

Preface

Future robots will be expected to work closely and interact safely with humans as well as the environment. Among various sensing modalities needed to perceive and react to the events of the real world, the sense of touch is particularly important as it enables awareness of the body and differentiating “me” from “not me”. Unlike other senses (e.g. vision, audio), it involves complex physical interaction, and plays a fundamental role in estimating contact properties such as shape, texture, hardness, material type and many more. The sense of touch provides action related information, such as slip, and helps in carrying out actions, such as rolling an object between fingers without dropping it. Touch sense modality also helps in understanding the rich interaction behaviors of real world objects—which depend on their weight and stiffness; on how their surface feels when touched; how they deform on contact and how they move when pushed.

From historical perspective, the robotics community has emphasized the need for touch/tactile sensing in robots for a long time and ‘sense of touch’ has been a component of robotics for roughly as long as artificial vision and auditory sense modalities. Touch sensing began to develop in the 1970s—albeit at a slower pace, when compared with the development of other sensory modalities. The extent to which the ‘sense of touch’ was utilized largely remained restricted to joint force/torques or simply ‘intrinsic touch sensing’—which can probably be attributed to the focus largely on the industrial robotics during the initial era of automation. Both, from safety and operational point of view, intrinsic touch and vision are considered to be more convenient and suitable for an industrial set up. For this reason, until the end of last decade, research on sensors and sensors based robotics was biased toward using vision and intrinsic touch sensing. This is evident from large number of articles, published in various robotic related journals and conferences, where vision and joint force/torque sensors have been employed in various robotic tasks. The first special issue on ‘sense of touch’ in robotics, published by IEEE Transactions on Robotics (TRO) appeared only in 2011.

As far as tactile sensing (or extrinsic sensing) in robotics is concerned, early surveys show that a wide diversity in the types of tactile sensing devices emerged in the 1980s. Early works on tactile sensing focused on the creation of sensor devices

using new transduction techniques and a large number of experimental devices and prototypes were built and reported in the literature. Particular attention was given to the development of tactile sensing arrays for object recognition. The creation of multifingered robotic hands during 1980s increased the interest in tactile sensing for robotic manipulation and thus started appearing the works utilizing tactile sensing in real-time control of manipulation. The new applications demand features such as mechanical flexibility and conformability and accordingly new designs and materials for tactile sensing started receiving attention. While the development of tactile sensors for robotic fingertips and hands continued, the application areas such as motion planning in unstructured environment brought whole body sensing to the fore. As a result, many sensitive skin design projects were undertaken in the late 1980s and 1990s. Over a period of time, robotics itself has undergone paradigm shift. In addition to the manipulation and exploration tasks, the new generation robots are also expected to interact safely. As a result, there is an increased interest in developing large area or whole body tactile sensing structures that allow a robot to carry out a task while maintaining physical contact. The discussion on ‘sense of touch’ in robots is now not restricted to the sensing hardware and related issues only. The whole body skin concept in robotics has also brought up challenging issues related to data handling, data representation, effective utilization of the tactile data and overall system integration. This book presents many such issues and discusses them with an aim to push forward the research toward “effective” utilization of tactile sensing in robotics.

This book contains eight chapters, divided into two parts: Part I and Part II. Part I (Chaps. 1–5) explains the WHY, WHERE, WHAT and HOW components of tactile sensing and summarizes the current knowledge about the sense of touch. We begin with a discussion on the role and importance of tactile sensing (in humans and robots). Various terms associated with the sense of touch are then defined to present a clear picture about the scope of this book within ‘sense of touch’. Then we discuss more on human touch sensing, the ability of humans to perceive the world through sense of touch, and how human touch sensing can be a reference for the robotic tactile sensing. We then explore the expectations and requirements of a robotic tactile sensing system, considering issues related to task, electronics, mechanics and engineering, with an aim to understand how tactile sensing can be made an effective component of robotic devices. In the last chapter of Part I, we present a detailed discussion on the state of the art in the field of tactile sensing. The various chapters have been selected to provide insight into the mechanisms and issues that underlie the development of effective tactile sensing system. The first part therefore contains most of the general information that a reader would like to know about tactile sensing in robotics and also the issues that one would face while trying to make tactile sensing an effective component of robots. Part II (Chaps. 6–8) of the book is about integrated tactile sensing systems on silicon chip. In particular, various stages of development of POSFET (Piezoelectric Oxide Semiconductor Field Effect Transistor) devices based tactile sensing chips are presented in these three chapters. Part II of this book presents the research that Dr. Ravinder S. Dahiya conducted during his doctoral studies at the University of Genova and Italian Institute of Technology,

