Photometric Correction of Stereographic Image Pairs

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Abstract

Differences in Photometric characteristics between images acquired during stereographic imaging may significantly reduce the effectiveness of their subsequent display or analysis. While uniform global differences can easily be corrected by applying traditional histogram matching techniques, these methods are not capable of dealing with differences that are object or distance dependent. We have developed a procedure to adjust locally, visual characteristics of one image in a stereo pair to match the alternate image. Objects, and their boundaries, are segmented in both images by detecting edges and depth discontinuities, and these features are used to partition the images into connected components. Where possible, stereo correspondences between components in each image are identified and used as the basis for local color correction. The fully automatic procedure is able to remove visible differences in most cases, but further development remains before the system will be sufficiently robust.

Introduction

Typically, stereographic image pairs are acquired on film or digitally, by methods such as synchronized exposures using multiple lenses and detectors; as a single exposure employing some form of beam splitter; or as a sequence of exposures by a single acquisition device which is moved appropriately between exposures. Whatever the acquisition paradigm, errors of either a geometric or photometric nature may occur. These errors can be a result of many factors such as different acquisition times, inadvertent camera motion between acquisitions, film-processing inconsistencies, differences between digital detectors, differences between lenses, and inaccuracies in the relative orientations of lenses. For stereopsis to be easily achieved when viewing stereoscopic image pairs, the geometric relationships between corresponding points must conform to the requirements of epipolar geometry and other visual differences must generally be small.

This manuscript is primarily concerned with correcting for inconsistencies in the photometric characteristics between images. More specifically, it is stipulated herein that for a given stereo image pair, their geometry is correct and one image is considered to be photometrically correct, while the alternate image is inconsistent with the first.

Prior attempts to adjust images in a pair of stereo exposures have generally relied on global methods such as various forms of white balancing or histogram equalization. These methods can be automated in a manner that provides reliable results in most cases, and are used routinely within our laboratory for postprocessing stereo image pairs. While these methods are able to correct for many types of systematic color shifts, they are inadequate for cases where differences are depth dependent or where surface reflectivity is such that an object's appearance changes rapidly or discontinuously with changing angle of view.

To improve our automated postprocessing procedures, we have been investigating object-based methods that attempt to identify corresponding foreground objects and adjust their photometric characteristics if there are significant disparities. This task is closely related to the problem of determining depth from stereo correspondence, as both involve matching objects between images in a stereo pair - which has proven to be very difficult. In fact, these tasks do not have a theoretical solution in general because it is possible to contrive stereo image pairs having no corresponding regions. In general, stereo image pairs will have some regions which correspond and some that do not, and in this situation there may be considerable ambiguity in how regions are to be identified together. Note that this ambiguity occurs both in computerized analysis as well as when a scene is being viewed by human observers, and is the source of many psychophysical depth illusions. The ultimate goal of this project is to use the information in a stereo pair to adjust the images to make it easier for viewers to achieve stereopsis.

Color Space Disclaimer

Within this manuscript we have deemphasized issues related to the exact color space under consideration and whether the color space has a true metric in the mathematical sense. While this allows us to sidestep many difficult technicalities, the main reason this is desirable is that many of our images are acquired with radiation sources other than light (e.g., x-rays) and assignment of a pseudocoloring is somewhat arbitrary. When these images are displayed they are subject to the constraints of color spaces and perceptual metrics, but the algorithms developed herein are applied to the originally acquired data and issues related to color spaces are not relevant at that point.

Methods

For the purposes of this manuscript, it is assumed that in the image pairs being processed the image planes are coplanar and that scan lines in each image are parallel to their common baseline. These conditions are sometimes specified by saying that the images have been rectified [1]. We also assume that the images were acquired or artificially generated at projection angles that are reasonably representative of human vision, and that the images are of normal kinds of scenes that have not been specifically contrived to defeat computer algorithms.

