Co-Ordinated Motion Control of Robotic Arm For Micro-Positioning Under Industrial Environment

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Abstract- *In most of micro, small and medium enterprises in India, adhesive application on small parts is done manually. Dispensing application is one of those which require accurate path to follow and apply a uniform coat of liquid material. In such a case micro positioning is mandatory. In advanced industrial automation robots plays significant role to atomize such task with precision. Proposed system is the application of industrial automation with PLC. This paper describes development of gantry robotic arm for 3 degree of freedom(X-Y-Z) directing by using circular and linear interpolation. The proposed system fulfill the requirement of reliability, speed, accuracy, flexibility required for sealant dispensing application over protective casing of gearbox.*

Keywords- robotic arm, degree of freedom, accuracy, repeatability, micro positioning, cost, security, PLC, interpolation, HMI.

I. INTRODUCTION

Robotics is an emerging field nowadays, it is already playing very important role in industries. With advancement of industrial automation an robotic arm applications developed to reduce the cost of hiring people, making system more human independent and increasing the efficiency and production by many folds .

Recently in small scale industries, the common method of sealant application is manual where only skilled worker can apply uniform coating all over the parts. For such applications micro positioning in mandatory. This process makes system human dependent which increases labor cost as well. Also, it leads to a lot of inaccuracies due to human fatigue and wastage of sealant. There are very risky areas of machines which can cause grave human injury[7]. Industrial robots can be projected to do same thing precisely.

Figure 1. Uneven application of sealant by labor on casing

Robotic arm plays significant role in industrial robotics. Researchers have developed control system based on PLC, RaspberryPi, Arduino for directing the robotic arm.

The main objective of this paper is to summarize the overall development in robotic arm for micro positioning applications suitable for medium scale industries. As we aimed at saving manpower and increasing efficiency, we have developed a cost effective control system for robotic arm using PLC for sealant application on casing with help of circular interpolation.

The content of paper here is: section II express the work related to controlling techniques of robotic arm, section. The proposed methodology explained in detailed in section III, section IV represents results and discussion and overall work is concluded in section V.

II. LITERATURE SURVEY

The objective behind literature survey is to study different technique used for controlling of robotic arm and find the best choice for sealant dispensing affordable for small scale industries.

In [1], the authors proposed 2 degree of freedom robotic arm in x-y plane. They performed simulation analysis on model for accuracy and range calculation. They have also discussed the mathematical modeling of arm controlled using arduino microcontroller. Authors have derived forward and inverse kinematics mathematical equations for model and implemented the same but drawback is that limited flexibility and they have not mentioned it's performance in industrial area. In [2], author aimed at developed an robotic arm controlled using RaspberryPi via LAN and WAN. Due to use of PCs for control of robotic arm the cost of software development reduced. The only reason behind this is usage of high level languages . They have considered the factor of accuracy and safety of operator but have not evaluated the performance of system. Also reliability is not tested in real time industrial environment.

In [3], authors have developed 4 degree of freedom PLC robot manipulator with closed kinematic chain. They have used robot kinematics for cartesian space positioning and also explained the mathematical modeling of inverse kinematics which differ from inverse kinematics equations of 2 DOF. It gives high accuracy and robustness but drawback of this system is the hardware cost which is mainly due to use of Allen-Bradley PLC which is not manufactured in India. Due to this it is not perfect choice for small scale industries. In [4], authors have used PLC as a controller for robotic arm. User commands the PLC through Human Machine Interface (HMI). PLC accordingly controls the motor via a servo drive. As they have programmed the PLC using ladder diagram, it gives openness to customer to extend which is main benefit of this system but they have not mentioned any mathematical model or algorithm used and not even evaluated system performance.

Based on overall survey we conclude that Arduino based control system decreases programming complexity, but it increases hardwiring when used for directing robotic arm. It cannot sustain electric shocks and vibrations making system unreliable in industrial application. While control system based on RaspberryPi is mainly used for internet connectivity. It does not support decisions which need to be made during a realtime application ignoring operator's safety. On other hand, PC based control system do not have reliability required by harsh industrial environment, so there is need of protective case which increases the overall cost[3]. All hardwiring on machines has been now reduced due to PLC- programmable logic controller. Biggest advantage is that logic of the machine can be changed without much alteration on the electrical side[7]. PLCs also keep a watch over integrity of plants and operator's safety. Modern PLCs execute a complex computational mathematical calculations and equations along with their programming languages making it feasible to implement any kind of algorithm that can be used for controlling robotic arm[3]. Besides, PLCs provides the feature of uploading the code from the controller and modifying it, which is not possible on PC-based control systems whose software is a compiled executable. One can also debug the code in online simulation. For this reason, PLC programs can be updated and extended by customer without any need of the original source code, which makes PLCs "open" systems.

