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Force & Compliance Detection on Robot Gripping Manipulator

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Abstract

Conventional methods for remotely controlled gripper robotic systems are usually limited to visual and auditory. A way to increase the performance of such gripper is to incorporate the sense of touch into the human-robot interaction. Sense of touch allows the user of the robotic system to feel what makes robot operation more realistic. This paper addresses the compliance and force issues on a robot hand gripping manipulation system. Experimental work performed on strain gauge sensory equipped at the jaws of a robot hand to measure the force and compliance of selected flexible objects. We carried out some experimental procedures of force measurement by using a strain gauge separately and on a steel rod (jaw of gripper). Wheatstone bridge arrangement was used with high sensitivity strain gauge sensors to calculate the stress applied on the steel gripper jaws of forces ranged between 1N to 20N. More tests were performed on the mechanical properties of the polymers material used to find the stability point object between gripper jaws without fracture. The results demonstrated that the strain gauge sensor can effectively be used for deformation and compliance measurements. Furthermore, the results also demonstrated the effectiveness of the proposed strategy based on gripping force and deformation of objects.

Keywords: Compliance, force, Gripper jaws, strain, strain gauge.

Introduction

Grippers are subsystems of handling mechanisms which provide temporary contact with the object to be grasped. They ensure the position and orientation when carrying and mating the object to the handling equipment. The majority of the researches in the area of grippers utilize electric or pneumatic actuators and two parallel fingers. Electrically actuated grippers generally utilize DC or stepper motors to provide the motive force. Transmission systems like ball screws, gears, pulleys or other mechanical linkages are necessary to convert the motion of the actuator to the finger motion, adding to the complexity, size and weight of the gripper assembly. Grippers vary by form and task that they can perform. The usage area of a robot in industry is increased by using a single gripper with modular fingers or using multiple grippers which can be replaced easily. In robotics, sensors measure a physical property of the robot or of the objects in the environment and transform it into a signal which can be recognized and analyzed by the robot control [3]. Force sensors are used to measure the interaction force between gripper⁄effectors, the part to be handled and the environment. A principle of force sensor is when a force is applied to a block of rubber, it will change the shape, even though it's very much the deformation could be measured. By calibrating the block, which is measure how much it deforms when subjected to a sequence of known forces, subsequently it can be used to measure the force by measuring its deformation. Alternatively some materials can change their electrical resistance when mechanically deformed and thus can be used as a force sensor provided there is a means available to measure resistance change. This resistance change principle of force transducer will be used in this project. In some instances, researchers in robotics take leads from the study of human grip force dynamics. Duncan Jr. Howard Arthur (in1979) developed a gripping force sensor based on bonded strain gauges for computer controlled mechanical assembly, however his work has not covered the grasping and compliance effect issued. In a series of papers, H. Inooka and I. Kim [4, 6] describe a control strategy for robot hands based on the human precision grip dynamics. The authors needed to compensate for a lack of sensing technology in robotic hands, and do so by determining the onset of slip based on the change in velocity of the object being grasped. They develop a control scheme very close to that presented by Macefield et al. [6], and implement the findings. John Hollerbach, one of the major players in robotic hand research, authored a chapter in Vision and Action: The Control of Grasping entitled "Grasping in Human and Robot Hands [5]." Hollerbach gives an overview of the state of the research (in 1990) including grasp geometry, path planning, fine motion control, regrasping, finger and hand control, tactile sensing, and ending with robotic hand design. In terms of robotic manipulation, a fully integrated force/tactile sensor has been developed by G.Cannata [8] for the "machand", as well as a technique to compute the pressure centroid and the associated ellipsoid during contact [9]. A dynamical model for viscoelastic pads useful to quantitatively characterize the behavior of materials used to cover robotic hands was presented by [1], a control approach, exploiting the relation between the stiffness and the applied load, was proposed by [7] in order to arbitrarily change the overall stiffness of a robot hand. Using the robot "Obrero" has demonstrated the feasibility of the "tapping" exploration procedure by using a finger to tap objects and use the produced sound to recognize them. We present our work for developing a gripping force sensor based on bonded strain gauges sensor for grasping compliance objects that need low force.

