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Systematic Approach in Determining Workspace Area and Manufacturing Throughput Time for Configuring Robot Work Cell

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Abstract. This paper delineates the development process of a systematic approach in determining the workspace area, and manufacturing throughput time, of robot work cell. The primary goal of this work is to provide a fast and easy configuration model with minimal cost, human involvement, trial and errors adjustments. The configuration model is constituted based on the variant-shaped configuration concept with its mathematical model. Robot work cell configuration concept with its mathematical models are deliberated in this paper where integration of these findings will be able to provide a framework in modeling the graphical user interface (GUI) of the configuration model. This work utilizes the CATIA V5 software where it involves the CATIA VBA and macro tool. The completion of this work could provide a basis for future investigation in developing high quality configuration model of the multiple robot work cells.

Keywords. Robot work cells, configuration model, workspace area, manufacturing throughput time, CATIAVBA, CATIA macro

Introduction

Outlining optimal layout of robot work cell have turned out to be intensive challenge among analysts who are intrigued by the sector of configuration. This is due to the fact, it devours high cost venture [1], long outlining time, high expert comprehension and loads of human investment in designing the optimal layout [2][3][4]. In addition, it is many-sided to actualize in light of the fact that it wishes to account about the safety constituent [1][5]. Expecting to deal partially the issues, a configuration model was proposed for determining the robot workspace area, A_W with its manufacturing throughput time, MTT according the input data set by user.

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An underlying work on [1][5] were taken as reference for dealing with the safety constituent. The illustration of two-dimensional robot work cell with its safety measure as shown in Figure 1 was used to model the safety measure for multi-robot work cells.

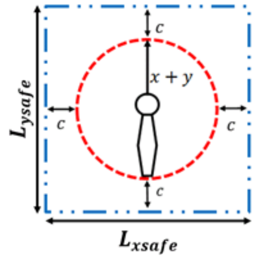

Figure 1. Illustration of 2D Robot Work Cell with Safety Clearance [1][5].

$$A_{safe} = L_{xsafe} \times L_{ysafe} = 2(x+y+c) \times 2(x+y+c) \tag{1}$$

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

With the development of safety constituents before, a variant-shaped configuration was formed which it could locate the near-optimal robot work cell layout. The variant-shaped configuration was constructed by joining along with at least one proportional squares next to each other according to the amount of robot used. The configuration was built by excluding the corner, half facing, diagonal and mix arrangement without considering rigid transformation condition (translation, rotation, reflection or glide reflection) [6]. Afterwards, the variant-shaped configuration was optimized through columns configuration and certain mathematical models was evolved where it is the key element to the invention of this configuration model.

The configuration concept with its mathematical model have been presented in this work where it provides a framework for developing the GUI of the configuration model. Then, a configuration model was invented by using the CATIA software where recently, it was utilized rapidly in designing of an automatic and intelligent system i.e. in [7] which proved that with the system, it able to reduce the development time, minimizing the errors and introduce technologies faster to the market [11][12]. At last, the robot workspace area, A_W and manufacturing throughput time, MTT of robot work cell are determined depends on the selection of configuration type. The outcomes of this work will enhance the way of configuring the robot work cell in future and the human-robot cooperation and additionally ease the setup cost and time in future.

1. Robot Work Cell Configuration

Certain works on configuration of optimal robot work cell were reviewed to analyse the raised issues which could be a great strategy in developing this model. A review [16] exhibited the optimal position for the depicted duties within the robotic manipulator workspace. This work used the response surface approach for the both path translation and rotation. In view of the approach, a robotic optimisation tool as the add-in to the RobotStudio has been produced. The approach was checked appropriately by optimising the positioning of the industrial robots with its path in 4 different showcases for achieving a negligible process duration. In spite of, this review just centered around single robot, though in the real application, one or numerous robots could be available in the work cell. Moreover, another review [17] presented an enhancement work for laying out multi-robot work cells in a vertical area plane where accentuation to produce the outer surface of a large fuselage panel. This work expects to boost the covered workspace among two robots without crash between both robots and workpieces. This work fit to accomplish a design that yielded sensible positions by tried on an existing layout. Anyhow, this work must be utilized for two robot as it were.