Nordson sealant equipment developed 2-station XYZ robot dispensing cell is also popular for its high speed operation increasing the production line. Similarly, FANUC LR Mate 200iD[6] articulated arm have 6 DOF have excellent performance and accuracy. It has covered overall market in world. It uses CNC commands which restrict the openness to user. [6][7] uses closed control system so customers are not able to extend without the support of manufacturer. CNC controller makes system expensive which is not affordable to medium scale industries.

In order to overcome the drawback of limited accuracy of some existing techniques and to develop cost effective product, we attempt to develop motion control robotic arm that can be used in micro-positioning application such as sealant dispensing on protective casing of gearbox with the help of circular and linear interpolation using PLC.

III. DEVELOPED SYSTEM

Our system consists of design and development of 3 DOF (X-Y-Z) robotic arm using circular and linear interpolation. We have also design and built control panel for the same.

A. System architecture

The block diagram of the automation system is shown in Figure 2. SMPS provides power to all devices.It is selected as per the current and voltage rating of PLC and stepper drive. The main components of the system are PLC, HMI, sensors, stepper drive, and robotic arm. In order to get to the initial position or home position we first need to define it. This is done with the help of sensors. The inductive proximity sensors are responsible for the same which acts as one of the inputs to PLC. Considering the factors like range, accuracy, life, cost etc., inductive proximity sensors have been used. For interfacing between operator and the PLC, HMI is used. It handles all user interactions such as input data from the operator and visualizations in order to support decisions which need to be made during a realtime application. HMI gives commands to PLC. The Programmable logic controller (PLC) controls all operation. After getting start command from user through HMI, the PLC initially monitors the state of motors, comes back to home position ensuring safety and then performs the predefined task as per modeling. The program of PLC can be changed without too many changes on the electrical side. It is programmed using Ladder diagram. Stepper drive gets pulses and direction of rotation from PLC. Stepper drive communicates with the motor thus controlling the motion of motor. As we want high speed operation, we have used 2 hybrid stepper motor with inbuilt encoder along X and Y axis. It is optical encoder which give high accuracy in terms of measuring angle, position, speed, revolution and distance. Stepper Drive, motor and encoder form a feedback mechanism. The Robotic arm is what facilitates the interpolation motion for sealant application.

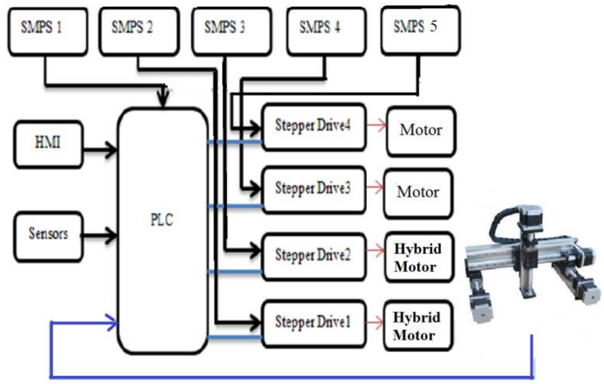

Figure 2. Proposed System

B. Workflow

Figure. 3 shows workflow of proposed automation system. We have used 3 sensors to define home position along X,Y and Z axis.

Initially, emergency stop button should be released then robot is checked for home position. If not then it waits for user command. On home command PLC gives priority for homing along Z axis as per the ladder logic so that dispenser does not harsh with part present on base surface. After that homing along X and Y axis is done parallelly. As jog speed and feed rate is input in mm/second we have converted it into pulses/second so internal calculations is done in order to get mm to pulses conversions. Then on start cycle command through HMI, PLC directs robotic arm to starting point of job. Job is covered in 108 points which is entered manually in ladder logic. Dispenser gets on and whole job is covered using circular and linear interpolation till internal register D0 reaches 108. This process repeats itself till it emergency stop is pressed through manual mode.

Most of workflow depends on ladder diagram and HMI programming. Logic of ladder diagram depends on circular and linear interpolation. This is done with the help of WPLSoft software for ladder programming and DOPSoft software for HMI screen designing.

