Part I.
INTRODUCTION and PROPOSAL

Part I of this dissertation presents an introduction to the image quality assessment approach proposed in this research. Following a brief summary and overview of the entire work in the first chapter, Chapter 2 discusses extant image quality research in medical imaging. The described shortcomings of many of those methods serve to motivate a novel image quality evaluation framework based upon the implementation of a model of human vision. The particular model utilized in this research is described in Chapter 3.

1. INTRODUCTION

Digital medical imaging systems produce pictures that radiologists utilize in inferring the status and function of the human anatomy. The radiologist's ability to determine an accurate diagnosis is related to the *quality* of those images: a clear and unambiguous representation of the relevant anatomical structures might enable the viewer to understand their pathology. Thus quality is a paramount attribute in the production of medical images, and the pursuit of images that best facilitate the radiologist in visual interpretation is necessarily tied to the measurement of human diagnostic accuracy.

1.1 Problem

Proposed image acquisition and processing methods must normally be evaluated via human observer experiments. As it is the human for whom the images are intended, clearly the best means for correlating image properties with human performance is to utilize humans as observers. This approach, when done properly, requires vast amounts of time on the part of trained, expensive observers. Furthermore, the results of such studies may not be applicable beyond the conditions that they examine.

Thus there is a tremendous impetus for the development of computed methods of image quality evaluation that avoid this arduous human commitment and that may be applied in many imaging situations. However, computed approaches possess limitations of their own that have made them in most cases insufficient for practical application. Medical images are consulted for the purpose of conducting an interpretive task, and the quality of an image is in the end the diagnostic success that the image avails. Many of the computed methods fail to incorporate this essential tenet of image quality research: simple statistics about properties of the image often lack an explicit relationship to performance of an actual task. Those methods that do make an attempt at defining and measuring quality with respect to a task are hindered by the simplifying assumptions they make in their computations that aren't realistic for the complex visual tasks in image interpretation.

1.2 Purpose

A computed method for image quality measurement must be predictive of human assessment, and it ought to parallel that evaluation for many potential tasks or imaging systems. The solution that is proposed here is to utilize as the basis for quality decisions the performance of a visual model that explicitly implements the mechanisms of the human visual system. In this way, an appropriate model might stand in the place of the human subject, carrying out one or more visual tasks that are integral to the evaluation of the imaging system. With a knowledge of the equivalence of the model and human, the performance of the *model* could be used as the basis for optimization or comparison of imaging systems. The viability of this approach relies almost entirely upon the predictability of the results from the vision model employed. Admittedly, our understanding of the mechanisms of human vision is in many respects limited. However, there seems to exist presently, in the area of representation of visual form, sufficient theory to justify an attempt to compare human and visual model performance for several strictly-defined medical imaging estimation tasks.

The core model of shape perception, developed at this university contemporaneously with this dissertation research, was adopted for this novel image quality approach. The core is a medial description of object shape, capturing succinctly the position of the object's middle and its corresponding widths. The core is constructed from edge measurements made at many scales, or aperture sizes, on the original greyscale image data; this multiscale approach allows a representation of objects that is invariant to transformations of position, orientation, and size, and provides cores for larger scale objects robustly even in the presence of smaller scale image degradations such as noise or blur. Many tasks in medical image interpretation involve the perception of shape, and the core model offers both theory and mechanism for the computation of those tasks. More importantly, there is evidence that suggests that the core may be a perceptual mechanism in the human visual system for capturing shape information.

The purpose of this dissertation research was to apply the core model of human vision in an attempt to simulate the performance of the human observer in two estimation tasks in images and to measure the correlation of the model and human performance for those tasks. Specifically, image quality was investigated for the imaging modalities of angiography and portal imaging. An estimation task was chosen for each of those modalities; stenosis estimation and treatment field positioning are tasks that are both medically important and calculable by the core model. Performance for those tasks was measured for both the human and the model as two parameters of each of those imaging systems were varied. Variations in system blur and noise were simulated in the angiography studies, while various levels of two parameters to SHAHE contrast enhancement were applied to digitized portal images. Following the implementation of the core model for the computation of these clinical estimation tasks, the ultimate purpose of this research was to compare the model performance with that of the human. A demonstration, for those particular tasks, of the equivalence of human assessment with that for a model of the human visual system would serve as at least an initial indication of the power of such an approach.