Force, Stress/Strain Measurement

Determination of the Gripping Force. The gripping force can be sensed directly by measuring the jaw surface strain with resistance-type strain gauges. Developing a gripping force sensor based on bonded strain gauges. There are many objects that appear visually similar but can be easily distinguished using strain gauge sensing. Furthermore a robot is able to distinguish visually similar objects that have different elasticity properties by using only the information obtained from the strain gauge sensor. However, most of the objects in the real world are not rigid solids Polymers material for example, needs very low force to be gripped. The maximum force was selected to be approx 20 N, so our force measurement was performed within this range. A Wheatstone bridge configuration consisted of four strain gauges. Each pair of strain gauge responded to a maximum compressive strain, and the other pair of strain gauge responded to a maximum tensile strain induced by the bending. Both gauges were mounted to the same gripper jaw. Fig. 1 illustrates the two jaws robot gripper with strain gauge.

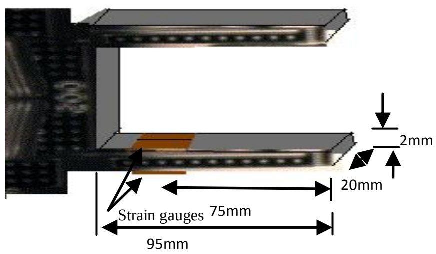

Fig. 1. The gripper with strain gauge mounted

A compliance object held still in the hand or gripped by a robot gripper, without any rotary or translator movement, constitutes a physical system at rest. The assumptions made in the analysis of the system are:

1) The material of the object is homogeneous.
2) The angle or orientation of the object with respect to the ground plane is known.
3) The gripper-object system is at rest and in a state of static equilibrium.
4) The object is from polymers material.
5) The position points which connect the object with gripper of jaw are known and constant.

The gripper-object system is considered to be in static equilibrium when there is no macroscopic motion; in this situation, a balance of force is maintained. This assumption excludes any situation where damages or permanent deformations may occur to either the object or the gripper due to excessive forces and torques, or to any micro-motion.

Required Sensitivity of Strain Gauge. Resistive strain sensors can be made of several materials. To convert the change in resistance to strain, the sensitivity factor (gauge factor) of the strain gage material must first be determined. The sensitivity factors of common strain gage materials are listed in the following Table 1.

Table 1 Sensitivity factors of some alloys used for strain gauges [10]

Material	Sensitivity Y(s)
Platinum (Pt 100%)	6.1
Platinum-Iridium (Pt 95%, Ir 5%) Platinum-	5.1
Tungsten (Pt 92%, W 8%)	4.0
Isoelastic (Fe 55.5%, Ni 36% Cr 8%, Mn 0.5%) *	3.6
Constantan / Advance / Copel (Ni 45%, Cu 55%) *	2.1
Nichrome V (Ni 80%, Cr 20%) *	2.1
Karma (Ni 74%, Cr 20%, Al 3%, Fe 3%) *	2.0
Armour D (Fe 70%, Cr 20%, Al 10%) *	2.0
Monel (Ni 67%, Cu 33%) *	1.9
Manganin (Cu 84%, Mn 12%, Ni 4%) *	0.47
Nickel (Ni 100%)	-12.1

*Isoelastic, Constantan, Advance, Copel, Nichrome V, Karma, Armour D, Monel, and Manganin are all trade names owned by the respective owners.

