CCIT Report #613
February 2007

Illumination Multiplexing within Fundamental Limits

Netanel Ratner Yoav Y. Schechner
Dept. Electrical Engineering
Technion - Israel Inst. Technology
Haifa 32000, ISRAEL
ratner@tx.technion.ac.il yoav@ee.technion.ac.il

Abstract

Taking a sequence of photographs using multiple illumination sources or settings is central to many computer vision and graphics problems. Recently, a growing number of methods use multiple sources rather than single point sources in each frame of the sequence. Potential benefits include increased signal-to-noise ratio and accommodation of scene dynamic range. However, existing multiplexing schemes, including Hadamard-based codes, are inhibited by fundamental limits set by Poisson distributed photon noise and by sensor saturation. The prior schemes may actually be counterproductive due to these effects. We derive multiplexing codes that are optimal *under these fundamental effects. Thus, the novel codes* generalize *the prior schemes and have a much broader applicability. Our approach is based on formulating the problem as a constrained optimization. We further suggest an algorithm to solve this optimization problem. The superiority and effectiveness of the method is demonstrated in experiments involving object illumination.*

1. Illumination Multiplexing

In computer vision research and image-based rendering, objects or people are often acquired under variable lighting directions [3, 5, 7, 16, 17, 20, 21, 22, 23, 28, 29, 31, 34, 35, 40]. Such images are then used for object recognition and identification [3, 16, 25, 27, 34, 35], rendering [6, 16, 23, 29], shape estimation [10, 12, 13, 14, 39, 40] and analysis of specularities, shadows and occlusions [30]. Traditionally, such images were taken by moving a light source around the object, or by sequential operation of individual sources in a constellation. However, recently, there is growing interest in using illumination which is not based on single point sources. Rather, it is based a sequence of images, in each of which lighting may simultaneously arrive from several directions or sources [5, 16, 18, 24, 31, 32, 33, 37]. Some of the benefits include significant improvement in signal noise ratio (SNR) [32] (See for example Fig. 1), significant reduction of dynamic range problems in the presence of saturated pixels, and convenience when photographing people [37]. Other advantages mentioned are efficiency of the acquisition process and image representation, and image enhancement by simultaneous use of flashes and ambient lighting.

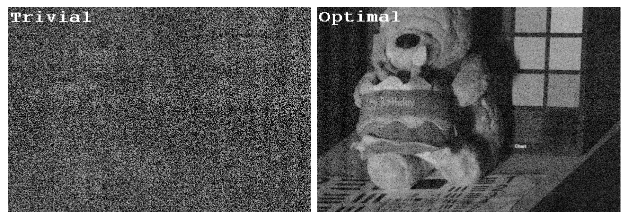

Figure 1. [Left] An image taken under a single light source. [Right] An image of the same scene, decoded from multiplexed illuminated objects. It is decoded as if illuminated by the same single source. The multiplexing code is optimal.

The question is, given all the possibilities of simultaneous operation of sources, what is the optimal way to multiplex the sources in each frame. Ref. [32] suggested that Hadamard-based codes should be used. However, its analysis did not account for a very important problem: image noise depends on the image irradiance itself, which may make Hadamard multiplexing counter productive, as was later experienced by [37]. Fundamentally, this is due to *photon noise*, which exists even in images no matter the quality of the camera, as it stems from the quantum mechanical nature of light. Moreover, no prior study accounted for saturation when seeking optimal lighting. This is despite the acknowledgment that saturation and scene dynamic range are important aspects when using multiple sources [32, 37].

This paper directly seeks multiplexing codes that are optimal under the fundamental limitations of photon noise and saturation, in addition to camera readout noise. This problem and its solution have implications much broader than computer vision and graphics. The reason is that multi-