Design, Analysis, Manufacturing and Testing of a SCARA Robot with Pneumatic Gripper for the Poultry Industry

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Abstract. Soft robotics is replacing conventional robots in fields requiring interaction with fragile objects. Namakkal district of Tamil Nadu is responsible for over 90% of egg exports in India. Most of the eggs are processed and palletized manually which causes a lot of money on human labor. This paper discusses the design of a SCARA robot which uses asymmetric flexible pneumatic bellow actuator (AFPBA) to palletize the eggs to reduce the processing time and human labor. The design, analysis, manufacturing and testing details have been provided. The manufactured prototype was able to successfully lift 200 grams without slippage.

1. Introduction
India is the third biggest producer of eggs in the world with almost 95 billion eggs being produced annually. That means that on a given day an average of 260.3 million eggs are processed. Almost 90% of the egg exports are done by the Namakkal district of Tamil Nadu. On conducting a study of different egg distributors in this district, it was seen that most of the expense in the industry was because of the need for a great amount of human labor to process the eggs. To prevent any kind of spoiled goods reaching the consumers, strict quality control is placed. Eggs need to be candled to check for any anomalies and the weight graded and palletized before produce gets to the market. Eggs being fragile objects, these processes are manually carried out by humans to prevent any damage. Given that a single person process approximately 5000 eggs a day it becomes quite difficult to carefully inspect each egg. Sometimes hairline cracks maybe overlooked which results in bad quality eggs to be exported. SCARA robots [1] can be employed in these scenarios to palletize the eggs for export. This reduces the time for processing and helps increase the export amount. But conventional hard robots fail to do these tasks. Eggs being fragile objects would break if any excess force was applied by the end effector. This situation calls for the development of a customized robot with a soft gripper to handle the eggs [2,3,4]. A SCARA robot can be used to perform the pick and place action for the palletization of eggs. This would increase the speed of production and reduce the amount of human labor required to these tasks. The works done by Ganesha Udupa et al. in developing an AFPBA made from hyper elastic materials [5-11] has been studied and modified to make a gripper that provided firm grasping and a good amount of bending.

2. Market analysis
In order to find out if the cost of implementation and maintenance of the SCARA is profitable compared to using manual labour, a study was conducted in the Namakkal district of Tamil Nadu. During the study with RDS egg distributors, one of the major distributors in the district, it was found...
that nearly 75000 eggs were processed at any given day. It requires 10-15 labourers a day to palletize these eggs. Given that the cost of each labour is approximately 750 rupees ($10). This gives us an approximate labour cost of 337,500 rupees ($4585). The cost taken to procure the components and build the robot and manipulators are 200,000 rupees ($2718). As the robot is made using cheap and commercially available components and has a low amount of moving parts, the maintenance of the robot is very low.

3. Design of the robot and actuator

3.1. Pneumatic actuator

For the manufacture of the pneumatic actuator, both nitrile rubber (Table 1, Figure 1a) and silicone rubber were good candidates as they provided good deflection as shown by the previous works done on asymmetric flexible pneumatic bellow actuator. The actuator has a semi-circular cross-section with a length of 10cm and eccentricity of 0.87. The eccentricity was value was selected as 0.87 because the gripper gave the maximum stable deflection at that value (Table 2). Values above 0.87 were unstable and hence were not used. The semi-circular corrugations were provided for maximum deflection. Molding was then used to manufacture the actuator (Figure 1b).

| Table 1. Properties of acrylonitrile rubber. |
|---------------------------------------------|
| Property          | Value                      |
| Density           | 1000 kg/m$^3$              |
| Shear Modulus     | $2.9 \times 10^6$ N/m$^2$ |
| Poisson Ratio     | 0.49                       |
| Ultimate tensile strength | 13.787 MPa |

| Table 2. Eccentricity vs deflection angle for semi-circular corrugation at 5 bar. |
|---------------------------------------------|
| Eccentricity | Bending angle |
| 0.11         | 0.0000        |
| 0.42         | 6.7489        |
| 0.76         | 9.1115        |
| 0.83         | 7.7372        |
| 0.85         | 7.5705        |
| 0.87         | 26.7550       |
| 0.92         | 12.9560       |
| 0.96         | 7.9325        |
| 0.97         | 6.5324        |
| 0.99         | 7.1692        |
| 1.01         | 23.0800       |
| 1.45         | 27.9730       |
| 1.47         | 35.8920       |
| 1.87         | 18.7260       |
| 1.96         | 14.5200       |
| 1.99         | 10.5870       |
| 2.04         | 6.2815        |
| 2.14         | 2.8724        |
3.2. SCARA robotic manipulator
The selective compliance provided by SCARA robot makes it a good choice for packaging applications. They are easy to design, prototype and maintain. Even though parallel robots provide higher speed, the eggs will be prone to slippage. Hence SCARA robot has been used for building the robot.

