Design and Implementation of a 4-Bar linkage Gripper

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Abstract: *Design of the end-effector of a robot is of high importance. This is the part of a robot that actually interacts with the object and does grip it. Without a suitable end-effector, a robot cannot function properly. Poorly designed gripper may result in slip of a component from the jaws of a gripper and even damage parts sometimes. A component may be hold with instability, and this can decrease system reliability. In this paper, discussion is made on design considerations that one needs to take into account while designing the 4-bar linkage gripper. The control system applied for it is also briefed.*
Keywords: *Robot, gripper, end-effector, FSR, force sensor resistor, 4-bar link.*

I.   Introduction

A gripper is an end-of-arm tooling used in a robot for grasping, holding, lifting, moving and controlling of materials. Human hands have been the most common, versatile, effective and delicate form of material handling. But, for repetitive cycles, heavy loads and under extreme environments, grippers had to be developed as a substitute to human hands. In 1960s, after the emergence of modern robots, grippers replaced human hands on numerous occasions. Robot-gripper systems are found to be effective for repetitive material handling functions in spite of their initial capital and ongoing maintenance expenses because of their reliability, endurance and productivity. However, the cost of grippers may be as high as 20% of the cost of a robot, depending on the application and part complexity [1].

For manufacturing systems where flexibility is desired, the cost of a suitable gripper may even go higher since they require additional controls, sensors and design needs with regards to being able to handle different parts. In the 21st century, under the influence of globalization, manufacturing companies are required to meet continuously changing demands in terms of product volume, variety and rapid response. Flexible and reconfigurable manufacturing systems (FMS and RMS) have emerged as a science and industrial practice to bring about solutions for unpredictable and frequently changing market conditions [2].

Several research projects exist among these industrial gripping systems. Researchers are working on the imitation of the flexibility of the human hand. Examples are the Karlsruher Hand, the IFASH developed at RWTH Aachen and the DLR-Hand [3]. They stated high-end technology not suitable for general industrial use.

There are some applications where adaptive industrial gripper solutions could be helpful to decrease setup times of handling systems and achieve a high flexibility of the whole automation system. One example deals with the handling of car reflectors. Automobile suppliers have to produce different kinds of car reflectors, sometimes hundreds of versions for current car types and for the accessories market [4].

II.   Gripper Design And Configuration

Wright et al. [5] compared grippers with human grasping systems. They classified grasping systems considering design requirements of grippers into three categories as under.
- •   Compatibility with a robot arm and controller
- •   Secure grasping and holding of an object
- •   Accurate completion of handling task.

Many industrial applications of grippers were described, and guidelines for gripper design were presented by them.

Pham et al. [1] summarized the strategies for design and selection of grippers to suit different applications. In their study, variables affecting the selection of a gripper were listed as:
- • component type,
- • task to do,
- • environmental condition within the work volume,
- • type of robot arm, and
- • control conditions.

1.   Guidelines Of Gripper Design

There are different guidelines for respective typical gripper designs. Sometimes, one guideline may indicate one design direction, while some other may suggest the opposite. So, it is not possible to apply all the

guidelines to any one design. Each particular situation needs be examined carefully, and a decision is to be made to change the appropriate guidelines. The design guidelines are as follows [1,5]: -

- Minimization of gripper weight: This allows quick acceleration of a robot for performing the required task.
- To grasp objects securely: This allows a robot to move at a high speed thereby reducing the cycle time.
- To grip multiple objects with a single gripper: This can avoid tool change.
- Encompassing fully the object with the gripper: This holds the part securely.
- Not to deform an object during grasping: Some objects are easily deformed and care needs be taken to grasp these objects.
- To minimize finger length: This is done for the fact that longer the fingers of a gripper, more they are going to deflect when grasping an object.
- To design for proper gripper-object interaction: If a flat surface is used at a finger, then a high friction interface is desired, else the part would not be aligned properly and high friction increases secured grasping.

2. Selection Of Four Bar Linkage Gripper
Incorporating 4-bar linkage in the gripper provides some advantages over normal gripping systems, such as

- The total workspace of the gripper gets reduced, resulting in less space required for the working of the gripper. Figure 1 compares the workspace of two different grippers.
- The pressure is applied gradually on the gripped object rather than somewhat abruptly in case of normal grippers, reducing the chances of deformation of the object.
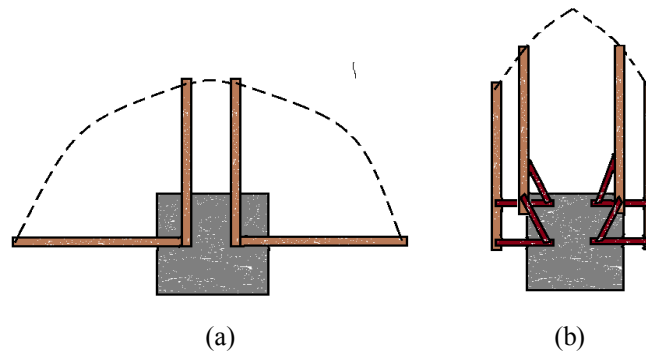

