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Research, Design, and Simulation of Automatic Welding Line for KIA K3000S's Trunk

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Abstract: Automatic welding lines are used popularly in industry, especially in car manufacturing. In Thaco-Kia Company, the truck assembly process is still done by workers with manual processes. This paper focuses on designing an automatic welding line of KIA K3000S's trunk to help the company reduce cost of production, save the time, and enhance the working efficiency. Our goal is designing an automatic assembly system of a side part of the trunk. First, the mechanical part is designed including robots, flex track, flex lifter, and supported parts. Next, we build the controller of the automatic system. After that, an automatic control algorithm of total system is considered. Finally, this algorithm is simulated and verified by an industrial robotic software.

Keywords: *Welding Line, ABB Robot, Gripper, Trunk, Automatic System*

Introduction:

KIA K3000S is one of the most used trucks in Vietnam today. This type of truck is assembled and manufactured by THACO Company. The trunk of KIA K3000S includes three parts: main body, top part, and side part. This paper concentrates on improving the assembly process of the side part of the trunk. This process consists of four main stages.

In first station, there are three workers bring metal bars and assembly them into the skeleton of the side part. Figure 1 shows the work of three workers. Next the fixture keeps them together for preparing to MIG welding. After completion, the skeleton is moved to the second station. At this station, two workers bring metal sheet to put on the top of the skeleton and the frame is moved to third station.

At this station, two worker will bring spot welding gun to weld the metal sheet stick into the structure. Figure 2 shows the activity of two workers using spot welding gun. At final station, two workers will check again and move the complete product to the next system.

Figure 1: Three workers at first station

Figure 2: Two workers with spot welding gun

Whole process uses nine workers, so the productivity is affected after long time. Each worker at third station will weld about 100 points. They can produce 50 production per day. However, the quality of the product is not uniform.

For improving quality and increasing productivity, this paper concentrates on designing an automatic assembly and welding system. The mechanical design is considered in next part. After that, electrical design is done. Finally we verify our design by simulation.

Mechanical Design:

In this part, we will show the mechanical design of the automatic system. Figure 3 shows the dimension and structure of the frame that we need to make. The dimension is 3400mm x 960mm x 40mm. The frame make from galvanized square tubing steel bar whose dimension is 40mm x 40mm x 3.5mm. Metal sheet make from inox. The total mass of the frame is 75 kg.

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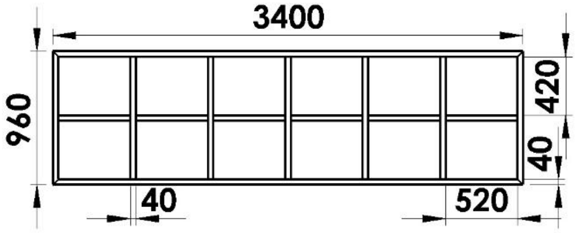

Figure 3: Dimension of the frame

Firstly, we design a transportation system to move the frame from one station to other station. A flex lifter is used to carry the frame during manufacturing. Figure 4 shows the picture of the flex lifter. The total dimension is 1900mm x 660mm x 320mm. The mass is 750kg. Load capacity is 600kg.

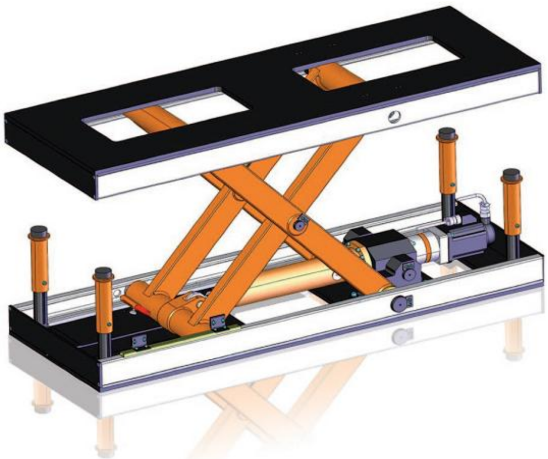

Figure 4: Flex Lifter

The track that we use is Flex Track IRB 501-66. Capacity of the track is 900kg. Velocity is 1.5m/s and acceleration is 1.5m/s^2. The shape of the flex track can be seen in figure 5.

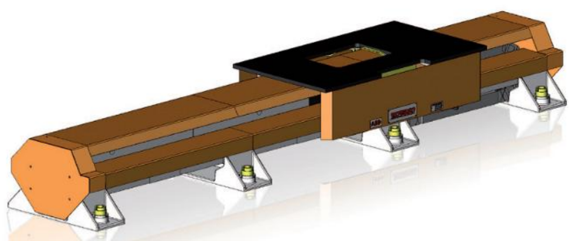

Figure 5: Flex Track IRB 501-66

Next we will design each station of the system. Our whole system include seven robots and they are arranged around the flex track.

