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Tactile Flow and Haptic Discrimination of Softness

Antonio Bicchi, Enzo P. Scilingo, Davide Dente, and Nicola Sgambelluri*

Summary. Haptic perception involves both cutaneous perception, through mechanoreceptors lying on the skin, and kinaesthetic perception mediated by the position of the fingers. Analogously, artificial devices should replicate both these perceptual channels, as well. While kinesthetic information is satisfactorily replicated by current technology, cutaneous information is still a challenging task to be provided. In order to comply with this goal, a computational model of perceptual flow, inspired to established models for vision, has been recently extended to the tactile domain. It has been shown that tactile flow encodes important information on relative motion and segmentation of tactual scenes. In this chapter we illustrate how previous results on the "contact area spread rate" with softness detection can be conveniently explained in terms of integral of tactile flow over the contact area.

10.1 Introduction

In the analysis of human and artificial vision, optic flow has been widely recognized to be crucial in fast sensorimotor coordination and feedback. Optical flow is basically an abstraction of raw data coming from the sensor (retina or camera), that extracts information on the relative velocity of the sensor and the visual target by observing how fast the target image grows over time. Different image sequences may have identical optic flow, so that there is a loss of information. However, optic flow of artificial images can be easily computed, and this information has been successfully used in several applications (for instance, in estimating the time-to-contact for automobiles proceeding in a line, thus enabling collision avoidance strategies). On the other hand, experimental evidence has been obtained through Functional M.R.I. techniques that some cortical areas are specifically excited by optic flow, thus proving that it is deeply rooted in human psychophysics. In this chapter, we inquire into the existence of a similar concept in a different sensorial domain, that of

* A. Bicchi, E. P. Scilingo, D. Dente and N. Sgambelluri are with the Centro Interdipartimentale di Ricerca "E. Piaggio", Università di Pisa, Italy.

F. Barbagli et al. (Eds.): Multi-point Interaction with Real and Virtual Objects, STAR 18, pp. 165–176, 2005.

tactile perception. The goal of such investigation is twofold: on one side, there is a fundamental interest in the psychophysics of a less-explored perceptual channel such as touch; on the other hand, many possible fallouts may ensue in disciplines where a sensorial substitution and simplification would be important: haptic displays for VR and prosthetics are two examples. In particular, we are interested in establishing whether a description of "tactile flow" can be given that codifies important information for manipulation operations; is amenable to implementation in haptic displays and/or prosthetics, and has a connection to the psychophysics of touch in humans. Some of these questions have a positive answer, while others are still open, even though we have encouraging preliminary results. We will show how tactile flow can be defined in terms of the displacement of iso-strain curves on the surface of bodies in contact at varying the overall compression force, and how this definition is consistent with the "Contact Area Spread Rate" observed under increasing load. In particular, the strict analogy between the time to contact paradigm in vision and the tactile flow in touch was explored.

10.2 Optic Flow: a Review

Any image can be segmented in a set of pixels. To each single pixel is associated a single intensity value, which itself is the result of many factors, as the intensity, color, reflectance, etc. This intensity value can be detected by a local measure at each spatial point (E(x,y)). During a movement a sequence of images is produced. By extracting two images separated by a discrete time interval, it is possible to define *optic flow* as a vector field describing this intensity change by indicating the motion of features from one image to the other one. In other words, optic flow [90] is the distribution of apparent velocities of movement of brightness patterns in an image that arises from relative motion of objects and a viewer or from changes in light sources. The human brain analyses this flow field to obtain several information about the environment. The optic flow field contains proprioceptive, segmentation and exteroceptive information [20]. Proprioceptive information refers to both rotational and translational egomotion and orientation. Segmentation regards splitting and merging scene zones on the basis of flow discontinuities. Exteroceptive information concerns position, motion, form and orientation of objects. In robotics, optic flow may be fruitfully exploited to recover scene depth, detect object trajectories, avoid collisions. It is also experimentally proved that an area in human cortex responds specifically to optic flow revealed by fMRI (functional magnetic resonance imaging) [203].

A traditional technique to calculate the optic flow is the assumption that the total spatial and temporal derivatives of the images brightness remain constant. Let $E(x, y, t)$ denote the brightness at time t of an image point (x,y). If $u(x, y)$ and $v(x, y)$ are optic flow components x and y at that point, and under the assumption that image brightness in each image point is stationary