Haptic perception in human robotic systems

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Introduction

Why is haptic perception essential in human robotic systems? This question is often posed in connection with humanoid robots. First of all, humanoid robots are intended to assist people in a typical human environment. A person expects a humanoid robot to think, move, act, and communicate in a human-like manner. This also includes the usage of typical human senses like vision, hearing and tactile sensing. Second, a robot manipulating items in an unstructured environment like a person's home needs to have some haptic feedback: information whether an item is firmly grasped or sliding is important for handling objects. Third, different kinds of haptic and tactile feedback are required for moving and acting in a human-built environment: collision detection just as well as haptic feedback for actions or control by a human operator.

Different types of haptic feedback require an acquisition of environmental data by different kinds of haptic sensors. Most commonly, force torque sensors in the wrists or other joints of the robot are used. In addition, tactile input is achieved by sensor matrices based on various physical working principles. Sometimes, data inputs of depth perception and surface perception have to be combined to achieve an optimal haptic sensing.

This chapter mainly focuses on tactile sensing of a humanoid robot, illustrating the working principle of resistive sensor arrays used as an artificial sensitive skin, classifying different types of contact, and giving an insight into a current project of a humanoid robot.

Tactile sensor system

A tactile sensor system normally consists of discrete sensor cells, so called 'texels'. They are arranged in homogeneous matrices, detecting an applied load profile. For data acquisition, the measurement converter is connected to a local intelligence, a sensor controller, digitising the sensor signals and pre-processing them. A host system processes the data made available by the controller and extracts characteristics. The data can be used, e.g., for reactive control of a robot. The measurement principles of the tactile sensor cells found in literature are based on three major classes: optical, capacitive and resistive effects. Optical sensors commonly utilise force dependent absorption or reflection of light beams [1]. They are very insensitive against corrosion and electromagnetic disturbances. For high area applications, like covering a whole robot system, the interconnection between the texels, commonly done by PMMA fibre cables, and the detection circuit becomes too complex. Another common approach for optical tactile sensors is to measure the scattered light from a lightened transparent polymer material by using a CCD camera [2]. These sensors can be used for tactile object recognition and orientation sensing in grippers, but are not suitable for surface covering.

Capacitive sensors can be found as single cell sensors as well as tactile sensor matrices with low drift and a high reproducibility [3]. They utilise the change of capacitance between two electrodes covering a deformable dielectric. These changes in the range of a few femto farads are very difficult to detect, therefore a complex signal conditioning electronic is needed. Due to the required high sensitivity of the electronics, capacitive sensor systems in general are very sensitive against electromagnetic interferences. Another approach integrates a capacitive texel matrix into a single chip with the signal conditioning. This greatly improves the interference robustness and enables high resolution tactile sensing [3]. Like optical tactile sensors, these sensors are suitable for gripping purposes but not for surface covering.

Of particular interest for service robotics are resistive tactile sensor systems. They utilise the effect that the resistivity of the interface between two surfaces changes according to the applied load. This was first discovered by the French electrical engineer Theodore du Moncel in the late 19th Century. He discovered that an electrical current flowing between a sooty metal plate and a nail is modulated by acoustic waves. Based on this conclusion, he invented the carbon microphone which revolutionised telephony [4].

Resistive tactile sensing

Today, instead of a sooty metal plate, conductive polymers are used for resistive tactile sensors. The load-dependent change in resistivity is acquired using an electrode matrix and – in comparison to that of capacitive sensors – simple signal conditioning electronics. It shows a hyperbolic style characteristic between the applied load and the electrical resistance. This nonlinear behaviour is of special interest, e.g., in collision detection, since for light-weighted contacts to its surface the sensor is more sensitive than at high loads – the measurement range is expanded. In addition, resistive tactile sensors in general are very robust on overpressure, shock and vibration due to its simple construction. Different resistive sensor systems can be found in literature and in industrial applications. Commonly, the electrodes for detecting the resistance are mounted on the facing sides of the sensor material co-axial to the direction the load will be applied, as shown in Figure 1.

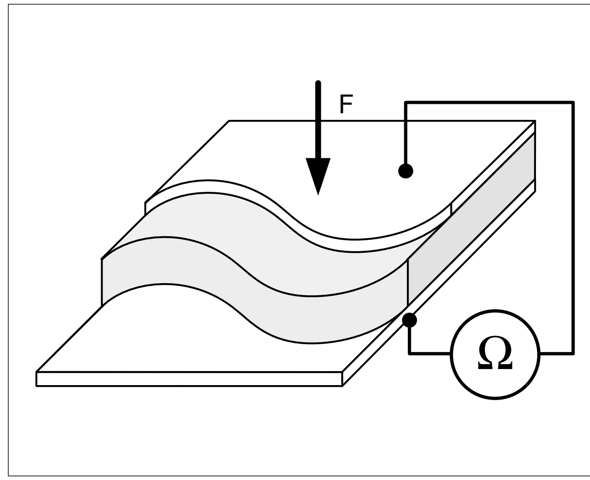

Figure 1. Double sided contacting of the sensor material

This arrangement enables an easy construction of tactile sensor matrices by adding horizontally and vertically aligned electrode stripes onto the sensor material, realising a network of force sensitive resistors. Those sensor matrices are proposed (e.g., in [5–7]).

While contacting the sensor material from both sides, the load has to be applied over the upper electrode. This is unfavourable, since the sensor material is usually flexible, whereby the upper electrode is exposed to a bending stress reducing the life time of the sensor. Therefore, we proposed another construction of the sensor cells by placing both electrodes on the back side of the sensor material, bypassing the fatigue problem.

With an arrangement as shown in Figure 2, even foams can be used as a sensor material without bending the electrodes by applying a load to the sensor cell, provided that the sensor is mounted on a rigid surface. At the Institute of Process Control and Robotics at the University of Karlsruhe a resistive tactile sensor system for service robots has been developed [8]. It con-