Robot Cell Planning

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***Abstract*—**A new approach to determine the machine layout in flexible manufacturing cell, and to find the feasible robot configuration of the robot to achieve minimum cycle time is presented in this paper. The location of the input/output location and the optimal robot configuration is obtained for all sequences of work tasks of the robot within a specified period of time. A more realistic approach has been presented to model the problem using the robot joint space. The problem is formulated as a nonlinear optimization problem and solved using Sequential Quadratic Programming algorithm.

***Keywords*—**Robotics, Layout.

I. Introduction

FLEXIBLE Manufacturing Cells (FMCs) have been widely implemented in modern factories. For an efficient utilization of the material handling system used to serve the machines, the layout of the FMC must take into account the performance characteristics of the material handling system.

In developing the layout of FMC served by an industrial robot, the location of L/UL points is determined by taking into consideration the reachability and mobility criteria of the robot. Using these considerations, machines are located within the feasible and achievable region of the robot.

The optimal cell layout is obtained by minimizing the cycle time of the robot joints required to perform a sequence of travel. Minimizing the cycle time of the robot will enhance the production rate of the manufacturing system and increase the life of the robot. Many researchers were concerned in optimizing the travel time of the robot joints between a group of machines work sites, and in determining the optimum sequence of the robot between different worksites. Fenton et all [2], presented a method to obtain the optimal robot configurations for minimum travel time and minimum joint displacement between two positions. Dissanayake and Gal [1], propose a method to obtain the optimum sequence of travel between work sites, robot configuration and robot base location such that the total time of travel is optimized. Mata and Tubaileh [3], presented two algorithms to find the layout of machines and the feasible robot configurations corresponding to machine work sites, such that the travel time and robot joint displacement are optimized. In their study, robot operational characteristics and machine dimension and orientation are considered in developing the final cell layout.

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All previously mentioned works concerned in robot workstation planning, assume constant joint velocity to determine the travel time between two work sites. This approximation is reasonable to some extent, but is not accurate, since it is well known in robotic control, that the robot starts and ends its trajectory with zero joint velocity.

Unlike other previous works which assumed that the joint velocities are constant, this paper provide a more practical technique used in real industrial robots to control the velocity of the joints at the start and end of robot trajectory, and controlling the maximum permitted velocity and acceleration of each joint. In order to achieve this, the robot joint displacement is modeled as function of time. This function is approximated to a third order polynomial. By determining the coefficients of these polynomials, the robot motion can be controlled in an implicit manner while developing the layout of the cell.

II. Considerations of Robot Cell Planning

The layout of the robotic manufacturing cells depends in the following factors:

A. Robotic Operational Characteristics

The robot workspace and limits of joints movements must be considered in a early stages of machine layout.

B. Material Flow between Machines

The material flow between machines affects the sequence of travel of the robot between all machines work sites. The number of trips that the robot must perform between two pairs of machines during a specified period of time is provided by a flow matrix.

C. Cycle Time

It is required to find the optimum layout of machines and the feasible robot configuration, such that the total cycle time of the robot between all work sites is minimized.

This approximation is not normally applicable in real operation conditions, since a constant end effector velocity, which is a normal operation condition, does not implies a constant joint velocities. In addition, these formulations do not allow the user to control the velocity and acceleration of the joints, such as to start and end robot motion with zero joint velocity and to limit the velocity and acceleration of the robot to a maximum value. In order to satisfy this condition, this paper models the joint displacement between a pair of machines work sites J and k as a third order polynomial of time

$$q_i^{jk} = a_i^{jk} + b_i^{jk}(t_i^{jk}) + c_i^{jk}(t_i^{jk})^2 + d_i^{jk}(t_i^{jk})^3 \qquad (1)$$

Where q_i^{jk} is the displacement function of the ith joint between positions j and k, t_i^{jk} is the time required by joint i to travel between positions j and k, and $a_i^{jk}, b_i^{jk}, c_i^{jk}$ and d_i^{jk} are the coefficient of the polynomial of the ith joint.

The polynomial must saisfy the following conditions:

$$t = 0 \qquad q_i^{jk}(0) = q_i^j \qquad \dot{q}_i^{jk}(0) = 0 \tag{2}$$

$$t = t_i^{jk} \qquad q_i^{jk}(t_i^{jk}) = q_i^k \qquad \dot{q}_i^{jk}(t_i^{jk}) = 0 \tag{3}$$

$$q_i^{jk}(t_i^{jk}) = q_i^{kh}(0) \tag{4}$$

Where q_i^j, q_i^k and q_i^h are the joint coordinates corresponding to the worksites j, k and h respectively. Applying this procedure to all joints, the robot configuration at each work site will be determined.

D. Dimension and orientations of machines

III. PROBLEM FORMULATION

In order to simplify the problem formulation, an approximated method is used to describe the objects found in the FMC. Machines of rectangular or irregular shapes are modeled by means of evenly separated circles of identical radius. The number and radius of circles are selected such that the circles will envelop all corners of the machine. The orientation of the machine is represented by the angle between the x-axis and the line that passes through the centre of the machine and the L/UL point, see Fig. 2.