Another review [18] provides a system with its method for optimising of the position of the distinctive workstations in the industrial robot work cell. The created system and its technique include one or many tasks and the industrial robot for carrying out these tasks. This work plans to upgrade the execution of the robot and in addition improve the efficiency of the automated work cell. In any case, the review was not material in the cases which utilized more than one robots. Additionally, an innovative layout approach was advanced [19]. The created approach depends on the Differential Evolution (DE) where it is used for solving the Facility Layout Planning (FLP). Robotic work cell layout was one FLP example hat was portrayed in this work. The mathematical FLP model incorporates couple of limitations and optimisation objective was proposed and a computerized design improvement was created for fulfilling the 3-D representation exhibit for the optimal layout. Yet, this work requires highly skilled and experienced worker for comprehension the approach.

Furthermore, an optimal robot positioning for tasks execution was presented [3]. This work expects to enhance the base position of an industrial robot to reach all predefined tasks and in addition limit the cycle time. Apart from that, this work integrated the robot inverse kinematics and collision avoidance with a derivative-free optimisation algorithm. The results of this work had effectively given a plausible arrangement in upgrading the cycle time for a robot station by placing the robot in optimal position. Be that as it may, future work would be centered around the improvement of the positions for a few robots, and on the programmed formation of the optimization approach. Another configuration review [1] shows an approach for effectively arranging different robots work cell. This motivation behind this review is to furnish quick design approach with less human inclusion at zero further speculation. In this review, the variant-shaped configuration was optimized by grouping the number of configuration into the columns configuration. As the outcome, the probable optimal robot work cell layout has been settled. Nevertheless, this work requires further investigation in determining the optimal layout for configuring various robot work cell and in addition making the PC based setup.

All the prior reviews demonstrate that there have been numerous techniques for the configuration of the robot work cell. Yet, there are many issues that emerge in view of the vulnerability interest for an optimised configuration system. Consequently, this work expects to settle the partially raised issue by proposing a systematic approach in developing a configuration model where it includes a safety and diverse arrangements for up to ten numbers of robots. Likewise, this work intends to make an innovative configuration model with minimal the configuration cost, human contribution at low venture and additionally fulfill the user necessities.

2. Development Process of the Configuration Model

2.1. Capture Conceptual Design of Configuration

In this activity, a configuration concept is determined where it begins with identifying and later optimizing the variant-shaped configuration wherein probable optimal robot work cells with its pattern in the form of mathematical model is exhibited. The mathematical model is extracted with the help of the MATLAB software. Later, workspace area, A_W and manufacturing throughput time, MTT equations were derived for each of the probable optimal robot work cell.

2.2. Design GUI of the Configuration Model

A completed GUI of the configuration model is generated by using the CATIA VBA and macro. Four levels of user form will be designed where each of the level will running their own specific tasks. The previous configuration concept with the derived mathematical models were utilized and the procedure of generating the GUI is eloborated through this activity.

2.3. Verify the Proposed GUI

The completed GUI of the configuration model is verified by executing a set of user data based on the selection of conguration types (normal configuration, configuration with minimum workspace area, configuration with minimum throughput time and configuration with both minimum workspace area and throughput time). The outcomes of the verification is presented and discussed through this activity.

3. The Proposed Configuration Model

A GUI of the configuration model is invented wherein it comprises of four different levels of user interface. First level user interface is used to begin the configuration process. Once user click the “Start” button, the next level of user interface will appear automatically (Figure 2).

In the second level user interface as shown in Figure 3, user is asked to select the “Number of Robot” based on the quantity of robot used and the configuration types.

Figure 2. First Level User Interface.

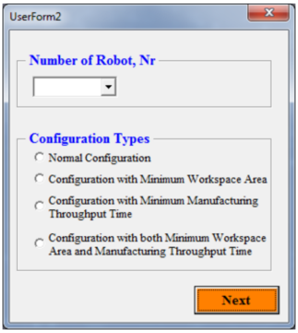

Figure 3. Second Level User Interface.

Thereafter, the procedure of identifying the optimal layout of robot work cell would be started. The current program of this level contains the following concept:

The concept of variant-shaped configuration was utilized and optimized by grouping the number of configuration into the columns configuration. It was grouped according to the same total number of robot in the references line at the horizontal plane. Additionally, the columns configuration must avoiding the rigid transformation and diversity position. The 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 or same optimal layout. In addition, this configuration involves a simple arrangement condition wherein the configuration with the corner, half facing, diagonal and mix arrangement was prevented [6]. As the results, the probable optimal robot work cell layout has been finalized and the data has been tabulated as shown in Table 1.