Platinum and Nickel which are not used in the pure form are listed for comparison purposes only. Element metals often have very good conductivity as seen in the case of copper and they also have high temperature coefficients that make them unsuitable as strain sensors. The ideal material would have high resistivity and zero temperature dependence such that the sensing current can be kept low and the sensor produces true readings at all temperatures. Several alloys have been developed for that purpose. Constantan is a copper-nickel alloy, usually consisting of 55% copper and 45% nickel, that is used for strain gauges. The exact composition of copper and nickel is selected such that the change in resistance due to thermal expansion is mostly cancelled out by the temperature coefficient of resistance of the strain gauge. This makes constantan a popular choice in commercial strain gauges. Manganin is another alloy with improved temperature coefficient over constantan but it is less sensitive to strain. As mentioned earlier the resistance changes with strain because of a geometrical factor and a piezoresistive effect. Metals are generally not piezoresistive whereas semiconductors are dominated by this effect in which case the resistivity ρ is non-constant. The gauge factor is slightly above 2 for most metals but it can be 100-200 for semiconductors [2]. In order to develop a sensor module for application in haptic force feedback system, strain gauge was used as sensors suitable to be mounted in the gripper.

Selections of Materials. The choice of material model is important and may not always be obvious. To understand the behavior of the compliance materials, it is necessary to perform material testing. A good way to evaluate material behavior is to do tensile tests at different rates. This will, among other things, show elasticity effects in the material. Some of the material properties are provided by the material supplier, but they need to be complemented with further material tests. The polymer used in this study is plastics thermoplastic as High Density polyethylene HDPE material, Supplied in granular form plastics thermosetting as Bakelite material and plastics elastomeric as Rubber material. They are tested in compression at room temperature as a function of strain-rate. Many polymers that undergo loading above the yield stress stretch uniformly for a few percent and then, instead of breaking, they fail by forming a neck.

The neck may get steadily thinner until break, or it may stabilize at some point and then the shoulders travel along the specimen. In this case, the phenomenon is called cold-drawing. Necking is a geometrical behavior, which typically starts before the softening on the engineering stress-strain curve. Furthermore strain will change the softening process into a hardening process until failure. Another interesting feature of polymers materials is that they show a different behavior when they are exposed to compression compared to tension.

The Tensile Test. In order to accurately model the material behavior, a reliable set of experimental data over an adequate range of strain rates is required. The stress-strain testing of polymers is a formidable task due to the difficulty of conducting such tests to very large strains while maintaining a homogeneous state of deformation. Tensile tests with constant displacement rate were performed on all test specimens for comparison with the simulated tensile test results. The test equipment measures applied displacement versus obtained load. This data can not directly be transformed to true stress and true strain, since the cross section area decreases with the strain. Due to the lack of test equipment that could measure this area decrease, we had to find this in another way.

Choice of Gripper. Two-jaw gripper of robot is the simplest type of jaw grippers. Two-jaw gripper consists with two gripping fingers that apply pressure externally or internally on the object depending on the jaw design. Depending on shape and size of the object , the jaw-fingers can be designed different for an accurately and securely movement. The two-jaw grippers can be used for large and small objects. A cantilever arrangement as shown in Fig. 2 was made for using the strain gauge as a force sensor. In this arrangement, the strain gauge was pasted on a beam. Steel rectangular bar of known young's modulus at a predefined distance from one end, gauge length being parallel to the length of the beam.

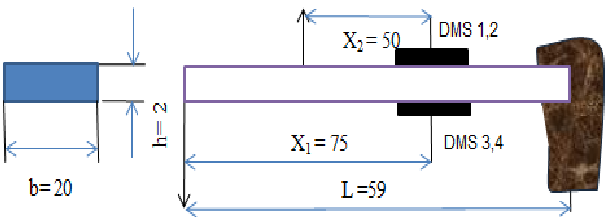

Fig. 2. Dimensions of the gripping rod

Results and Discussion

From the data collected during the experiments on characteristics of strain gauge sensor, the predicted deflections and strains were calculated. The measured values of deflection and strain were then compared to their corresponding predicted values using percent error.

Strain Gauges Characteristic Test. Number of tests determines the linearity of strain gauge over various loads. Fig. 3 shows the calibration equations determined from these tests. The relationships show a high degree of linearity over a wide range of loads and forces. It can be noticed that the application of a loads causes an elastic stretching movement.