Overlapping between a pair of machines is prevented if the distance between the circles that belong to deferent machines is equal or exceeds the summation of radii of both circles. While, collusions between machines and robot arm is avoided by limiting the distance, D_{ik}, between the ith link and the centre of the kth circle which represent the machine, see Fig. 1.

The location of the robot end at the jth machine work-sites is represented in the Cartesian space by the vector $\vec{x}^j = \{x_1^j, x_2^j, \ldots, x_m^j\}$. Although, in order to address the constraints proposed to avoid machine overlapping as well as the constraints implemented to avoid collision between robot arms and machines, it would be necessary to find the coordinates of the geometric centers of circles used to represent a machine.

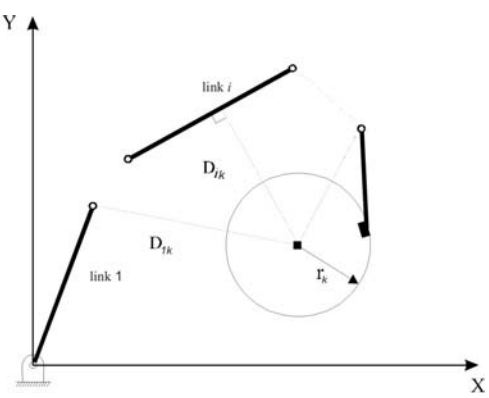

Fig. 1 Distance calculation from the centre of the machine to each robot link

The Cartesian coordinates of the centre of each circle (x_{1k}^j, x_{2k}^j) shown in Fig. 2, where k=1,…, $\psi(j)$ is the number of circles that model machine j, can be stated through a simple trigonometric relation as function of input/output point, machine orientation α^j and machine radius r^j.

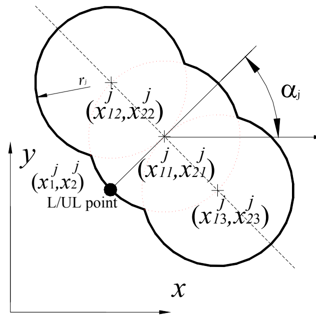

Fig. 2 Calculation of the coordinates of circle centers

Consider a robot of n degree-of-freedom with its base fixed at the origin of the Cartesian reference frame system. The robot will visit a set of N work sites located at the counter of each machine, the location of which is described by L/UL points, denoted by $\vec{x}^j \in R^m$, $j = 1,\ldots,N$, and machines in the floor of the cell α^j, where m is the Cartesian workspace of the robot.

Therefore, the machine layout in robot cells is addressed as follows:

$$\text{Min} \sum_{k=1}^{N}\sum_{j=1}^{N} f_{jk}\left(t_i^{jk}\right) \quad , \quad i = 1,\ldots,n \tag{5}$$

where t_{jk}^i is the travel time done by ith joint between the jth and kth robot configuration .

Subjected to:

$$\vec{x}^j = FK(\vec{q}^j, \vec{b}) \tag{6}$$

$$q_i^{jk} = a_i^{jk} + b_i^{jk}(t_i^{jk}) + c_i^{jk}(t_i^{jk})^2 + d_i^{jk}(t_i^{jk})^3 \tag{7}$$

$$q_i^{jk}(0) = q_i^j \quad q_i^{jk}(t_i^{jk}) = q_i^k \tag{8}$$

$$\dot{q}_i^{jk}(0) = 0 \quad \dot{q}_i^{jk}(t_i^{jk}) = 0 \tag{9}$$

$$q_i^{jk}(t_i^{jk}) = q_i^{kh}(0) \quad j=1,\ldots,N, \; k=1,\ldots,N, \; h=1,\ldots,N \tag{10}$$

$$\dot{q}_i^j \le \dot{q}_{\max} \qquad j=1,\ldots,N \tag{11}$$

$$q_{\min}^j \le q_i^j \le q_{\max}^j \qquad \begin{matrix} j = 1,\ldots,N \\ i = 1,\ldots,n \end{matrix} \tag{12}$$

$$\sum_{k=1}^{\Psi(j)}\sum_{p=1}^{\Psi(i)} \left(x_{1k}^j - x_{1p}^l\right)^2 + \ldots + \left(x_{mk}^j - x_{mp}^l\right)^2 \ge \left(r^j + r^l + d^{jl}\right)^2$$

$$j = 1,\ldots,N-1 \qquad l = j+1,\ldots,N \tag{13}$$

$$\sum_{i=1}^{n}\sum_{k=1}^{\Psi(j)} \left[D_{ik}\left(\vec{q}^j\right)\right]^2 \ge \left(r^j\right)^2 \qquad j = 1,\ldots,N \tag{14}$$

where (5) is the objective function which intend to optimize the cycle time of all robot joints for all possible sequences of travel represented by the flow matrix f_{jk}. Constraint (6) states the direct kinematics relationship between the position of the robot end and its join coordinates, which enable one to model