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Force/tactile sensor for robotic applications

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ABSTRACT

The paper describes the detailed design and the prototype characterization of a novel tactile sensor[1] for robotic applications. The sensor is based on a two-layer structure, i.e. a printed circuit board with optoelectronic components below a deformable silicon layer with a suitably designed geometry. The mechanical structure of the sensor has been optimized in terms of geometry and material physical properties to provide the sensor with different capabilities. The first capability is to work as a six-axis force/torque sensor; additionally, the sensor can be used as a tactile sensor providing a spatially distributed information exploited to estimate the geometry of the contact with a stiff external object. An analytical physical model and a complete experimental characterization of the sensor are presented.

1. Introduction

Since the early days of robotics, researchers have recognized that equipping a robot with many sensors is a way to confer them autonomy sufficient to perform tasks in unstructured environments. This sensory system should provide information to the robot about physical properties of different nature. Among these properties, when manipulation tasks are considered, the sense of touch is of paramount importance. Tactile sense is used by humans to grasp and manipulate objects avoiding slippage, or to blindly operate in an dynamic environment. An artificial tactile sensor, by mimicking the human touch, should possess the capability to measure both dynamic and geometric quantities, i.e. contact forces and torques as well as spatial and geometrical information about the contacting surfaces. Each of these may be measured either as an average quantity for some part of the robot or as a spatially resolved, distributed quantity across a contact area [1]. A definition of tactile sensor is given by Lee and Nichols [2]: *a device or system that can measure a given property of an object or contact event through physical contact between the sensor and the object*. The one above is probably the best, and at the same time the broadest definition of a tactile sensor.

Most of the tactile sensors already developed are constituted by an array of sensing elements, called *taxels*,[2] integrated into the fingertips of a manipulator end effector. Already in 1982 Harmon [3], defined a first set of tactile sensor design parameters, making a list which is still widely used by researchers today. These features are absolutely general and application dependent, thus not definitive. Other very important design parameters may be found in [4], which is more focused on the feature of an entire *sensing skin* and on the integration of such a skin on a complex manipulator structure. A recent and comprehensive review on features that tactile sensors should possess and technologies used to realize them can be found in [5]. Very few commercial devices are currently available, even tough many technologies have been proposed in the scientific literature to build tactile sensors. This is mainly due to high manufacturing complexity and cost. In particular, prototypes of tactile sensors that use the following different technologies can be found: resistive [6–11], piezoelectric [12,13], capacitive [14,15], magnetic [16,17] and optoelectronic [17–21]. With reference to the optoelectronic technology, that exploits the electromagnetic properties of light, more details are described in the following since the prototype presented in this paper is based on this technology. Widely used sensors are based on Fibre Bragg Gratings (FBG). Typical examples are the two sensors discussed in [18], which exploit the relationship between the variations of the FBG wavelength and the external force applied to the FBG. The sensors based on optical fibres are expensive and difficult to integrate into complex robotic structures (e.g. anthropomorphic hands, robotic arms) because of the bending losses that occur in the fibres routing. Other sensors are based on scattering by small or big particles (compared to the wavelength used) and make use of highly scattering materials such as foams. An example of how foams can be used for tactile sensing technology can be found in [19], where the urethane foam

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[1] Euopean patent pending, Application no. EP11425148.1.
[2] The word *taxel* derives from the union of the words "tactile element".

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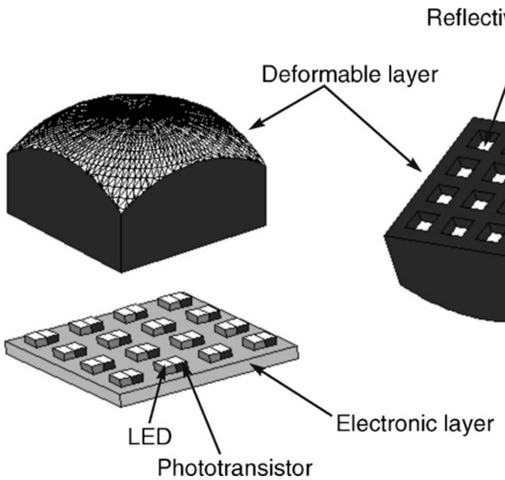

Fig. 1. Structure of the force/tactile sensor.

