Vol. 8(29), Jul. 2018, PP. 3907-3914

Contents list available at IJMEC

International Journal of Mechatronics, Electrical and Computer Technology (IJMEC)

Journal Homepage: www.aeuso.org

PISSN: 2411-6173 - EISSN: 2305-0543

Robotic Assembly of Linear Pneumatic Actuator Components

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Abstract

This work was about the automatic assembly of linear pneumatic actuator components based on an industrial robotic arm and programmable logic controller (PLC) system. Automated PLC-conveyor belt system was programmed and configured to deliver pneumatic actuator parts. A Mitsubishi industrial SCARA robot was then programmed to communicate with the PLC-conveyor system and utilized to pick and place the parts with high speed, ultimately assembling the completed actuator. Major developments in this project involve the electrical connections and ladder logic programming for the conveyor belt and other discrete sensors and end devices, development of a single multifaceted gripper to be able to pick up each different part and precise position teaching and movement programming of the robotic system. The goal was for a repeatable process with a complete build success rate of 90%. This target was nearly achieved (~80%) though high variability throughout the process will require additional attention if the initial target is to be reached.

***Keywords:** Linear Pneumatic Actuator, SCARA robot, Sensors, Robotic Assembly*

1. Introduction

Ever since the very first installation occurred in 1961 for a New Jersey General Motors assembly plant, the manufacturing industry has relied heavily on the industrial robot for its high speed, precision, and accuracy in order to maximize productivity and improve both product quality and process reliability [1-4]. Though industrial robots are now present in nearly every major mass-production manufacturing operation across the globe, they are continuously being adapted to new types of applications and are constantly being improved where they already exist [5-9]. It is typically well understood that the high initial cost to implement a fully automated robotic manufacturing or assembly system will eventually be earned back through reduced labor costs and improved product quality when compared to a strictly human assembly process. Sometimes it is desired to capture the benefits offered by robotic automation though it may not be feasible in some instances with the extremely high initial cost required [10-12]. The objective of this project is to provide a proof-of-concept for a complete singular robotic assembly operation; therefore saving labor costs compared to a conventional manual labour system while also avoiding the high initial cost needed for a multi-robot, multi-step system. Such a system represents a middle ground between a fully automated line process and a conventional personnel assembly setup in terms of efficiency and cost. The robotic system to be used is one of Mitsubishi Electric's horizontal type SCARA (Selective Compliance Assembly Robot Arm) robots. These robots are designed for a wide variety of industrial applications involving high-speed pick-and-place and precise assembly operations. The task to be demonstrated by the end of this project is the assembly of small pneumatic actuators. The scope of the project involves developing a process using the MELFA BASIC V programming language for a Mitsubishi CR750-D controller and RH-6FH-D SCARA robot to pick, place and maneuver several parts to construct a basic linear pneumatic

Article History:
Received Date: Mar. 21, 2018
Accepted Date: Jun. 26, 2018
Available Online: Jul. 01, 2018

actuator. RT Toolbox 2 was used as the robot controller program development environment. Various different commands and types of motion were required to precisely align and fit the components together. Restrictions in directional clearance, force required and alignment were considered in the development of the process. The various actuator components being heavy, smooth and differently sized / shaped also required a lot of additional consideration while developing the project. A conveyor belt system which also includes a slot sensor, light stack and several push & toggle buttons is to be used to deliver each part to be used in assembly. An Allen Bradley micro850 series PLC was used to control the conveyor belt relays and other I/O components and to signal to the robot when a part is in position and ready to be picked up. PLC programming will be performed using Rockwell Automation's Connected Components Workbench software. A specialized gripper was designed and fabricated to handle the various sized parts. Solidworks 3D CAD software was used in conjunction with a 3D printer (PRUSA) and the Prusa slicing software to accomplish this. One larger sized actuator was targeted for assembly during this project.

