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Industrial Synchronised Manipulator for Fitting Operation Using Inverse Kinematics

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ABSTRACT

In today's world many manufacturing task would be simply impossible without industrial robots. In modern manufacturing industries there are many applications where the manipulators have to perform complex and coordinated task like fitting, screwing, pick and place operations etc. in same work space. Thus, to ensure a collision free working synchronisation between manipulators is necessary. This in turn reduces chance of damage on the manipulators. Traditionally the execution of the collision avoidance had to be done manually but now modern technologies are used.

The setup in automated industries include: Industrial manipulators, communication between the manipulators, feedback from the manipulators, and the control of the manipulators. This project incorporates the above attribute by using a algorithm that utilises inverse kinematics.

Keywords: Industrial automation, Manipulator, Inverse Kinematics, Synchronization

1. INTRODUCTION

Various levels of automation include sensors/actuators, automatic Control, supervisory control, production control and Enterprise.[2]

All the levels of industrial automation require coordination and synchronization between all the components and parameters involved. The base layer consists of a large number of actuators to achieve the desired operation and various sensors to ensure that the task is achieved. The second layer consists of the controllers and driver circuits where the logical functions are performed in a sequence. In third layer of industrial automation the lower layers are monitored and various parameters are selected to modify the logical sequence. The last two layers are management of the whole production process and other services.

2. LAYOUT OF THE PLANT

The usual production industries have various manipulators, actuators and conveyors performing operations like fitting, painting, welding, etc. This paper presents the layout of an automatic production line for performing fitting operation. The bolting operation on the work piece is performed while it is on the conveyor. Here, the manipulator is a 2DOF robot with a gripping end-effector.When the work piece reaches the required position the manipulator collects the bolts positioned by the rack motor at a particular angle and blots the work piece. Here, the angle of the rack motor depends on the number of the fitting operations to be performed. This process is repeated as per required. The basic layout for the plant is shown in the fig.1.

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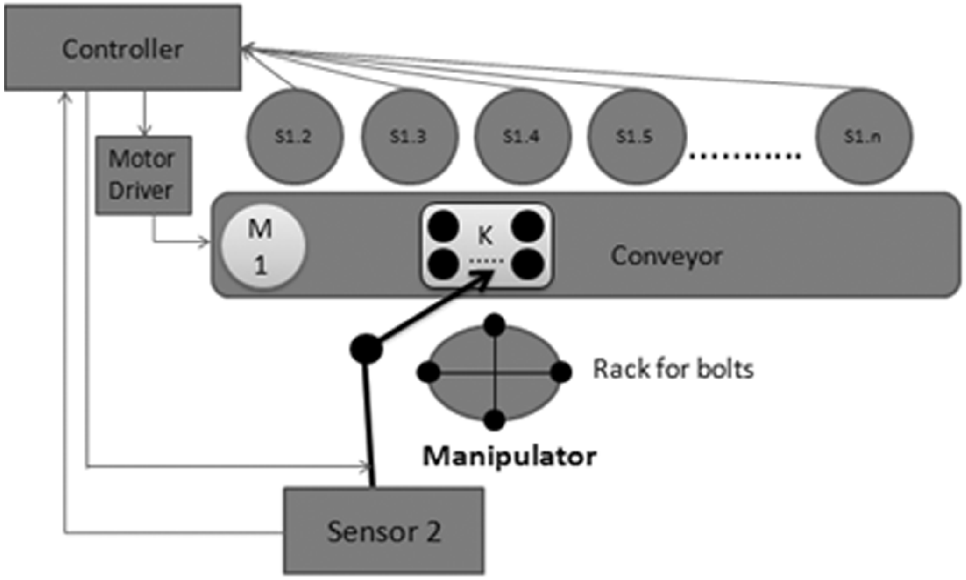

Figure 1: Schematic plant layout

3. INVERSE KINEMATICS

Inverse kinematics computes the joint angle from the specified values of the coordinates of the end-effectors using kinematics equations of the manipulator. [3] [1]

$$k_2= l_1+ l_2 \cos(\theta_2) \tag{1}$$

$$k_2 = l_2 \sin(\theta_2) \tag{2}$$

$$\gamma = a\ \tan_2(k_2, k_2) \tag{3}$$

Here, the K_1 and K_2 are total vertical and horizontal distances from the origin to the end effector. These three equations are used to calculate the respective angles for a particular configuration. We adapted the process of invere kinematics as we had data only about the end effector points so we have devised to use inverse kinematics.

