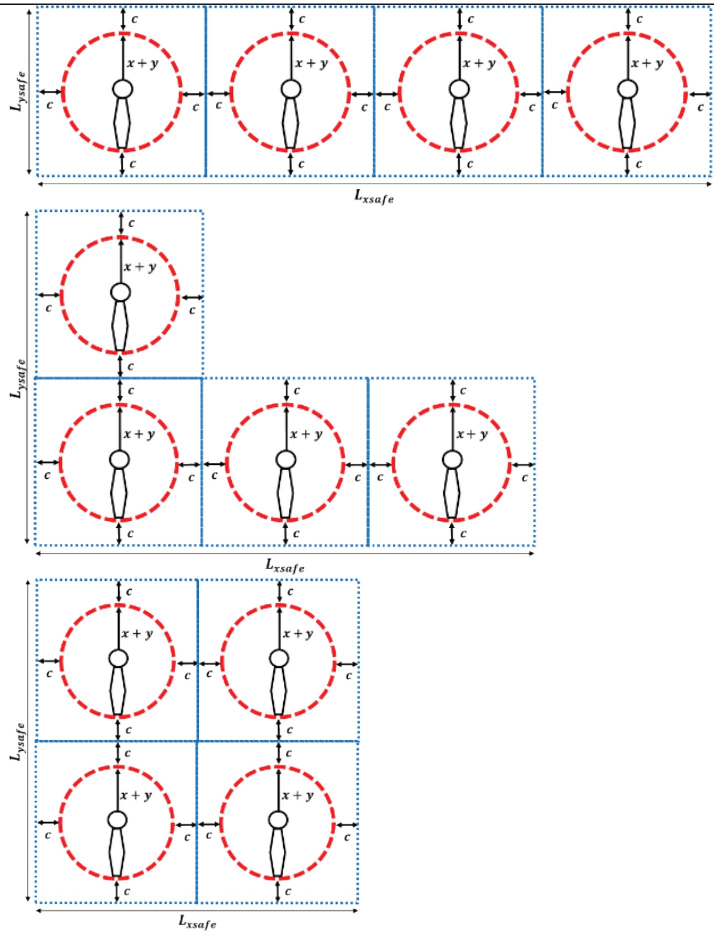
4	
5 • • • 10 Increment of N_r	4 Configurations • • • 22 Configurations Increment of $N_{p.o.c}$

As the N_r increased, the $N_{p.o.c}$ also increased. This pattern can be summarized as shown in Table 4.

Table 4: Optimum robot work cell configuration data

Number of Robot, Nr	1	2	3	4	5	6	7	8	9	10
Number of Optimum Configuration, Np.o.c	1	1	2	3	4	6	8	12	16	22

Based on the configuration results in Table 4, the following configuration pattern was successfully developed using MATLAB as shown in Figure 3. At this stage, the earlier configuration structure was optimized and the complexity was reduced where the identical shape or arrangement of configuration layout was grouped as one configuration layout.

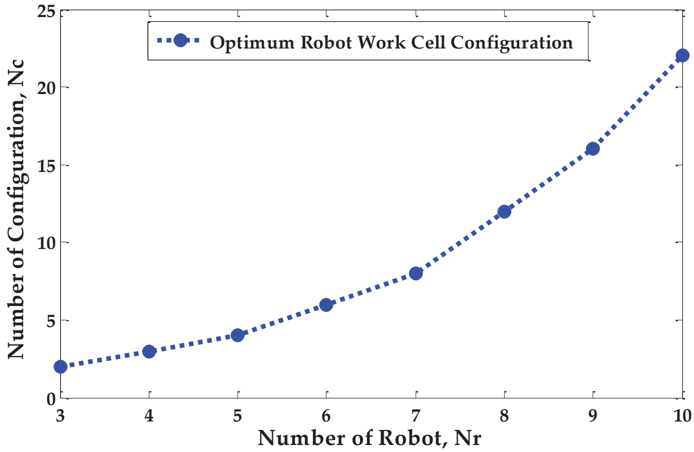


Figure 3: Configuration pattern

Using the Basic Fitting editor of the cubic plot and selecting the show equation checkbox with three significant digits, another line graph was plotted that fitted the overlaying on the earlier plot and a mathematical model was extracted. Thus far, the model was capable in providing the probable number of optimal configuration, $N_{p.o.c}$ for a different number of robot, Nr. One and two number of robots were excluded from this because only single optimal layout was present respectively. The extracted mathematical model from the cubic fitting is as follows:

$$Nc = 0.0328Nr^3 - 0.229Nr^2 + 1.277Nr - 0.595 \tag{2}$$

Later, the developed mathematical model in Equation (2) was evaluated using Microsoft Excel software. By inserting the values of N_r which starting from three numbers of robots, the evaluation results are presented as in Table 5.

Table 5: Evaluation results of the mathematical model

Number of Robot, Nr	Number of Probable Optimal Configuration (Evaluation)	Number of Probable Optimal Configuration (Actual)
3	2.0606	2
4	2.9482	3
5	4.165	4
6	5.9078	6
7	8.3734	8
8	11.7586	12
9	16.2602	16
10	22.075	22

By rounding off the evaluation results in Table 5 and comparing it with the actual values, it can be concluded that the results meet the actual values. Thus, the proposed mathematical model was accepted. Afterwards, the final optimal layout is discovered based on the types of configuration.

4.2 Programming Structure

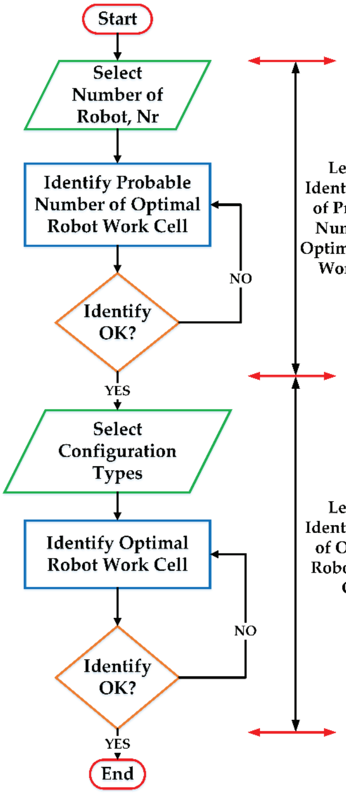


Figure 4: Programming structure of ACS

Figure 4 illustrates the details of ACS programming structure to determine a safe and optimal robot work cell based on the customer requirements. The whole programming structure was divided into 2 different levels. The 1st level was to focus on identifying the probable number of the optimal robot work cells. The users were asked to select the number of the robot, N_r. Thereafter, the procedure of identifying the probable number of the optimal layout would begin. In this level, equation (2) would be utilized. 2nd level proceeds by determining the optimal robot work cell. In this level, users must select the types of configuration such as normal configuration, configuration with minimum workspace area, configuration with minimum throughput time and configuration with both minimum workspace area and throughput time. At this level, the probable optimal layouts of certain number of robot would be classified into different types of configurations. After that, the optimal robot work cell was proposed and presented.

4.3 Graphical User Interface (GUI)

The GUI was explained by designing single robot work cell in CATIA V5/Mechanical Design/Assembly Design. In this work, six (6) degree of freedom (DOF) of articulated type industrial robots with fixed dimension had been selected. This type of industrial robot was chosen because it is one of the most widely used robot in industries. The process of design was recorded using a macro recorder. Then, a set of code was generated where later, the generated code was edited using the user form in VBA editor according to the planned programming.

Next, a user form was created in CATIA/Tools/Macro/Visual Basic Editor as the custom GUI screen to interact with users (Refer Figure 5). The user form comprised two different frames where 1ST frame was used to process the 1ST level programming structure meanwhile 2ND frame was for the 2ND level programming structure. The combo box in frame 1 was used to select the number of robot used, N_r and the four option buttons in the frame 2 was used to select the types of configuration. The three command buttons were used to run the intended configuration, reset the input information and exit from the GUI respectively.