Genova, Italy. The fabrication of tactile sensing chips and further extensions in this directions have been carried out at Fondazione Bruno Kessler (FBK), Trento, Italy. The chapter-wise detailed information is given in following paragraphs.

Chapter 1 provides an answer to the questions—‘WHY’ and ‘WHERE’ the tactile sensing is needed. The role and importance of tactile sensing, first in humans and then in robotics, is explained with a number of examples. Some new application areas (e.g. biomedical, human–robot interaction, rehabilitation, and prosthetics etc.) where tactile sensing plays key role are also presented.

Often, robotic tactile sensing has been associated with detection and measurement of (only) forces in a predetermined area, which is only partly true. A real world interaction involves contact parameters which can be a mechanical stimulation (force, stress, roughness etc.) or other parameters like temperature, hardness, moistness etc. Thus, Chap. 2 attempts to answer the ‘WHAT’ component of tactile sensing by defining various terms related to ‘sense of touch’. First, the terms related to ‘sense of touch’ in humans, and then analogous terms for robotic tactile sensing are presented. Finally, a classification of robotic tactile sensors, on the basis of transduction method, task to be done, location of sensors on robot’s body and their mechanical/physical nature, has been presented.

A large number of studies on human touch sensory modality have addressed many problems that are challenging to roboticists as well. In this sense scientific studies on human sense of touch can throw some light on the development of a tactile sensing system that can be effectively integrated and used in various robotic tasks. With this aim, a discussion on the physiology of human ‘sense of touch’ its role and perceptual importance in humans, supported by a number of studies, are presented in Chap. 3. Based on these studies, various design hints for robotic tactile sensing are derived.

The overall performance of any system is dictated not only by the isolated quality of the individual components, but also by how these components integrate to achieve the goal. With this aim, Chap. 4 provides an in-depth discussion on the development of robotic tactile sensing system, keeping in view the application and system related expectations and requirements. The application requirements such as measurement of a specific contact parameter, the hardware (electrical/mechanical) requirement such as compatibility of new sensor with existing hardware, physical requirements such as conformability, and practical requirements such as cost-effectiveness etc., all together place many constraints on the development of a tactile sensing system. The design of tactile sensors and finally their integration of the robot, are a result of many trade-offs. For the first time, this book presents a discussion on such requirements and expectations and, wherever possible, alternative solutions are suggested. The effective integration of such sensors and structures on various robotic platforms will allow researchers to develop new cognitive algorithms involving touch information from large areas. In addition to robotics, such structures will also help to understand human interaction with the environment. Chapter 4, together with Chap. 5, provides an answer to the question—‘HOW’ robotic tactile sensing should be developed or has been developed? The discussion in this chapter can serve as a reference for the design of tactile sensing systems.

Chapter 5 provides a state of the art of robotic tactile sensing including, the tactile sensor technologies, the materials and the methods, for miniaturized sensors and schemes for large area skin like coverage. The discussion in this chapter is supported with selected examples of tactile sensors/sensing arrays reported in literature. Relative advantages and disadvantages of various methods and the recent trend for developing tactile sensing system are presented. Touch sensing structures such as electronic skin, that are flexible, conformable, stretchable and thus suitable for covering large body parts of robots, are being increasingly investigated nowadays. A critical evaluation of various tactile sensors or sensing arrays is presented, keeping in view the tactile sensing system and associated issues, presented in Chap. 4.