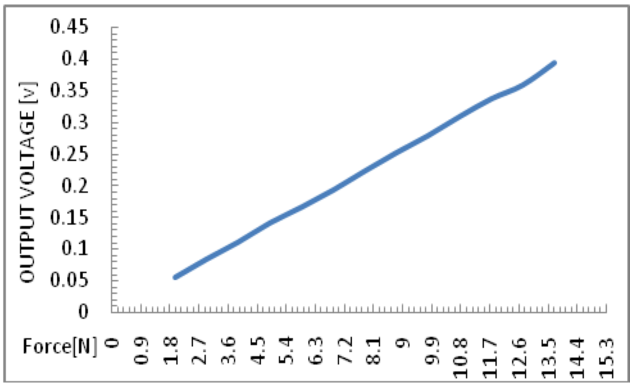

Fig. 3. Calibration results for output voltage using applied force

Tensile Test on Compliance Materials. The mechanical properties of polymers are specified with many of the parameters, that is, modulus of elasticity, and yield (critical) and tensile strengths. For many polymeric materials, the simple stress–strain test is employed for the characterization of some of these mechanical parameters. The mechanical characteristics of polymers, for the most part, are highly sensitive to the rate of deformation (strain rate), the temperature, and the chemical nature of the environment (the presence of water, oxygen, organic solvents, etc.).

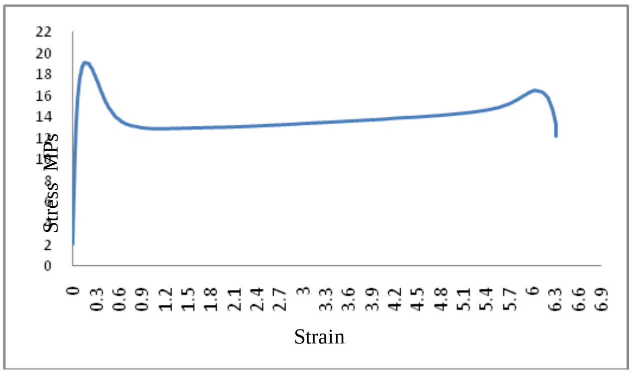

Fig. 4. Stress-strain curve for a typical grade of HDPE

Fig. 4 shows the stress-strain curve for a typical grade of HDPE, to describe elastic properties of linear objects whether it is in the form of expansion and compression, a convenient parameter is the ratio of the stress to the strain of 0.8 Gps called the "Young's modulus" or "Modulus of Elasticity" of the material. Young's modulus can be used to predict the elongation or compression of an object as long as the stress is less than the yield strength of the material. The yield strength corresponds to the first maximum (just beyond the initial linear-elastic region) of the stress-strain curve. This reading in the stress window located above the plot as the critical point is 19.9Mpa and the curser point is dragged along the stress-strain curve is 12.2 MPs. The approximate percent elongation corresponds to the strain at fracture multiplied by 100 (i.e., 633.67%) minus the maximum elastic strain (i.e., value of strain at which the linearity of the curve ends multiplied by 100—in this case about 4%); this gives a value of about 629.67%EL

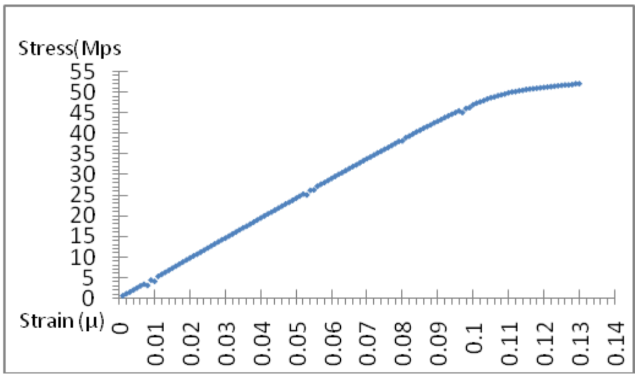

Fig. 5. Stress-Strain curve for a typical grade of Phenol-Formaldehyde (Bakelite)

