Development of Trajectory Design of a Planar PRR Redundant Serial Manipulator

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ABSTRACT

Robot usage in the industry increase every year by the developments in technology. Industrial robots not only timesaver but also ensures the quality of the products in machining operations. Robots specialized for machine tool operations have limited utilization compared to those which for assembly, welding, or pick & place operations. In this paper we focused on the development and verification of a planar manipulator path trajectory which will going to do surface finishing operation on a work piece. To do this first we define a desired path and the unknown coefficients of joint variables have been calculated by performing direct and inverse kinematic analysis and applying the conditions of position, velocity, and acceleration of the given trajectory. Obtained trajectory of the end effector has been tested on both simulation and real task space. Results of theoretically calculated trajectory have been verified by computational simulation and end-effector trajectory of the prototype has been verified via motion tracking system with cameras.

Keywords

Trajectory Planning, Robotic surface finishing, Robot manipulators

1. INTRODUCTION

In recent years robot usage in daily life is increasing day by day. In the industrial field, the usage of robots not only increases the quality of the manufactured parts, but also shortens the production time of the produced parts. Robot manipulators can be defined as kinematic chains formed by connecting rigid links to each other. Robot manipulators in industry is utilized in many areas such as pick & place, painting, additive manufacturing, grinding, assembly. Robotic grinding methods are used in industry for better quality surface finishing operations.

One of the earlier studies about robotic grinding is done by H. Huanga et al. 6-axis robotic grinding system was used for development of a path planning and tool optimization for automate a manual overhaul of turbine vane. [1] Another earlier study was done by Akbari and Higuchi, a grinding disks tool adjustment were done for a six-axis articulated robot system. Different tool angles were applied to a aluminum alloy workpiece to find an optimum tool angle [2]. One study for trajectory planning were presented by Uzunoglu et al. A macro-micro manipulator designed for shorten the processing time by mounting on CNC laser cutting machine. In the mentioned study, a micro manipulator working with a laser cutting mechanism was designed, the acceleration of the end effector was increased and thus the machining times were decreased [3]. Mousavi et al. focused on kinematic and dynamic approaches by finding a trajectory path to provide smooth walking motion for a bipedal robot. [4]

In the present study, we focused on the development and verification of a planar manipulator shown in Figure 1, which is planned to be utilized for grinding and surface finishing operations. For this purpose, a planar PRR serial manipulator has designed as a redundant system for end effector position tracking, and trajectory of the end-effector has developed. A desired trajectory has been created for the end effector of serial RR portion of the manipulator and joint variables regarding to the given trajectory have been defined as polynomial functions. The unknown coefficients of joint variables have been calculated by performing direct and inverse kinematic analysis and applying the conditions of position, velocity, and acceleration of the given trajectory. Final trajectory of the end effector has been obtained by the implementation of polynomial functions corresponding to the prismatic joint, which provides improvements on the planar trajectory. Obtained trajectory of the end effector has been tested on both simulation and real task space. Results of theoretically calculated trajectory have been verified by computational simulation based on direct kinematic analysis. At the end of the study, desired end-effector trajectory of the prototype has been verified via motion tracking system with cameras. Future works of the study will include an enhanced user interface and integration of bed design for work pieces to perform grinding operations.

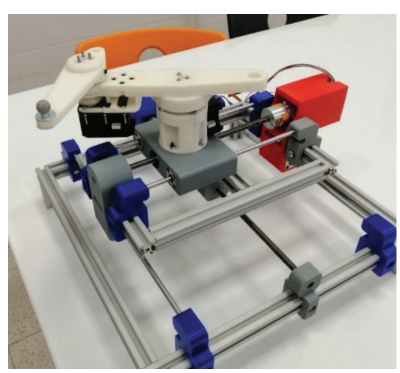

Figure 1. Prototype of planar PRR serial redundant serial manipulator

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2. KINEMATICS OF PRR MANIPULATOR

In order to achieve our goal we decided to create 3 degrees of freedom PRR redundant serial manipulator. Although the end-effector of the system has sufficient degrees of freedom with the help of 2 revaluate joints for the planned trajectory, a prismatic joint was added to the manipulator. A redundancy occurred in the manipulator due to this added prismatic joint. This redundancy formed will provide optimization for the planned path. Kinematic representation of the created manipulator is shown in Figure 2 and its denavit-hartenberg parameters is given in table 1 in the below.