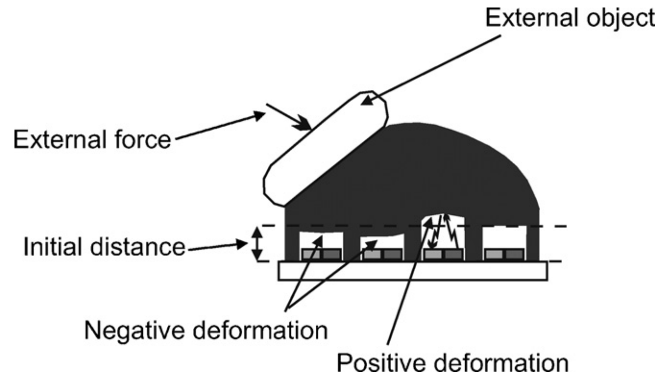

Fig. 2. Sketch of the working principle.

presents a cavity, whose dimensions vary according to the external force applied. When the cavity is compressed, the scattered energy density varies, and by detecting this variation, it is possible to reconstruct the external force magnitude. The main drawback of this sensor type is related to the stochastic nature of the scattering phenomenon [22], therefore the measurement process is characterized by a lack of repeatability. The prototypes proposed in [20,21] use CCD cameras to measure tactile images. These solutions involve large volumes, weights and costs that complicate the integration into robotic hands. In [17] a sensor prototype with two different measuring systems is presented. One of these uses an LED and four phototransistors to measure the deformation in the centre of an elastic dome and then these deformation measurements are experimentally related to the external vertical force applied to the dome. In the proposed configuration, the sensor works as a simple force sensor with a soft interface.

The force/tactile sensor proposed in this paper exploits the thorough study based on Finite Element (FE) modelling conducted in [23] where the working principle has been presented for the first time. There, only a simplified prototype with limited sensing capabilities was tested with the aim of showing only the feasibility of the approach, while the main focus was on the mechanical characterization and optimization of the device.

The sensor is based on the use of optoelectronic technologies and it aims to overcome most of the problems encountered in the works cited above, mainly: difficulty of the integration into small spaces, high costs, repeatability and complex conditioning electronics. The sensor has different capabilities, i.e. it can measure the six components of the force and torque vectors applied to it,

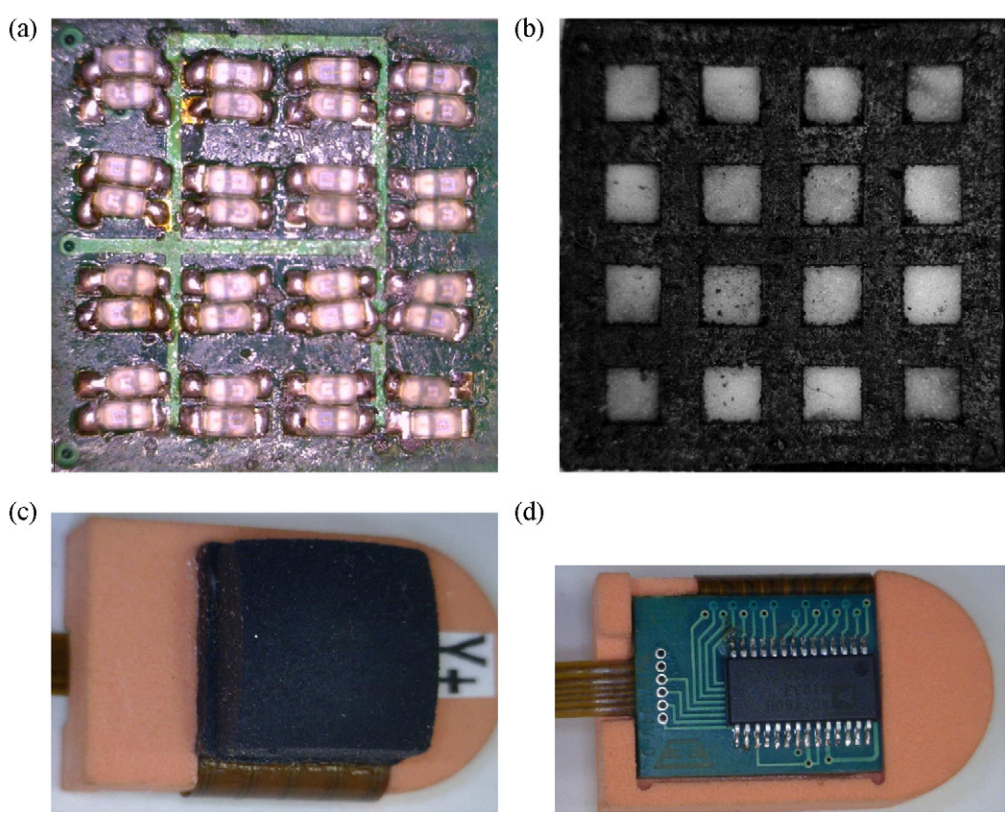

Fig. 3. Some pictures of the sensor prototype: (a) electronic layer, (b) bottom view of deformable layer, (c) top view of assembled sensor, and (d) bottom view of assembled sensor.