$$\cos\theta 2 = \frac{x \wedge 2 + y \wedge 2 - L1 \wedge 2 - L2 \wedge 2}{2(L1\, L2)} \tag{4}$$

$$\tan\theta 1 = \frac{y\left(L1 + L2Cos\theta 2 - xL2Sin\theta 2\right)}{x\left(L1 + L2Cos\theta 2\right) + yL2Sin\theta 2} \tag{5}$$

The schematic diagram is as shown in the figure:

The angles are formed by constraining the link lengths and end effector points at a particular configuration. The link angles are found using the above stated two formulae where in the inputs are L_1,L_2,X,Y. So we had the data about our link lengths and the end effector orientation so we achived the required angles respectively. The two configurations have same link lengths and different angles to achieve the task completion. [5]

The fig.3 shows the distances of the two work stations from the robot base and the heights respectively which results in the (x,y) co-ordinates of them. The conveyor is placed at 150 cm and the bolt picking station is placed at 300 cm from the robot base. For this kind of an application a simple Planar 2 DOF manipulator is sufficient to perform the operations.

Inverse Jacobian method is used when linkage is complicated. Iteratively the joint angles change to approach the goal position and orientation. Jacobian is the n by m matrix relating differential changes of q to differential changes of P (DP). Jacobian maps velocities in joint space to velocities in Cartesian space. [4]