Chapter 6 presents the first phase of the development of tactile sensing chip and the experimental characterization of these tactile sensing chips. In the first phase, 32 elements MEA, epoxy-adhered with thin piezoelectric polymer films, are developed as tactile sensing arrays. Design aspects like spatial resolution, capability of recording dynamic contact events, multifunctionality etc. of these tactile sensing arrays are inspired from discussion presented in Chaps. 3 and 4. The development of MEA based tactile sensor arrays provides a feasibility study for the POSFET (Piezoelectric Oxide Semiconductor Field Effect Transistor) based tactile sensing chips presented in Chaps. 7 and 8.

Chapters 7 and 8 present high performance and high resolution POSFET devices based tactile sensing chips. The tactile sensing arrays and chips presented in Chaps. 6–8 have been fabricated at FBK, Trento, Italy. The novel aspect of a POSFET device is that it presents an integral sensor unit comprising of transducer (i.e. piezoelectric polymer) and the first electronic unit (i.e. transistor): in this way, the sensor and conditioning electronics are brought closer and hence the overall response is better than that of conventional approach, in which, the sensor and conditioning electronics are placed at a distance. The ‘integral sensor unit’ thus conforms very well with the ‘Sense and Process at same place’ concept, presented in Chap. 4. The POSFET based tactile sensing chips, presented in simplest form, can be easily extended to accommodate interface and local processing circuitry. In fact, such advances have been presented in Chap. 8, where CMOS implementation of POSFET chip (having sensors and conditioning electronics on chip) has also been discussed. Design aspects like spatial resolution, capability of recording dynamic contact events, multifunctionality etc. of these tactile sensing chips are inspired from discussion presented in Chaps. 3 and 4. The 5×5 and 4×4 POSFET devices based tactile sensing chips, presented in Chap. 8, have high density, good spatial resolution and a linear response over a large range of dynamic forces. The capability of tactile sensing chips to detect dynamic stimulus (varying, both in space and time) is demonstrated. In addition to the high performance, a tactile sensing solution must also possess properties such as mechanical flexibility. The current research on mechanically flexible POSFET tactile sensing chips is presented at the end of Chap. 8.

“Smart materials” like piezoelectric polymers (e.g. PVDF-TrFE) are of interest as transducers in rapidly expanding range of applications. They are capable of sensing dynamic forces and temperature. They are key components of the tactile sensing chips presented in Part II. The basic theory behind their use as sensors and actuators is given in Appendix A. It is valuable to use some form of theoretical model

to assess, the performance of a transducer; the effects of design changes; constructional flaws and electronics modifications etc. Instead of evaluating the transducer and conditioning electronics independently, it is advantageous to develop and implement the theoretical model of transducer in such a way that overall sensor (i.e. transducer + conditioning electronics) performance can be optimized. To this end, the electrical model of piezoelectric polymers and its implementation in SPICE are presented in Appendix B. The model can be used to evaluate the performance of polymers over a wide range of frequencies and same is true for the POSFET tactile sensing devices presented in Chaps. 7 and 8. Using the SPICE model, a discussion on various design issues associated with polymers, is also presented. Finally, the design of charge and voltage amplifiers, used to measure the piezoelectric polymer response, is described in Appendix C.

With its multidisciplinary scope, this book is suitable for graduate students and researchers coming from diverse areas such as robotics, material science, humans sense of touch, electronics, microsystems, and instrumentation. To better explain the concepts the text is supported by large number of figures. The technological trends and other applications of tactile sensing are presented in the book. We hope that this book will provide a valuable resource to students encountering this subject for the first time, as well as to the experts who have contributed so much to our understanding of the robotic sense of touch.

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