Estimating objects' weight in precision grips using skin-like sensors

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Abstract. The estimation of object's weight is a very challenging problem due to limitations on tactile technology and robust and fast controllers that can adapt to friction state changes. In this article we study the weight estimation using skin-like tactile sensors, which provide accurate 3 dimensional force measurements on the finger tips of Vizzy, a robot with human-like hands. The sensor reading from the fingertips are analyzed and segmented in order to find the most adequate stages of the movement for the computation of the weight. The analysis is based on the difference of the load force between the grasping and holding up stages, which provides a good estimation of the object's weight for different objects and various repetitions of the experiments.

Keywords: Weight estimation, humanoid robots, tactile sensors,Vizzy robot

1 Introduction

Humans are able to execute manipulation actions that aim at adapting the gripping force while grasping objects, using rough weight guesses from vision as initial estimation, followed by tactile afferent control loop that provides robust and precise grasp such as the precision grip. The capability of a fast adaptation using the tactile sensors relies on the high density of tactile afferents (about 140 afferents/cm^2) in the fingertips and the specialized action-phase controllers [3], which allow to sense accurately large areas of the objects when compared to the current technologies for robotic hands tactile sensing. Nevertheless, studies on grip control and slippage detection for robotic hands have shown the plausibility of haptic feedback for robots in simplified experimental setups. In addition to the technological limitations, adaptive object manipulation requires robust switching control algorithms and independent-mode controllers that provide a fast response, and at the same time model unstable states such as grasping in the presence of dynamic friction. All these challenges are closely related to the weight estimation of objects by humanoid robots in uncontrolled environments, which is the long-term objective of our work.

Fig. 1: Example of the initial robot configuration before the execution of a precision grip experiment for weight estimation

In this article we address the weight estimation of objects, by executing manipulation actions with the humanoid robot Vizzy [4], which has two hands very similar to their human counterparts. Fig. 1 shows the robot right at the beginning of a weight estimation experiment. Although the robot was mechanically designed for power grasps, Vizzy is able to execute precision grips for medium size objects. We focus on the weight estimation of objects during the execution of precision grips, using skin-like tactile sensors at the fingertips [5]. The sensors provide an estimation of the force from the changes in the magnetic field, considering three main elements: (i) a 3 dimensional hall effect sensor, (ii) a magnet and (iii) a silicon cover for the magnet. The changes in magnetic field due to the deformation of the silicon part are mapped onto 3 dimensional forces, which provide the tactile perception to the silicon cover. These 3 dimensional forces estimated by the sensor are analyzed over time in order to find the different stages of the precision grip execution. The sequence of stages is as follows: (1) initial positioning of the hand around the object,(2) object grasping and lifting, (3) holding, (4) returning the object to the initial position and (5) returning the robotic hand to the initial position. These stages are segmented for all the sensors that touch the object, and the estimation of the weight of each object was based on the assumption that the difference between the forces exerted by the robotic hand in the stages 2 and 3 along the three directions sum up to the weight of the object (i.e. the change in the load force due to gravity). In addition, we consider that the friction force keeps a constant value during the stages 2 and 3, which is valid if there is no relative movement between the object and the sensors (no slips nor oscillations). Therefore, the friction component of the force is removed by calculating the difference between the forces in stages 2 and 3.

We evaluate the weight estimation algorithm on two objects with different size and shape, and also increasing the weight of the objects by adding water.

The results show that the tactile sensor provide good estimation of the weight while having skin-like skills.

2 Related Work

Recent developments in tactile sensing such as BioTac[1], OptoForce[2] and the skin-line magnetic-based [5] sensors have opened the door to explore the challenging area of grip control [7,1] and slippage detection [6] for robotic hands. Since autonomous grip control using tactile sensors is still an open research problem due to technology limitations and development of controllers that are able to operate in different conditions such as the changes between static and dynamic friction. A robust set of controllers should be able to switch between states and adaptively change the control reference in order to manipulate autonomously objects with different materials and shapes. Thus, the autonomous weight estimation is a very challenging problem that has to consider physical properties (i.e. static and dynamic friction), autonomous switching between control modes and the contact points on the object. Thus, the weight estimation of objects is usually done in simplified settings where for instance the object shape fits very well the gripper shape and the robot arm is carefully designed for the weight estimation by following the moving crane approach [2]. In that work, the manipulation action is a power grasp where the friction problems are not present, but the authors are able to estimate online the object weight in a very short time (0.5-0.7secs.). In [2], the voltage signals of the load cell (sensors) are analyzed offline in order to characterize the different manipulation stages. Then, associations between the voltage response and the manipulation stages lead to an ad-hoc algorithm for the segmentation of the signal. Finally, the average value of the signal in the selected interval is utilized to learn the parameters of a regression function that maps load cell voltages onto weights. As in [2], we analyze the signal response over time and identify the manipulation stages. However, we address a more challenging manipulation problem, the two-fingertip precision grip of a humanoid robot hand, where the friction issues arise. In the following we describe the characteristics of the hand.

