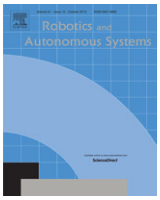
Robotics and Autonomous Systems 62 (2014) 46–52

Contents lists available at ScienceDirect

Robotics and Autonomous Systems

journal homepage: www.elsevier.com/locate/robot



Detection and prevention of slip using sensors with different properties embedded in elastic artificial skin on the basis of previous experience

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ARTICLE INFO

Article history:
Available online 8 August 2012

Keywords:
Soft finger
Multimodal distributed sensors
Force control of grasp

ABSTRACT

In dexterous robotic manipulation, it is essential to control the force exerted by the robot hands while grasping. This paper describes a method by which robot hands can be controlled on the basis of previous experience of slippage of objects held by the hand. We developed an anthropomorphic human scale robot hand equipped with an elastic skin in which two types of sensor are randomly embedded. One of these sensors is a piezoelectric polyvinylidenefluoride (PVDF) film which can be used for the detection of pressure changes. The other is a strain gauge which can measure static pressure. In our system, PVDF films are used to detect slipping, and strain gauges to measure stresses which are caused by normal and shear forces. The stress measured by the strain gauges is used as input data to a neural network which controls the actuators of the robot. Once slip is detected, the neural network is updated to prevent it. We show that this system can control the grasp force of the robot hand and adapt it to the weight of the object. By using this method, it was shown that robots can hold objects safely.

1. Introduction

To realize dexterous manipulation in a continuously changing environment is a great challenge in the field of robotics [1]. The tactile sense plays an important role when people manipulate objects. For instance, without tactile information, it is difficult to maintain the stability of grasped objects [2]. Similarly, the tactile sense is a key to advanced robot manipulation, and it has been investigated in recent years [3]. Control of the grasping force is one of the main issues in this research.

Many methods have been proposed for obtaining the optimal force to be exerted by a robot to achieve a balance between excessive grasp force and slipping. The method proposed by Howe and Cutkosky [4] is a typical one. In this method, the earliest stages of slip between the skin and an object are detected. If incipient slippage can be detected, the robot hand can modify the grasp force and prevent the slipping. Tremblay et al. [5] used skin acceleration sensors to detect incipient slippage. They showed that the sensors can sense vibrations which are induced by incipient slips and demonstrated that these sensors enable grasp force control. However, this approach was not sufficient to completely prevent sliding of the object. Yamada et al. [6] developed an artificial finger skin with ridges in which polyvinylidenefluoride (PVDF) films are embedded, and showed its sensing capability for the detection of incipient slip. Canepa et al. [7] proposed a system for detecting incipient object slippage by neural network processing and sensing normal and shear stresses using arrays of PVDF. Maeno and Kawai [8] developed an artificial skin in which regularly embedded strain gauges are used to detect a partial incipient slip by calculating the stick area between the skin and an object. However, these systems take too much space to be embedded in a human scale robot hand. Additionally, most of these studies used sensor systems which were designed with specific purposes, and as a result these systems lack versatility. Hosoda et al. [9] proposed an artificial soft fingertip equipped with artificial skin in which PVDF films and strain gauges are randomly embedded. Tada and Hosoda [10] showed that it is possible to detect micro slips from vibrations caused by slips using the PVDF films embedded in this artificial fingertip and an artificial neural network which is trained with the output of a visual sensor. They demonstrated that the robot can detect slips and can increase its grasping force while the weight of the object increases gradually. However, the prevention of slippage was still not sufficient.

These approaches are based on the prediction of entire slips from local micro slips. If a precise incipient slip can be detected, the gross slip can be prevented. They have the advantage that it is possible to predict the exact slippage without knowledge of the friction coefficient, and the method is biologically plausible [11]. On the other hand, they require a sensor system with specific structures we have mentioned above or high spacial resolution and high sensitivity in order to detect the precise earliest stages of slippage from the change of the condition of contact. Additionally the reaction time of the robot finger to prevent gross sliding of the grasped

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doi:10.1016/j.robot.2012.07.016

object from occurring is limited because the transition from an incipient slip to an entire slip is a continuous event that is short in time. For safe robot manipulation, it is necessary to predict slips early enough to prevent them from occurring. Various advanced types of tactile sensor with high spatio–temporal resolution have been developed in recent years [3], but it is still not easy to apply them to a human scale robot hand. Some researchers use a different approach from that previously discussed to detect slippage with microelectromechanical systems (MEMS) technology [12,13]. They demonstrated detecting stick–slip transitions using a multi-dimensional micro sensor chip under a elastic skin by calculating the force acting the surface of the skin. They are very attractive, but such MEMS technology is still too difficult to use, and it requires an accurate model of the skin and accurate calibration.