In first station, we use two robots to grasp the metal bars and put them on the fixture table to assemble a skeleton of the product. The dimension of fixture table is 3920mm x 1380mm. The fixture is rotated by a robot IRBP L300. The robot is chosen for grasping metal bars is IRB6640. After finish assembling, we use two other robots to weld to stick metal bars together. We choose robot IRB1600 with H-range is 1.45m for this duty. All component of the first station are shown in figure 6.

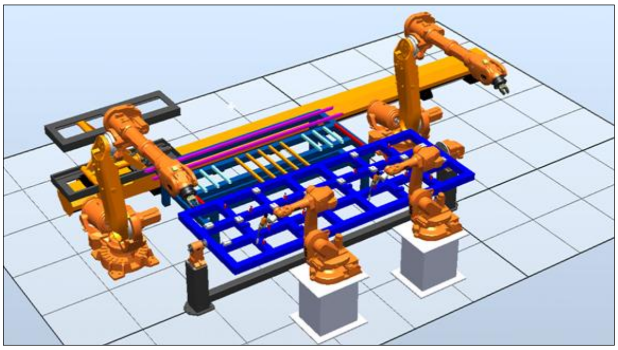

Figure 6: First station of the automatic system

The second station use one robot IRB6640 to grasp the metal sheet and put it on the skeleton. After that, two other robots IRB6640 carry welding gun to make spot welding at several points to finish the product. All elements of the second station are shown in figure 7.

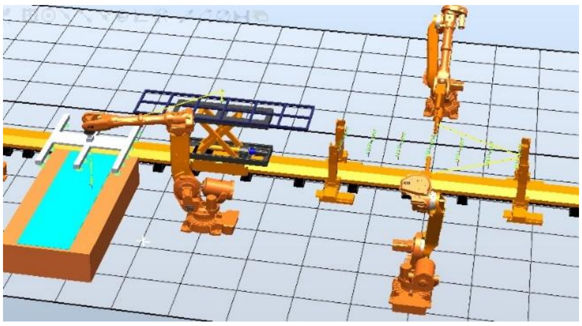

Figure 7: Second station of the automatic system

Kinematic problems:

In this part we will solve the forward kinematic position of the robot IRB6640, the most used robot in this paper. DH table can be seen in table 1.

Table 1: DH parameters

i	**a_i (mm)**	**α_i (^{0})**	**d_i (mm)**	**θ_i (^{0})**
1	320	90	725	θ_1
2	1280	0	0	θ_2
3	200	90	0	θ_3
4	0	90	1142	θ_4
5	0	-90	0	θ_5
6	0	0	200	θ_6

From DH parameters, we can find the relationship between the tool frame, frame of the welding gun, and the base frame, called transformation matrix ${}^0T_6$.

$$ {}^0T_6 = {}^0T_1\,{}^1T_2\,{}^2T_3\,{}^3T_4\,{}^4T_5\,{}^5T_6 = \begin{bmatrix} n_x & s_x & a_x & p_x \\ n_y & s_y & a_y & p_y \\ n_z & s_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1) $$

Where parameters of orientation can be expressed by

$$n_x = c_1 s_5 c_6 s_{23} + c_5 \left(s_1 s_4 + c_1 c_4 c_{23}\right) + s_6 \left(s_1 c_4 - c_1 s_4 c_{23}\right) \quad (2)$$

$$n_y = s_1 s_5 c_6 s_{23} - c_5 \left(c_1 s_4 - s_1 c_4 c_{23}\right) - s_6 \left(c_1 c_4 + s_1 s_4 c_{23}\right) \quad (3)$$

$$n_z = -s_5 c_6 c_{23} - s_{23} \left(c_4 c_5 + s_4 s_6\right) \quad (4)$$

$$s_x = c_1 \left(c_4 c_5 c_{23} - s_5 s_6 s_{23}\right) + c_6 \left(s_1 c_4 - c_1 s_4 c_{23}\right) + s_1 s_4 c_5 \quad (5)$$

$$s_y = s_1 \left(c_4 c_5 c_{23} - s_5 s_6 s_{23}\right) - c_6 \left(c_1 c_4 + s_1 s_4 c_{23}\right) - c_1 s_4 c_5 \quad (6)$$