(a)   (b)

Figure 1.(a) Workspace of 2-bar linkage gripper, (b) Workspace of 4-bar linkage gripper

III.   Design And Analysis Of The 4-Bar Linkage Gripper
1.   Gripper Configuration
The gripper developed was configured with a four bar linkage design for its wide applications and utilization of minimum workspace. The gripper consists of four rectangular aluminum flats arranged according to a four bar linkage gripper configuration. The fingers are flat and rectangular in shape. The base of the gripper was made of a rectangular aluminum bar for light weight consideration to ease machining. Holes are made in the bar for fitting the bearings. The gripper is guided by using a worm and spur gear arrangement to convert the rotational motion to linear motion. To control gripping of object, two standard round commercial force sensors are used. These are of force sensor resistor (FSR) type sensors with Flexi-force model 402 working in the range of 10gm to 1kg (0.1N– 10N), and are used to measure the applied force. Another standard commercial square force sensor resistor FSR (Flexi-force model 406 working in the range of 10g to 1kg (0.1N– 10N)) as shown in Figure 2, is used to measure the intial weight of the object that is to be gripped. These three sensors are tactile sensors. The actuator used to drive the four-bar linkage gripper is a permanent magnet dc motor of 10rpm, 2A 12 V rating.

(a)   (b)
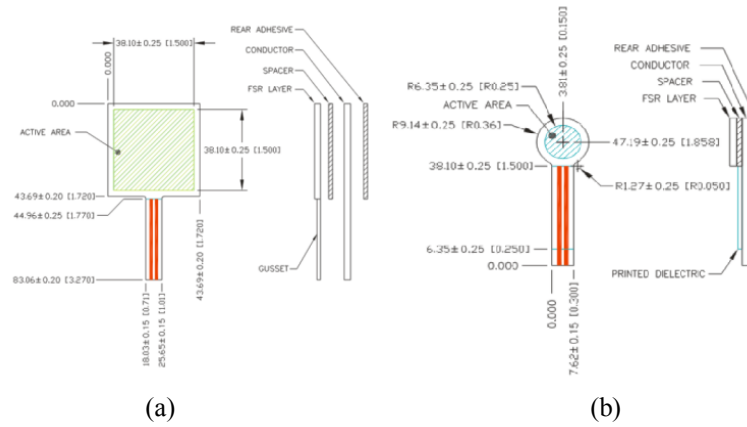
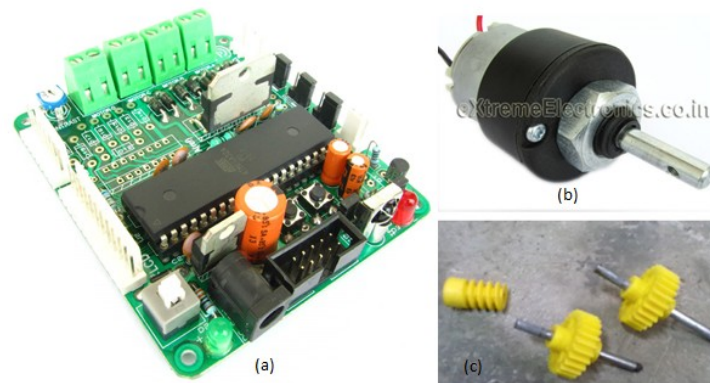Figure 2.(a) Square FSR (b) Round FSR

Figure 3. (a) Atmega 16 Xboard, (b) DC Motor, and (c) Worm gear and worm wheel

An Atmega 16 Board manufactured by Extreme Electronics, Inc. is used to control the actuation required. Figure 3 shows the items used. The design of the gripper has been made taking into some restrictions as long fingers require high torque, and short fingers impose restrictions on object dimensions. Hence bars are selected as per suitable dimensions for the construction of the gripper. A deformable complaint rubber material is used at the face of the fingers that come in contact with the workpiece, so as to decrease the pressure to apply on the object, increase interface friction, and avoid deformation from the uneven application of force. The gripper designed does not fully encompass the object. Figure 4 is the photographic view of the 4-bar linkage gripper.
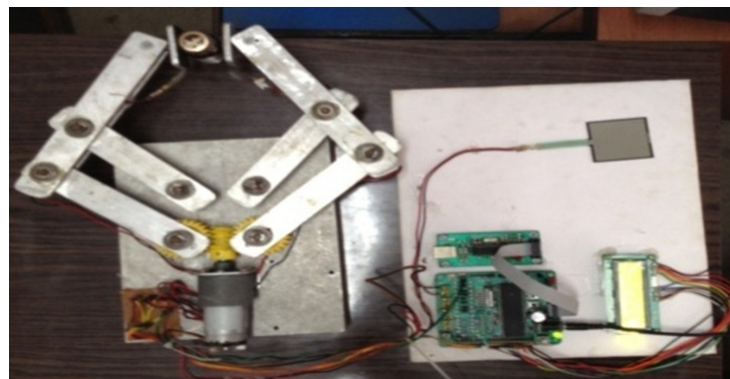

