Simulation of Pick and Place Robotics System Using Solidworks Softmotion

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***Abstract*—This paper present the design of pick and place robotics system using Solidworks software. It involved design a cartesian and articulated arm with different gripper and being analyze by using simulation xpress study and motion study. Three dimension computer aided design (3D CAD) software enhance the skill and knowledge of designing automation and robotic for industry. The robot design need to be accomplished in 3D CAD to shorten the robot development time, increase the productivity of the designer and improve the speed and quality of robot design. The Solidworks 3D CAD software consist of four sections which is manual drawing, part module, assembly module and drawing module. The robotics system has simulated using Solidworks softmotion simulation software. The results of simulation xpress study and motion study of the articulated robot arm part and assembly are presented to demonstrate the pick and place robotics system.**

Keywords-Solidworks 3D CAD; simulation xpress study; motion study

I. INTRODUCTION

In recent years, the automation in robotic industry has been change a lot by the power of design technology. The combination of the design and robotic technology introduced the easiest process of making a robot for industrial use. For present and featured, the robotic automation is the most important components used at all types of factory which has potential for flexibility and intelligent in performing tasks, acceptable cost and high level of quality [1]. Before the robotic implementation, the industry used human strength faced a problem such low product quality, low production rate and high financial investment.

An industrial robot is comprised of manipulator which is to provide a movement that enables end effector to do a specific task. It include an assembly of links and joints which can be divided into three categories which is body, arm and wrist, as shown in Figure 1 [2].

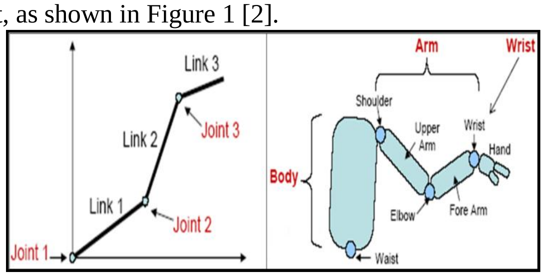


Figure 1. Robot links, joints and manipulators.

Robotic automation come out with variety of shapes whereby each robot have their own capable of various manipulators and posses a different movement system such cartesian, cylindrical, spherical and articulated arm, as shown in Figure 2. Work envelope is the work space that represent minimum and maximum reach of the robot manipulator [2].

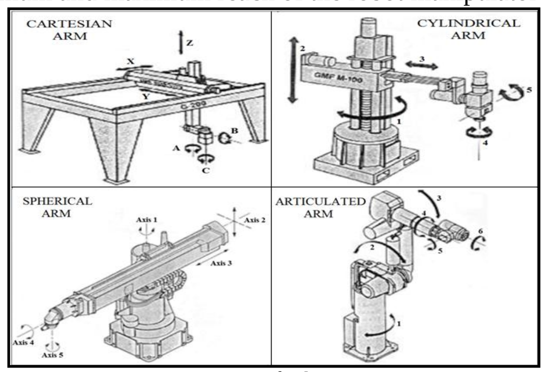


Figure 2. Types of robot geometries.

The design and robotic technology introduce the system that virtually design to model a real world robot into three dimensions (3D) [3]. A virtual design in the computer be can defined as computer aided design (CAD). This project use 3D CAD robotic automation design based on Solidworks software. The 3D CAD is use to fulfil software and hardware design desired while it is also helped to shorten the robot development time, increase the productivity of the designer and improve the speed and quality of robot design [4]. Without using Solidworks 3D CAD, the robot is difficult to be created, robot development time is more longer and any of design changes is hard to be adjusted. The pick and place robotics system was developed for grasp, pick and assemble the base, cylinder and cover product to become one complete product by using movement combination of cartesian robot, articulated robot arms and conveyors.

The objective of this project are:

- To design a cartesian robot and articulated robot arms with different gripper for pick and place robotics system which enables to understand the 3D geometry model.
- To analyze the pass stress analysis of articulated robot arm's base by using simulation xpress study.
- To analyze the movement of articulated robot arm operation by using motion study.
- To enhance student the knowledge of designing automation and robotic for industry by using Solidworks 3D CAD software.