Table 1. Probable Ideal Robot Work Cell Layout [6].

Number of Robot, Nr	1	2	3	4	5	6	7	8	9	10
Number of Probable Optimal Configuration of Robot Work Cell, Nc	1	1	2	3	4	6	8	12	16	22

Next, the configuration pattern was successfully developed using MATLAB as shown in equation (2) (Figure 4 and 5). This equation will assist in determining the number of possible configuration, N_C according to the number of robot, N_r.

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

Third level user interface (Figure 6) is utilized to calculate the workspace area, A_W and manufacturing througput time, MTT of the robot work cell. In this level, user need to input the robot information such as the robot arm length (mm) and the robot tooling and workpiece length (mm). Also, the manufacturing throughput time data such as the inspection time, t_i, process time, t_p, move time, t_m and queue time, t_q. Based on the previous study [1][5][11], new workspace area, A_W and manufacturing throughput time, MTT equations were derived. The derived workspace area, A_W equation is as follow:

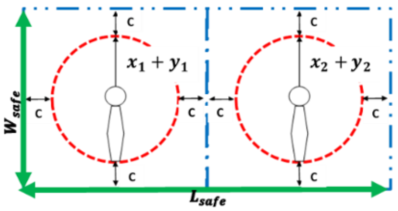

Figure 4. Illustration of Safe Multiple Robot Work Cell.

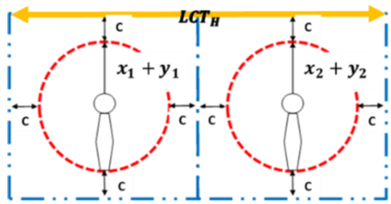

Figure 5. Illustration of Manufacturing Throughput Time for Multiple Robot Work Cell.

$$A_w = L_{safe} \times W_{safe} \tag{3}$$

$$L_{safe} = \max \sum_i^n [2((x_i + y_i)... + (x_n + y_n) + (n \times c))] \tag{4}$$

$$W_{safe} = \max \sum_{i}^{n} [2((x_i + y_i)\ldots + (x_n + y_n) + (n \times c))] \tag{5}$$

$$1 \le i \le \infty \text{ and } 1 \le n \le \infty \tag{6}$$

To provide a reliable solution to this formula, dimension for both L_{safe} and W_{safe} must be in the maximum dimension. Meanwhile, the derived manufacturing throughput time, MTT equation is as follow:

$$MTT = \sum_{i}^{n} (RCT)_n + \sum_{i}^{n} (RCT)_n \tag{7}$$

Where;

$$MTT = LCT_H + LCT_V \tag{8}$$

$$LCT_H = LCT_V = \sum_{i}^{n} (RCT)_n \tag{9}$$

$$RCT = T_m \tag{10}$$

$$T_m = t_p + t_i + t_m + t_q \tag{11}$$

The equation was modelled through the summation of the robot cycle time, RCT in the horizontal and vertical manufacturing line cycle time, LCT_H & LCT_V where both of LCT must be the maximum dimension. For the LCT_V, the first horizontal line is excluded.

Finally, the fourth level user interface as in Figure 7 is presented where the final robot workspace area, A_W and manufacturing throughput time, MTT with the proposed optimal layout are displayed.

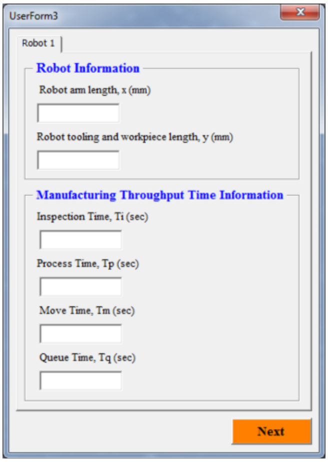

Figure 6. Third Level User Interface.

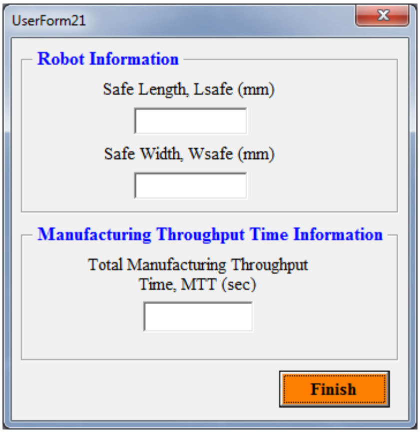

Figure 7. Fourth Level User Interface.