Figure 4. 4-bar linkage gripper arrangement

2. Governing Equation

The primary aim of the gripper mechanism is to convert input power into required motion and force to grasp and retain an object. Figure 5 represents the free body diagram of the proposed Four Bar Linkage Gripper from where Equation 1 has been deduced.

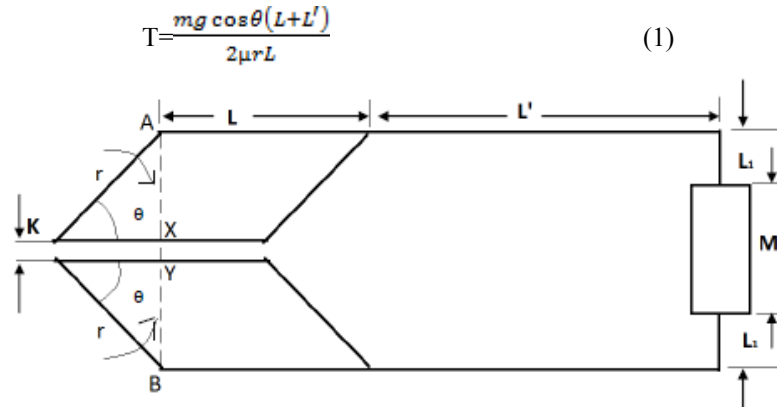$$T = \frac{mg\cos\theta(L+L')}{2\mu rL} \qquad (1)$$

Figure 5. Free body diagram of the 4-bar linkage gripper

Equation 1 can be regarded as the governing equation of the proposed robotic gripper. The key points regarding this equation is that

- in this equation, the weights of the various parts of the gripper are taken as negligible. However, only the weights of the moving parts of the gripper need to be taken into consideration. Weights of rigid parts do not affect the equation
- this equation will be applicable in both cases of Horizontal and vertical gripping of the object. For both cases, calculations are the same. In the experimental studies, horizontal gripping is used for gripping of the object.
- In both positions (Horizontal and vertical) of the gripper, the deformations (Bending and Elongation) of the links are taken to be negligible.
- Variables in this equation are m, T, θ & μ
  - μ -> The frictional coefficient between the gripping surface and the object, μ, can be calculated experimentally using Sine bar.
  - m -> The mass of the gripped object, m, can be obtained experimentally using Digital Balance.
  - θ -> Calculation of the angle, θ, can be done as follows,
    $$\theta = sin^{-1}((M+2L1-K)/2r)$$
  - T -> The torque required for gripping the object, can be calculated from the governing equation using formula,
    $$T = mg\cos\theta\,(L+L')\,/\,(2\mu rL)$$

IV. Force Sensor Calibration

The experiment was set up as shown in Figure 6. Different weights are used for calibrating force sensor taking into consideration the maximum force that can be applied to the sensor as par its data sheet. The whole sensitive area should be subjected to the applied force. Both the square sensor and the circular sensor were calibrated for proper working.
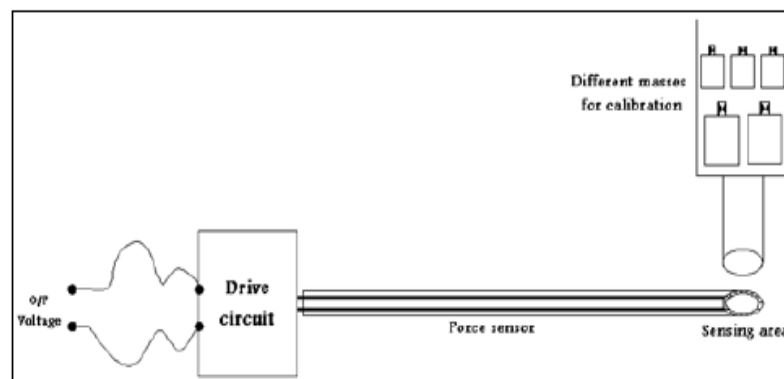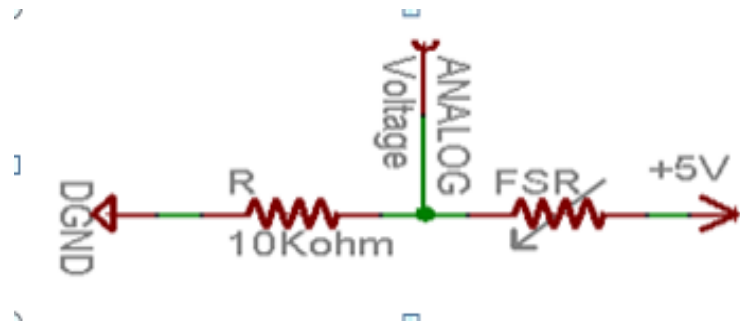