From literature reviewed, the examples of academic journal that brainstorm the ideas for this project such as, "Virtual Design of Multi-axis Positioning for Robotic Application" [1]. This project design the robot arm using

CAD system, they used robot Fanuc M-6iB as a reference on the design, and using finite element (FE) to analyze the joints and manipulators movements. Second academic journal is "Design, Simulation and Control in Virtual Reality of a RV-2AJ robot" [5]. It also use CAD software to develop geometric model, it solves the kinematic and schematic of robot arms by using calculations and presents the equations. Simulate it with Matlab software, which is geometrical model exported into Matlab.

II. METHODOLOGY

The methodology is the overview of all the works and process done in order to complete this project. The flowchart contains of four important sections which is manual drawing, part module, assembly module and drawing module, as shown in Figure 3.

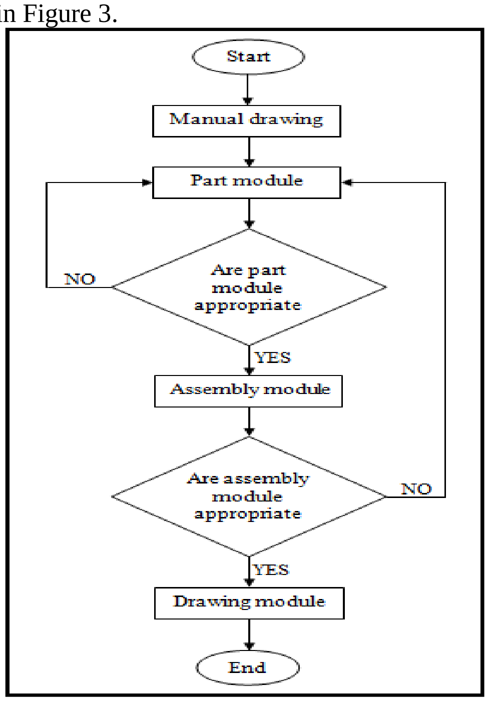


Figure 3. Methodology flowchart.

A. Manual Drawing

Manual drawing is a drawing on paper. It give first impression on how to build the parts and workstation in appropriate sizes and shapes. All parts that included in the workstation such cartesian robot, articulated robot arms, conveyors, products and tables must be in the manual drawing before being design in Solidworks software.

B. Part Module

Part is the initial section that need to be done by using Solidworks 3D CAD software. It is consists of four units which are Solidworks user interface, sketching, part modeling and simulation xpress study [6].

a) Solidworks user interface: Solidworks user interface is a native Windows interface. Some important aspects of the interface are pull down minus, toolbars menus, feature manager design tree and task pane windows.

b) Sketching: Sketching is the lesson about the introduces the basic modeling in Solidworks. Sketching is the act of creating a 2D profile comprised of wireframe geometry. In order to create a new sketch, must choose a planes by default which is front, top and right. Sketch entities offers variety of sketch tools for creating profile geometry which is line, circle, rectangle, arc, sketch fillet, point and others. Linear dimension are used to measure a dimension of part sketching. Sketch fillets are used to round off sharp corners in a sketch. There have several sketches features which is extrusion, revolve, sweep and loft. Extruded features is frequently being used.

c) Part Modeling: Part modeling process includes sketching and creating boss, cut and fillet. Create the feature by extruding the sketch into a boss and used the sketch geometry such rectangle. Extruded boss or base feature will be the boss with a top. The boss features does not have a existing reference plane because it sketch plane is a planar face of the model. Extruded cut apply same procedures with the boss features which is make a sketch and extrusion but it is used to remove the extruded model. Fillet is a selected edge whether single or many selection that used to connect with another parts in a smooth fashion through tangent curve.

d) Simulation xpress study: Formerly known as COSMOS xpress is a pass stress analysis tool. It enables to determine the part created will withstand or not the loading that it will receive in the real world. It requires part informations such restraint, load and material. Fixtures commonly known as restraint or constraint is the part that remain fixed in place during the analysis. Load such forces and pressures used to induce stress and deform the part. Material is selected depending on properties and task specification. The results can be obtained in term of stress distribution, displacement distribution and factor of safety (FOS). Stress distribution also known as Von Mises stress is the yielding of material occurs when the Von Mises stress exceeds the yield strength in tension. Yield strength is a point at which material exceeds the elastic limit and will not return to its origin length or shape when the stress is removed. Displacement distribution also known as deformation displacement is the transformation of a body from a reference configuration to a current configuration caused by external loads and body forces. FOS is a method of specifying the allowable load for design or analisis by using a number. When FOS is less than 1.0, it indicate the material at that location overstressed and the design is not safe. When FOS is greater than 1.0, it indicate the material at that location is not overstressed and the design is safe [7].