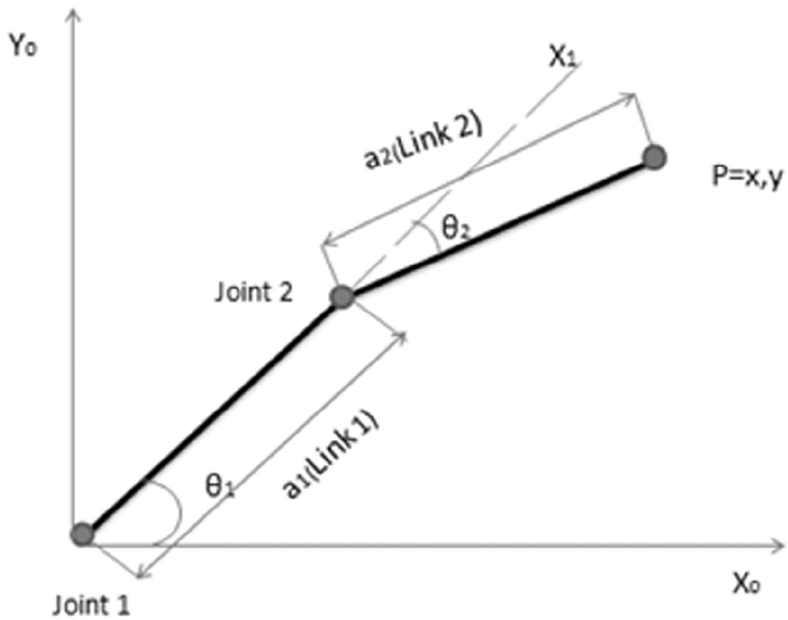

Figure 2: 2 DOF manipulator

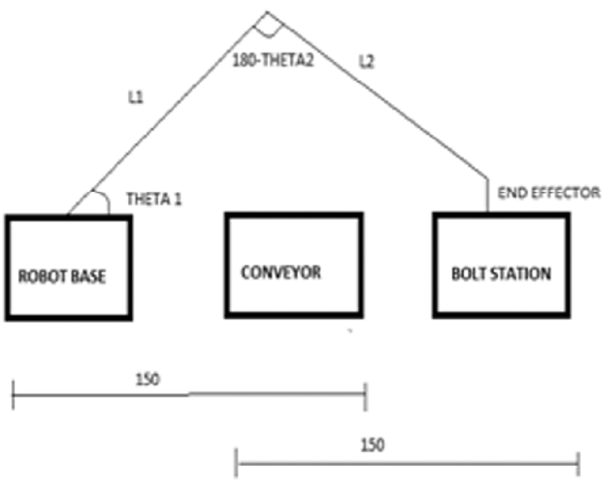

Figure 3: Inverse kinematics

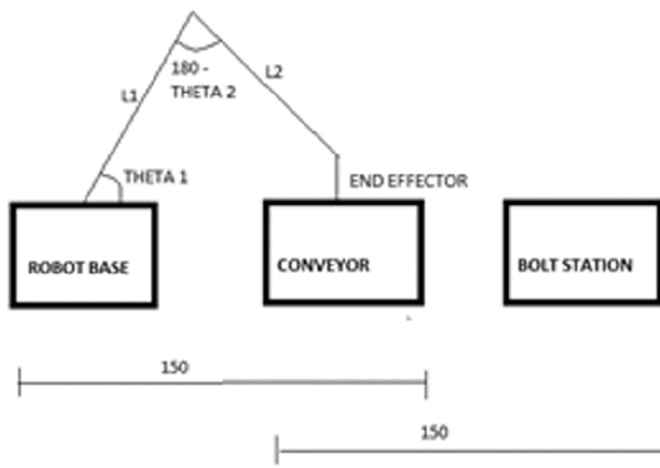

Figure 4: Inverse kinematics

$$\frac{dy}{dx} q = j^{-1} \frac{dy}{dx} x \tag{6}$$

$$j^{-1} = \begin{bmatrix} C12 / L1S2 & L12 / L1S2 \\ -(L1C12 + L1C1) / L1L2S2 & -(L2S12 + L1S1) / L1L2S2 \end{bmatrix} \tag{7}$$

Determinant of inverse Jacobian matrix is:

$$(C12S1 - S12C1) / (L1L2S2 \wedge 2)$$

If the value of determinant is zero for given task space coordinates then the resulting configuration is singular. Desired pose can be achieved by iterative determination of the joint angles.

4. CONTROL SYSTEM

The control operation for performing the synchronised motion of the manipulator, conveyor motor and the rake motor needs proper sensors and feedback system. The calibration of various sensors and actuators involved in the system is crucial.

The main controlling device used is ATmega 2560 which performs all the logical operations involved in the process.

4.1. Sensors and feedback system

The sensors outputs are fed to the controller where the data is processed and also sent to the supervisor. The sensors do not always give accurate values. Thus for rectifying the errors various filters are used. The sensor $S_{1\cdot n}$ used here can be an IR Sensor which senses the presence of the work piece. The work piece here would be painted black. So, whenever it approaches the IR sensor module the output value would be high. The analog sensor value is mapped from 0 to 2^8-1 = 255.

The physical system cannot work that accurately thus tolerance limits and allowances should be included to achieve the desired location. For better accuracy closed loop feedback system is used. The feedback here is provided. The S_2 sensor is to confirm the orientation of the manipulator. It can be an accelerometer or an IMU (Inertial Measurement Unit). The data from S_2 is mapped in the work space and the actual coordinates of the manipulator are fed to the controller. The controller then generates the control signal accordingly to minimize the difference between the actual and the desired orientation of the manipulator.[7][9]

The block diagram for the process is given the Fig. 5

4.2. Inverse kinematics and control

The high value of sensor $S_{1.n}$ suggest that the work piece is at the nth coordinate thus the manipulator's end-effector should reach that particular location. Substituting this coordinates in the equation of inverse kinematics of the 2DOF manipulator the joint angles can be computed. The algorithm includes the inverse kinematics operators. The input to this system is the co-ordinate location of the desired position and the output is the joint angels to be achieved. Mapping the whole system is very crucial to achieve the desired orientation of the manipulator. The base of the manipulator is considered as the origin of the system and all other components involved are mapped accordingly. The inverse kinematics algorithm is performed for each cycle for the coordinates to be achieved. The controller generates the control signal for the servo motors of the manipulator such that the computed joint angles can be achieved.

