A Low-Cost Force Measurement Solution Applicable for Robotic Grippers

R.V. Sharan and G.C. Onwubolu

Abstract

Industrial robots find profound usage in today's industries and an important characteristic required of such robots in pick-and-place operations is determining the gripping force when picking objects. This paper presents the use of a FlexiForce force sensor for measuring the gripping force when picking work-pieces using the two-finger gripper of a pick-and-place robot. This thin and flexible analogue force sensor is capable of measuring both static and dynamic forces. It has an output resistance that is inversely proportional to the applied force and easily calibrated and interfaced to a microcontroller with an in-built analogue-to-digital convertor. Through experimentation, a relationship between the weight of work-piece to be gripped and the force to be applied for gripping was determined. This was used to successfully manipulate work-pieces of various shapes and sizes up to the robot payload of 0.5 kg. Analysis of various forces acting on the work-piece was also carried out.

Keywords

Force sensor • Piezoresistive • Industrial robots • Pick-and-place

Introduction

Humans have the amazing ability to safely grasp objects of various shapes and sizes by only applying enough force. While such work can be carried out with ease and without much thought by humans, getting a robot to perform a gripping task can become very complicated depending of the application. Applying excessive gripping force when gripping a delicate object can damage the object or damage the gripping mechanism and actuator in the case of a rigid object.

The ultimate aim of robotics research is to develop intelligent systems that can operate autonomously and probably the key autonomous feature required of industrial robots in pick-and-place operations is applying the right force when picking objects. In the work reported in this paper, the use of a Tekscan FlexiForce force sensor to measure the force when gripping work-pieces using the two-finger gripper of a five degree-of-freedom pick-and-place robot, reported in [1–3], is illustrated.

With the incorporation of a vision system in its workspace, the robot is used for picking and placing work-pieces of different shapes and colors scattered on its work-plane, as specified by the user through a graphical user interface (GUI). The work-pieces vary in weight but weigh less than or equal to the maximum payload of 0.5 kg. The force sensor has been mounted on one of the gripping fingers and it sits below the rubber gripping pad.

While there are many off-the-shelf force sensors which can be used for such applications, the FlexiForce force sensor offers advantages such as low-cost, ease of mounting since it is thin and flexible, varying force range, and easy interface to control devices which other sensors may not offer. It finds usage in many applications and research such as robotics [4], airbags [5], surgery [6], toe forces [7], and knee forces [8].

R.V. Sharan (✉)
School of Engineering and Physics, University of the South Pacific, Suva, Fiji
e-mail: sharan_r@usp.ac.fj

G.C. Onwubolu
Knowledge Management and Mining, Toronto, Canada
e-mail: onwubolu@gmail.com

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Sensor Overview

The FlexiForce force sensor, shown in Fig. 1, is a piezoresistive type where the output resistance is inversely proportional to the applied force. Piezoresistive force sensors have an advantage over the capacitive types as they require simple read-out circuitry [9]. It is ultra-thin with a thickness of 0.203 mm, 14 mm wide and available in four different lengths with minimum and maximum sizes of 51 mm and 197 mm respectively. The sensor is also available in three different force ranges capable of measuring up to 440 N which can be increased further with the implementation of excitation circuitry as given in [10].

The sensor employed in this work is the A201 model with a length of 197 mm and a force range of 0–110 N. The active sensing area, which is circular in shape, is 9.53 mm in diameter and it comes with a three-pin connector. It offers a repeatability of less than 2.5 % of full scale with a response time of less than 5 microseconds. Currently, a package of four of this product is available at US$65 [10].

Force Measurement

The output at the force sensor terminals is resistance and when force is applied to the active sensing area of the sensor, the resistance at the terminals decreases from an infinite value at no load. Through experimentation, a relationship is determined to relate the load to be gripped and the sensor resistance. Firstly, masses at increments of 100 g, up to 1.0 kg, were put in between the two gripping fingers and then gripped until the load was fully grasped. A plot of the output resistance of the force sensor against the load being gripped is shown in Fig. 2.