C. Assembly Module

Assembly is the section that examined assembly modeling. It is consists of three units which are bottom up assembly, using assemblies and motion study [6].

a) Bottom up assembly: Bottom up assemblies are created by adding and orienting all the existing part in an assembly. Position of the first component to the assembly is fixed by default and being locked automatically into place they fall at assembly graphic area. Adding component is under defined make it free and simply to rotate and mates. Mate is to create relationship between component parts. It can be created using faces, planes, edges, sketch lines and points. Mate types such coincident, concentric and distance are frequently being used.

b) Using assemblies: The complete assembly modeling will be analyzed, edited and exploded state. Two stages in the analysis process which is analyzing the assembly and exploded assemblies. Analyzing the assembly has two types which is calculating the mass properties and checking for interferences. The mass properties allow to perform engineering calculations such computing mass. Checking for interference divide into two which is static and dynamic interference detections. Static interference detection used to detect interferences or clashes between static component assembly. Dynamic interference detection used to detect the collision dynamically while an assembly is moving. Exploded assemblies is a exploded views of the assembly by dragging components. Exploded lines is a part of exploded view which allow the explode line sketch to represent the explode path of the components.

c) Motion study: Formerly known as animator is a study of moving system or mechanism. It enables to create movies of assemblies. Three types of motion study which is animation, basic motion and motion analysis. The animation use key frames to drive the motion by using free hand drag or triad. Basic motion use motor, spring, gravity and collision to provide motion. Motion analysis is formerly known as COSMOS motion available in Solidworks premium advanced with force and torque, result and plot graph and damper. Animation wizard contains three types of animation which is a assembly is simply rotated, exploded view and collapse view. Motion analysis involves motor, gravity and contact. Motor is used to moves a component as if acted upon by a motor. There are two types of motors which is rotary and linear motor. Standard gravity value is $9.80665 m/s^2$. Contacts is used to simulates contact between selected components.

D. Drawing Module

Drawing is projected from the 3D model. It is consists of two types which are part drawing and assembly drawing [6].

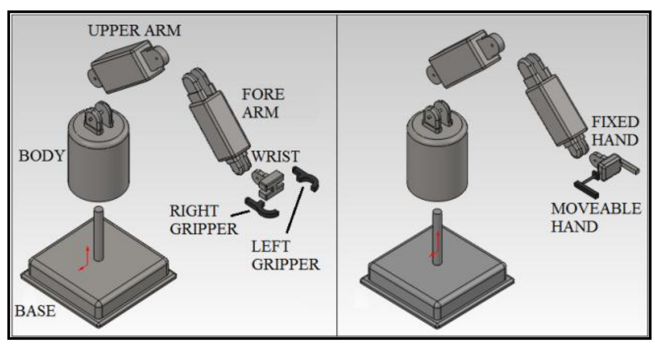
a) Part drawing: Part drawing is take a part and step through the creation of drawing file, sheet format and initial drawing views by using the part. Sheet format is landscape drawing include border and title block. The standard view is isometric, front, top and right sides of the components.

b) Assembly drawing: Assembly drawing have a unique requirements to specialized the drawing such bill of material and ballons. It used to display an exploded view of the assemblies.