Fig. 5 shows the stress-strain curve for a typical grade of Bakelite, to describe elastic properties of linear objects whether it is in the form of expansion and compression, a convenient parameter is the ratio of the stress to the strain of 35 Gps called the "Young's modulus" or "Modulus of Elasticity" of the material. Young's modulus can be used to predict the elongation or compression of an object as long as the stress is less than the yield strength of the material. The yield strength (critical point) corresponds to the first maximum (just beyond the initial linear-elastic region) of the stress-strain curve. The tensile strength corresponds to the stress at which fracture occurs. This reading in the stress window located below the plot as the critical point is 48 Mps and the curser point is dragged along the stress-strain curve is 52 M pa. The approximate percent elongation corresponds to the strain at fracture multiplied by 100 (i.e., 1.29%) minus the maximum elastic strain (i.e., value of strain at which the linearity of the curve ends multiplied by 100—in this case about 1%); this gives a value of about 0.3%EL.

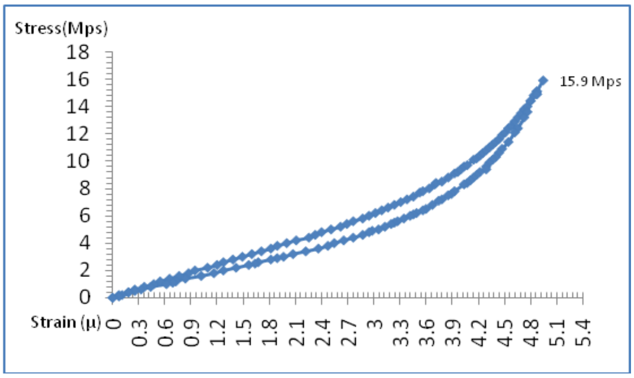

Fig. 6. Stress-strain curve for a typical grade of natural rubber

Fig. 6 shows the stress-strain curve for a typical grade of Natural Rubber, to describe elastic properties of linear objects whether it is in the form of expansion and compression, a convenient parameter is the ratio of the stress to the strain of 0.002 Gps called the "Young's modulus" or "Modulus of Elasticity" of the material. Young's modulus can be used to predict the elongation or compression of an object as long as the stress is less than the yield strength of the material. The deformation displayed by stress and strain curve is totally elastic and totally nonlinear; this elasticity (large recoverable strains produced at low stress levels). When comparing the stress/strain relationship of the beam (gripper) to the stress/strain relationship of the gripped objects (compliance materials) we find that there is a linear relationship between stress/strain of the strain gauge in the range of 3.71 Mps to 70.83Mps. Such a range covers the yield stress values of all the compliance materials. This ranges between 9 Mps for LDPE and 44Mps for Nylon. For example, the standard yield stress for HDPE is 26.2–33.1 Mps which almost agrees with the analytical beam (Gripper) Yield stress of the 19.1 Mps under 5.0994 N an effect force with output voltage 0.1445Vand strain of 92.381µε as presented in Fig. 7.

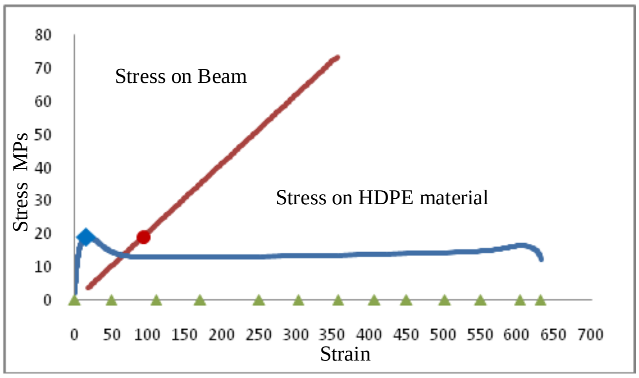

Fig. 7. Stress/Strain of the beam (gripper) and the gripped objectHDPE materials

Fig. 8 represents the yield stress for Bakelite. The standard tensile stress for Bakelite is 34.5–62.1 Mps. This value almost agrees with analytical beam (Gripper) Yield stress of the 47.9 Mps less than 12.749 N an effect force with output voltage 0.362Vand strain of 230.954με.

