Visual Inspection of Work Piece with a Complex Shape by Means of Robot Manipulator

A. Y. Bani Hashim, N. S. A. Ramdan

***Abstract*—**Inconsistency in manual inspection is real because humans get tired after some time. Recent trends show that automatic inspection is more appealing for mass production inspections. In such as a case, a robot manipulator seems the best candidate to run a dynamic visual inspection. The purpose of this work is to estimate the optimum workspace where a robot manipulator would perform a visual inspection process onto a work piece where a camera is attached to the end effector. The pseudo codes for the planned path are derived from the number of tool transit points, the delay time at the transit points, the process cycle time, and the configuration space that the distance between the tool and the work piece. It is observed that express start and swift end are acceptable in a robot program because applicable works usually in existence during these moments. However, during the mid-range cycle, there are always practical tasks programmed to be executed. For that reason, it is acceptable to program the robot such as that speedy alteration of actuator displacement is avoided. A dynamic visual inspection system using a robot manipulator seems practical for a work piece with a complex shape.

***Keywords*—**Robot manipulator, Visual inspection, Work piece, Trajectory planning.

I. Introduction

MANNUAL inspection is still the choice for final inspection in the quality controls. However, inconsistency in human inspection is real because humans can get tired after some time. Human is incapable of focusing on the repeating work. It is difficult and costly to hire and train human experts. It is fair to claim that human cannot achieve consistency as compared to automatic inspection, such as using a vision system. In fact, there are also cases where inspection tends to be tedious or difficult, even for the best-trained expert [1].

Recent trends show that automatic inspection is more appealing for mass production inspections. In such as a case, a robot manipulator seems the best candidate to run a dynamic visual inspection. Robot manipulator is a machine formed by a mechanism, including a number of degrees of freedom, often having the appearance of one or some arm ends in a wrist capable of holding a tool, a work piece or an inspection device [2]. A manipulator is a mechanical unit that provides motions or trajectories similar to those of a human arm and hand. A robot manipulator, on the other hand, provides trajectories by programmed instructions.

On a manipulator, the end of the wrist can reach a fixed point having a particular set of coordinates and in a specific orientation. This is realized by the application of an end effector where the end of the wrist in a robot is equipped with an end-of-arm tooling. An end effector may be equipped with tooling such as [3]: i) a gripper, a hook, a scoop, an electromagnet, a vacuum cup, an adhesive finger for material handling; ii) a spray gun for painting; iii) an attachment for spot and arc welding and cutting; iv) a power tool [4]; v) a measuring instrument.

Two basic structural types classify robot manipulator: the parallel structure and the serial structure [5]. For a serial structure, it is constructed in such a way as to form the shape of an elbow, wrist and shoulder [6]. One of the major advantages of the serial type over the parallel type is its workspace that is larger than that of the parallel type.

The purpose of this work is to estimate the optimal workspace where a robot manipulator performs a visual inspection process onto a work piece where a camera is attached to the end effector. While planning for the trajectory, the joints' position, velocity, and acceleration are carefully planned that the obstacles are to be avoided, and the tool is to travel along the shortest path, and the cycle time is within a desired one.

A vision system that is fixed onto a location has a limited image capturing area. The idea is to attach a camera onto the end effector. For the robot while in motion, the camera will have a wider capturing area and at an ideal angle with respect to the work piece with a complex shape (WPCS)

II. Method

This work carries out the following sequence of activities: identification of the method in path and trajectory planning; designing the program structure; developing the robot program; and assessment the robot's paths and trajectories.

A. Path and Trajectory Planning

A robot manipulator performs pre-planned tasks by controlling the rate of movement of its actuators. This process is known as the trajectory planning. The rates and sequences of actuator movement are programmed so that a desired path is obtained. A continuous map, $\gamma[0,1] \rightarrow \Theta$ with $\gamma(0)$ has a path that begins at a start point (q_o) to final point (q_f) in a configuration space. A trajectory is a function of time$q(t)$ such that $q(t_o) = q_s$ and $q(t_f) = q_f$. The difference $t_f - t_o$ is the time taken to execute the trajectory [4]. The trajectory itself explains the rate of actuator rotation on individual

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manipulator joint. Six functions define the trajectory for six actuators.