$$s_z = s_5 s_6 c_{23} - s_{23} \left(c_4 c_5 + s_4 c_6\right) \quad (7)$$

$$a_x = c_1 c_5 s_{23} - s_5 \left(s_1 s_4 + c_1 c_4 c_{23}\right) \quad (8)$$

$$a_y = s_1 c_5 s_{23} + s_5 \left(c_1 s_4 - s_1 c_4 c_{23}\right) \quad (9)$$

$$a_z = -c_5 c_{23} - c_4 s_5 s_{23} \quad (10)$$

And parameters of position are

$$p_x = c_1 \left(a_1 + a_2 c_2 + a_3 c_{23} + d_4 s_{23}\right) + d_6 c_1 c_5 s_{23} - s_5 \left(s_1 s_4 + c_1 c_4 c_{23}\right) \quad (11)$$

$$p_y = s_1 \left(a_1 + a_2 c_2 + a_3 c_{23} + d_4 s_{23}\right) + d_6 s_1 c_5 s_{23} + s_5 \left(c_1 s_4 - s_1 c_4 c_{23}\right) \quad (12)$$

$$p_z = s_{23} \left(a_3 + c_4 s_5\right) - c_{23} \left(d_4 + d_6 c_5\right) + a_2 s_2 + d_1 \quad (13)$$

From the relation between the position and the orientation of the tool frame and the base frame, we can find the value of joints if we know the value of position and orientation. This is inverse kinematic problem.

Electrical Design:

Our control system use IRC5 controllers of ABB Company. This is a special controller for control industrial robots from ABB, including two parts: driver module and control module. Each IRC5 controller can control maximum four different robots. The communication between IRC5 controllers is industrial protocol, and DeviceNet is the most used. Our controller includes four IRC5 controllers. The first IRC5 controls two robots IRB6640 to grasp metal bars, the flex track, and the flex lifter. The second IRC5 controls two robots IRB1600 to weld to fix the metal bar and control rotation robot. The third IRC5 controls a metal sheet grasping robot and two robots for spot welding robot. The fourth IRC5 controls four X-Y-Z axis to finish the product. Figure 8 shows our control system. Figure 9 shows the schematic of the first IRC5 controller.

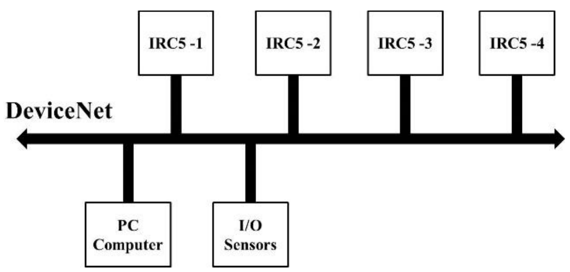

Figure 8: Control schematic of our system

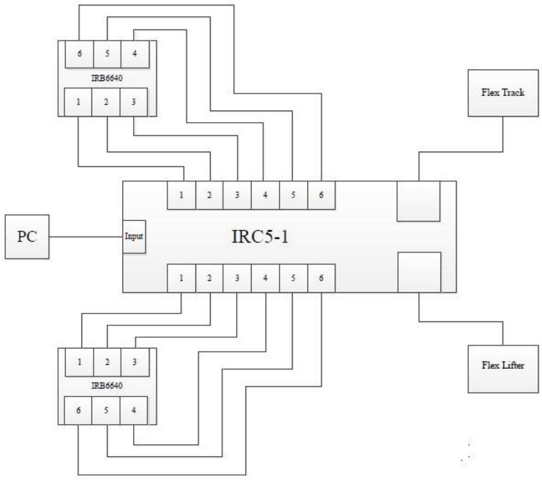

Figure 9: The first IRC5 controller

Control Algorithms:

In this part, we show the control algorithm. First, we check if there are metal bars or not. Next two robots will grasp metal bars to put them on the fixture for assembling the skeleton of the product. After finishing welding the skeleton, flex lifter moves the frame to the second station. In this station, one robot grasps the metal sheet and put it on the frame. Next flex lifter move the frame to the position of spot welding robots. They will continue to finish the product. Figure 10 shows our control algorithm.

