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Subhasis Chaudhuri · Amit Bhardwaj

Kinesthetic Perception

A Machine Learning Approach

Springer

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To
Syomantak and Ushasi

Subhasis Chaudhuri

My beloved family

Amit Bhardwaj

Preface

Haptics as an area of research has picked up a great momentum in the last two decades. The primary reason for such a proliferation of research is due to gradual and continuous development in mechatronics, making such devices available to the scientific community. A few such systems are now available for gaming and medical purposes. We expect a wider acceptance of such developments in practice as more and more such devices come into the market. However, all such devices currently work as stand-alone boxes and interoperability among these devices would be the key component in future developments. A proper standardization effort is required to provide this interoperability.

One of the major applications foreseen for haptics is in teleoperation. Being able to perceive the forces at the teleoperator end will provide a great boost in improving the performance of the operator. Researchers have been working on various aspects of designing a good teleoperation system that involves design of manipulators, kinesthetic and tactile sensing, data communication, delay compensating controllers, and immersion into the virtual workspace. The data communication module requires meeting quite a restrictive quality of service guarantee. This requirement is very severe for delay-sensitive haptic data. The currently available Internet is often unable to meet the demand. With the introduction of *tactile Internet*, we expect this constraint to gradually ease out in future. Notwithstanding haptic data communication shall continue to be a major issue in any teleoperation system over a shared network. Thus an appropriate haptic compression engine is required to be a part of such a teleoperation system.

How does one compress the haptic data without affecting the immersion of the operator into the virtual world? This brings in the question of the effect of data compression on haptic perception. Any perception-aware data compression technique utilizes the fact that a small change in the stimulus is often non-perceivable. Thus, when the temporal variation in the haptic signal is relatively very small, these data samples need not be transmitted. Several researchers have proposed different adaptive sampling strategies for haptic data and have demonstrated that a substantial reduction in data rate can be achieved. However, all these techniques require the determination of the perceptual threshold which is always dependent on the perceptual abilities of an individual. The primary motivation for this monograph is to design a methodology to estimate the subject-specific perceptual threshold. However, instead of considering both kinesthetic and tactile perceptions, the studies are limited to kinesthetic perception only.

The psychophysics of human perception is a classical area of research and has a firm foundation on methodical study of determining the perceptual threshold. However, such studies are quite limited as regards to analyzing kinesthetic perception since it is only very recently that such mechatronic devices are available which can exert a given amount of force with a reasonably good accuracy. In parallel, there has been a substantial growth in research in the seemingly unrelated area of machine learning that offers a number of excellent data-driven tools to arrive at a decision or to estimate certain quantities without one having to define a functional or parametric relationship. Although a functional relationship may offer to estimate the unknown quantity very efficiently, it may suffer from the assumptions, including those on the distribution of the measurements, when inappropriate. However, the use of machine learning techniques requires generation of a large number of ground-truthed data. In this monograph, we demonstrate how the recently developed machine learning techniques can be used to determine the perceptual thresholds. Thus, the purpose of the monograph is to provide an engineering perspective on how some of the traditional problems in classical psychophysics can be solved. Quite naturally, we were required to generate a huge corpus of human response data for various types of kinesthetic stimuli.

The book is addressed to a fairly broad audience. It is meant for graduate students studying the subjects of haptics, system science, and virtual reality. It may also serve as a reference book for scientists working in the area of human perception. For the benefit of such scientists, we plan to make all collected data available for further research. Needless to say, the monograph will be of great use to the practitioners developing various types of teleoperation systems. A basic familiarity of the readers with machine learning would help in better understanding of the book.

We shall be very happy to receive comments and suggestions from the readers.

Mumbai, India
July 2017

Subhasis Chaudhuri
Amit Bhardwaj

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A few figures in the monograph have appeared in some of our publications elsewhere. We are thankful to ACM, Springer, and IEEE for allowing us to reuse the figures.

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Mumbai, India
July 2017

Subhasis Chaudhuri
Amit Bhardwaj

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