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Original article

Kinematic analysis and geometrical improvement of an industrial robotic arm

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ABSTRACT

Industrial robots are the most manufactured and used types of robots in the production industry these days to minimize the labor cost. Many industries must have the benefit of using them for their batch production. In order to enhance its performance improvement of design of industrial robots is required, which will direct the further enhancement in the Robotics industry. Therefore, there is an effort to give the concept of optimum design of the robot by considering the different design parameters which makes it more efficient and reliable to use in the manufacturing industry. Nowadays, for optimization the modeling and simulation tools are the widely used to facilitate and accelerate the design processes such as dynamic simulation, structural analysis, optimization in order get an industrial robot design and optimization framework. In this research, focus is to investigate the feasibility of integrating tools from different domains such as Parametric CAD modeling and FEA, which gives a concept to the industrialist how to get an optimum arm design to increase their production rate etc. Inverse kinematic analysis which is done using Robo-Analyzer which has the ability to give optimum position and orientation of desired robotic arm, by considering the IKA, meta modeling is done to get an optimum design of arm using Solid works after that structural analysis of different designs are done using Ansys simulation tool, an optimum design of arm is recommended after evaluating the results.

1. Introduction

Robotics is an exceptional engineering science that deals with the design, modeling, control and use of robots. Today, robots guide people into daily life and take charge of their daily routine actions. The use range of robots is very wide, from toys to industrial robots and offices, to the very advanced required for space exploration.

A huge family of production equipment of the variety, which exists, is the one that delivers the movement required by a production process, like: arc welding, spraying, assembly, cutting, polishing, milling, drilling, etc. For such equipment's, more popular type is the industrial robot (Sorenti, 1997). Different configurations of manipulators are available as rectangular, cylindrical, spherical, revolute and horizontally articulated. A robot with horizontal revolute configuration, articulated robotic arm with selective compliance (SCARA) has four degrees of freedom in which two or three horizontal servo-controlled connections are shoulder, elbow and wrist. Finally, SCARA designed in Japan is normally appropriate for placing small parts for assembly lines, such as inserting electronic components (Taylan Das and Canan Dülger, 2005).

While the ultimate goal is real robotics, it is frequently very valuable to perform simulations prior to research with real robots. Simulations are easier to set up, cheaper, faster and more convenient to use. Building new robot models and performing experiments takes only a few hours. While a simulated robotics setup is less expensive than real robots and real-world setups, allowing better design consideration. Simulation frequently works faster than real robots, and all parameters can easily be displayed on the screen (Szabo, 2004). The ability to execute real-time simulations is especially important in the advanced phases of the design process. The final design can be confirmed before you start the

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costly and time-consuming process of building a prototype (Kazi et al., 2002).

So, there is need for precise and computationally competent manipulation dynamics which has been emphasized on a large scale in recent years. The modeling and simulation of robot systems through the use of different software programs will simplify the process of design, construction and inspection of robots in the real world. The simulation is significant for robot programmers to assess and predict the behavior of the robot and to verify and optimize the process path planning (Ionescu, Choynowski, and Constantin, 2002). Moreover, this saves time and money and will play an important role in the evaluation of production automation (Ionescu and Stefanoiu, 2002). Which may able to simulate opens a wide range of options to solve many problems creatively. You can research, design, visualize and test an object or even if it does not exist (Žlajpah, 2008).

Mechanical CAD Design which is based on section library, its Kinematic chains. Design.

- Selecting and testing the drive technique.
- Modeling the simulation with the help of blocks like Block Digital Simulation.
- Static and dynamic assembly of the part along with its Finite element analysis.
- Modeling .and simulation of particular the robot considering a multibody system.