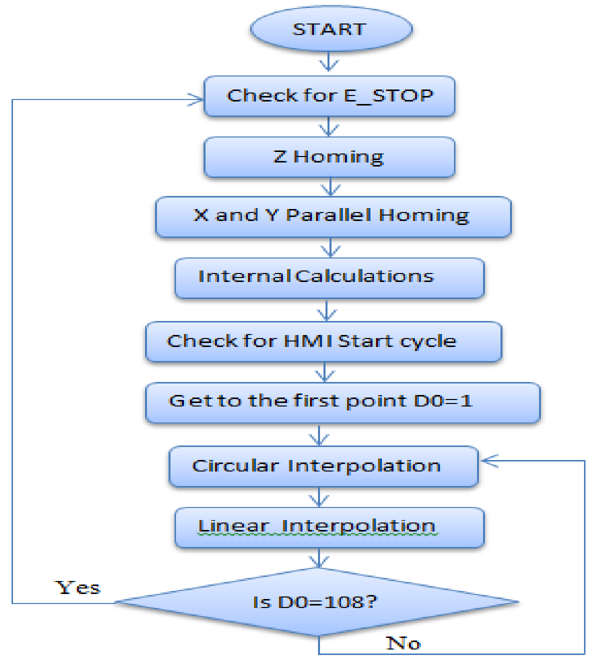

Figure 3. Workflow Of Developed System

C. Circular and linear interpolation

A translation of linear axis positions into curved tool motions is called circular interpolation. Circular Interpolation commands are used to move a tool along a circular arc to the commanded end position. Circular interpolation requires five pieces of information's; a center ,an endpoint, a radius, a feed rate and a direction of movement. These points are taken from datasheet of job. Circular interpolation is a motion of tool in circle. It may be a complete circle or less than. Linear interpolation is straight line between two points. Interpolation is done with help of positioning control application instruction in ladder diagram programming.

IV. RESULTS AND DISCUSSION

A. Ladder diagram

Figure.4 shows ladder diagram simulation results for working gantry robotic arm. In manual mode, motor is moved using DPLSR command. 2-axis Relative Position Arc Interpolation is done by DPPMR command which perform point to point linear motion and 2- axis relative point-to-point movement is done by DCIMR command which performs point to point arc interpolation motion.

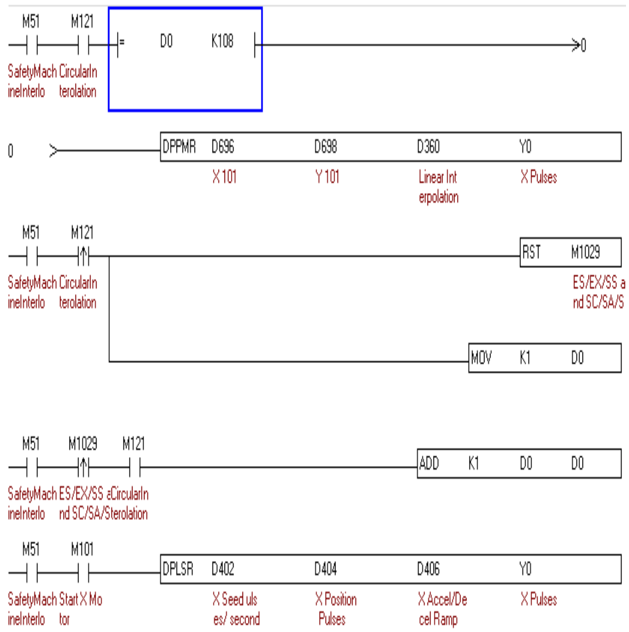

Figure 4. Snapshot Of Ladder Diagram

B. HMI Screen design-

HMI (Human Machine Interface) is a medium for information exchange and mutual communication between electromechanical system's and the user. It allows the user to complete settings through touchable images or keys on the user-friendly window.

Figure.5 shows Home screen designed on HMI designing software compatible with delta PLC called DOPSoft. Home screen contain three GOTO buttons which are used to jump on that particular screen.

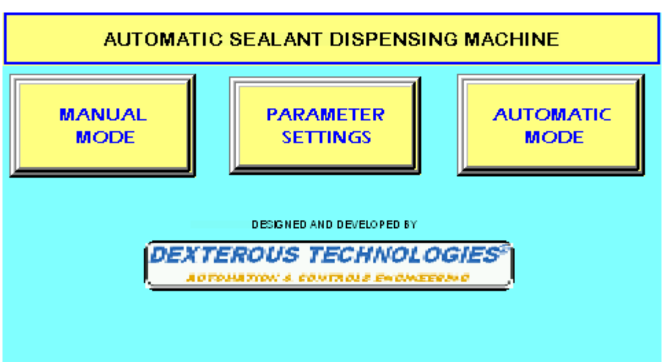

Figure 5. HMI Home Screen for Robotic Arm

Figure 6. shows automatic mode of HMI screen. Power Off indicates status of emergency stop by momentary button. Start cycle commands PLC to start repetitive action as per ladder logic. This is also done with the help of momentary button specifying read and write address. The other two are GOTO screen buttons.