3 Vizzy's hand design

In this work is used the robot Vizzy [4] to perform the grasps. Vizzy was designed as a human assistant for social interaction tasks. Vizzy has an anthropomorphic upper body with similar degrees of freedom and motion execution skills of a human. Regarding its hands, the palm and finger sizes and number of limbs are also similar to an adult person, but having only four fingers capable of grasping objects. The thumb and index fingers are actuated each one by a single motor,

[1] `https://www.google.com/patents/US7658119`
[2] `https://optoforce.com/file-contents/OMD-20-SE-40N-DATASHEET-V2.2.pdf?v14`

while the middle and ring fingers are coupled to one motor. The motor of a finger is coupled to a pulley, that pulls a fishing line string. The fishing line string is attached from the pulley to the last limb of the finger, such that the motion of one motor moves in an under-actuated manner the three limbs of each finger. In this work we only used two fingers: thumb and index, in order to perform the precision grasp. Regarding the sensors, the thumb has three sensors and the rest of the fingers have four sensors each. The sensors are presented in orange in Fig.2 and the ones used in this experiment are numbered from 1 to 4.

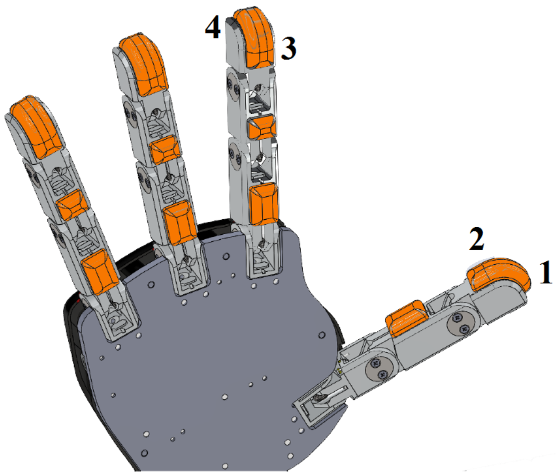


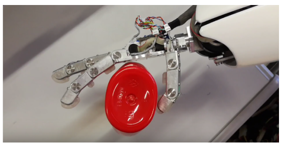
Fig. 2: Indexes of the force sensors in Vizzy's hand

These tactile sensors [5] are composed by a soft elastomer body with a small permanent magnet inside. Below the magnet there is a magnetic field sensing element (i.e. Hall-effect sensor). When an external force is applied on the elastomer, the relative magnet position changes and the Hall-effect sensor detects the magnetic field variation, that can be converted in a measure of the applied force. An air gap is left between the elastomer and the magnetic sensor in order to increase the sensitivity for small forces. The use of a 3-axis Hall-effect sensor allows the detection of the magnetic field variations along the 3 axis, meaning that the sensor is capable of measuring the force magnitude and direction in 3D. The presented tactile sensors are dependent on the contact area, that is unknown. The feedback of the measured Hall sensor provides the magnetic field vector. To achieve the force vector, some assumptions of the contact area are needed during the calibration process. The sensors are calibrated for a contact with a plane surface perpendicular to the Z axis of each sensor. The 2 sensors near the fingertips are covered with same elastomer piece but each sensor has its own individual calibration, made with a planar surface on top of that sensor.

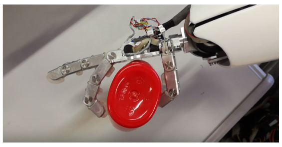
4 Experiment setup

The experimental tests were performed using two different objects (plastic containers) with similar shapes and surface characteristics but slightly different sizes (Fig. 5). In order to increase the variability of the test objects regarding the variable of interest, these objects were used in two different configurations: empty and partially filled with water. The movement executed by the robotic arm during data acquisition can be divided into a series of sequential steps described in the Introduction(1).

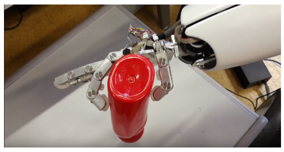
Fig. 3: Test objects: object 1 (left) and object 2 (right).



(a) Stage 1

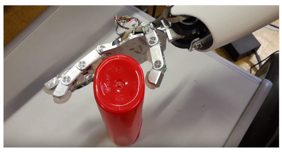


(b) Stage 2



(c) Stages 3 and 4

(d) Stage 5 (beginning)



(e) Stage 5 (end)

Fig. 4: Movement phases: 1-initial position; 2-object grasping and lifting; 3-holding; 4- landing the object; 5- return to the initial position.