4. Verification of the Proposed Configuration Model

For the verification activity, one number of robot and configuration with both minimum workspace area and manufacturing througput time are elected to represent the outcome as shown in the second level of user interface (Figure 8). Then, by clicking the “next” button, the third level user interface will be displayed as in Figure 9.

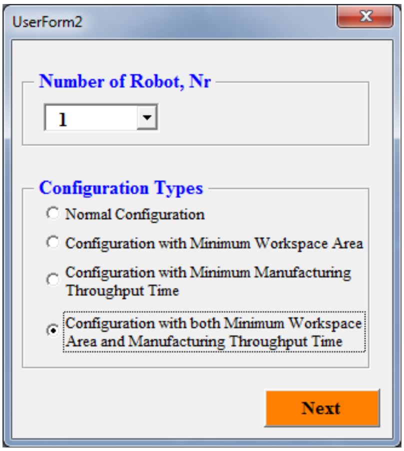

Figure 8. Second Level User Interface.

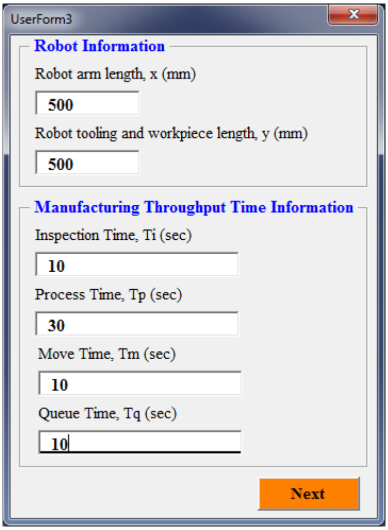

Figure 9. Third Level User Interface.

A set of data as in the third level user interface are required to be input in this user interface. Then, next level user interface as shown in Figure 10 will pop out by clicking again the next button. In the next level, the workspace area, A_W and manufacturing throughput time, MTT of robot work cell is calculated and presented with the proposed optimal layout. The “Finish” button in this user interface will exit the developed GUI of the configuration model as well as the CATIA drawing.

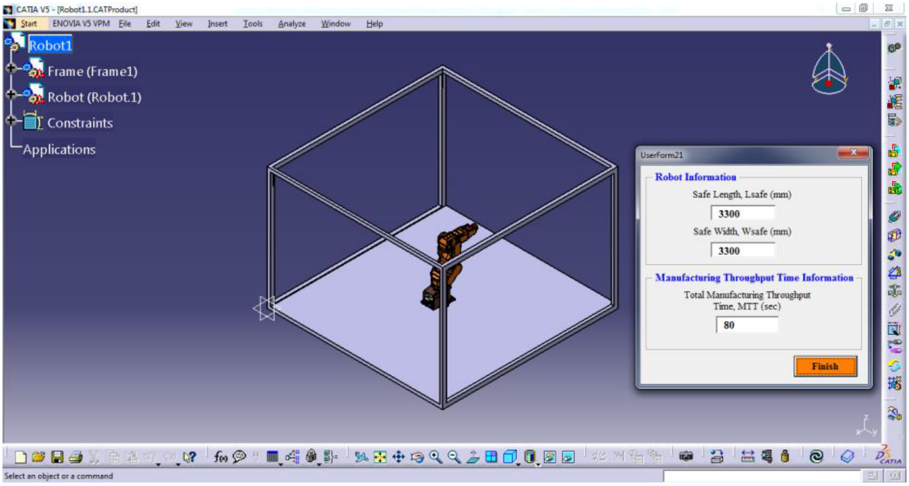

Figure 10. Fifth Level User Interface.

5. Conclusion and Future Work

A configuration model has been invented where the configuration concept, mathematical model with its GUI are presented. The fundamental motivation behind this work was giving a superior comprehension in the designing and developing of the configuration system. Besides, this work intended to give the quick and simple model for design engineers with the present of the significant data in regards to the robot work cell configuration system. In future, we will concentrate on the improvement of the configuration model which includes other complex user requirements.

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