Different kinematic analysis of an industrial robots can be performed by direct and inverse kinematics. While the direct kinematic analysis is well known, and as by the widely-used convention of Denavit-Hartenberg, it came to know that because of non-existence of unique solution it's the calculation is very complex and time-consuming (Tarkian et al., 2008). the inverse kinematics equations are laid the foundation for the dynamic analysis regarding the motion planning, and trajectory control of the robots (Spong and Vidyasagar, 2008). .Before the advancement of personal computers, only few institutions were able to perform Finite Element Analysis, making the design process extensive and exclusive in the automobile and aeronautic industries. Nowadays the use of this tool has become a routine in different areas of engineering, as stated by (Lad and Rao, 2014). "FE methods have become the standard techniques for evaluating the physical performance of structural systems in various engineering applications". Simulation as well as analysis of all these systems is performed in view of the flexibility of the robotic arm, usually with the help of FEA. If the system is highly complex, with many degrees of freedom and in large displacements, the FE analysis is very difficult in the preparation phase of our model that is the pre-processing and involves calculations which are totally time consuming (Tarkian et al., 2011).

In this article, our objective is to give industrialist an optimum design of an industrial robot arm, using inverse kinematic analysis which is be done by using RoboAnalyzer software, which gives the optimized position and orientation of the arm i-e the length of links, the way different links are made their joints, according to their specific operations. Once the IKA gives desired parameters of arm than a parametric CAD model is made to identify the opti-

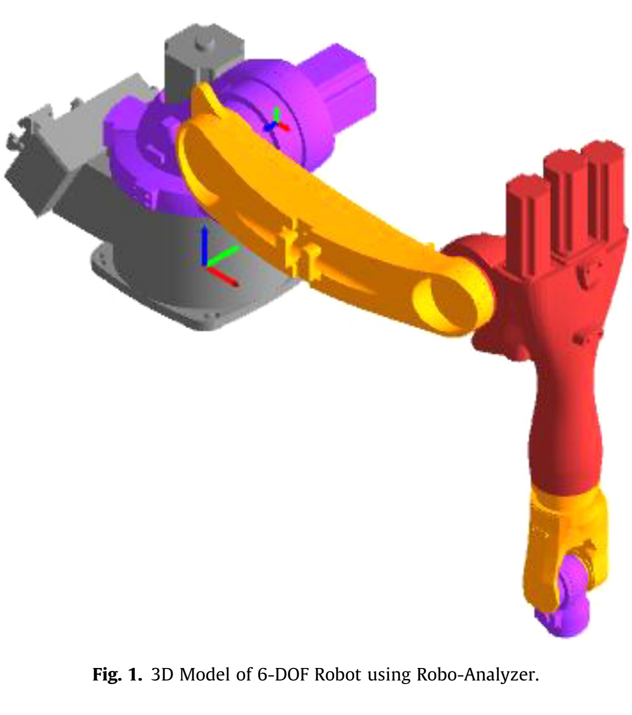

Fig. 1. 3D Model of 6-DOF Robot using Robo-Analyzer.

a)

$$\begin{bmatrix} 1 & 0 & 0 & 0.6 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0.135 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

b)

$$\begin{bmatrix} 1 & 0 & 0 & 0.12 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0.135 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

c)

$$\begin{bmatrix} 1 & 0 & 0 & 0.6 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0.135 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

d)

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & 0.62 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

e)

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

f)

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0.115 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

g)

$$\begin{bmatrix} 1 & 0 & 0 & 0.9 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & -0.335 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Fig. 2. a, b, c, d, e, f and g different Links Matrix's and EE configuration of 6-DOF Robot.

mized structure in other words we said that topology optimization is done to find the desired design parameters using finite element analysis simulation. FEA shows the distribution of stresses and displacement on a particular arm under different loading condition within their elastic limits which is useful to identify the optimum structure. Meanwhile, performing an FEA on different assigned tasks it has been clear understand that to get an optimum dimension of link on basis of FEA results its tools is not incorporated with different robot's design process directly which is a time-consuming procedure.