Consider a cubic trajectory based on a single joint trajectory. For a scalar joint variable, $q(t)$ at time t_o the joint variable satisfies constraint (1). A cubic trajectory and its derivative are defined in (2), whereas (3) is the algebraic representation of the trajectory. The constraints and definitions stated in (1), (2), and (3) are used to plan for robot's tool path where the actuator's angles of rotation, velocities and accelerations are realized through robot's program.

$$\left.\begin{array}{ll} q(t_o) = q_o; & \dot{q}(t_o) = v_o; \\ q(t_f) = q_f; & \dot{q}(t_f) = v_f; \\ \ddot{q}(t_o) = \alpha_o; & \ddot{q}(t_f) = \alpha_f. \end{array}\right\} \tag{1}$$

$$\left.\begin{array}{r} q(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 \\ \dot{q}(t) = a_1 + 2a_2 t + 3a_3 t^2 \end{array}\right\} \tag{2}$$

$$\begin{pmatrix} 1 & t_o & t_o^2 & t_0^3 \\ 0 & 1 & 2t_o & 3t_o^2 \\ 1 & t_f & t_f^2 & t_f^3 \\ 0 & 1 & 2t_f & 3t_f^2 \end{pmatrix} \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{pmatrix} = \begin{pmatrix} q_o \\ \dot{q}_o \\ q_f \\ \dot{q}_f \end{pmatrix} \tag{3}$$

B. Figures

The pseudo codes for a planned path are derived from the number of tool transit points, the delay time at the transit points, the process cycle time, and the configuration space that the robot makes. Table I shows the transit points (vertex-position), the assigned coordinates, the path that passes through the transit points. The tool has to travel through eight vertices along the path.

TABLE I
PLANNED TRAJECTORIES

Vertex	Position	X	Y	Z	Path	Remark
0	Home	x_0	y_0	z_0	7-1	Robot home
1	Initial	x_1	y_1	z_1	0-1	Ready to initiate path
2	P1	x_2	y_2	z_2	1-2	Defect area 1
3	P2	x_3	y_3	z_3	2-3	Defect area 2
4	P3	x_4	y_4	z_4	3-4	Defect area 3
5	P4	x_5	y_5	z_5	4-5	Defect area 4
6	P5	x_6	y_6	z_6	5-6	Defect area 5
7	End	x_7	y_7	z_7	6-7	Ready to return home

C. Document Modification

The Comau robot manipulator was used to realize the automatic visual inspection where the manipulator's function was to bring the camera to the pre-defined locations within the configuration space. The camera shootings were realized by another separate system.

Fig. 1 exhibits the experiment setup that consists of the robot itself, a work piece that is a car door, and a camera that is attached onto the end effector. The white markings were plastic straws that functioned as indicators that limit the configuration space. They provided the limit within which the camera should reach but to avoid any obstacles.

Prior to the realization of the inspection process, the setup was simulated in Workspace. Fig. 2 shows the simulated environment of the setup. The results obtained from the simulation would explain the behavior of the individual actuator and this would reflect to (1), (2), and (3).

Fig. 1 Experimental setup showing the work piece (car door) and the end effector where a camera were installed marked in the small box in the figure

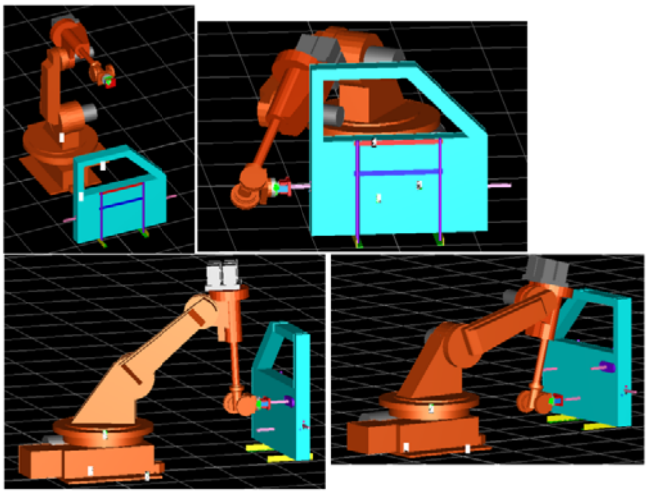

Fig. 2 Simulation for planning of manipulator's path and trajectories using Workspace

III. Results & Discussion

The realization of the experimental setup that was based on the simulation environment is shown in Fig. 2. The image frames are the four of the selected robot motion images during the inspection process. The frames show the transit points upon which the camera captured images of areas that were likely to have defects. There were five points where the tool needed to stop for a moment during which the camera would capture images of the defect areas. The images were then uploaded for image processing to determine the degrees of defects.

