Generation of a pick and place trajectory model for the tip of a robotic manipulator arm for an loading and unloading operation

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Abstract : In the work considered in this paper, a mathematical formulation of a pick and place trajectory is designed for a robotic manipulator arm which is used to do a loading and unloading operation & its simulation done using a graphical user interface developed in C++. Direct kinematics gives the position and orientation of the robot arm in the 3D space. Inverse kinematics gives the sets of joint variables that will satisfy the same position and orientation. In between these two kinematic problems, robot motion comes into the picture. The robot motion from the pick point to the place point (through a number of via points) consists of paths and trajectories. These paths and trajectories are nothing but the various possible routes that are taken by the robot to move from the source (pick point) to the goal / destination (place point) and traversed in a specified amount of time. Trajectory planning schemes helps us to interpolate / approximate between these pick and place points using a smooth motion. This PNP trajectory model which is formulated in the form of 4 matrices is given as input to the robot. The robot picks up the object from one place and keeps it at another place in a specified time through the via points. The trajectory obtained so is called as the PNP trajectory which consists of 4 points plus the intermediate or the via points, viz., the pick point, lift-off points, via (intermediate) points, set-down point, place point. The simulation results show the effectiveness of the method.

Keywords: Robot, Simulation, PNP, Job operation, Trajectory, Model.

I. INTRODUCTION

PNP robots exhibit Pick & Place type of motion or trajectory as shown in Fig. 1. Any typical robotic operation begins with the robot picking up the object. The main function of any robotic manipulator is to pick up an object from one particular place, which is in one particular position and orientation, and keep it at another particular place in another position and orientation [1]. Robot picks up an object from one place, moves along a specified path and keeps it at another place in a specified time, thus giving rise to a trajectory. The trajectory obtained so is called PNP trajectory. The pick and place points has to be explicitly specified by the user, whereas the path can be specified by the user or the robot can judge its own path using computer vision. The path that is taken by the robot to reach the destination may be the shortest one or longest one irrespective of overcoming the obstacles in its path of motion and preventing collisions with them. This operation is called as PNPO (Pick aNd Place Operation). The path or route that is taken by the robot from the pick point to the place point with the time information is called as the four point minimal pick and place trajectory. Any PNP trajectory will have 4 points passing through it, which are discussed in greater detail one in next section. They are the pick point, lift-off point, via points, set-down point & the place point.

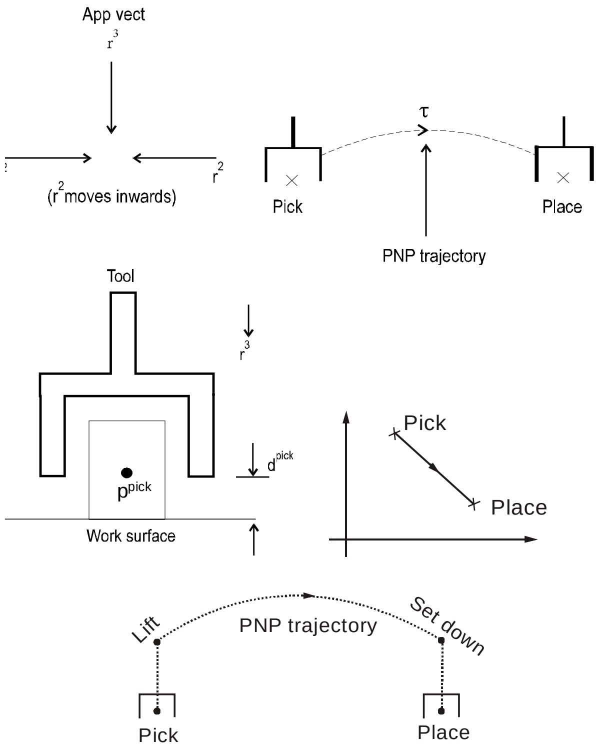

Fig. 1 : Pick point & the approach / sliding vector
A PNP robot & its trajectory

2. MATHEMATICAL MODEL OF PNP TRAJECTORY

Pick Point [p^{pick}] is the first point in the PNP trajectory. Object is picked up using the approach vector, which is perpendicular to the work surface, and sliding vector moving inwards (pick using fine motion). Object is picked up at its centroid G, i.e., tool-tip p and G of the object should be same. Here, d^{pick} is the distance of the object from the work surface to the centroid of the object at the pick point p^{pick} and p^{pick} (position of the object at the pick point) and R^{pick} (orientation of the object at the pick point) are to be specified by the user, i.e., the user specifies the pick point. To do this operation, give the matrix T^{Pick} as input to the Inverse Kinematic Problem (IKP). When this matrix is inputted to the IKP, sets of joint variables will be calculated and the tool will be properly configured so as to come and pick up the object. The position and orientation at the pick point is given by [1], [2]

$$T^{pick} = \begin{bmatrix} R^{pick} & p^{pick} \\ 0\ 0\ 0 & 1 \end{bmatrix} \qquad (1)$$