At the beginning of the test (stage 1, on Fig. 4a), the palm of the robotic hand was placed perpendicularly to the surfaces of the object where the contact would be established. The initial position of the object and the hand was defined according to two main criteria. On the one hand, there was no initial contact between them in order to assure that the sensors would not detect any significant force at this stage of the sequence. On the other hand, the relative position of the thumb and the finger had to be optimized in a way that the grip forces exerted by these fingers were approximately perpendicular to the surface of the object and parallel to the palm of the robotic hand. This was achieved by setting the thumb to an abducted position and the index finger in opposition to it. According to the GRASP Tanoxomy [1], this type of grasp corresponds to a precision grasp with pad opposition, which is naturally executed by humans to grasp small objects. The optimization of the initial relative position of the hand and the object has proven to be critical for the success of the grasp, particularly to prevent oscillations in posterior stages of the movement and to guarantee the appropriate contact between the sensors and the object. The following stage of the movement (stage 2, on Fig. 4) consisted in the movement of the thumb and the finger against the surface of the object without changing significantly their initial configuration. The final position of the fingers at this stage was tuned to optimize the compromise between minimizing the potential occurrence of slipping events during the lifting phase while not inducing any significant degree of deformation in the object. The following stage of the sequence was the lifting and holding of the object (stage 3, on Fig. 4). During these phases, the most relevant issue was to minimize the motion artifacts resulting from small oscillations of the object, which was accomplished by controlling the velocity of the movement of the robot's joints. Finally, both the objects and the robotic hand were returned to their initial positions (stages 4 and 5 on Fig. 4). and the robotic hand also returned to the configuration described in the first stage. The sequential movement was repeated over several trials for each one of the objects and the acquisition of the data from the sensors was performed using the Arduino Nano board. The raw data consisted of the magnitude of the forces along the three directions measured in each sensors reference frame. Matlab was used for real-time visualization and monitoring of the results as well as post-acquisition signal processing and extraction of the results.

5 Results

Figure 5 displays the results obtained in one of the trials performed with the test object 1, consisting of the magnitude of the three components of the force (F_x, F_y and F_z) over time, for one of the sensors of the robotic hand. The sampling frequency used for data acquisition was 20 Hz and each trial lasted for approximately 12.5 seconds, which was enough to perform the previously described sequence of movements and to obtain an appropriate number of samples in each one of the stages. The estimation of the weight of each object was based on the assumption that the difference between the forces exerted by the robotic hand in the stages 2) and 3) along the three directions sum up to the weight of the object. Another necessary assumption is that the friction (and resultant force) is constant during the movement, which is valid if there is no relative movement between the object and the sensors (no slips nor oscillations). Therefore, the

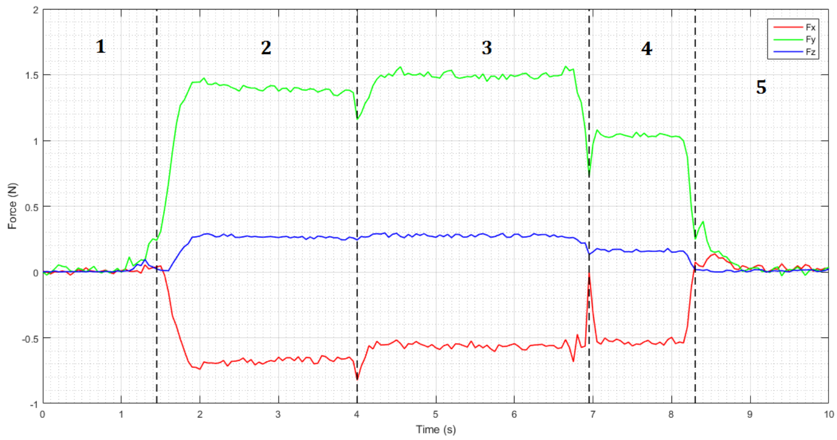


Fig. 5: Illustrative example of the results obtained for one trial performed with test object 1. The graphic represents the magnitude of the three components of the force (Fx, Fy, Fz) for one sensor over time as the sequence of movements is executed. The vertical lines along the time axis represent the temporal sequence of stages that constitute the overall movement: 1) initial position of the robotic hand; 2) lifting and grasping 3) holding; 4) returning the object to its initial position (in contact with the table); 5) opening the robotic hand.

friction component of the force is nullified by calculating the difference between the forces in stages 2) and 3). It was necessary to manually identify stages 2) and 3) for each one of the trials and compute the average force along the directions X, Y and Z for sensors 1, 2, 3 and 4 during those stages of the movement. The weight of the object was then estimated as the sum of the absolute difference between the average load and grip forces measured during stages 3) and 2), respectively 1. The mass was computed according to equation 2, where m stands for the mass of the object in grams, F_{Total} is the difference between the average forces in stages 2) and 3) that was identified as the weight of the object and g is the acceleration due to gravity. Table 1 summarizes the results of the mass for objects 1 and 2 in both configurations.