2. Methodology

2.1. Kinematic analysis

In order to find out the basic design parameter of desired type of robot RoboAnalyzer 3D Model based robotics software is used which gives the position and orientations of its End-effector, velocities of different joints and length of desired link by solving the inverse kinematics analysis. RoboAnalyzer acquires DH parameters of Serial robot. Manipulator with their revolute joints as an input. Later, it creates a 3Dmodel of the robots as for each DH parameters. The 3D monitoring window has certain zoom, pan and slant abilities using which. 3D model is observed from various angles, which help to develop the parametric CAD model.

2.2. CAD modeling

Based on the results of inverse kinematic analysis of 3D Model, a parametric CAD modeling is developed on Solid Works software, which can substitute the long process of structural remodeling. The structure knows how to be parametrically designed by means of one of said instruments in such a way that the geometry of the model cannot be controlled by modifying the constraints. Consequently, it can be used a CAD model in the design. Of the robot and the effective design can be achieved by altering the model constraints in each iterate. Parametric modeling became a competent and essential technique in technical design tasks.

2.3. FEA and optimization

In this work, finite element analysis has been performed to calculate the distribution of stress in the forearm of the robot from ABB of the parametric CAD model created by the CAD tool, which supports and fully supports the logging required for the automation process. Each iteration in the design process is to update the CAD tool geometry, SOLID WORKS, in the calculated finite element

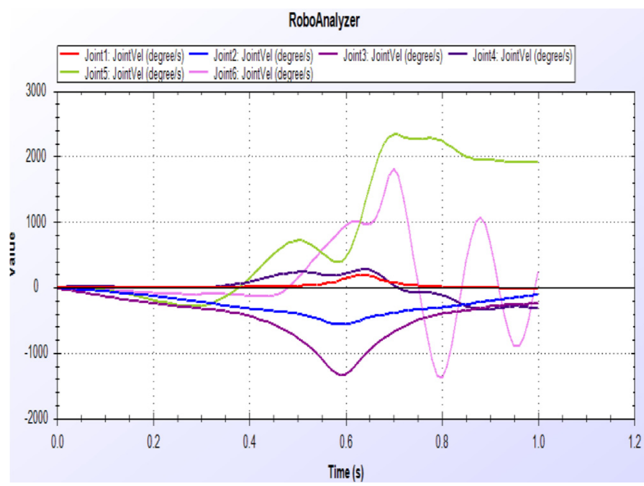

Fig. 4. Graphical representation of joints velocities.