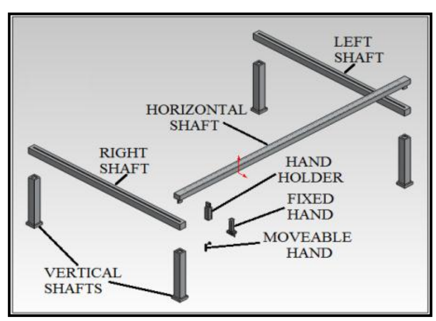
III. DESIGN AND SIMULATION OF PICK AND PLACE WORKSTATION

A. Design and assembly all the parts of the pick and place workstation

The design and simulation was built in the Solidworks 3D CAD software. The dimensions of each part was define to make all parts to be matched together. The smallest parts that do not affect the motion and assembly of robot were ignored. All of the cartesian robot and articulated robot arms were named to make easy for the next operations, as follows; robot 1, robot 2, robot C, base, body, upper arm, fore arm, wrist, gripper, vertical shaft, hand holder, moveable hand and others. Therefore, the cartesian robot and articulated robot arms was build. After part modeling, the individual components have been assembling into a single assembly file. The movement and rotation of joints were set up in the robot models and the motion analysis was introduced. Solidworks also has been used to simulate the whole automation assembly system. Figure 4 shows the components of assembling the robot. After assembled the robots, the other components for whole system that have been created were gathered into robot 1 assembly file, as follows; conveyor A, conveyor B, section A, section B, section C, section D, product base, product cylinder, product cover and others. The movement for each component was positioned carefully to get right speculation. Figure 5 shows the assembled robot parts. A motion for each part was created in this assembly file. The whole system model was shown in Figure 6.

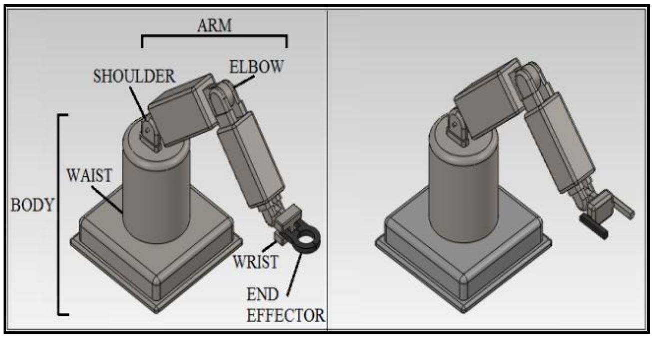


(a) Component of robot 1 (b) Component of robot 2

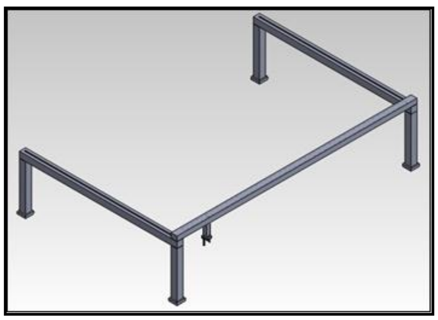


(c) Component of robot C

Figure 4. Component of robots: (a) robot 1, (b) robot 2 and (c) robot C.



(a) Assembly of robot 1 (b) Assembly of robot 2



(c) Assembly of robot C

Figure 5. Assembly of robots: (a) robot 1, (b) robot 2 and (c) robot C.

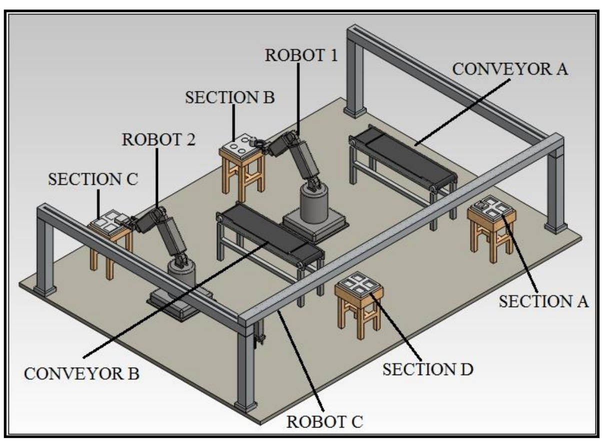
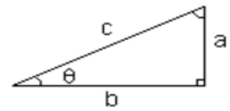


Figure 6. Pick and place robotics system.

