PRACTICAL CONSIDERATIONS IN EXPERIMENTAL COMPUTATIONAL SENSING

by

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As members of the Dissertation Committee, we certify that we have read the dissertation prepared by Phillip K. Poon titled Practical Considerations in Experimental Computational Sensing and recommend that it be accepted as fulfilling the dissertation requirement for the degree of Doctor of Philosophy.

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Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copies of the dissertation to the Graduate College.

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DEDICATION

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ABSTRACT

Implementing computational optical sensors often comes with various issues that many traditional sensors may not encounter.

CHAPTER 1

Introduction

This chapter introduces the reader to the concept of computational sensing and provides the motivation for the need to address the practical issues in experimental computational sensing.

Computational sensing is the concept that a joint design of the sensor hardware, often though coding of the analog signal combined with task specific algorithms can exceed the performance of a traditional sensor, which we call *isomorphic sensors*. While isomorphic sensors can provide flexible sensing in multiple applications. A computational sensor's task specific design—which considers both the architecture of the sensor and coding of the analog signal —naturally lends to performance increases.

Throughout this chapter and the rest of this dissertation we will provide many examples that highlight the differences between computational and isomorphic sensing.

Rather than a rigorous discussion, this chapter will discuss some of the major developments and contributions to the field of computational sensing on an intuitive level. This will familiarize the reader with important terminology and techniques common in the computational sensing community. The projects presented in this dissertation are a natural evolution of these developments. A rigorous discussion of the concepts is given in chapter 2. Then I will briefly discuss some of the challenges I and many other experimentalists and engineers have faced when developing computational sensing prototypes. Then the chapter will close with a brief look ahead to the rest of the dissertation.

1.1 A Historical Development of Computational Sensing

1.1.1 Isomorphic Sensing

Traditional sensors perform isomorphic sensing. In Greek, the word isomorphic loosely translates to equal in form. In the context of this dissertation, an isomorphic sensor is any sensor whose output signal resembles the signal of interest.

An good example related to this dissertation is the photographic camera. In the camera, the signal of interest is the object that is being photographed. Let's say the object is a tree. The analog instrument consists of the lens which is designed and fabricated to create an image that nearly *diffraction limited*—which means aberration free and therefore the only image degradation is due to the effect of diffraction from the finite aperture size of the lens—the analog hardware produces a nearly perfect image of the object at the image sensor, in this case a minified version of the tree.

The output signal should is a perfect (and perhaps scaled) copy of the object being photographed. Since we are ignoring the effects of optical resolution in this case, the spatial resolution of the camera is a function of the size of the optical image formed on the sensor divided by the pixel size. This makes sense because is the image is so small that it fits on a single pixel then

1.2 Dissertation Overview

CHAPTER 2

Formalism

This chapter introduces the reader to the more rigorous concepts and mathematical background that will required to fully understand the material presented in the later chapters of this dissertation.

A rigorous discussion of multiplexing and signal-to-noise ratio will be discussed, as well are various coding schemes used in various notable computational sensors as well as the ones in this disseration.

Since the Adaptive Feature Specific Spectral Imaging-Classifier (AFSSI-C) relies on a variation of Principal Component Analysis (PCA) and a Bayesian algorithm for coding design we will discuss some of the fundamental of Bayesian probability and the Log-Likelihood Ratios.

2.1 Multiplexing

2.2 Principal Component Analysis

2.3 Bayesian Rules and Log-Likelihood Ratios

2.4 Compressive Sensing

2.4.1 The Nyquist-Shannon Sampling Theorem

The Nyquist-Shannon Sampling Theorem states one must sample a signal with a sampling rate that is at least twice the maximum frequency of the signal to prevent aliasing Shannon (1949).

2.4.2 Sparsity, Incoherence, and the Restricted Isometry Property

2.4.3 Inversion

2.4.3.1 L0 and L1 Norm Minimization

2.4.3.2 LASSO and sparsity regularization

REFERENCES

Shannon, C. E. (1949). Communication in the presence of noise. *Proceedings of the IRE*, **37**(1), pp. 10–21.