Research Overview

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My research activities have been in the areas of Biological Vision, Image Processing, Multimedia Systems and Computer Vision. Presently I focus on Color Image Processing, Image Sampling and Interpolation, Medical Imaging and Video Coding.
The major aspects of my research are summarized under the following categories: (A) Early major studies and citations, (B) Recent studies and research-oriented teaching, (C) Present research and future plans.

A. EARLY MAJOR STUDIES AND CITATIONS

My main studies on the human visual system still play a major role in my present research as related to image processing, multimedia and computer vision. The impact of these earlier studies can now be better evaluated based on follow-up works and citations. My study on texture analysis was selected and included in an IEEE book summarizing the most significant contributions made over 50 research years in this area. In total, my publications (journal papers and conference proceedings) have been cited more than 1100 times.

My basic research in the area of biological vision has introduced a comprehensive model of the human visual system. It was based on physiological and psychophysical findings and accounted for major properties known about the visual system. It stimulated further development of a new generalized approach to vision modeling using localized Gabor spectral-position analysis of images in the combined space. Three major works have been published based on this research. The first, devoted to the generalized scheme [1], has been well received and cited 375 times (according to Scholar, more than 200 times according to ISI) with steady increase in the number of citations until present days. Today, when people introduce new approaches to vision they usually cite this work [1] as a major contribution. Some of the citations come also from other fields, like Geoscience and Microscopy.

The second study [2], considered the major task of the visual system in texture analysis, based on the framework introduced in [1]. This paper, which is also cited frequently (182 by Scholar, approx 100 citations by ISI) has gained a special recognition by the IEEE along with other 46 "most significant articles from over thousands of articles published since 1943''. The book was published by IEEE Press [3]. One of the articles in this book is by Nobel Laureates Hubel and Wiesel, whose papers were a major source of data and inspiration for my work. This study has also led to a US Air force report on real-time generation of imagery in wide field-of-view flight simulators [4] and was later published in [5]. Other early studies related to image recognition [6] and sampling [7] have been cited 91 and 38 times, respectively (Scholar). A detailed list of citations according to both Scholar and ISI is attached.

B. RECENT STUDIES

In recent years I have concentrated on three major aspects of image processing and multimedia: (I) Image sampling and Interpolation – focusing on the process in which images are acquired and stored, as well as the relationships between analog and digitized images; (II) Color image processing and compression – in particular providing preferred alternatives *to the common RGB or YIQ/YUV representation; (III) Video and multimedia systems, especially encoding and trans-coding, offering low complexity algorithms that outperform presently available methods, partly based on a patent registered in the US, Japan, Europe and Canada.*

I. Image sampling and Interpolation [8-10]
Most signal processing applications are based on discrete-time signals, although the origin of most sources of visual information is analog. In the first study [8] the task of signal representation by a set of functions was considered. Focusing on the representation coefficients of the original continuous-time signal, the question considered here is to what extent the sampling process preserves algebraic relations, such as inner product, intact. By interpreting the sampling process as a bounded operator, a vector-like interpretation for this approximation problem has been derived, giving rise to an optimal discrete approximation method different from the Riemann-type sum often used. The objective of this optimal method is in the min-max sense and no bandlimitedness constraints are imposed. Tight upper bounds on this optimal and the Riemann-type sum approximation schemes are then derived. We further consider the case of a finite number of samples and formulate a closed form solution for such a case. The results of this work provide a tool for finding the optimal method for approximating an L2 inner product, and to determine the maximum potential representation error induced by the sampling process. In a subsequent study that consequently followed [9], this approach was further generalized and the problem of approximating L2 inner products by means of *generalized* samples was considered. In [10] a new approach to image interpolation was introduced, using exponential functions related to stochastic autoregressive image modeling. Accordingly, the corresponding image interpolants can be implemented effectively using compactly-supported exponential B-splines. A tight L2 upper-bound on the interpolation error is then derived, suggesting that the proposed exponential functions are optimal in this sense. Experimental results indicate that the proposed image interpolation approach outperforms currently available methods of comparable order. Furthermore, a unified approach to image interpolation by ideal and non-ideal sampling procedures was derived. The conclusion is that this proposed Sobolev-based framework could be instrumental and a preferred alternative in many image interpolation tasks.

II. Color image processing and compression [11-13]
Color information plays a major role in image processing and visual communication although presently most algorithms and tools are developed mainly for monochromatic (black and white) images. Usually, the processing of color images is performed either in the RGB color space or in another color space chosen rather arbitrarily, such as YUV or YIQ. In the first study [11] a new approach to color image representation and compression was introduced. A rate-distortion model for color image compression was introduced and employed to determine the optimal color components and optimal bit allocation for compression. It has been shown that the discrete cosine transform can be used to transform the RGB components into an efficient set of color components suitable for coding. The conclusion is that the new approach can significantly improve presently available methods for color image compression and communication. In a later study [12], a Correlation Based Approach (CBA) is presented. Instead of de-correlating the color primaries, we employ the existing inter-color correlation to approximate two of the components as a parametric function of the third one, considered here as the *base* component. We then propose to encode the parameters of the approximation function and part of the approximation errors. Here too, we use the rate-distortion theory to find the optimal color transform to be applied prior to

coding. The results show that the new CBA algorithms are superior to presently available algorithms that are based on de-correlation, such as those implemented in JPEG.

Furthermore, since the color correlation is particularly high locally, in an additional study [13] the image is first sub-divided into regions where for each region the correlation is analyzed and exploited separately. The size of the encoded regions is gradually reduced to allow progressively a more refined description of the transmitted image. Compression results of this progressive approach were presented and compared with JPEG as a typical example of the de-correlation approach, indicating that the proposed new approach could serve as a superior alternative to such compression techniques.