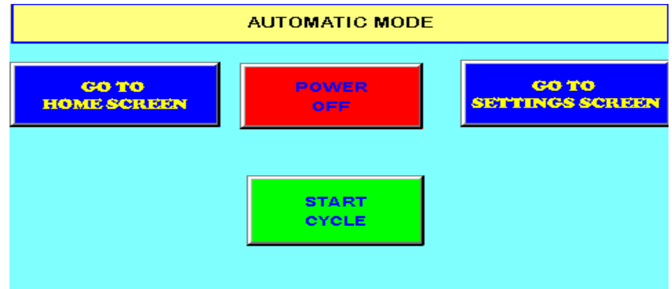

Figure 6. HMI Screen Automatic Mode

Figure 7. shows parameter setting screen of HMI. The operator is able to set Sealant feed rate and linear speed via numeric entry in mm/second.

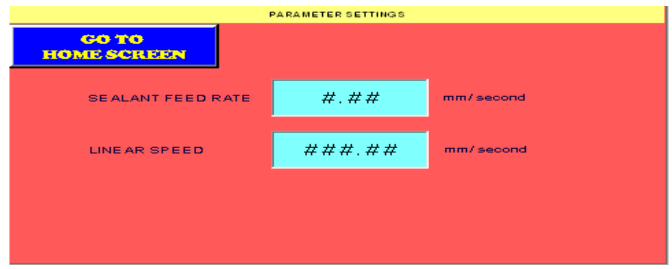

Figure 7. HMI Sreen Parameter Settings

Figure 8. shows manual mode of HMI screen. Power Off indicates status of emergency stop by momentary button. Jog speed is set via a numeric entry in mm/second. And motor can be moved in forward and reverse direction by momentary button with the help of read and write address.

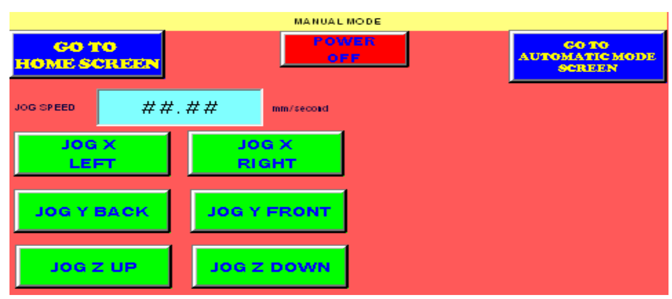

Figure 8. HMI Screen Manual Mode

C. Electrical control panel

The control panel schematic is developed in Eagle software. PLC control panel also called as PLC Automation Panel. It is one of the best and capable kind of control panel. Various electronic and electrical circuit fitting are commonly used in control panel. We have implemented control panel with extremely capable of giving higher output at less power consumption.

Control panel board size is 560 X 560 mm. Figure.9. represent electrical control panel. It consist of 3 layers. First layer consist of bank of two level terminal block for 24V DC and GND and AC section. It also includes single level terminal block for sensors, light and other components so that wirings can be easily taken out. AC section includes circuit breaker and contactor. It is separated from DC section to avoid interference and noise. Second layer consist of PLC SV28 and SMPSs. SMPS G31-60-24 is for PLC and SMPS G31-250-48 are for hybrid motors. In this layer fuse is used for protection of PLC whereas potential earthening block is used for earthening to SMPS. Third layer consist of stepper drivers, relay and SMPSs. Stepper drive SEA5045 for z motor and dispenser, RMCS1110 for x and y motor. Relay SPDT is used for isolation purpose. SMPS G31-120-24 is for motor along z axis and SMPS G31-60-24 is for dispenser.