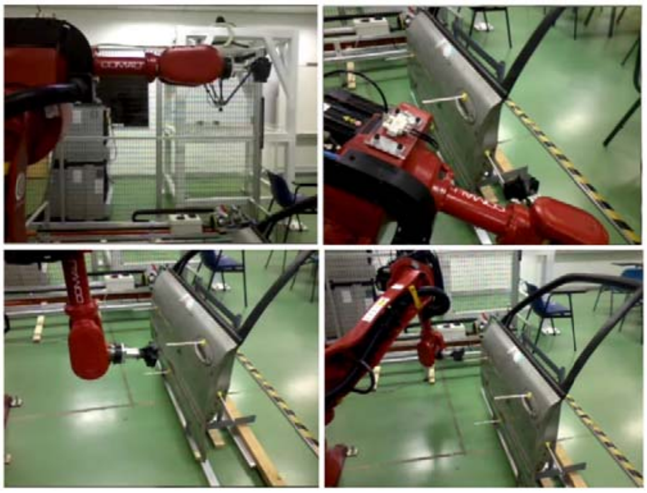

Fig. 3 Realization of manipulator planned path and trajectory using Comau robot

Prior to robot initiation, the results obtained from Workspace (see Fig. 4) explain the joints' behaviors. The behaviors dictated that in order to complete a cycle of visual inspection; the joints would need to displace on some degrees of angular position. It is observed, in Fig. 4, that all joints were active during the inspection process from start to end. If this were to be implemented onto the actual robot program, there would have been unnecessary energy usage. From Fig. 4, joint–4 is seen to consume the most energy, whereas joint–6 was the least. The simulated cycle time was less than 80 seconds.

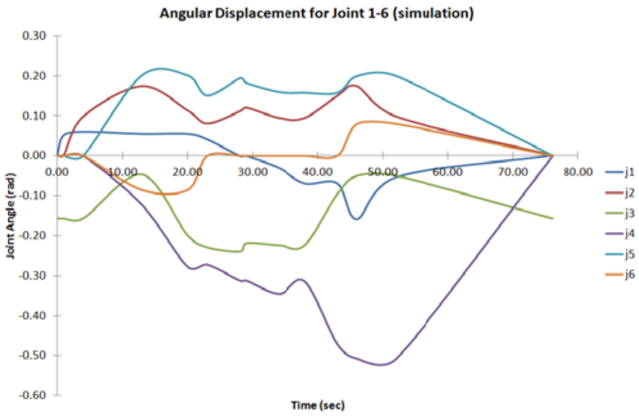

Fig. 4 Joints' angular position behavior on simulation

Based on the simulation results, it was observed that not all joints needed to be controlled in order to achieve the optimum configuration space following the specifications listed in Table I. Fig. 5 shows the actual joints' behavior for a cycle time of 25.02 seconds. It is less than that the simulation cycle time because of the improved configuration space. In Fig. 5, it is observed that all joints displacement were moderated where each displaced accordingly. All joints were functioning while the tool in motion.

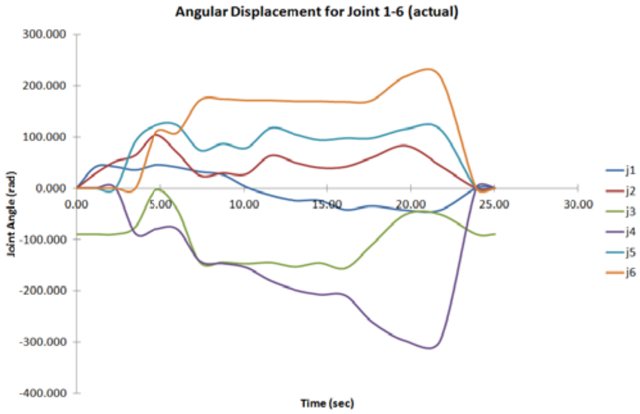

Fig. 5 Joints' angular position behavior on realization of robot program

There were rapid speed changes where all joints were functioning throughout the cycle (see Fig. 6), whereas in the actual setup, most of the joints are somewhat steady during the mid-range of the cycle (see Fig. 7). The mid-range of the cycle was where the inspection was carried out. During simulation, the robot had a rapid start and a fast end. Similarly, in the actual implementation, the trajectories were fast start and rapid end. This is further explained in Figs. 8 and 9 where the robot had slight decelerations in simulation environment, but with considerable rapid decelerations in the actual setup.