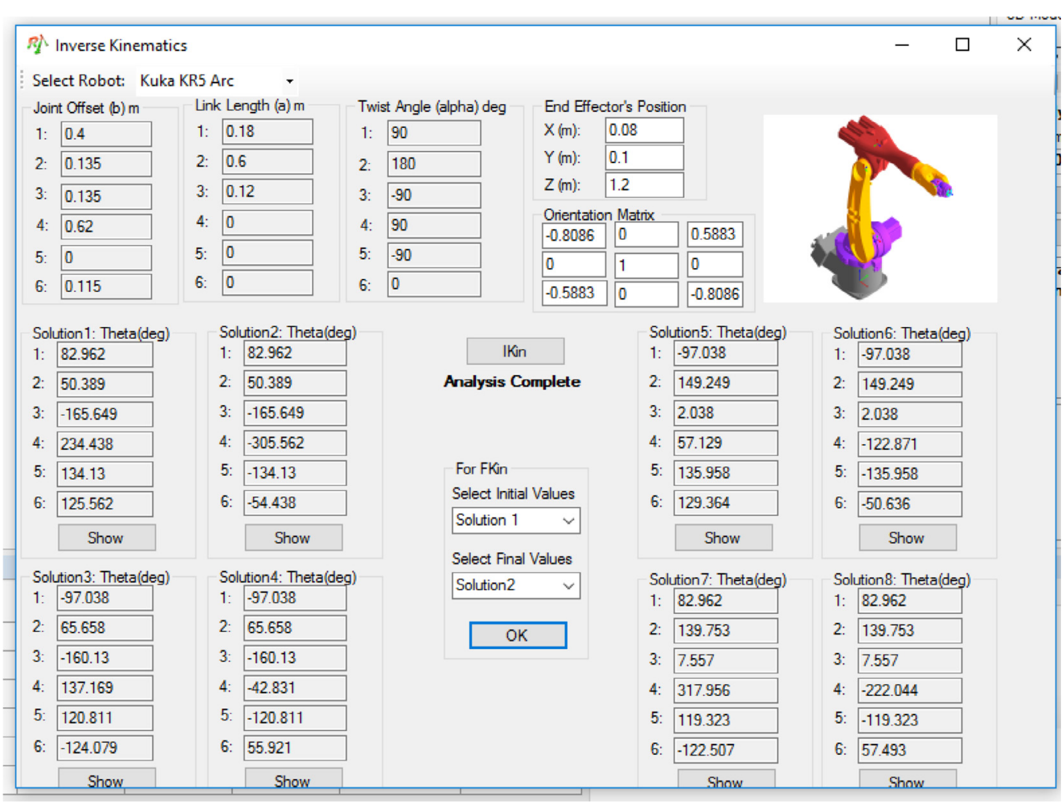

Fig. 3. Inverse Kinematic Analysis chart.

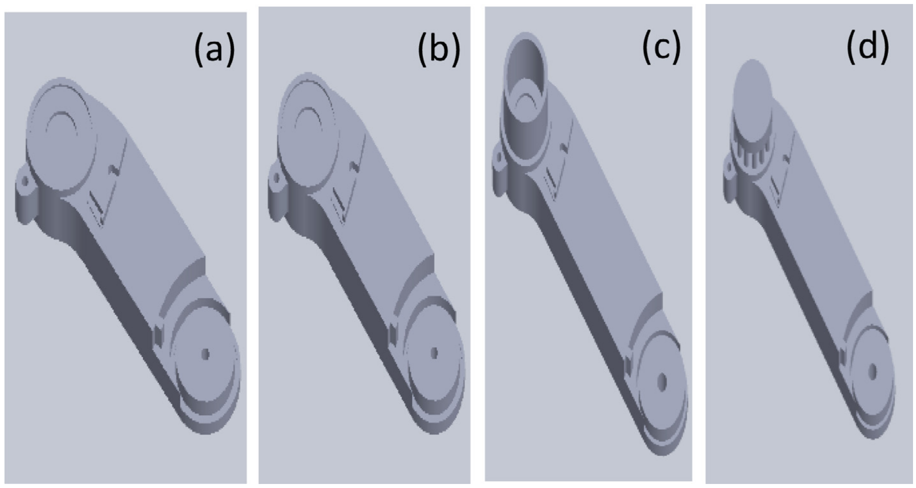

Fig. 5. a, b Altered modeling an arm and c, d representation of joints connections approach.

and force and torque analysis software to modify the simulation in the corresponding region in the finite element model. The finite element analysis value of the post-maximum stress is transferred to the Simulation interface.

3. Solution

3.1. Kinematic analysis

The kinematics. Manipulator in a main problem of the Automatic regulate the robot manipulators. Here we discussed the theoretic background. Of the. Analysis of KUKA KR5 of an educational robotics arm kinematics. Here we present that the revolution robot consisting of six rotations,