Fig. 1 FlexiForce force sensor

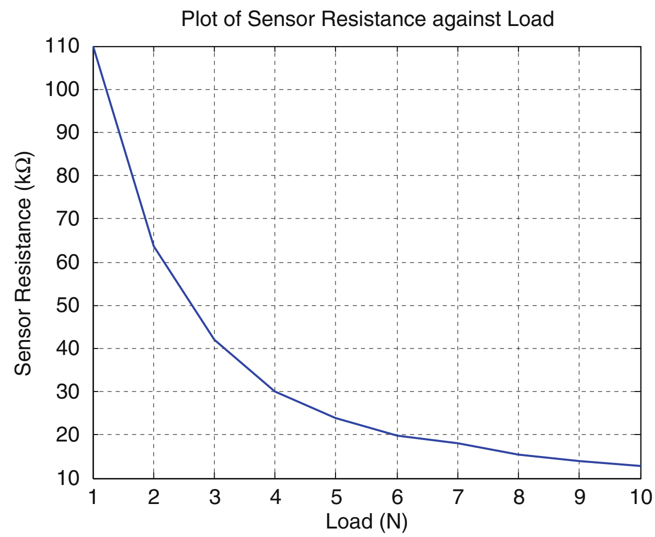

Fig. 2 Relationship between the load being gripped and the force sensor resistance

Mathematically, this hyperbolical relationship is approximated using Microsoft Excel as

$$R_S = \frac{115.61}{W^{0.9618}} \tag{1}$$

where W and R_S denote the weight of the load and the resistance at the terminals of the force sensor respectively.

The in-built 8-bit analogue-to-digital (ADC) convertor of the PIC16F877 microcontroller is used for force measurement. However, the ADC reads analogue voltage values and due to the small force range considered for this work, a simple voltage divider circuit, with a source voltage V_S of 5 V and load resistance R_L of 20 kΩ, was preferred for converting the sensor resistance to voltage over the circuit given in [10]. The load voltage is then given using the voltage divider rule as

$$V_L = \frac{R_L}{R_S + R_L} V_S \tag{2}$$

where R_S can be found using (1) for the load to be gripped.

The force sensor is connected to the analogue pin A0 of the microcontroller. Since the microcontroller has an 8-bit ADC, the input voltage from the force sensor V_L has a range from 0 to 255 corresponding to $0 - 5$ V respectively. The input voltage corresponding to the 8-bit value v is then determined as

$$V_L = \frac{v}{255} \times 5. \tag{3}$$

However, (1) does not give the relationship between the gripping or sensor force and the load being gripped.

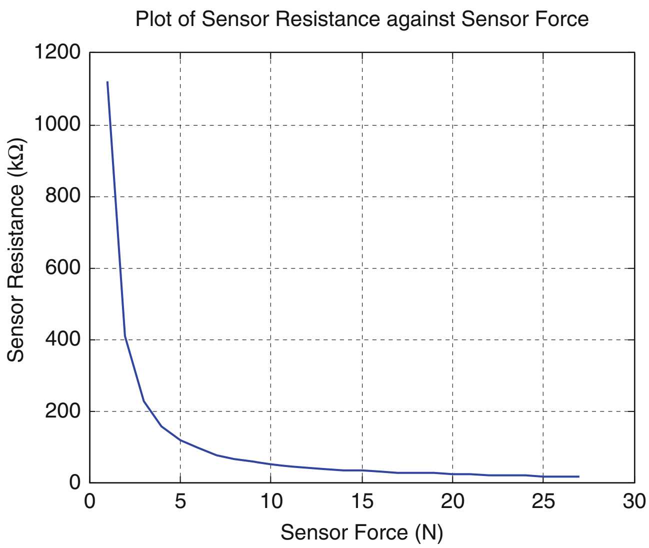

Fig. 3 Relationship between the sensor force and the sensor resistance

Therefore, another experiment is performed to determine this relationship by applying known forces normal to the sensor. Similar to the previous experiment, the force sensor resistance decreases hyperbolically with an increase in the force on the sensor, as shown in Fig. 3.