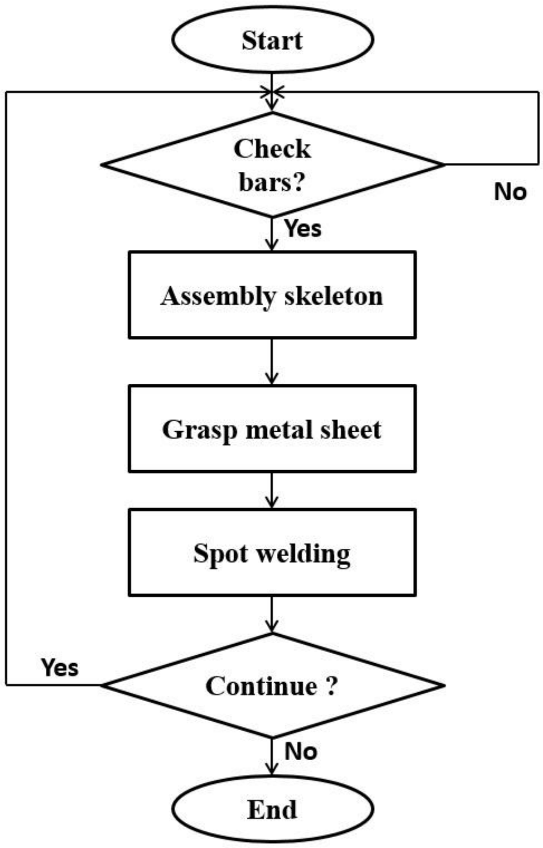

Figure 10: Control algorithm

Results and Discussion:

In this part, we present the results of our simulation. We use software Robot Studio of ABB Company to verify our algorithms. This is a special one for controlling industrial robots. The code of the software can be downloaded directly to the real robot controller without modifying anymore.

Figure 11 shows the activity when two robots IRB6640 grasp vertical metal bars. Figure 12 shows when they grasp small horizontal bars. Figure 13 and figure 14 show the working of two robots IRB1600. They weld the front side of the skeleton. Figure 15 shows when they weld the back side.

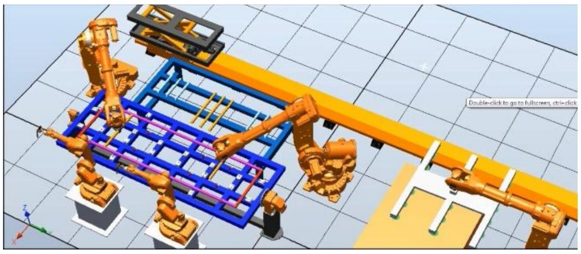

Figure 11: Two robots grasp vertical bars

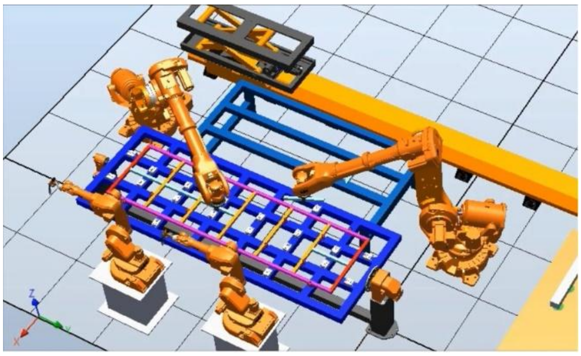

Figure 12: Two robots grasp small horizontal bars

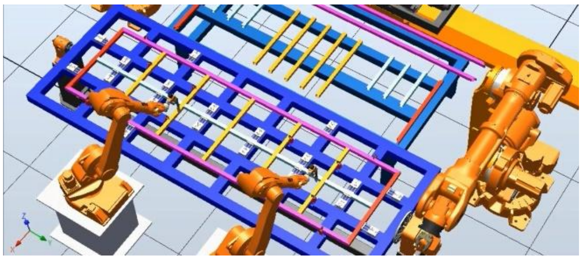

Figure 13: Two robot weld the skeleton

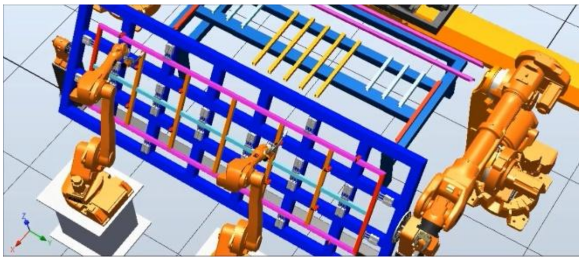

Figure 14: Two robots weld the far points

Figure 16 shows then one robot IRB6640 grasps the skeleton and put it on the flex lifter. Figure 17 shows when robot IRB6640 grasps the metal sheet and pit it on the top of the skeleton. Figure 18 shows the preparation before doing spot welding. Figure 19 shows the working of two spot welding robots at first points. Figure 20 shows the activity of two spot welding robots at the sixth column. We need to weld totally seven columns.