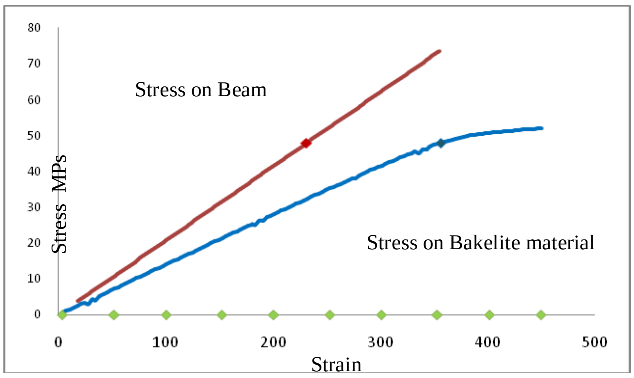

Fig. 8. Stress/Strain of the beam (gripper) and the gripped object(Bakelite).

It is clear from Fig. 9 that the material of natural rubber has no critical point (Yield stress) and is totally nonlinear. It is concluded that for flexible materials (Elastomers) the force required to grip is hard to be determined and therefore other means are required.

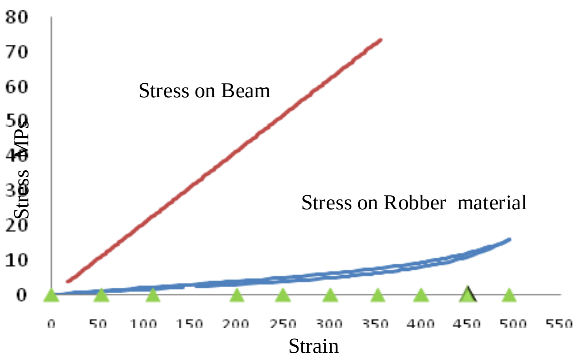

Fig. 9. Stress/Strain of the beam (gripper) and the gripped object (NR materials).

Conclusion

This research work studied the behavior of compliant material and their characteristics. The study also focused on the stress and strain measurements in an attempt to determine the relationship between force and power and hence determine the gripping force of the grippers taking into account the mechanical characteristics in terms of yield stress. The range of force used to characterize the sensor has been chosen from 1N to 20 N of force. Forces of this magnitude are more frequently applied. Also the length of the beam used the simulated the jaw gripper considered in this study is impractical to use in large objects volumes. A length of 95mm has been used for convenience in calculations. The strain produced in the strain gauge is directly proportional to the length L. The value of output voltage may change, however other length may apply and the behavior of the sensor shall remain unchanged. Experiments proved that different polymers have different tensile strengths, Young's modulus and yield strength, for example - Bakelite has the highest tensile strength and Young's modulus, whereas NR and HDPE have the lowest. We can conclude that polymers with higher Young's modulus usually exhibit low or no yield strength as high Young's modulus material is rigid. Bakelite is the strongest, as it withstands large amount of force before it reaches the breaking point. However, Bakelite can easily reach the breaking point almost immediately once the maximum load is applied. HDPE on the other hand requires less amount of force to break, but it exhibits longer time to break for yield even when a maximum force is applied. We can also conclude that the combination of high tensile strength and high yield strength can lead to tougher material. Tensile properties are important for us to determine which material is suitable for a specific application to ensure quality. All in all, tensile test is important, simple and relatively inexpensive to determine tensile properties. When comparing the stress/strain relationship of the beam (gripper) to the stress/strain relationship of the gripped objects (compliance materials) we find that. There is a linear relationship between stress/strain of the strain gauge in the range between 3.71 Mps to 70.83Mps. Such a range covers the yield stress values of all the compliance materials this ranges between 9 Mps for HDPE and 44Mps for Nylon 6.6. The yield stress for Bakelite happened to be 48Mps which almost agrees with analytical beam (Gripper) Yield stress of the 48.3 Mps under 12.89 an effect force with output voltage 0.336Vand strain = 249.61 $\mu\varepsilon$. The material of natural rubber has no critical point (Yield stress) and is totally nonlinear. It is concluded that for flexible materials (Elestomers) the force required to grip is hard to be determined and therefore other means required.

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