This paper presents a method to predict slip from the global strain of the artificial skin on the basis of previous experience and to control the grasp force of the robot hand in order to maintain grasp stability using the sensors embedded in the artificial skin. In previous work [10], the strain gauges were used only to distinguish the direction of movement of the robot hand. We use the randomly embedded strain gauges to predict slip. The skin strain results from normal stress caused by the force that the robot hand exerts and from shear stress caused by the force of friction between the hand and objects. The normal stress must change according to the shear stress in order to prevent slips and excessive force. However, it is difficult to distinguish the condition of skin stresses from the outputs of the strain gauges embedded in the elastic skin because of many factors. Thus, in the system presented here, an artificial neural network is used to control the force. The input data in form of the skin strain measured by the strain gauges is fed to the network. If a slip is detected from vibrations measured by the PVDF films, the network is trained to discriminate whether the skin strain corresponds to the condition in which the hand is supposed to change its force. Through experience, the robot itself can learn sufficient conditions of its skin to prevent grasped objects from sliding down, and can hold them without slipping and without excessive forces by adjusting the exerted force.

In Section 2, we present the architecture of the anthropomorphic robot hand and its control system which are used for the experiments in the following sections. The detection of slips using PVDF films is described in Section 3. The artificial neural network used to control the force is described Section 4. A simple grasp force control test using the method which we propose in this paper is described in Section 5. In Section 6, we discuss the proposed method and conclude this paper.

2. System description

2.1. Artificial skin and sensors

Fig. 1 shows the artificial skin and a finger of the robot hand which were used for the experiments described in this paper. The artificial skin is a modification of the anthropomorphic robotic soft fingertip which was proposed by Hosoda et al. [9]. The skin is composed of two layers. The inner skin layer is made of soft urethane resin (Hitohada gel Hardness 0, Exseal Co., Japan). This urethane has a softness similar to human skin, whereby its compressive elastic modulus is 11.8 N/cm^2. The softness of the skin not only provides an increase in the stability of grasping but also transmits events to the sensors which occur between the hand and an object. The inner skin is wrapped in a thin outer skin made from relatively stiff nonfoamed polyurethane (Surface coating agent HC-25, Exseal Co., Japan) to prevent damage to the inner skin and sticking between the inner skin and objects, since the inner skin is fragile and has strong stickiness.

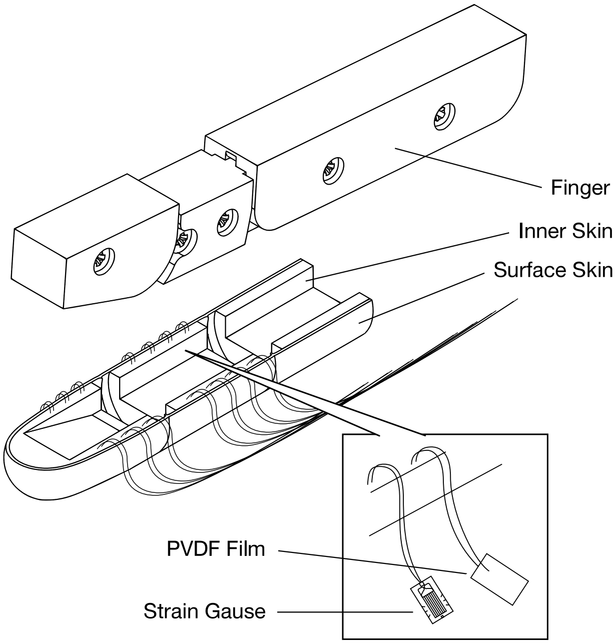

Fig. 1. A finger of the anthropomorphic robot hand and the artificial skin in which sensors are randomly embedded.

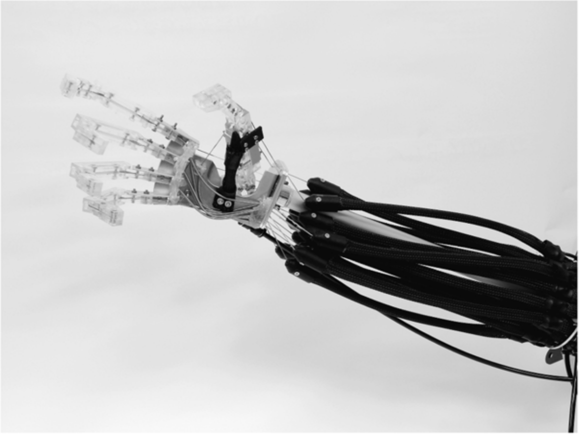

Fig. 2. Robot hand used in this experiment.

PVDF films cut to 5 mm squares and strain gauges are randomly embedded in the inner skin. A PVDF film is a thin and flexible piezoelectric sensor. It can measure pressure changes as a electric charge is generated at its surface when it is strained. In contrast, this property is not suitable for measuring static pressure. On the other hand, a strain gauge is constructed from a conductive wire that changes its resistance when it is bent. We embedded strain gauges (KFG-1-350-C1-11, Kyowa Electronic Co., Japan) in the skin to measure static pressures. These two types of sensor were inserted into a mold and Hitohada gel was cast into the mold of an adult finger. The PVDF films are used to measure vibrations caused by slips, and the strain gauges are used to measure skin strain. In this experiment, these sensors are embedded only in the index finger.

2.2. Anthropomorphic robot hand

Fig. 2 shows the anthropomorphic human scale robot hand that we designed. The robot hand is formed in a human-like structure and has five fingers driven by pneumatic muscle actuators through tendons. We use McKibben pneumatic muscle actuators. When