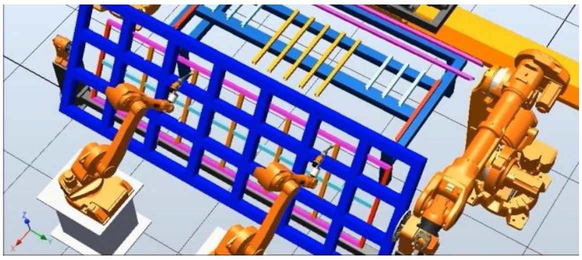

Figure 15: Two robots weld back side

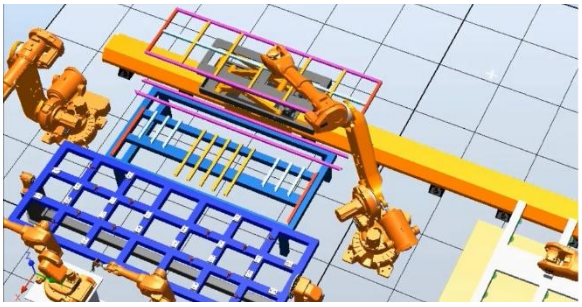

Figure 16: Robot grasp skeleton and put on flex lifter

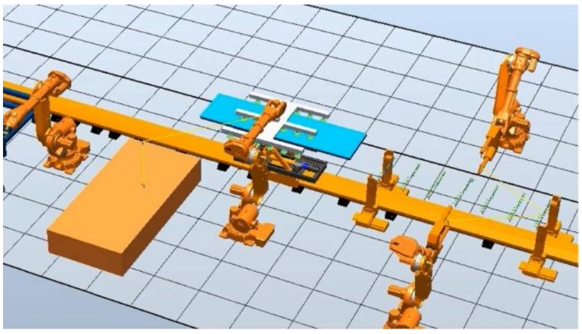

Figure 17: Robot grasp metal sheet

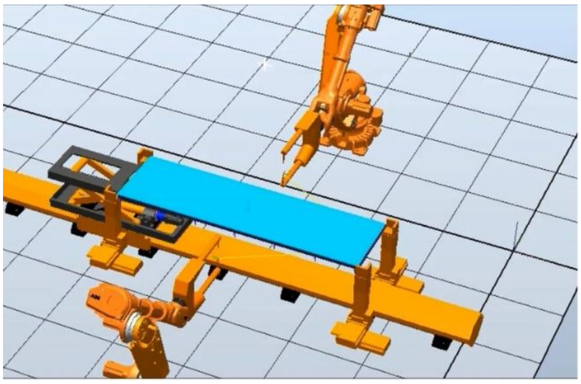

Figure 18: Preparation for spot welding

The simulation proves that our algorithm is accurate and can be used in the real factory. We have simulated whole working of the system from assembling metal bars to spot welding task.

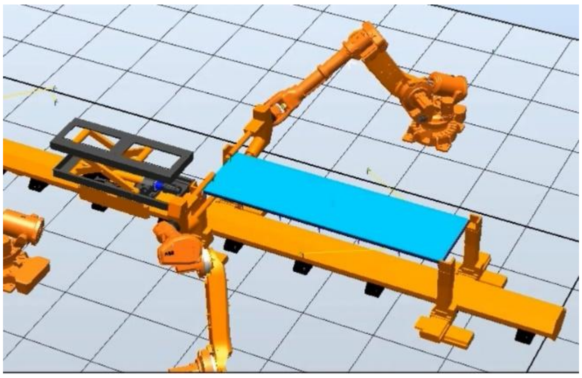

Figure 19: Two robots start spot welding

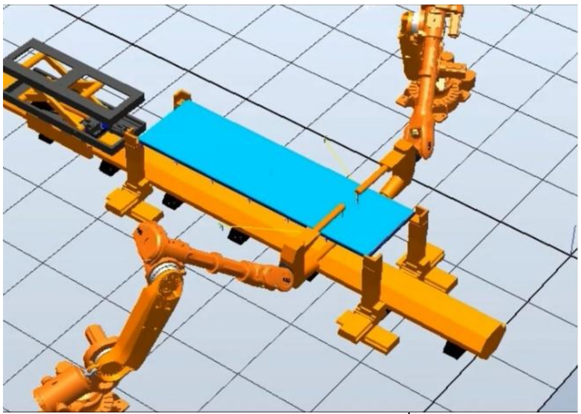

Figure 20: Two robots weld 6th column

Conclusion:

This paper concentrates on designing an automatic welding and assembly system a side part of a trunk of KIA K3000S. Our system use total seven robots for this task. The algorithm has been proposed and verified by simulation. However, the cost of this design is so high and need to be considered by the leader of the company.

Acknowledgement:

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