B. *Simulation of the pick and place workstation*

The operation of pick and place robotics system is follow by the sequences. Hand holder of robot C move to section A to grasp and pick product base then placed it onto belt of conveyor A. Roller 1 of conveyor A rotate to move product base to the other side. Robot 1 move to grasp and pick product cylinder at section B then placed it into product base. Hand holder of robot C grasp and pick product cylinder and base combination then placed it onto belt of conveyor B. Robot 2 move to grasp and pick product cover at section C then placed it onto product base and cylinder combination. Roller 2 of conveyor B rotate to move completed product to the other side. Hand holder of robot C grasp and pick completed product then placed it into storage slot of section D. Hand holder of robot C then return to its origin location.

Positioning of the components which have an angle such upper and fore arm need to be calculate in order to placed it at the desired position. Pythagorean Trigonometric Identity was used to place upper and fore arm at the correct angle. The equation of Pythagorean Trigonometric Identity as stated as below:



$$\sin\theta = \frac{a}{c} \qquad \dots(1)$$

$$\cos\theta = \frac{b}{c} \qquad \dots(2)$$

$$\tan\theta = \frac{\sin\theta}{\cos\theta} = \frac{a}{b} \qquad \dots(3)$$

IV. Result and Disscussion

After accomplish this project, the 3D model was obtained and the pick and place robotics system has been built by combination of robots. The results was obtained from two types which is by using simulation xpress study and motion study.

A. *Simulation xpress study*

In the pass stress analysis, the results has been analyzed by focusing on base of robot 1. Select all faces and edges except the cylinder's face and edge of the base as the fixtures to remain fixed during the analysis. Apply force as a load at the top face of cylinder and direction to negative Y-axis. All the mass that the robot base accommodate include body, upper arm, fore arm, wrist and gripper has been calculate. The total mass is 22.21084kg. By referring Newton Second Law, it can calculate the force apply to the robot base. The equation as stated as below:

$$F = m\,a \qquad \dots(4)$$

F = force (N)
m = mass (kg)
a = acceleration (m/s^2)

Newton Second Law used to describe the force of gravity on object. The acceleration due to gravity is always 9.80665m/s^2. This means that the force due to gravity is F = 22.21084 (9.80665). Therefore, estimated force applied is 217.8139N. Stainless steel was assigned to robot base material because it is cheaper in price but has high corrosion resistance [8]. Stress distribution, displacement distribution and factor of safety (FOS) are the obtained results.

Figure 7 show the stress distribution result, the maximum value is 0.586MPa while the minimum value is 0MPa. It is to test the strength of cylinder when force applies. The maximum value located at the end of cylinder because that is the highest part that accommodate the force or stress applies. Yield strength value is 292MPa means the strength of cylinder can maximum accommodate until this value. If the force or stress applies more than 292MPa, the cylinder part will yield. Figure 8 show the displacement distribution result, the maximum value is $3.005e^{-004}$mm and the minimum value is $1.000e^{-030}$mm. It is to test the displacement of cylinder when force applies. The maximum changes of the displacement after imposed with the force or stress is $3.005e^{-004}$mm. Figure 9 show the FOS result, the maximum value is 55,732,192.00 and the minimum value is 498.65. It is to test the safety of base design when force applies. The lowest FOS value found in the robot base design is 498.65 greater than 1.0, indicate the material at that location is not overstressed and the design is safe.

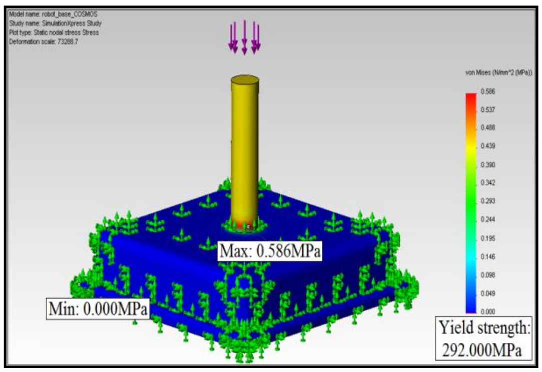


Figure 7. Stress distribution.