A final demonstration was conducted as a final deliverable of this project. The demonstration consists of building the actuator multiple times each to demonstrate the precision and repeatability of the process developed. The initial targeted success rate was 90% - in terms of completed full repetitions without errors or miss fittings. Following figures show the components of linear pneumatic actuator and workstation setup of the SCARA robot.

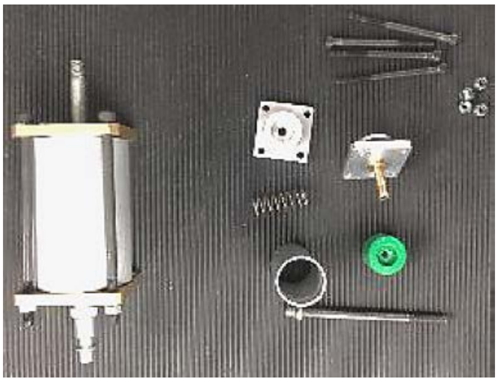

Figure 1. Pneumatic actuator (assembled and disassembled)

Figure 2. Workstation setup

2. Project Implementation

The project implementation can be broken down into major phases/steps in which each has required various engineering fundamentals in the planning, design, testing and problem solving in order to create the fully functioning system. Each of the major steps in the project's life has been laid out below with details into what work has been conducted and some potential constraints that have been identified.

2.1. Equipment Setup and Resource Collection

This phase of the project includes gathering all the resources necessary and initial robot setup required to for the subsequent phases. Manufacturer manuals for the RH-6FH-D robot, CR750-D controller and R32TB teaching pendant were downloaded for reference. The space chosen to operate the robot required access to a 25 psi air supply (for gripper open/close functionality), 240V 3-phase AC power outlet and a standard 120V AC outlet. Additionally, enough space to provide an obstruction free safe operating area was essential. Pneumatic tubing was cut to length and the fittings were assembled and subsequently leak-tested to ensure reduced pressure loss, this is important as the pneumatic gripper needs to apply enough force as it closes to hold some of the heavy solid parts. Tools required to change the gripper and alter robot fittings were identified and collected. Finally, small physical adjustments were made to the default robot setup, namely the gripper attachment on the rigid z-axis beam was raised to allow enough vertical clearance for working with some of the taller parts.

2.2. Work Procedure

A work procedure was planned in order to provide an overall sense of the construction order for the pneumatic actuator. A simple map of where each part is to be laid out, the order of assembly and where on the workspace it takes place was produced. This was required to determine how each part arrived down the conveyor, how the gripper needs to approach for pickup and how the part is to be placed and fastened. This work-order was taken into consideration during the gripper design phase. For example the gripper could not be taller than a specific value or else it would contact the conveyor before picking up the spring. The physical restrictions of the robot's range of movement were investigated during this phase.

1. Piston/plunger moved to temporary holding position
2. Base moved to build square
3. Spring place on base
4. Piston/plunger moved from temporary hold position and placed through base
5. Housing placed over base and piston
6. Top placed on assembly
7. Press assembly to fit

Finally an overall high level process was created that both the robot and PLC programs were based off of. A graphical flow of this process can be seen below:

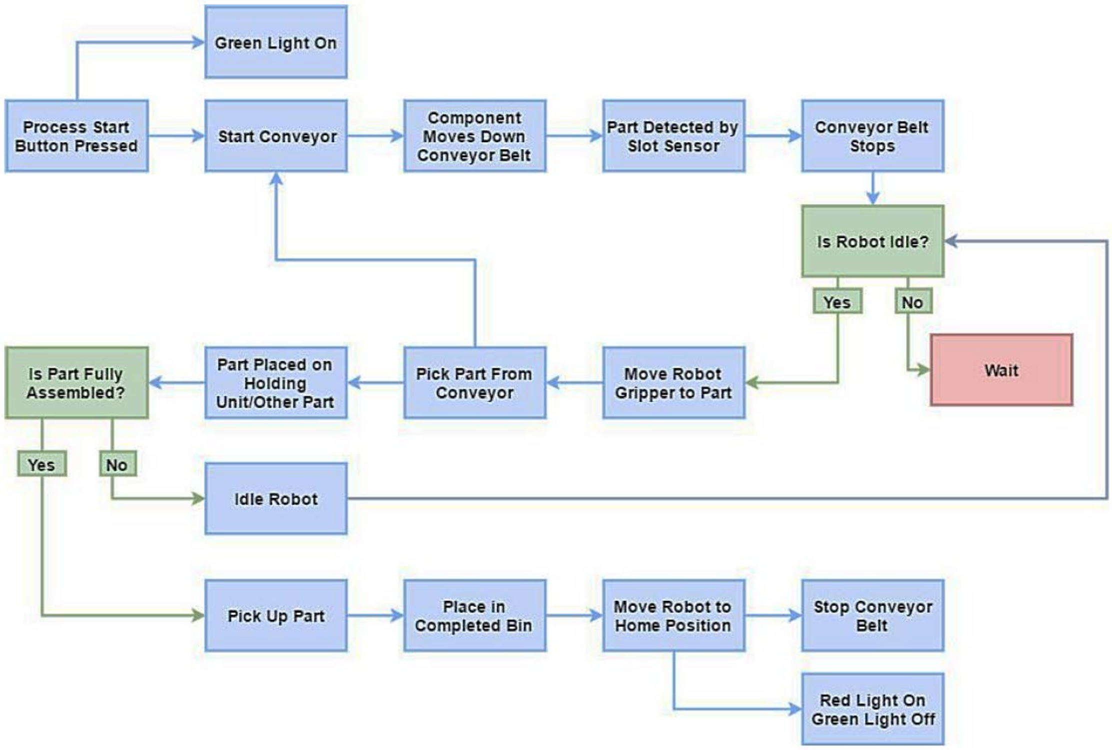

Figure 3. High level process flow chart

2.3. Robot Controller Configuration

Networking the robot controller to a PC via Ethernet was required in order to operate the robot in automatic mode. The default IP address was determined from the front panel of the robot controller and entered into the RT Toolbox communication parameters. The operating mode of the robot, controller program slot 1 (what we are to be using) was changed to 'CYCLE' mode, this made the program loaded to slot 1 only run once, which is ideal for developing and testing the process. In an actual real-world application, the mode would be switched back to standard, allowing the process to repeat automatically once implemented. A simple test program was written and transferred to the robot controller to test the setup. In this phase, the procedure to manually control the robot via the teaching pendant and to import current position settings was also determined. This was important as it allowed us to manually and precisely teach points to the robot and transfer the coordinates back to the program being developed. Adjustments were then made to the soft position limits applied to the robot in order to give us additional movement clearances - particularly in the Z-axis where we need more room to pick and place the taller parts of the assembly. The force sensor limit in the z-direction was also altered, allowing the robot to deliver additional downward force to fit the 'tight' parts of the actuator together without the robot controller erroring out and stopping the assembly.

2.4. PLC & Discrete I/O Device Setup

The physical digital IO connections were made between the PLC and the conveyor components (motor, slot sensor, push buttons, toggle switch and light stack) and between the PLC and robot controller I/O. The PLC has been wired to an IO board to simplify making the connections, as shown in Figure 4. All PLC programming was done in ladder logic using Rockwell Automation Connected Components Workbench software on the engineering workstation. For testing, the PLC was connected in monitoring mode to view the status of I/Os and rungs on the laptop.