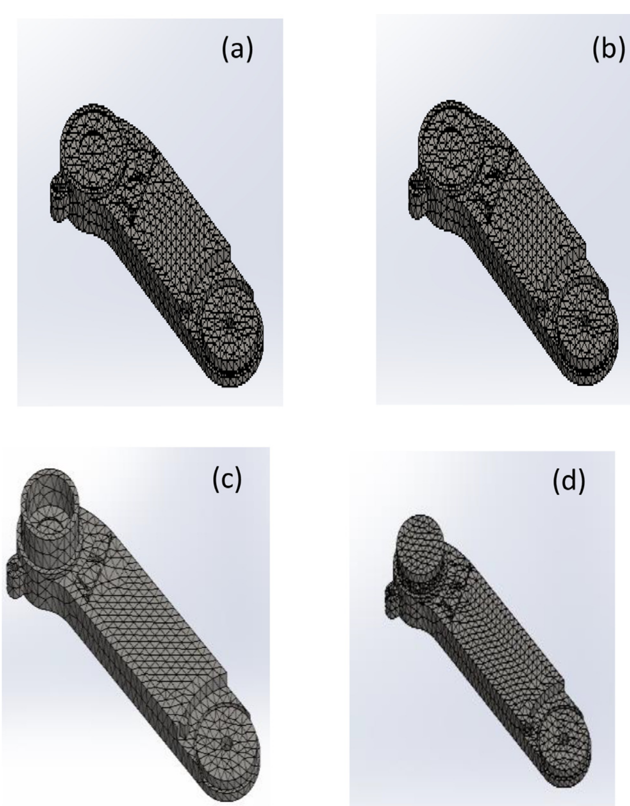

Fig. 6. Fine Meshing of different geometries.

Joint. Offset (b): Length of connections of the normal perpendicular to the joint axis.

Length of link (a): It is determined as the. Distance measured between the mutual perpendiculars axis.

Torsion angle (α): It is the angle formed between the orthogonal. Projections of along the pivot axes in a plane perpendicular to the usual normal.

Joint. Angle (θ): The angle among the orthogonal. Projections which is normal perpendicular to the. Plane perpendicular to the pivot axes.

For the each type of connection, each DE parameter is variable, the so-called joint variable, while the further three remaining parameters are called constant and connection parameters.

Fig. 1 represents the 3D Model of 6-DOF Robot using Robo-Analyzer and Fig. 2a–g represents the different Links Matrix's and EE configuration of 6-DOF Robot.

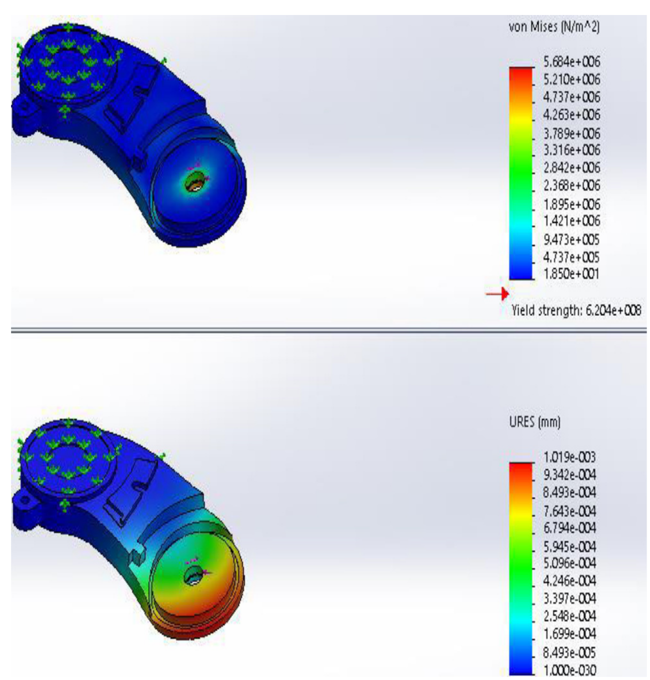

Fig. 7. Representation of the Von-Mises and displacement plot for altered geometry 1.