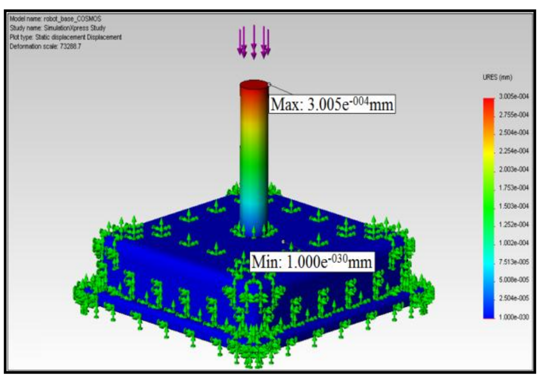


Figure 8. Displacement distribution.

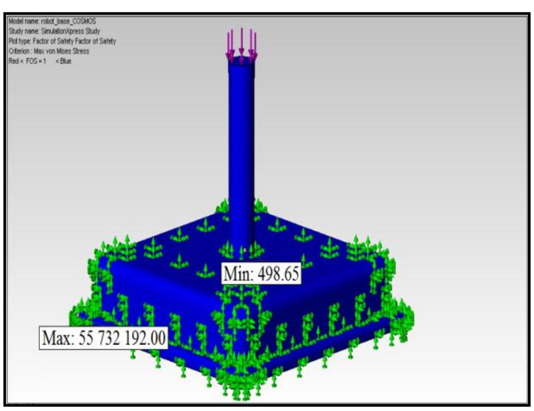


Figure 9. Factor of safety.

B. Motion study

In the motion analysis, the results have been analysed by focusing on motor analysis of a robot 1 when moving product cylinder from section B to conveyor A. The analysis at shoulder, elbow, wrist and waist joint will be explained in details. All the joint analysis come out with two graphs which is displacement versus time and angular velocity versus time. It proved the displacement of rotary motor is rotate on the time given and the highest angular velocity on the specific time.

The timeline for robot 1 is explained. At 0s until 3s time bar, shoulder joint move to positive Y-axis in 10 degree, elbow joint move to negative Y-axis in 5 degree and wrist joint fixed to negative Y-axis in 0 degree. At 3s until 6s time bar, waist joint rotate to positive X-axis in 90 degree, as shown in Figure 10.

Figure 11 show the results for shoulder joint. From the displacement versus time graph, it shows 10 degree displacement in 3s. From the angular velocity versus time graph, it shows the highest angular velocity is 5 degree per second at 1.5s. Figure 12 show the results for elbow joint. From the displacement versus time graph, it shows 5 degree displacement in 3s. From the angular velocity versus time graph, it shows the highest angular velocity is 2.5 degree per second at 1.5s. Figure 13 show the results for wrist joint. From the displacement versus time graph, it shows 0 degree displacement in 3s. From the angular velocity versus time graph, it shows the angular velocity is 0 degree per second. Figure 14 show the results for waist joint. From the displacement versus time graph, it shows 90 degree displacement from 3s until 6s. From the angular velocity versus time graph, it shows the highest angular velocity is 45 degree per second at 4.5s.

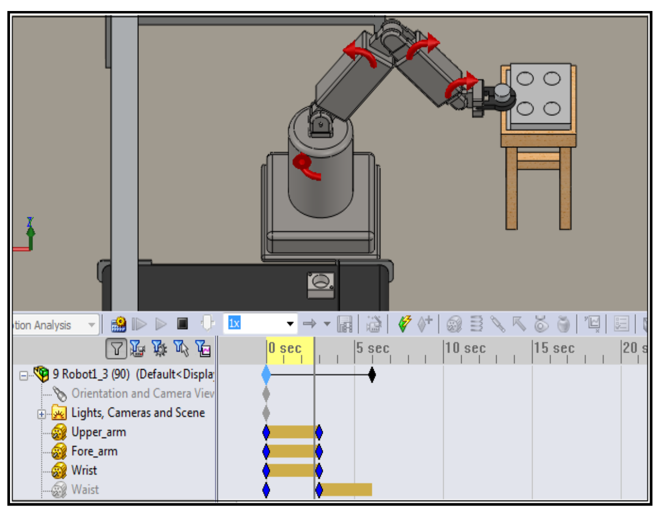
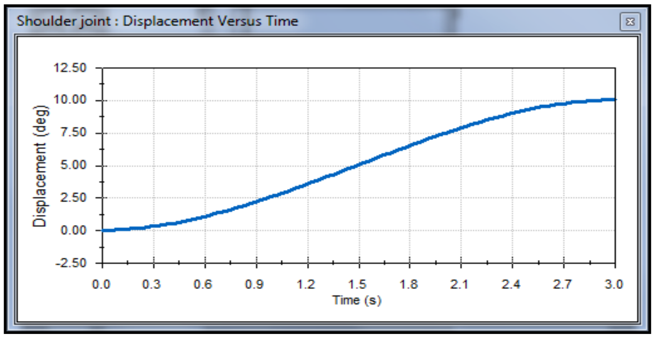
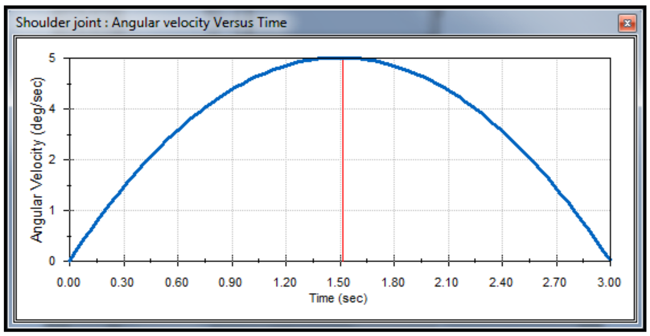