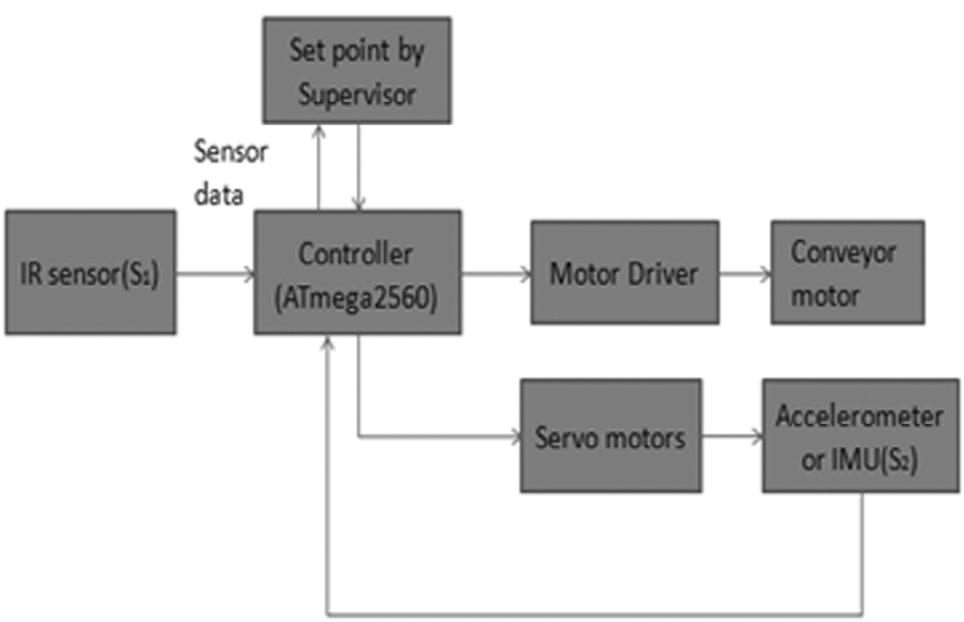

Figure 5: Control system diagram

The position control of the servo motor is achieved through PWM (Pulse Width Modulation) signal generated by ATmega 2560 corresponding to the angel generated by the inverse kinematics. Servo motor has an inbuilt feedback system which ensures accurate positioning of the manipulator and rake for holding the bolts. The position and speed control of the conveyor dc motor is done using LM298N dual full bridge motor driver. The PWM output from atmega 2560 has values which range from (0-255) which are used for speed control and direction control is achieved by changing the sign of the input PWM signal which is fed to the motor driver. [6][8][10]

4.3. Supervisory control

The supervisory control is the third stage of the automation control. It enables the supervisor to monitor and control the process accordingly. Any Interrupt signal given by the Supervisory control to the AT mega 2560 is given maximum priority. The data from various sensors used in the process are fed to the supervisor computer by serial communication through Controller interface. The supervisor can take decisions according the data input and data can be processed and also analysed. A circuit breaker switch is also provided in case of emergency.

‘K’ is number of columns to be processed (here bolted). ‘n’ represents the number of work piece that can be processed in a cycle. These two parameters are set by the supervisor and the tasks are performed in loops accordingly. By this parameter the production rate can be changed according to the demand.

The flow chart of the sequential process is given below:

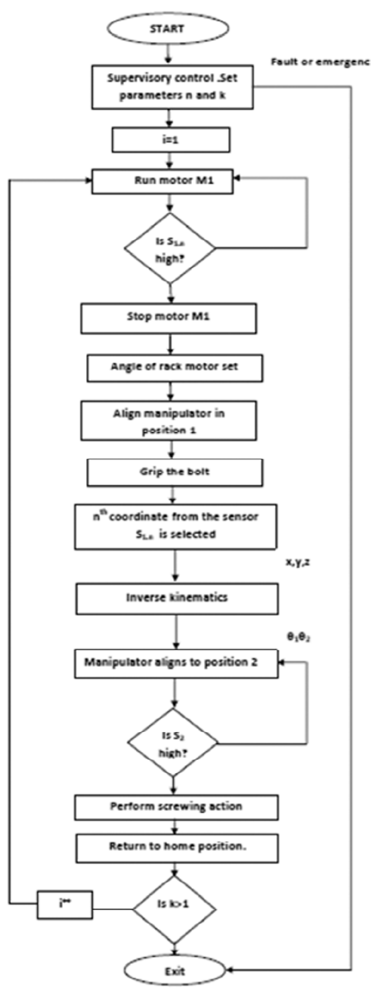

Figure 6: Flow chart for the control system

P1 - position of rack

P2 - position of the work piece

M1 - motor of the conveyor

M2 - motor of the manipulator

M3 - motor of the gripper

K - Number of times the loop is repeated

n - number of S_1 sensor

i - Loop variable

5. CONCLUSION

Synchronized robotic manipulator with Collision free operation for industrial application can be achieved using the above algorithm with proper sensors and setup. Other industrial applications like painting, welding etc. and robotic applications where synchronization is crucial can also implement this concept. This concept can also be used to synchronize the manipulators with each other.

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