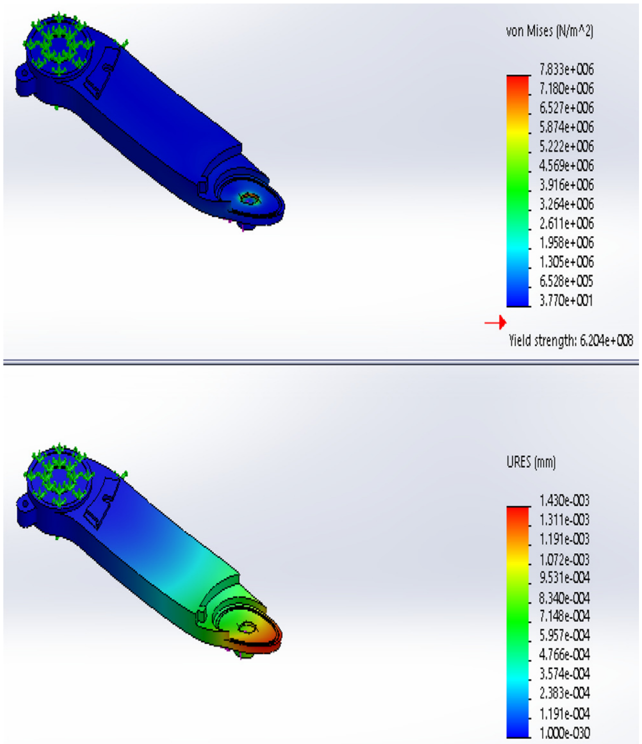

Fig. 8. Representation of the Von-Mises and displacement plot for altered geometry 2.

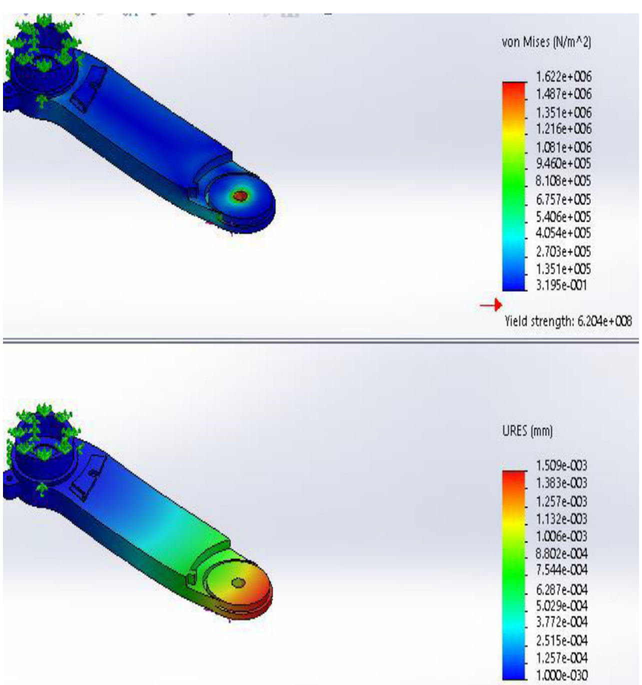

Fig. 9. Representation of the Von-Mises and displacement plot for Cylinder connection.

3.2. Inverse kinematic analysis

The inverse process that calculates the common parameters that attain a position and location of an end effector is identified as inverse kinematics. Which specifics the joint velocities of partic-

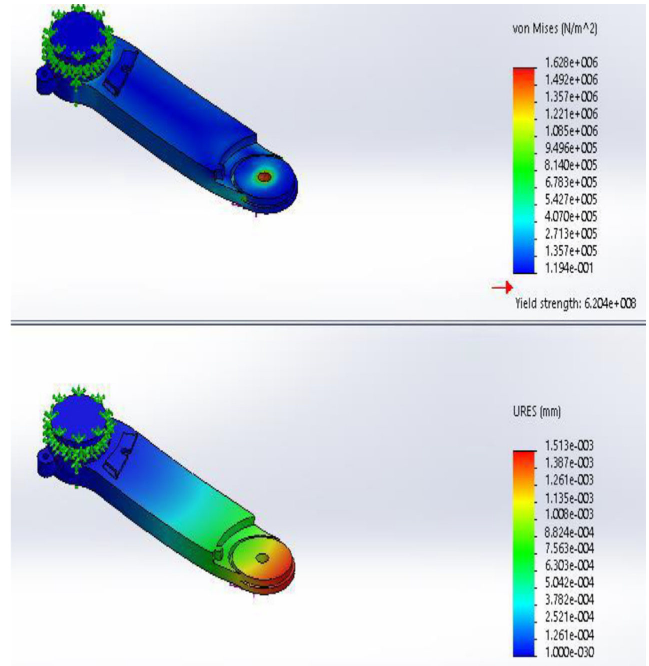

Fig. 10. Representation of the Von-Mises and displacement plot for Flange connection.

ular links which provides a required location of the end Effector. Requirement of the robot's motion so that the final effector achieves a desired task, called motion planning. Fig. 3 represent the Inverse Kinematic Analysis chart for particular robot type and Fig. 4 shows the graphical representation of different joint velocities.