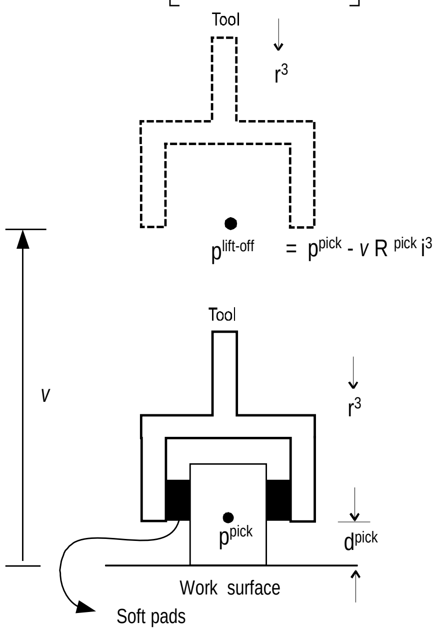

Fig. 2 : Lift-off operation

Lift-off Point [$p^{lift\text{-}off}$] is the second point in the PNP trajectory (Fig. 2). It is a point very near to the pick point, but situated directly above the pick point by a small amount of distance *v* so that the orientation of the tool at lift-off point is the same as that of pick point, i.e., $R^{lift\text{-}off} = R^{pick}$, but position p is different. (use fine motion to bring the object to the lift-off point). Position of the lift-off point is obtained by moving backwards along the approach vector from p^{pick} by a distance *v*, so that $p^{lift\text{-}off} = p^{pick} - v\, R^{pick}\, i^3$. To do this operation, give the matrix $T^{Lift\text{-}off}$ as input to the IKP [3]. When this matrix is inputted to the IKP, sets of joint variables will be calculated, the robot comes from the home position, picks up the object using fine motion and exactly lifts it up using the fine motion and stops at the lift-off point. Note that from the IK, knowing the position of the tip, approach vector, length of the tool, the position of the wrist is obtained by using the equation $p^{wrist} = p - d_n r^3$. The position and orientation at lift-off point is given by

$$T^{Lift\text{-}off} = \begin{bmatrix} R^{Pick} & p^{Pick} - v R^{Pick}\, i^3 \\ 0 & 1 \end{bmatrix} \qquad (2)$$

Set-down Point [$p^{set\text{-}down}$] is the third point in the PNP trajectory and is analogous to the lift-off point as shown in Fig. 3. It is a point very near to the place point and directly above the place point, but situated by a small amount of distance *v* so that the orientation of the tool at the set-down point is same as the orientation of the tool at the place point ; i.e., $R^{set\text{-}down} = R^{place,}$ but position p is different. (bring the object to the set down point using gross motion). Position of the set-down point is obtained by moving backwards along the approach vector from p^{place} by a small amount of distance *v*, so that $p^{set\text{-}down} = p^{place} - v\, R^{place}\, i^3$. It is the point where the initiation of the object placement just begins, i.e., the robot is about to place the object. To do this operation, give the matrix $T^{Set\text{-}down}$ as input to the IKP [4]. When this matrix is inputted to the IKP, sets of joint variables will be calculated, the robot comes from the home position, picks up the object using fine motion and exactly lifts it up using the fine motion and reaches the set-down point using the gross motion. The p and R at set-down point is given by [1]

$$T^{Set\text{-}down} = \begin{bmatrix} R^{Place} & p^{Place} - v R^{Place}\, i^3 \\ 0 & 1 \end{bmatrix} \qquad (3)$$