Figure 10. Timeline for robot 1.

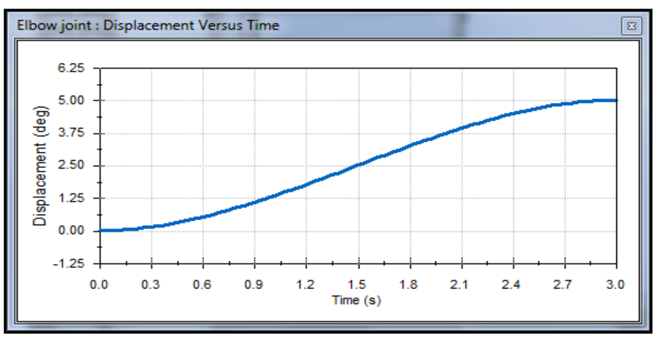


(a) Displacement versus time

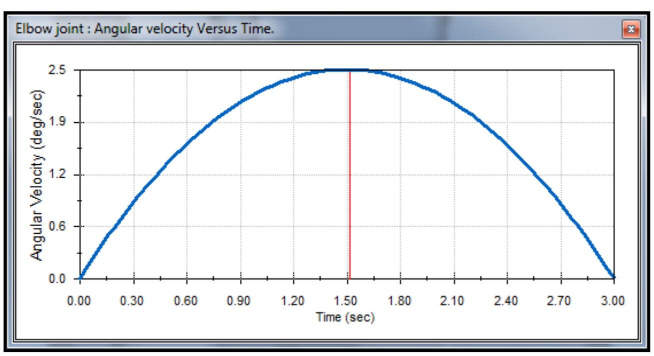


(b) Angular velocity versus time

Figure 11. Shoulder joint: (a) a displacement versus time and (b) a angular velocity versus time.

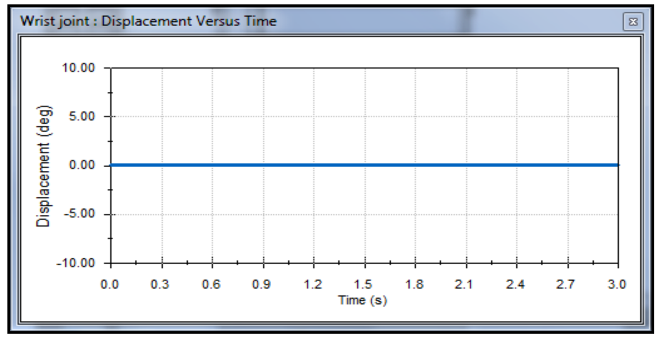


(a) Displacement versus time

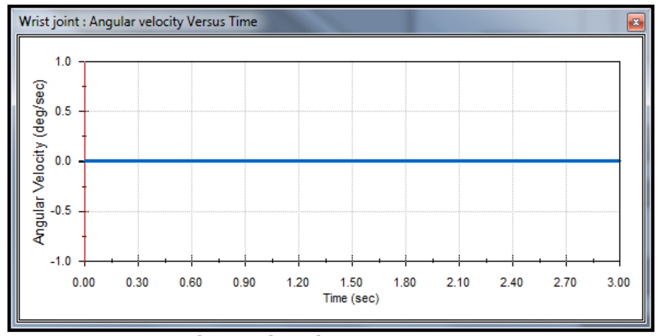


(b) Angular velocity versus time

Figure 12. Elbow joint: (a) a displacement versus time and (b) a angular velocity versus time.