The relationship between the sensor force F_S and the sensor resistance R_S is approximated using Microsoft Excel as

$$R_S = \frac{933.64}{F_S^{1.2452}}. \tag{4}$$

Equating the two resistances from (1) and (4) and making F_S the subject of the formula yields

$$F_S = 5.35W^{0.7724}. \tag{5}$$

Hence, (5) is used to estimate the force needed to grip work-pieces of different weights.

Analysis

The free-body diagram depicting the gripping of a work-piece using the two-finger gripper of the robot is shown in Fig. 4. The two normal forces $\mathbf{F}_N$, are the forces applied by the gripping fingers while the friction force between the gripping fingers and the work-piece is designated as $\mathbf{F}_R$.

Assuming that just enough force is applied to grip the work-piece and that the two normal forces and the two frictional forces are same, with a payload of 0.5 kg or 5 N, the frictional force $\mathbf{F}_R$ will be approximately equal to 2.5 N. Also, the normal force, which is equal to the sensor force, is determined using (5) to be 18.55 N.

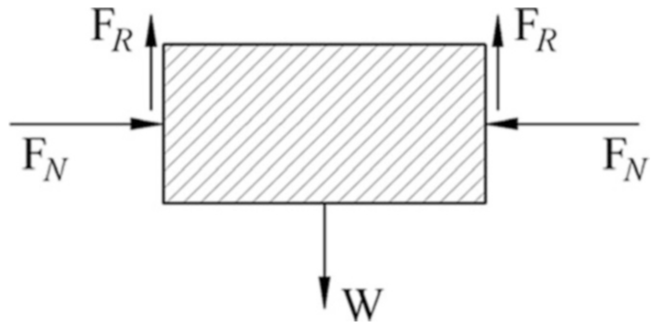

Fig. 4 Free-body diagram showing the forces acting on a work-piece

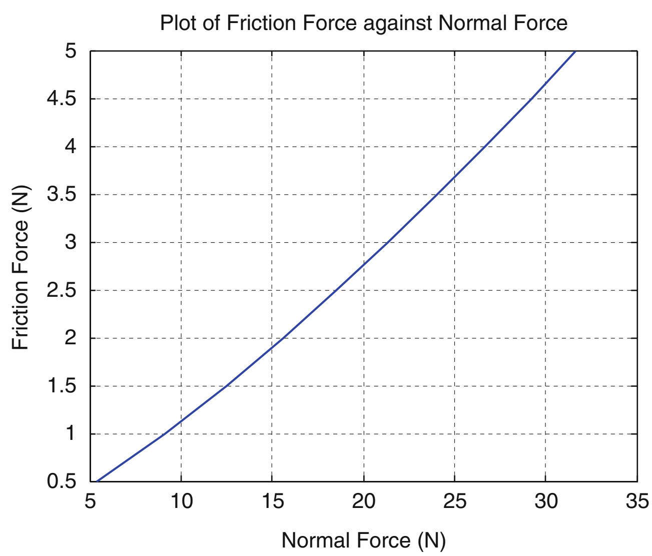

Fig. 5 Plot of friction force against the normal force

Similar analysis was done for loads from 1 N to 10 N at increments of 1 N and the plot of the friction force against the normal force is shown in Fig. 5.

The slope of the approximately linear curve obtained gives the coefficient of static friction between the work-piece and the rubber gripping pads which is calculated to be approximately 0.17.

Conclusion

The FlexiForce force sensor was used to successfully grip work-pieces of various masses up to 0.5 kg which is the maximum payload of the pick-and-place robot. This was achieved by manually specifying the gripping force in the test codes of the microcontroller. However, during fully autonomous operation, the system is currently unequipped to determine the weight of the work-pieces. As such, gripping is carried out with view of the maximum payload. A future goal is to make this system more intelligent whereby it can determine the weight of work-pieces itself and then apply the corresponding gripping force. Also, while rigid work-pieces were used in this experiment, further work needs to be done to see the performance of this sensor when manipulating delicate objects.

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