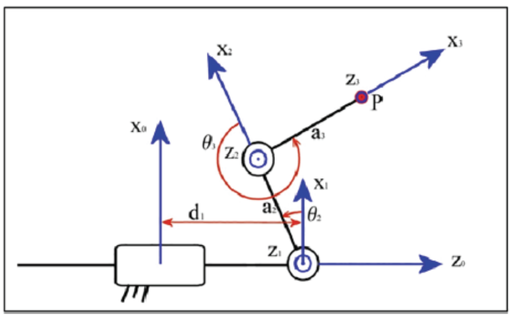

Figure 2. Kinematic representation of the given manipulator

Table 1. Denavit-Hartenberg parameters of the given manipulator

Joint	α_i	a_i	d_i	θ_i
1	-π/2	0	d_1	0
2	0	a_2	0	θ_2
3	0	a_3	0	θ_3

The direct and inverse kinematic analyzes of the manipulator were performed according to the denavit-hartenberg parameters specified in the above Table 1 and the kinematic representation shown in Figure 2.

To find the end-effectors position (Px,Py)

$$p_x = a_2 Cos(\theta_2) + a_3 Cos(\theta_2 + \theta_3)$$
(1)
$$p_z = d_1 - a_2 Sin(\theta_2) - a_3 Sin(\theta_2 + \theta_3)$$

When d_1=0 for the simplification of the equations the equation (1) turns to

$$p_x = a_2 Cos(\theta_2) + a_3 Cos(\theta_2 + \theta_3)$$
(2)
$$p_z = a_2 Sin(\theta_2) - a_3 Sin(\theta_2 + \theta_3)$$

To find the θ_3 we simply take square of each equations (2) and find θ_3

$$\theta_3 = cos^{-1} \frac{{p_x}^2 + {p_z}^2 - {a_2}^2 - {a_3}^2}{2 a_2 a_3} \quad (3)$$

After finding of the θ_3 the equation set (2) were rearranged like the equations in (4)

$$p_x = k_1 Cos(\theta_2) - k_2 Sin(\theta_2),$$
$$p_z = -k_1 Sin(\theta_2) - k_2 Cos(\theta_2),$$
(4)
$$k_1 = a_2 + a_3 Cos(\theta_3),$$
$$k_2 = a_3 Sin(\theta_3),$$

With the usage of equations (4) θ_2 can calculate like;

$$\theta_2 = \text{Atan2}(-p_z, p_x) - \text{Atan2}(k_2, k_1) \quad (5)$$

For detailed kinematic equations and calculations our previous study can be seen.[5]

3. PATH PLANNING

A desired path was created for the end effector to follow considering that the designed PRR serial manipulator will be used in surface finishing and grinding operations in the industrial area in the future.

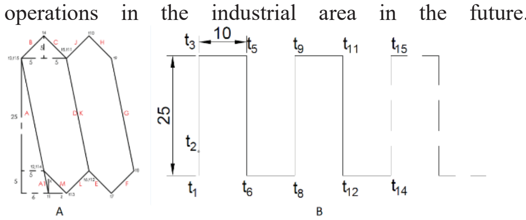

Figure 3 A) Planned path that RR portion of the manipulator will follow B) Planned path for the end-effector will follow on the work piece

The figure above shows the desired path that the robot's end-effector will follow. In Figure 3A, the path that the robot's RR part is required to follow is shown. Figure 3B shows the planned version of the path that the end-actuator of the manipulator will follow through the workpiece. The prismatic joint on the robot is used to provide the real desired path to be created on the workpiece. The straight lines between t_1 and t_{14} shown in Figure 3B shows the part of the motion that takes place in a one cycle, and the part starting with the dashed line shows the beginning of the second cycle. With these cycles, the workspace of the manipulator on the workpiece increased. The positions of the θ_2 and θ_3 revolute joints have been proposed as a function depending on the time equations (6).

$$\theta_{k,i}(t) = a_{k,i}t^3 + b_{k,i}t^2 + c_{k,i}t + d_{k,i} \quad (6)$$

$k = 2,3.\ i = 1,2,\ldots.14.$

Equation (6) is rewritten for each specified point on the parth and all simultaneously solved together.