Solidworks 2018 was used for drafting the prototype. The manipulator provides three degrees of freedom without the end effector. 3d printed components using PLA (polylactic acid) was used to build the prototype(Figure 2a and 2b).

4. Analysis of Actuator
4.1. Analysis of gripper
The gripper selection of the gripper configuration was based on previous work done in the design. Ansys was used for the analysis of the gripper. Two different prototypes were manufactured and tested to find the optimal material that provided a good amount of bending and withstood the pressure supplied. Even though both materials provided a decent bending, Silicone rubber tends to burst at 2 bar pressure. Hence actuator made from nitrile rubber was used to do the bending test (Figure 3). The
amount of deflection given by the actuator is shown in Table 3. The results almost coincide with the analysis results from previous works.

| Pressure (bar) | Deflection in degrees |
|---------------|-----------------------|
| 1             | 5                     |
| 2             | 12                    |
| 3             | 20                    |
| 4             | 24                    |
| 5             | 32                    |

Table 3. Pressure versus deflection values for pneumatic actuator.

4.2. Analysis of SCARA

Adams solver was used to conduct the motion study of the manipulator (Figure 4). Iterative finite element solver in Solidworks 2018(FFEPlus) was used to perform the structural analysis of the manipulator designs. The prototype was successfully manufactured and functioned perfectly. The end effector consisted of 4 AFPBA connected using a 3d printed mount. After the manufacture and assembly (Figure 5), the manipulator was able to lift weights up to 200 grams.

Figure 4. Dynamic analysis of SCARA robot.
Figure 5. Assembly of SCARA robot with pneumatic flexible bellow actuator.

5. Control System

Control of a soft robot is a difficult task as the equations that used for the kinematics of rigid bodies fail to apply in the case of a soft robot. Hence a control system is required to provide optimum pressure to lift objects. The Control system and the electronic components used have been specified below(Figure 6).

5.1. Nvidia Jetson Nano

Nvidia Jetson Nano has been used as the main processor for egg detection. As a lot of eggs needs to be palletized in a short amount of time, the image processing requires to be done as fast as possible and therefore it was necessary to use a small and powerful processor to do the task accurately and effectively. It also solves the inverse kinematics of the manipulator using trigonometry after locating the position of the egg.

5.2. Camera

A raspberry pi camera is used and mounted on the end effector to locate and centralize the gripper on top of the egg to be picked. The identification of the location is done by colour tracking the egg and
then actuating the SCARA to move till the centroid of the actuator coincides with the centre of the image.

5.3. Sharp, Flex and Force sensors
Sharp sensor is used to measure the proximity of the end effector to the egg. This sensor was employed as the camera could not be used to obtain the depth information. The sensor enables the SCARA to position itself for firm grasping. It also prevents accidentally ramming the gripper onto the egg. Flex sensor was used to study the deflection given by the AFPBA at different pressures. This was required to control the pressure output by the regulator to achieve optimum bending. Force sensor is employed to prevent slippage of the grasped object.

5.4. Pressure regulator
Pressure regulator is used to control the pressure output to the actuators so that the desired amount of bending is achieved. In the prototype we have used 12V solenoid pressure regulators.

5.5. Arduino mega
Arduino Mega 2560 has been used for controlling the motors and the pressure regulator. It takes the angle of each motor and the pressure to be applied as the input and actuates the motors and regulators.

5.6. Motors, Drivers and linear actuator
The prototype used rhino servo motor which came with its own motor driver. It had a rated torque of 120kgcm at 10rpm. The linear actuator used is a 6V L12-P linear actuator that provides a stroke length of 100mm.

6. Conclusion
Nitrile rubber has been selected as the optimal choice for manufacturing the gripper. Prototype of the gripper was 3d printed and assembled. The deflection of the end effector with change in pressure is measured. A control system was created to control the end effector force, prevent slippage and study the effectiveness of the actuator. The actuator was able to lift weights of up to 200 grams safely without slippage. The prototype proved to be effective in accomplishing the task. Further testing and improvement required before implementing the design in the industry.

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