$$F_{Total} = \sum_{i=1}^{4} [|F^3_{x,i} - F^2_{x,i}| + |F^3_{y,i} - F^2_{y,i}| + |F^3_{z,i} - F^2_{z,i}|] \tag{1}$$

$$m = \frac{1000 F_{Total}}{g} \tag{2}$$

The experimental results are a reasonable approximation of the actual mass of both objects with water. However, the standard deviation for these objects is considerable, which is mainly due to fluctuations in the initial positioning of

Table 1: Experimental mass of test objects 1 and 2 in both configurations (E-Empty and W-With Water)

Object Index	Object Configuration	Mass (g)	Experimental Mass (g)	Standard Deviation (g)
1	E	40.0	73.8	8.1
	W	94.0	94.6	13.8
2	E	26.0	52.0	19.2
	W	76.0	78.5	7.4

the object that resulted in a non-optimal contact between the sensors and the surface of the objects that compromised data acquisition. Moreover, due to technical constraints, it was not possible to achieve the desired number of trials. On the other hand, the experimental mass of the test objects in the empty configuration exhibits a significant deviation from its actual value. Since the sequence of movements was maintained for both configurations, it was verified that, regarding the test objects in the filled configuration, the added weight resulted in more stable contact points and, in general, more reproducible measurements. This fact contributes for the difference in accuracy observed between the experimental results for both configurations. Another relevant conclusion is the systematic overestimation of the mass for both objects and configurations. This overestimation can be explained by the acquisition of data from two sensors at each fingertip that do not contact the surface of the object in an optimal position. In fact, as can be observed in [reference to an image that illustrate the grasp], the contact is established in an intermediate position between the two sensors, which represents a deviation from the optimal position (at the center of the sensor's surface). Nevertheless, if only one sensor was used under similar circumstances, an underestimation of the mass would be expected.

6 Conclusions and Future Work

This experimental work allowed us to obtain satisfactory results regarding the estimation of objects' weight on precision grips using skin-like sensors integrated on the humanoid robot Vizzy. However, more accurate and reproducible results will require an optimization of the experimental protocol concerning the positioning of the contact points between the sensors and the object's surface. For future work, one possible direction would be the adaptation of the data processing to achieve an estimation of the weight of deformable objects, for which the assumption of a constant friction force during the holding stage of the movement is no longer valid. Another relevant direction would be a more autonomous data processing in order to allow a real-time identification of the stages of the movement useful for weight estimation. This would be a crucial advancement towards an online estimation of the objects' weight, which could ultimately be used for real-time adjustments of the grip forces in order to avoid the occurrence of slip events during grasping. The elastomer body that contains the sensor is not tailored to measure weight. In an ideal scenario the sensor is at equal distance to the surface of contact. A spherical shape would be more suitable for this measurements instead of the one portrayed in Fig.2.

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References

1. Sachin Chitta, Jürgen Sturm, Matthew Piccoli, and Wolfram Burgard. Tactile sensing for mobile manipulation. *IEEE Transactions on Robotics*, 27(3):558–568, 2011.
2. Dana Copot, Clara Ionescu, Ioan Nascu, and Robin De Keyser. Online weight estimation in a robotic gripper arm. In *Automation, Quality and Testing, Robotics (AQTR), 2016 IEEE International Conference on*, pages 1–6. IEEE, 2016.
3. Roland S Johansson and J Randall Flanagan. Coding and use of tactile signals from the fingertips in object manipulation tasks. *Nature Reviews Neuroscience*, 10(5):345–359, 2009.
4. Plinio Moreno, Ricardo Nunes, Rui Pimentel de Figueiredo, Ricardo Ferreira, Alexandre Bernardino, José Santos-Victor, Ricardo Beira, Luís Vargas, Duarte Aragão, and Miguel Aragão. Vizzy: A humanoid on wheels for assistive robotics. In *ROBOT (1)*, pages 17–28, 2015.
5. T. Paulino, P. Ribeiro, M. Neto, S. Cardoso, A. Schmitz, J. Santos-Victor, A. Bernardino, and L. Jamone. Low-cost 3-axis soft tactile sensors for the human-friendly robot vizzy. In *2017 IEEE International Conference on Robotics and Automation (ICRA)*, 2017.
6. Zhe Su, Jeremy A Fishel, Tomonori Yamamoto, and Gerald E Loeb. Use of tactile feedback to control exploratory movements to characterize object compliance. *Frontiers in neurorobotics*, 6, 2012.
7. Nicholas Wettels, Avinash R Parnandi, Ji-Hyun Moon, Gerald E Loeb, and Gaurav S Sukhatme. Grip control using biomimetic tactile sensing systems. *IEEE/ASME Transactions On Mechatronics*, 14(6):718–723, 2009.