Figure 6.Arrangement of FSR Calibration circuit

Figure 7. Circuit arrangement for FSR Calibration

For converting force into voltage signal, the FSR device is tied to a resistor in a voltage divider configuration as shown in Figure 7. In the configuration shown, output voltage decreases with increasing force. Measuring resistor, R, is chosen to maximize the desired range of force sensitivity and to limit current. The output is described by Equation 2:

$$Vo = Vcc \ (R \ / \ (R + FSR)) \qquad (2)$$

The interrelation between weight and voltage for both models of FSR is shown in Figure 8.
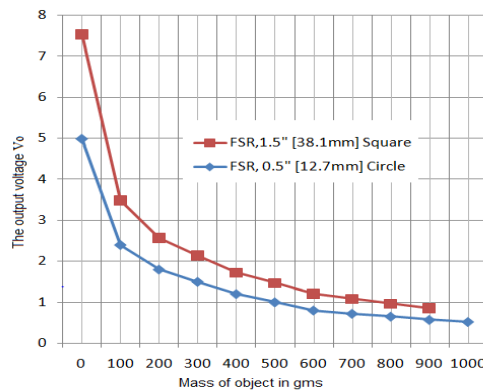

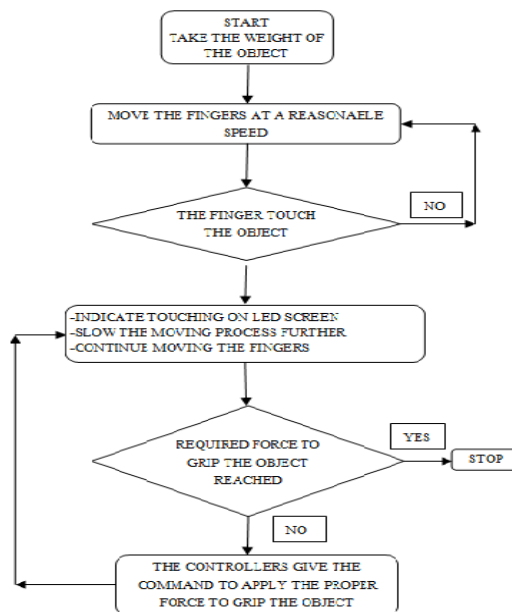Figure 8. Graph showing relation between mass of object and voltage

Figure 9. Flow chart of the control system

V.   Robotic Gripper Control System

To build the proposed controller system, one needs to get information about the system characteristics for use in experimental work. Hence, input/output variables of the system are measured and processed. The input variable to the system is the weight of the object which is used to calculate the required force to be applied on the object that is F_{app}. The deformable compliant rubber material covering the contact area of the fingers is important to allow a wide range of force control for solid objects as well as decreasing the pressure on the object and increasing the friction. Hence, one needs to calibrate the variation of the applied force F_{app} by the gripper finger at different input forces. After calibration of the force sensor, the input is fed to the controller system where it uses the data for further processing. The control system includes the FSR at the end of the robotic fingers and the control board. The FSR feeds the amount of force that is being applied to grip the object and also acts as a feed back system preventing excessive application of force. The Control system stops the actuation as soon as the required force to be given is reached and thereby prevents the object from getting deformed.

VI.   Experimental Analysis

Experimental work was carried out to verify the performance of the gripper. Every part of the gripper was verified from design to manufacturing to control aspects. The mechanical system performance of the gripper was tested and required refinements were performed. Sensors were calibrated and their necessary drive circuits were built. Figure 9 shows the flow chart that describes the experimental strategy and proposed algorithm.

VII.   Conclusion

In this paper, a robotic gripper design and its implementation for the purpose of grasping soft deformable objects is presented. The designed gripper has been found to be efficient. The advantage of using 4-bar linkage gripper is that a single motor is used for its actuation, and also its workspace requirement is less. A new control algorithm is proposed to adjust the motion of fingers of the gripper for grasping the object without the risk of crushing or dropping the object. The gripper is also programmed to determine slip of object by using slip sensors. The gripper designed is simple, economical, and able to handle a wide range of objects through easy control.

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