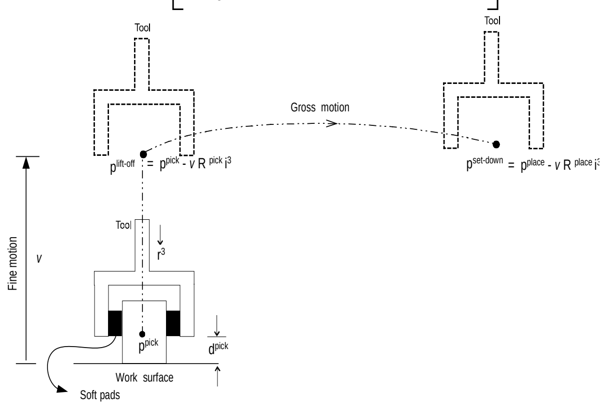

Fig. 3 : Object being lifted from pick to set-down point

Place Point [p^{place}] is the final point of the PNP trajectory. It is the point where the object has to be placed in the desired position and orientation (place using fine motion). Object is placed using the approach vector 90° to the surface & sliding vector moving outwards. d^{place} is the distance from the surface to the centroid of the object at the place point p^{place}. The p^{place} (position of the object at the place point) and R^{place} (orientation of the object at the place point) are to be specified by the user [6]. To do this operation, give the matrix T^{Place} as input to the IKP. When this matrix is inputted to IKP, set of joint variables will be calculated, the robot comes from the home position, picks up the object using fine motion and exactly lifts it up using the fine motion, reaches the set-down point using the gross motion and places the object at the place position in the desired position and orientation using the fine motion as shown in Fig. 4. The p & R at the place point is given by [1], [5]

$$T^{Place} = \begin{bmatrix} R^{Place} & p^{Place} \\ 0\ 0\ 0 & 1 \end{bmatrix} \tag{4}$$

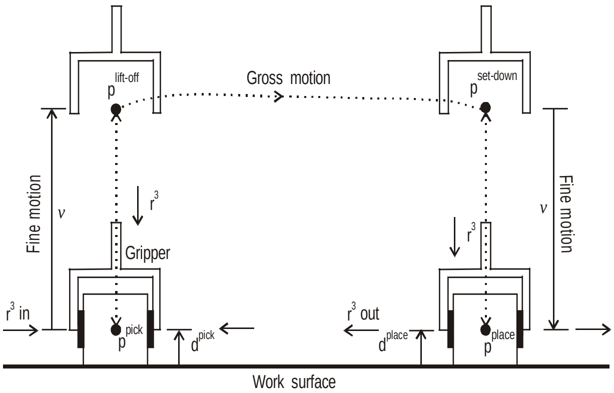

Fig. 4 : Sequence of operations from the pick point to the place point via the lift-off & the set-down point

If all the 4 matrices T^{Pick}, $T^{Lift\text{-}off}$, $T^{set\text{-}down}$ and T^{Place} are given in succession as input to the inverse kinematic problem, the robot comes from the home position, picks up the object (using fine motion) lifts up (using fine motion), transports the part from lift-off point to the set-down point using gross motion, gets ready to place the object and places the object in the desired position and orientation (using fine motion) [8]. If any obstacles are present in the work space, then a number of via points (intermediate points) are used to move round the obstacles to avoid collision by sensing them and circumventing the obstacles as shown in Fig. 5. Note that lift-off and set-down points are visited twice in a PNP trajectory as shown in Fig. 5 [7].

A typical 4 point minimal PNP trajectory is shown in Fig. 5. The constraints for doing PNPO are [1]

- If $d^{place} = d^{pick}$, object is picked up from the work surface and placed exactly on the work surface [1].
- If $d^{place} > d^{pick}$, the placed part or object is unsupported (hanging in air) when it reaches the destination and the robot opens its fingers and the object or the part falls down because of gravity (some inaccuracy has been resulted) [5].
- If $d^{place} < d^{pick}$, an attempt is made by the robot to penetrate the object into the work surface when part is placed, as a result of which the part slides in between the fingers of the gripper if the work surface is hard OR the part moves into the work surface if the work surface is soft [6].
- So, for effective PNPO, the constraint is [1]

$$d^{place} = d^{pick} \quad \& \quad p_3^{Place} = p_3^{Pick} \tag{4}$$

This is shown in the Fig. 6.