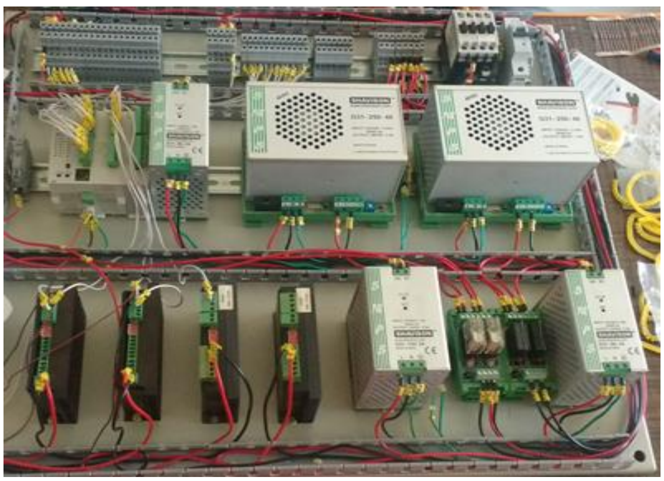

Figure 9. Control Panel Of Developed System

D. Hardware model

Figure.10. shows hardware model of 3 DOF gantry robotic arm developed. We have developed this arm using stepper motor. We have used hybrid stepper motors along X and Y axis as these motors offers encoder count 4000 per revolution with selectable gear ratio on RMCS1110 drive. By controlling pulse rate by PLC, motor's speed is controlled. A step angle of 1.8° can be achieved through stepper driver SEA5045 used to drive permanent magnet stepper motor along Z axis by keeping micro step switch position to 128. It is seen that when micro step is reduced then the speed of motor is increased. Controller used in our system is Delta DVP 28SV-T type as it satisfy our high speed output requirement. SMPS G31-120-24 is selected based on current rating of 5amps and voltage rating of 24V for z motor and G31-250-48 for hybrid stepper motor along x and y axis have current rating of 5A and voltage rating of 48V . Home sensors used are nothing but cylindrical type 12-24V DC 3 wire PNP type inductive proximity sensors EGT08*1.5AP024-2000L used in order to come back to initial state of operation and start new cycle. The ladder diagram programing is burnt in PLC using USB to serial convertor.

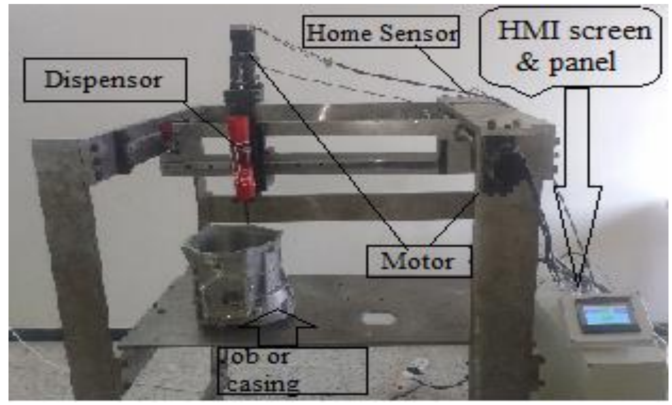

Figure 10. Prototype Of Robotic Arm

E. Testing procedure

A 2pin RS-485 command port is available on the drive for debug and tuning routines. When connected it to a computer the drive parameters can be accessed by simple commands using any Modbus Master Poll Software. Here we have used Rhino hybrid tuner V2 software for speed and accuracy testing of motor. An additional hardware used to execute this process is USB to RS485 Converter. Once the connection is done, slave address is selected to communicate with drive. In this case, valid slave addresses are only 2; one for x motor and other for y motor. Once a valid slave address is selected the drive start communicating to software.

On the Parameters section all parameters are loaded from the currently connected drive. When we change the slave address from 1 to 2, the parameters are loaded for the new slave i.e. 2 (y motor). When the drive is connected the motion data is polled every few milliseconds which are specified in Update Interval drop down box. This data is shown in then 'Stream Data' Section. It shows realtime information about motor's data like actual Position error between given command and current position, actual 32 bit position of encoder (from startup or set position), approximate speed in RPM, exact angular positon of encoder in counts and degrees, approximate current. Figure.11. shows the testing results in which position error is 1 and speed is 2517 in form of pulses.

Figure 11. Testing Results.

V. CONCLUSION AND FUTURE WORK

In this paper we attempted to develop a control system capable of fully executing sealant dispensing on protective casing of gearbox with the help of circular and linear interpolation. It minimizes human error, increase the efficiency in terms of speed of 50mm/sec and accuracy increasing the production my many folds.

Only one fourth of circle faces overlapping on which work can be done in future. It also expected to be best solution to get reliable and precise motion control system. Thus, our system is best choice suitable for small scale industries for micro positioning applications.

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