4. PROTOTYPE AND SIMULATION

Before manufacture the prototype of the designed manipulator, it was simulated with the help of 3D models created in CAD programs. In the prepared simulation, the motion of the RR portion of the manipulator was observed by performing the position control together with the previously found θ_2 and θ_3 equations (6). Then, the motion of the entire manipulator was observed by activating the prismatic joint. MATLAB Simulink model prepared for simulation is shown in figure 4 below.

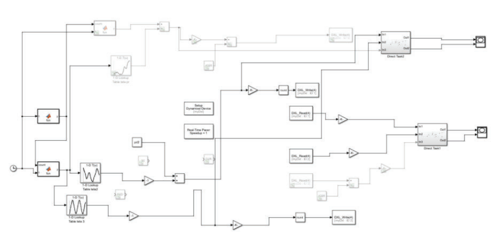

Figure 4. MATLAB Simulink Model

After the simulations were completed, the prototype of the manipulator was created with the help of 3-D printers using 3D models prepared for simulation. 3 servo motors were used on the prototype of the manipulator. In order to provide the linear motion created by the prismatic joint, a mechanism is designed with the help of linear bearings and a screw shaft. Final version of the created manipulator is shown in Figure 5 below.

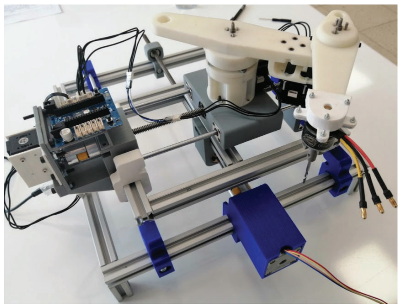

Figure 5. Final version of the PRR manipulator

5. VERIFICATION OF THE RESULTS

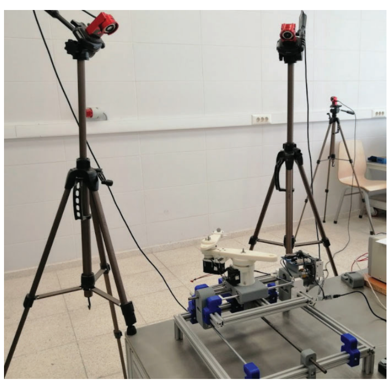

Figure 6. Opti-track motion tracking system

The data obtained as a result of the simulation and the data obtained from the motion tracking system shown in Figure 6 were compared as a verification study. The comparison was carried out in two different ways. First, the RR portion of the manipulator was activated and the data obtained in this part are shown in Figure 7.

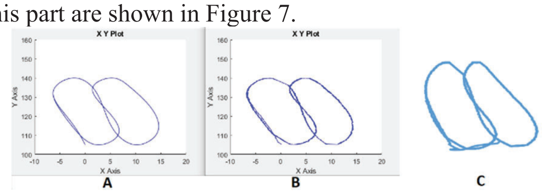

Figure 7. Graphic of the end-effectors position when the RR portion of manipulator is activated A) Simulation results B) Signal data read from motors C) Camera observation data

Then, as shown in Figure 8 below, the RR portion of the manipulator was deactivated, and the end-effector position time graph obtained by operating the prismatic joint.

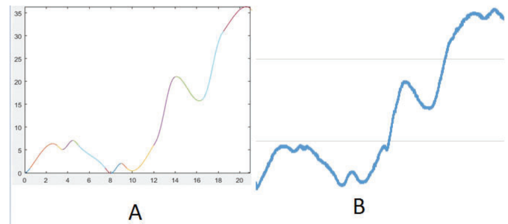

Figure 8. Prismatic joint position time graphic A) theatrical calculations B) Motion tracking data

Finally in the figure 9 the end-effectors position graph is showed when all off the motors are activated.

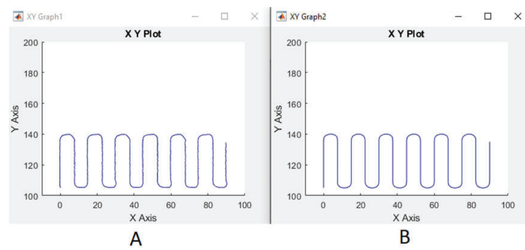

Figure 9. End-effectors position graph A) Signal data read from motors B) Simulation data

At the end of the study, desired end-effector trajectory of the prototype has been verified via motion tracking system with cameras and signal read from the motors. Future works of the study will include an enhanced user interface and integration of bed design for work pieces to perform grinding operations.

6. REFERENCES

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