3.3. Modeling

In order to consider the cost facture, toughness and required working time for specific operation there is need to improve the design which we said topology optimization should be done in order to find out the perfect design of the arm. While doing the topology optimization, it was essential to understand which part of the geometry can be altered or removed with no influencing on the stress allocation results in the FEA design. For that an initial FEA was done and the region that is were far away from the highly-stressed regions were labelled. After that the useless features of geometry like screws and fillets that are far away from the pointed highly stress distributed regions were eliminated and the simple geometry was transferred to the FEA software as the final geometry. Fig. 5A and B shows the comprehensive and simplified geometries of the arm. By observing the change in geometry, to ensure quality characteristics such as the robotic arm of mass moment of the center of inertia and gravity does not change significantly after simplification, in accordance with the nature and the original pattern.

3.3.1. Defining the connections

Because the arm is in the analysis of static structural stress, you need to define the support in the shoulder fixed. Typically, the rod pivot is connected to the base assembly by means of bolts. For the simulation, the reported FEA models are defined as part of the interaction with each other, which is done by determining the contact area in the model. Below figures shows the cylinder, flange and bolts connection approach for the arm. Fig. 5C and D represent the cylinder and flange connection modeling of an arm.

4. Simulation

Now we are focused on the implementation of the FEA. It should be stated that since the one of the objective of our work is to examine whether it is possible that different tools from different domains are integrated, including FEM in a draft framework, there was no sense in concentrating on the details of a single domain.

To solve the problem for determination of the maximum. Stress, static structural analysis is done using Solid Works Simulation, the following needs to be done.

4.1. Meshing

The quality of the FEA results can be significantly changed with the change of mesh size, by which the user present required model in a better way under different sceneries. A large No. of elements size selected resulted from a. fine mesh which increases the solution processing time significantly, but on the other. Hand, poor number of elements which produces results which does not clear the structure as the structures are mesh dependent and doesn't denote the real stress. Distribution. To test the result structure is solved at different mesh sizes, which shows the results varied with mesh size and simulation time increase for different mesh size quality. So, we have a meshed surface of different geometries, Fig. 6 – expressed the fine meshing of different geometries.

The inverse kinematic analysis which is done by RoboAnalyzer software shows the position and orientation of different links and joints of KUKA KR5 Robot with the help of graph, which helps to understand the trajectory path followed by a certain robot and gives the knowledge how far we can change the design parameters of an arm for parametric CAD model or how far the topology optimization is done and, form the FEA results of different sizes of the arm it is observed that at definite length of thickness is required to handle the robot easily with least stress and deformation causes and by changing the size causes the results to be changed drastically. The Von-Mises stress and displacement result of different configuration is shown in above figures, from that results we have seen that by change the mesh element size from course to fine changes our simulation result and similarly, the method of connection of an arm with other element is observed greater impact during the handling of robotic arm and the bolt connection approach expresses greater maximum Von-Mises stress than cylinder and flange approach. Figs. 7 and 8 represent the Von-Mises and displacement plot for an altered geometries of an arm while Figs. 9 and 10 represent the plots for cylinder and flange connection approach.

5. Conclusion

During industrial robot design, engineers have manually evaluated different tools that helps them for designing such as CAD and CAE tools used after the complete kinematic analysis through different approaches, equation etc. This process takes considerable amount of time and effort. Furthermore, the process of FEM simulations such as meshing and post processing is very iterative and time consuming. In this work, an alternative way to perform FEA will be presented. The main objective of my work is to relief engineers from time consuming and iterative work that would lead to further developments in robotics industries.

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