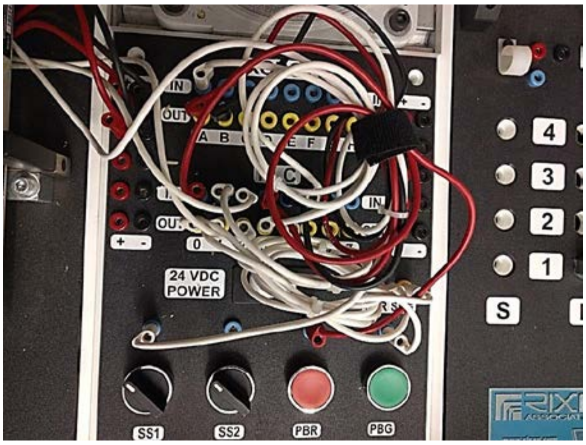

Figure 4. PLC and Robot controller I/O connections

2.5. Gripper Design

A gripper design for the robot that can pick up the different sized components of the actuator assembly is required. Initially fine measurements of the actuator components with a digital caliper are to be taken. SolidWorks CAD software is then to be used to design the gripper prototypes with a 3D printer used to fabricate them. Below is the initial Solidworks model for the proposed redesigned gripper prototype, as shown in Figure 5. As highlighted by the top view figure (bottom right corner) it can be seen that arcs have been extruded at the base of the gripper arms as well as at the midsection. The arm arc will assist when assembling and moving the base, covering and top portions of the assembly. As for the midsection arc, it will be used to pick and place the spring component.

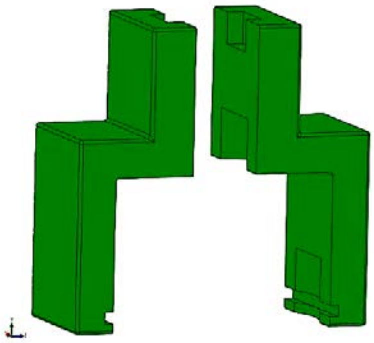

Figure 5. Initial gripper Solidworks model

After this design was printed and attached to the robot, there were some issues that were noted. The base and the housing of the actuator were difficult to pick up as the dimensions of the gripper were slightly too wide. During testing, this resulted in these parts slipping and falling after being picked up. Additionally, it was found that the gripper was too long, which did not allow it to pick up the spring before the end would contact the conveyor belt.

The modified gripper design was successfully implemented into the final assembly process. Challenges however were still encountered, the manufacturing material which was used to create both proto type one and two did no possess the correct texture. This in turn made it difficult to compensate for the reduced surface area near the bottom portion of the gripper, which was corrected by with the addition of rubber bands. The use of rubber bands allowed for the design to keep its functionality which was offered by the semi-circle indents while also addressing the texture issue. Problems regarding the symmetrical aspect of the pneumatic actuator proved to be one of the greatest issues impacting repeatability, since both the housing base as well as the inlet base were of greater mass the effect of the reduced symmetry was magnified, making pick and place movements difficult to successfully carry out. All other portions of the assembly were however automated to a repeatability of 98-99%.

3. Testing and Discussion

3.1. Testing and tuning

Testing was conducting by stepping through each line of code individually at a significantly reduced speed. Tweaks to the code and defined positions were continuously made accordingly to enhance program repeatability. Once we were fairly confident with the positioning and programing the success rate was tested. A 90% success rate was the initial target, though the actual success rate was closer to 80%. With additional time and resources more emphasis could be placed on reducing variability, particularly on conveyor belt placement using optical imaging technology and physical conveyor guides to aid in positioning. Following figure shows the major system components and connections diagram where Ethernet connections are displayed in blue color.