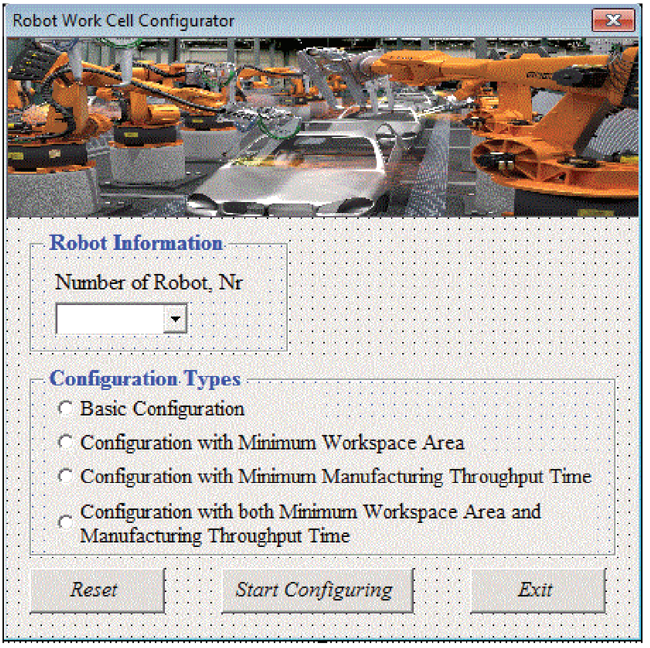


Figure 5: User form of ACS

The completed user form was run by giving the information data as shown in Figure 6. Then, the optimal robot work cell was automatically created in the CATIA mechanical design window as shown in Figure 7.

