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Electronic Skin: achievements, issues and trends

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Abstract

The skin is one of the main organs of the human body and as such it implements many different and relevant functions, e.g. protection of the inner body organs, detection of cutaneous stimuli, etc. Due to its complexity, the development of artificial, or better, electronic skin (e-skin) is a very challenging goal which involves many different and complementary research areas. Nonetheless, the possible application areas are many and very relevant: e.g. humanoids and industrial robotics, artificial prosthetics, biomedical instrumentation, cyber physical systems, for naming a few. Many research groups are addressing the development of e-skin and the research scenario is exciting and continuously evolving. Due to its very peculiar features, the development of electronic skin can be effectively tackled using a holistic approach. Starting from the system specification definition, the mechanical arrangement of the skin itself (i.e. soft or rigid mechanical support, structural and functional material layers, etc.) needs to be designed and fabricated together with the electronic embedded system, to move toward aspects such as tactile data processing algorithms and the communication channel interface. In this paper, we present and assess the achievements of our research group in this field focusing on the following aspects: (i) The manufacturing technology of sensor arrays based on piezoelectric polymer (PVDF) transduction; (ii) The mixed-mode interface electronics; (iii) The tactile data processing algorithms; (iv) The electronic embedded system. Future trends and research perspectives will be also presented.

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Keywords: E-skin; piezoelectric polymers; tactile data processing; electronic embedded systems

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1. Introduction

The development of electronic skin (e-skin in the following) is a hot research topic due to its relevant countless applications e.g. in robotics and in biomedical systems [1, 2]. The functions of e-skin are basically: 1) to protect the inner electronic system from damages due to interactions with the outside (e.g. impacts, humidity); 2) to convey the mechanical stimulus in a convenient way to the beneath distributed sensor arrays: the geometrical arrangement of e-skin patches, the geometry of the protective layer on top of the e-skin structure and the composition of the protective layer contribute to an effective implementation of this task; 3) to acquire and to pre-process sensor signals in a convenient way; 4) to extract in an effective and reliable way the meaningful and necessary information for the task at hand (e.g. automatic reflexes, contact type recognition, surface feature detection, etc.); 5) to transmit the information to the next higher level of the ICT infrastructure of the system (e.g. the local communication bus). Each of such operations can be organized in many other tasks which jointly concur to implement the extrinsic/cutaneous tactile system. What is more, from the previous considerations, it seems that the e-skin should be flexible (i.e. conformable to the system to be applied on) and stretchable e.g. to support joint movements, and processing must be implemented in real time for using the tactile information in the system control loop.

The different e-skin tasks are far from being properly addressed and still in their infancy even if many research groups are addressing the topic with numerous different approaches at each level of the problem.

Our research group is being addressing this topic since roughly 10 years in a holistic way, managing the seamless design and implementation of the mechanical and electronic systems of the e-skin. With reference to the above system organization, we mainly focused on the development of: 1) sensing arrays based on a technology exploiting piezoelectric polymers as sensing materials; 2) the interface electronics; 3) tactile data processing algorithms; 4) dedicated digital embedded electronic systems. In this paper, we will review main achievements in these areas. The paper is organized as follows: Section 2 describes the sensing material and presents a survey on the on-chip integration of tactile sensors. Section 3 presents tactile data processing algorithms. Research issues related to the effective implementation of an embedded electronic system for e-skin is illustrated in section 4 and a presentation of the current approach to tackle some issues in the field is then given. Conclusions and future perspectives are reported in section 5.

2. Tactile sensing arrays

2.1. Sensing material and large area sensor array technology

The first step in e-skin development is to identify the adequate *functional* material to enable certain sensing capabilities. As the functional skin requirements are debatable and ‘application dependent’, piezoelectric polymer films of Polyvinylidene Fluoride (PVDF) [3] have been chosen as meeting the target requirements of mechanical flexibility, high sensitivity, detectability of dynamic touch (1Hz-1kHz frequency range) and robustness.

Commercial PVDF sheets (100μm thick) from Measurement Specialties Inc. are stretched and poled. Stretching at temperatures below the polymer melting point and poling by the application of very high electric fields (~100V/μm) give the polymer sheets the symmetry of an orthotropic material [4]. Linear constitutive equations [4] are commonly used to describe the material intrinsic transduction of the mechanical stimulus into a charge signal, but care is required to account for the way the piezoelectric film is integrated into the skin, which also includes a substrate and a cover layer.