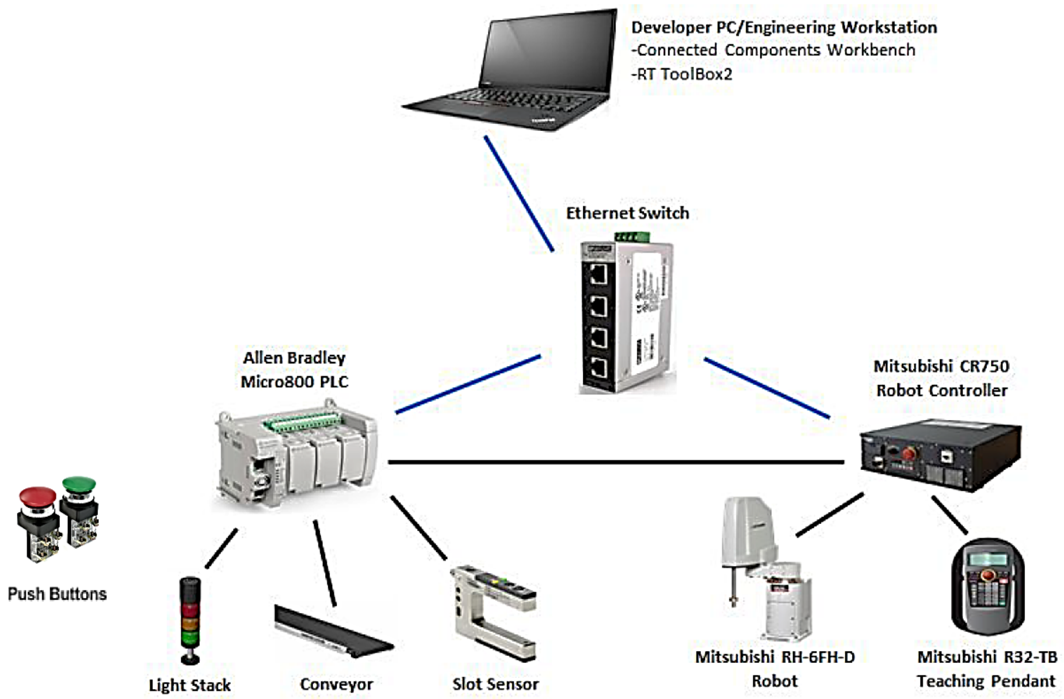

Figure 6. Major system components and connections diagram (Ethernet connections shown in blue)

3.2. Discussion

To date, in modern industry the best overall way to assemble components is through the use of an automated multiple robot assembly line, where each robot is programmed to do one single specific task. Such a process offers extremely fast production with reduced labour costs (as wages are not required for human workers), better plant safety, enhanced consistency (due to less variability of a robot) which will ultimately lead to better product quality. Unfortunately such a configuration requires an immense upfront cost and requires a very large amount of physical space. Therefore the practicality of a "single-robot assembly process" that this project is demonstrating would appeal to companies looking to capture the benefits of automated assembly without such large initial cost and space requirements. Although not as fast as a multiple robot system, single robot assembly is still significantly more cost effective and more attractive than a traditional human assembly process, therefore representing a middle ground between the two methods. It is likely that new start-up companies where expenditure capital and physical space is often very limited can seriously benefit from implementing a single-robot-assembly process. A robot can work day and night, does not require compensation, cannot get injured, and offers better precision and speed. All that would be required is an initial setup and some periodic preventative maintenance.

Another alternative use to what is discussed above would be for the use in simulation based testing, where a single-robot assembly operation could serve as an initial test bed for a large-scale automated manufacturing process. This would demonstrate each task is doable for the type of robot and provide excellent feedback for future design considerations. Implications for the project involve increased manufacturing range and interchangeability. Having the process designed is able to accommodate a variety of projects through the use of customizable gripper design and improved process optimization will allow for the current line of MELFA SCARA industrial robots to expand into a multitude of markets. The increased interchangeability will allow for the robot to perform a range of functions with only having to replace the main gripper attachments, allowing for a single robot to do multiple tasks which will assist in the productivity and energy/space savings of future facilities.

Conclusions

Overall the objective of the project was to successfully demonstrate the concept of a complete single-robot-assembly process by assembling a pneumatic actuator. This was demonstrated by the end of the term using a Mitsubishi industrial SCARA robot to build a basic pneumatic linear actuator. Success criteria were to be based off of multiple completed assembly runs without error to demonstrate the repeatability and robustness of the process. The targeted success rate was 90% however the final achieved success rate was closer to 80%. Improvements have been identified which can further improve the reliability and repeatability of the process if implemented. The analyzed literature spoke of creating a more unified MELFA robot community through the normalization of certain robotic components and processes, which aligned with the overall proposed scope, goals and outcome of this project.

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