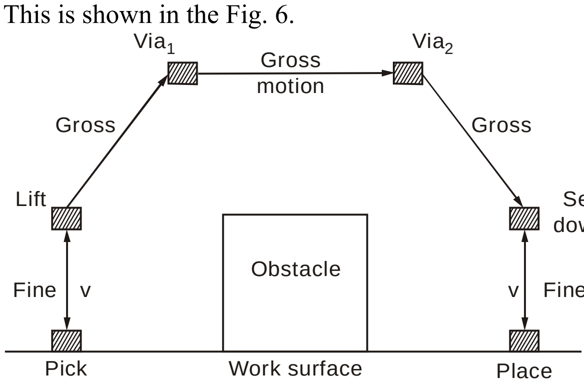

Fig. 5 : A typical 4 point minimal PNP trajectory

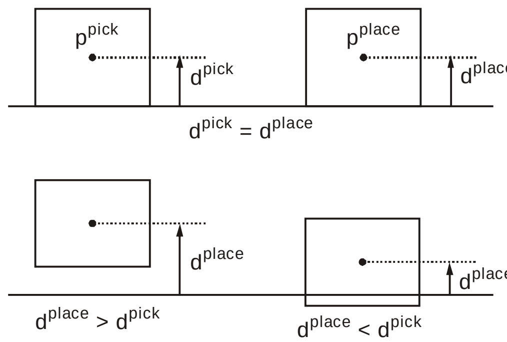

Fig. 6 : Constraints for doing effective PNP operation

The sequence of PNP motions shown in Fig. 5 is called as the minimal four point PNP trajectory. Any PNP trajectory has got 6 knot points (pick, lift-off, via 1, via 2, set-down, place) and 5 individual sub-trajectories (pick-lift off ; lift off-via 1 ; via 1-via 2 ; via 2-set down ; set down-place). A horizontal work surface is assumed for doing the PNP operation [7]. If part feeders etc., are used, then use different PNP surfaces or levels and the height of the stack comes into picture [9].

From the PNP trajectory, we see that robot reaches or approaches the object using fine motion and picks it up. This operation given by T^{Pick}. Using fine motion technique, object or part is lifted from the pick up point to the lift-off point. This operation is given by $T^{Lift\text{-}off}$. Using gross motion, object or part is transported to the set-down point [1]. This operation is given by $T^{Set\text{-}down}$. During this transportation, if any obstacles occur or come in the way of robot motion, a number of via points or intermediate points has to be visited in order to over come the obstacle (move round the obstacle, circumvent the obstacle). This operation is given by $T^{via\text{-}1}$ & $T^{via\text{-}2}$. At set-down point, the robot is about to place the object, i.e., the initiation of the object placement just begins. The robot places the object at the place point using fine motion techniques in the desired p and R and then comes back to its home position. This operation is given by T^{Place}.

3. SIMULATION RESULTS

A graphical user interface (GUI) was developed in C++ language and a 4-axis SCARA robot was used for the simulation purposes. The mathematical model is used to generate the pick and place points. Once the pick & place points are specified as 3D input to the robot, the robot does the PNPO. The results of the simulation are shown in the Figs. 7 to 10 respectively.

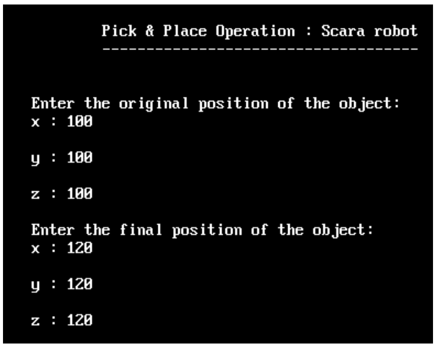

Fig. 7 : Inputs to the PNP operation

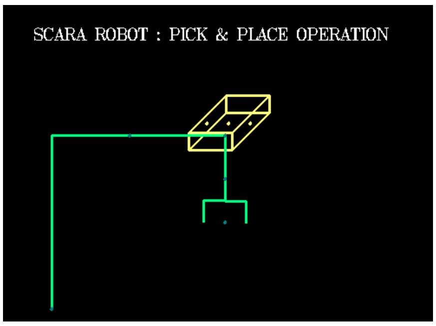

Fig. 8 : SCARA robot in home position (Ref)

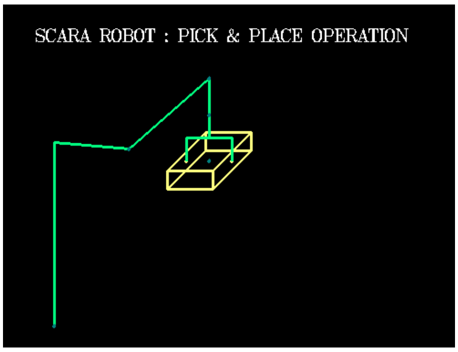

Fig. 9 : SCARA robot coming from home position & picking the object

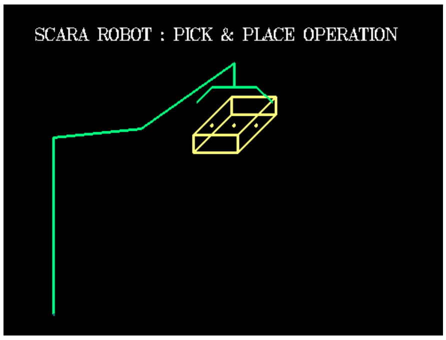

Fig. 10 : SCARA robot coming from home position & placing the object

4. CONCLUSION

A mathematical model of the trajectory generation for a 4-axis SCARA robot was developed and this was used as input to the robot in the simulation performed using a GUI in C++. The simulation results show the effectiveness of the developed method.

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