III. Video and multimedia systems [14-18]

Following a basic study at Bell Labs and a patent registered in the USA, Japan, Canada and Europe [14], the topic of video coding and trans-coding was further considered and analyzed in recent years. The model used in this patent is based on several observations, the major one is that for each area of the image, a *localized history* can be characterized. Accordingly, future frames of the video sequence can be encoded using code-words obtained by a process of localized Vector Quantization (VQ). This method can provide a compression ratio of over 100:1 with high quality of the perceived video sequence (PSNR > 30dB). The work presented in [15] describes a computational approach to multimedia communication networks using this patent. In related recent studies [16, 17] the problem of changing the bit-rate of the video stream was considered. This process of trans-coding is becoming of major interest in today's networks, where video communication is conducted between different systems of various bandwidth and display capabilities.

We have also developed algorithms for *color* video coding that benefit from the 2D version of the color correlation-based approach. In the (spatio-temporal) 3D case, the video stream is subdivided into 3D blocks of variable size according to the contents along the spatial and the temporal axes. Initial experimental results [18] show that this new approach to video coding outperforms presently available methods, such as MPEG.

Research-Oriented Teaching

So far I have supervised more than 30 graduate students as a primary supervisor. Most of these studies have been published as either journal articles or in international conferences. In addition to major core curriculum courses, I have taught several courses directly related to my research with overwhelming response of the students. The course on ``Visual and Auditory Systems'' (joint graduate/undergraduate) is attended in recent semesters by over 100 students per semester despite the intensive work and effort involved. My graduate course on ``Image Processing'' is attended by more than 30 graduates this semester. Many of these students select later on research topics in this field. Over the years I have invested in teaching, and it is my conclusion that such an investment is rewarding when students select a subject and a supervisor for their research thesis.

C. CURRENT AND FUTURE RESEARCH

I presently work on further developing a unified framework for color image processing, along with practical aspects of medical imaging and theoretical issues of interpolation. Initial results have been published already in leading international conferences.

(1) Color Image Processing: I plan to develop a unified framework for color image processing and coding based on an optimized approach. Such a framework along with distortion modeling and analysis should optimize the stages of encoding and color processing for visual communication. The objective mean-squared error (MSE) and, in particular, the visually-oriented *weighted* mean-squared error (WMSE) will be used to account for both quantitative and subjective visual fidelity. We will try to exploit the high inter-color correlations of the RGB primaries to develop a correlation-based coding approach. In fact, the two approaches can *jointly* provide a general a correlation/de-correlation based framework. This new color processing approach could be helpful in several fields of machine vision, including image analysis and demosaicing. For operators such as disparity estimation in stereo vision, edge detection and possibly image retrieval, the correlation of primary colors may be better exploited in optimized color spaces. These proposed approaches to color representation and coding are likely to provide an efficient framework of color image processing and low level computer vision.

(2) Biomedical imaging [19-22]: The topic of biomedical imaging was dealt with recently in several Interdisciplinary graduate theses. In the work of Eyal Braiman, a new approach to diagnosis of acute myocardial infarction using tissue deformation in echocardiographic imaging was proposed [19], financed partly by the German-Israeli Foundation (GIF) [20], using ultrasound tools. Other works on ultrasound imaging focused on improving the display resolution [21, 22] in collaboration with Dr. Moshe Bronshtein of the Alkol Institute of Ultrasound in Obstetrics and Gynecology. In a research work with Prof Rafael Beyar and Sharon Harell, a computerized approach to quantitative analysis of the *Myocardial Blush Grade* in patients undergoing angiography was developed using X-Ray tools. These days an Interdisciplinary thesis on retinal illumination (with Prof Ido Perlman of the medical school and Gil Rivnai) is in final stages. Recently, a research proposal was submitted with faculty members of the medical school of the Technion, suggesting to conduct research on the use of MRI to assess the severity of mitral regurgitation by proximal flow convergence in comparison to Echo-Doppler. I plan to continue with these studies on medical imaging in the coming years.

(3) On Interpolation Methods using Statistical Models [23-25]: Deeper analysis of interpolation methods is planned based on recent studies with Ronen Sher [23] and Shira Nemirovsky [24], both are recent graduate students. In Sher's work, a new approach to image interpolation using spatial relationships between adjacent pixels of an image was introduced. In the first stage of the proposed algorithm the localized structural relationships in the input image are studied based on the sparse version of the image. In the second stage, the relationships and the concluded governing rules of the image are used to build an interpolated image. Sher's results indicate a significant reduction in the blockiness and smoothing effects compared to existing methods. This new method is also applicable to one-dimensional signals such as audio. A related study was carried out by Shira Nemirovsky using a wide-sense Markov model, defined in terms of minimum linear mean-square error estimates [24]. In this work, we addressed first-order (auto-regressive) wide-sense Markov images with a separable autocorrelation function. Having developed relations between the statistics of the image and its sampled version, we could propose a new method for texture interpolation. In addition, we have developed a new fidelity criterion for texture reconstruction based on the decomposition of an image texture into its deterministic and stochastic components. Experiments with naturally textured images, as well as a subjective forced-choice test, demonstrated the advantages of the proposed method over presently available interpolation methods, both in terms of visual appearance and quantitatively. A patent related to this work was recently filed by the Technion [25]. This research is still ongoing. Recently new results related to image and texture Interpolation were published in a conference [25]. Presently associated aspects are considered in a study carried out by Micha Kalfon, a graduate student, referring to color textures recognition. A related work on image retrieval is conducted by an additional graduate student, Dmitry Sezganov.

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