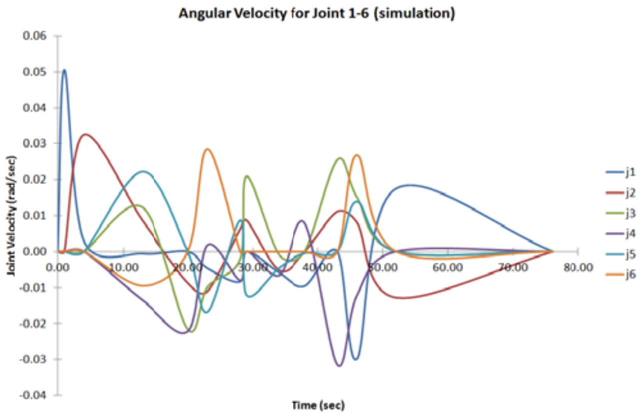

Fig. 6 Joints' angular velocity behavior on simulation

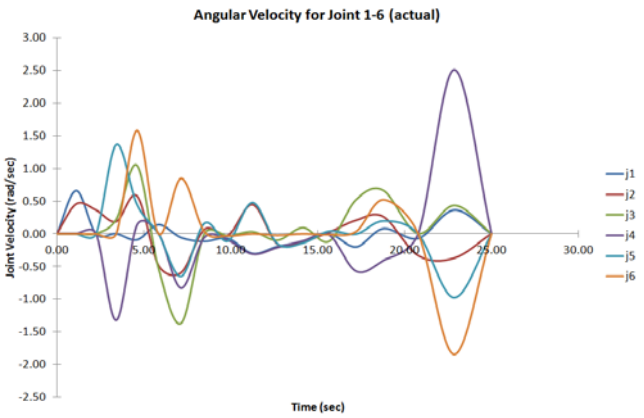

Fig. 7 Joints' angular velocity behavior on realization of robot program

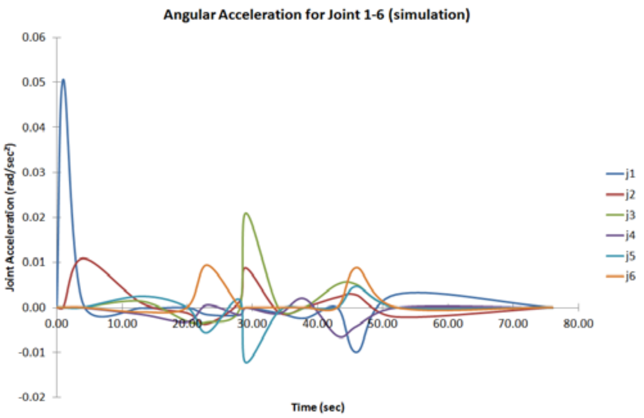

Fig. 8 Joints' angular acceleration behavior on simulation

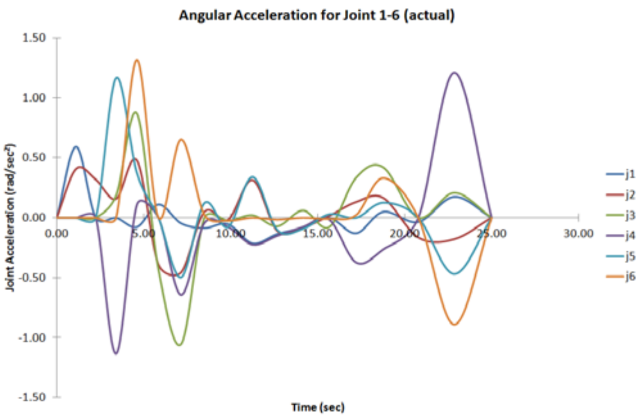

Fig. 9 Joints' angular acceleration on realization of robot program

IV. Conclusions

A robot configuration space may be planned by the application of (1), (2), and (3). The trajectories of an individual joint may be observed from the plots of respective curves. From this, the robot can be programmed such that the joints will be instructed to rotate by mean of actuators that receive some degrees of electric current from the drivers. This project provides a solution to automatic visual inspection where a camera is attached onto the end effector. The camera will capture images at pre-defined stopover. A special configuration space was designed so that the cycle time is optimum, and the camera will be at the right pose at every transit point. Express start and swift end are acceptable in a robot program because useful works usually not presence during these moments. However, during the mid-range cycle, there are always useful tasks programmed to be executed. For that reason, it is acceptable to program the robot such as that speedy alteration of actuator displacement is avoided. In short, a dynamic visual inspection system using a robot manipulator seems practical for a WPCS.

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