1.3 Thesis

As the highest quality images are those that allow optimal diagnostic accuracy by humans, the test of the efficacy of a model-based image quality measurement is whether its accuracy for some relevant task is correlated with that of humans. It is not essential that the model perform identically to the human for any particular image parameters. What will determine the efficacy of such an approach is whether, as the physical characteristics of the image are manipulated, the performance of the model varies in the same way as that of the human. When image degradations cause the human to perform poorly, the model should do poorly as well. Likewise, an optimal image presentation should enable superior performance for both the human and the model. The research in this dissertation sought to compare the performance of humans with the core model of human shape perception for two estimation tasks across a range of image manipulations. It was the thesis that task accuracy of the core model would indeed track the accuracy of the humans, and that the model would enable a determination of image acquisition and processing parameter values for the production of images for optimal human interpretation.

1.4 Claims

The implications of a computed measure of image quality are both obvious and attractive. From a basic comparison of two imaging systems to the extensive exploration of the parameter space of a complex processing algorithm, there are multitude of applications for a method that would allow relatively rapid and economical feedback in the production of images for the crucial human undertaking of clinical diagnosis. The methods proposed here go in theory beyond anything that has been attempted in the way of computerized assessment. What is explored in this work is the explicit use of a model of the operation of the human visual system. The model carries out shape-based tasks that are integral to the evaluation of any imaging system. A claim is that this level of representation of human performance is necessary for an image quality measurement to truly and widely predict what is best for human utilization. Moreover, this quality framework might be put to broad use wherever there is a proven model for the diagnostic task in question. Finally, there is a clear need for the development of measures of image quality with respect to estimation tasks, and both the model-based approach studied here and the particular model adopted for it ought to be considered as viable solutions.

The particular implementations of the visual model were not found to be completely predictive of human performance in the situations investigated in this work. There are no claims about the readiness of this approach for immediate use. However, there were many positive observations about the results, and future research will modify and re-test aspects of the model and its implementation as dictated by these discoveries. Also, the experimental designs themselves that were presented in this work for the evaluation of the visual model are reusable mechanisms for future exploration of this and other models. Renovations and refinements to a model can be rapidly examined in realistic conditions with this testing procedure. Lastly, the methods for the angiography experiment include principled descriptions of the physical properties, blur and noise, that may vary in an imaging study; it is hoped that these measures will be considered as standards for that purpose. The descriptions and discussions in this dissertation will offer both promise and criticism for these claims surrounding a image quality measurement based upon the principles of human visual perception.

1.5 Overview

This dissertation describes the background and then specific components of two experimental investigations. It is divided into three distinct parts. Part I provides an introduction and motivation for the experimental endeavors later in the work. Chapter 2 discusses the way that image quality measurement is done, and proposes an alternative approach that puts to work a model of human vision. The core model of shape representation, the psychophysical evidence supporting it, and its computer implementation are all contained in Chapter 3.

Part II lays the groundwork for the experiments. Two imaging modalities and their accompanying tasks, which were together the basis upon which the visual model was compared with the human, are described. Chapter 4 explains angiography and vessel stenosis estimation as well as how the model was implemented to perform that particular task. Likewise, Chapter 5 explains an important distance estimation task performed with radiation therapy portal images and concludes with the particular adaptation of the core model that was developed for that task.

In Part III, the experiments that probe the correspondence between the model and the human are detailed. Chapter 6 contains the specifications for the two experimental designs, including parameter level choices and the psychophysical considerations for the human observer experiments. A host of statistical analyses and conclusions are proffered in various forms in Chapter 7. Finally, Chapter 8 speculates about the successes and failures in the correspondence between the model and human results. This final chapter, moreover, discusses both the implications of what was discovered and learned from this investigation and what remains to be done to further explore the possibilities suggested by this initial foray into applying our understanding of human perception.