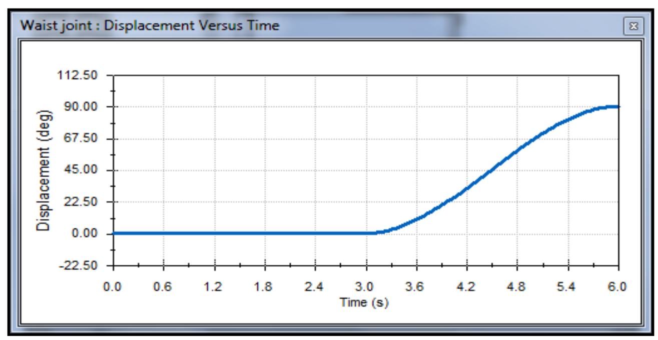


(a) Displacement versus time

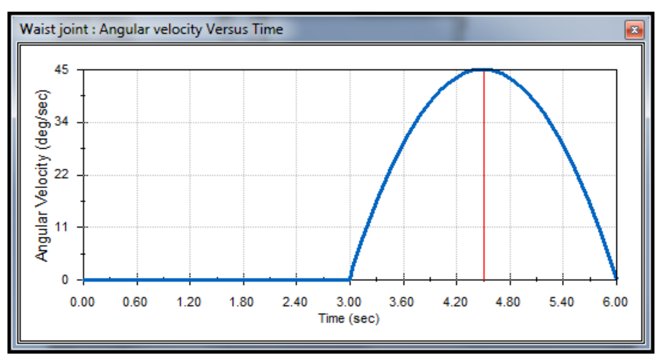


(b) Angular velocity versus time

Figure 13. Wrist joint: (a) a displacement versus time and (b) a angular velocity versus time.



(a) Displacement versus time



(b) Angular velocity versus time

Figure 14. Waist joint: (a) a displacement versus time and (b) a angular velocity versus time.

V. CONCLUSION

Solidworks 3D CAD software was used to design a cartesian robot, articulated robot arms, conveyors and products that include in the pick and place robotics system. It also include three dimension of parts and assemblies modeling, stress analysis and motion simulation of the workstation operation. The cartesian robot and articulated robot arm was been chosen for this operation because of the ability in doing various task, acceptable cost and high level of quality. All combination of parts and assemblies in one assembly file create appropriate movement of the pick and place robotics system. Simulation of the assemblies allow to detect errors on the design and any modification on the assemblies is automatically adjust the parts modeling. The simulation xpress study provide pass stress analysis to ensure the design safe for the user. The motion study created appropriate movement in the workstation operation. Both of the analysis study are shortens the design period and improve the design efficiency. By completing this project, the student exposed with designing automation and robotic for industry by using Solidworks 3D CAD software besides it is a valuable knowledge.

VI. FUTURE RECOMMENDATION

In Solidworks, certain sections need to be improved. The simulation xpress study, after run the analysis in order to obtained the results such stress, displacement and factor of safety, there have a animation to show that the part deform as expected or not. It is better if the animation results of the part deform can be saved into a video. It is much useful for the user to look at the animation of part deform rapidly and determine what exactly happened on the parts that being analyzed. It really helpful in order to gain a better results on the simulation xpress study analysis. Secondly, in order to gained better performance and to support the result in the motion study, it must have a combination between Solidworks simulation and LabVIEW. By this integration, it will allow to develop virtual prototyping using linear motion and rotary motion. All the Solidworks motion study data such position, acceleration, velocity and torque then can be controlled using LabVIEW.

VII. ACKNOWLEDGEMENT

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