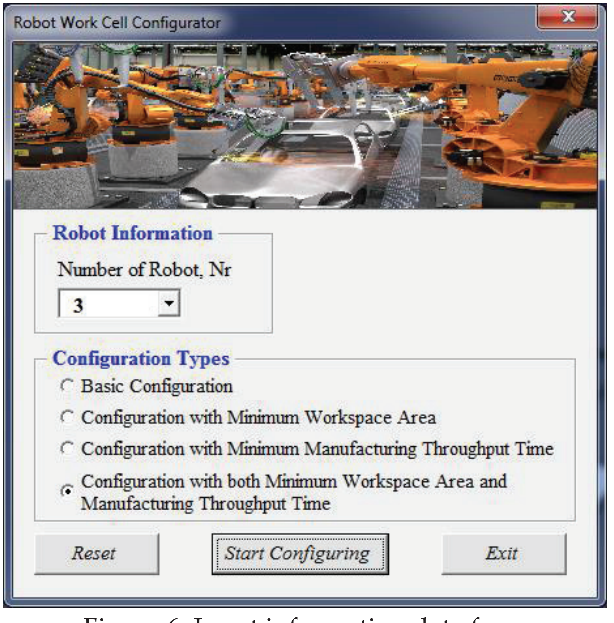


Figure 6: Input information data form

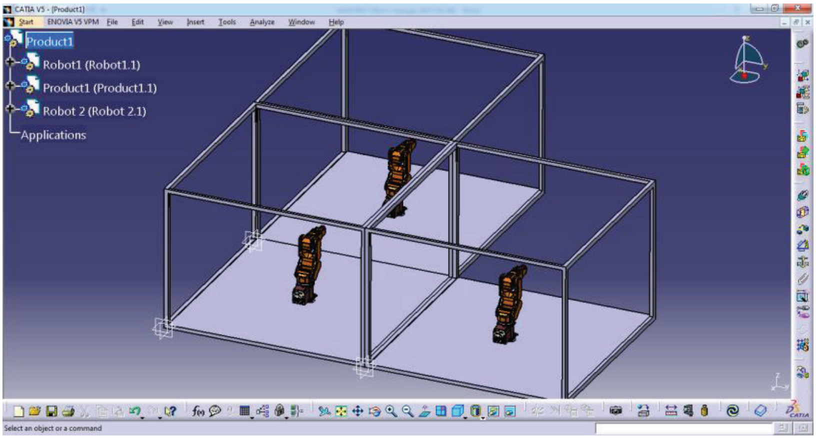
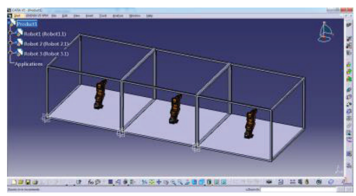
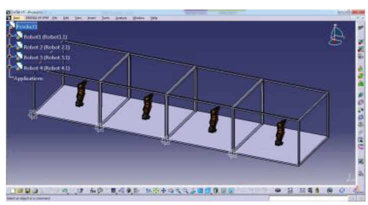
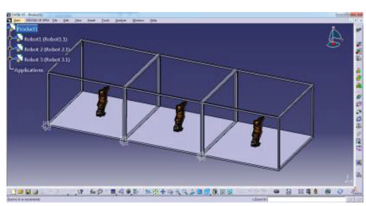


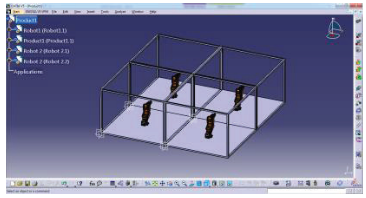
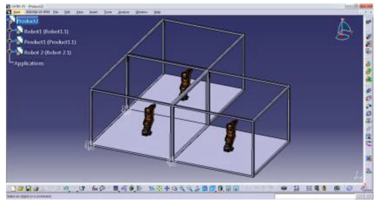
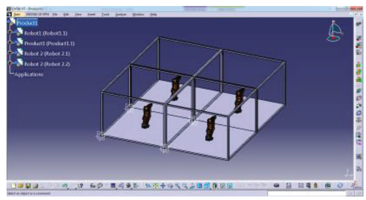
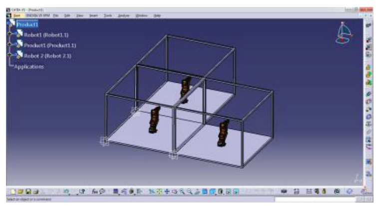
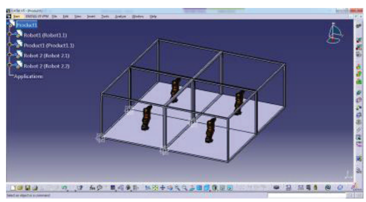
Figure 7: Generation of robot work cell

4.4 Verification Result

For the verification activity, 3 and 4 number of robots with various configuration types were run to present the results of the developed GUI as shown in Table 6.

Table 6: Verification results of the ACS of robot work cell

Number of Robots, Nr	Configuration Types	Proposed Optimal Robot Work Cell
3	Normal Configuration	
4	Normal Configuration	
3	Configuration with Minimum Workspace Area	

4	Configuration with Minimum Workspace Area	
3	Configuration with Minimum Manufacturing Throughput Time	
4	Configuration with Minimum Manufacturing Throughput Time	
3	Configuration with both Minimum Workspace Area and Manufacturing Throughput Time	
4	Configuration with both Minimum Workspace Area and Manufacturing Throughput Time	

5.0 CONCLUSION AND FUTURE WORK

An ASC has been developed with its proposed methodology where the configuration and programming structure with its working procedure of GUI are discussed. The essential purpose of this work is to provide a better understanding in the designing and developing of the ACS. Furthermore, this work aims to provide the fast and easy configuration system for design engineers with the present valuable information regarding the robot work cell configuration system. The future work will focus on the development of the new ACS which involves other challenging user requirements.

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