Object Segmentation

Each image in a pair is first segmented into coherent regions over which chromanence and brightness vary continuously. The process begins by identifying boundaries with an edge detector based on Cranny's algorithm [2]. Images are then partitioned into connected components over which the continuity constraints are enforced. An attempt is then made to establish stereo correspondence between images by independently matching epipolar pairs of scanlines to derive disparity and occlusion information. Our goal is to identify discontinuities in depth which indicate boundaries of objects. These methods have been proposed in computer vision literature by many [3-5] but the specific algorithm we employ, which was first proposed by Birchfield and Tomasi [6], is cvFindStereoCorrespondence(),contained in the openCV library. In this process, because we are primarily interested in larger forground regions, non-uniform regions and very small objects are either suppressed or combined into larger regions, while larger objects are retained. Not all regions can be unambiguously matched between images by this process. Unless the stereo correspondence can be determined with a high degree of confidence, the program does not attempt to correct the region. For each pair of corresponding connected components, a linear correction function that minimizes the sum-of-squares difference is determined.

We have developed software to implement these methods. The algorithms have a number of thresholds and parameters that need to be specified but otherwise operate automatically.

Luminance-Based Figures-of-Merit of Stereo Correspondence

As part of this work we have been investigating measures that are related to the amount of stereoscopic information contained within stereo image pairs. For a given pair of images, the central question is how closely one can come to generating the images in some sense, from projections of a geometrically viable 3D scene. In general, for scenes consisting of opaque surfaces, this does not have an analytical solution, and the effort required to solve it computationally is prohibitive. Thus, an optimal solution is not known and it is unlikely that there is a single measure that captures all aspects of stereo correspondence. Nevertheless we have devised two luminance-based figures-of-merit to measure different aspects of stereo correspondence. Both of these are most useful for evaluating small changes in images that are known to be related by stereo projection, and both behave somewhat unpredictably for large changes or for random images.

The first method produces a 2D scatter plot of luminance values from corresponding pixel pairs taken from the two views. The scatter plot is then analyzed for its degree of clustering, central tendency, and for certain aspects of its symmetry. This method does not require normalization but can be defeated when it is applied to image pairs that are not related by stereo projection. An example of a scatter plot generated by the method is shown in figure 1. This particular plot was generated for the left-eye and corrected right-eye images in figure 3. Note that the strong preponderance of points along the diagonal indicates that the images are very similar, while the deviation from linearity of the distribution is attributed to stereo disparity.

The second method begins by identifying the closest object appearing in both views. The two images are then aligned horizontally so that this object is in registration between the images and only the overlapping parts of the images are considered further. For each scan line in each image, pixel values are integrated along the scan line, and the resulting function is normalized so as to have a maximum value of one. The root-mean-square difference between each pair of corresponding scan lines is calculated and summed over all such pairs. For stereo pairs this gives a small value, and for random pairs a high value.

Test Image Pairs

As part of the development process, a number of synthetic pairs of images were generated, having known spatial relationships and photometric differences. These were intended to be of a very simple design, but they allowed the various algorithms to be tested. One such example is shown in figure 2 and discussed in the results below.

We also tested the procedures described above on a number of test image pairs that had been acquired with a pair of consumer digital cameras that had shutters wired together so that they would perform synchronously. In each case, one image in the pair showed both global and local differences relative to its reference image. These differences either occurred spontaneously because of inconsistencies in the cameras' automatic exposure calculation; by differences in the relative positioning of bright and dark objects relative to the cameras' sensors; by placing neutral density filters over one camera only; or more likely, by the authors intentionally misadjusting white balance and speed settings. An example of one of these pairs is shown in figure 3.

In our laboratory we are mainly interested in the application of stereographic methods to radiographic images. This is becoming increasingly important as Radiology moves toward the digital acquisition of large 3D datasets. Figure 4 presents a stereo pair of x-ray projections of a breast that were acquired with a breast tomosynthesis system. A single breast exam may acquire many such pairs and these kinds of procedures necessitate automated image correction.

All stereo pairs were processed with the above algorithms and a figure-of-merit was calculated before and after the correction.

Results

Figure 2a and 2b represent right- and left-eye projections of a 3D space consisting of a square, circle and triangle at varying distances from the observer. Colors of the image in 2b were intentionally changed to test our algorithm's ability to make a suitable correction. Note that colors in each object were altered separately so there is no global adjustment that can adequately reduce the differences. Figures 2c and 2d show the result of the segmentation and depth evaluation, and our use of gray values to label the depth of each object. The corrected version of 2b is shown in 2f.

Figure 3a and 3b are the left- and right-eye views of a stereo pair, where 2b exhibits an overall blue cast, and the small yellow boat on the right appears to have been incorrectly recorded. Manually removing the blue cast did not greatly improve the hue of the small boat. However, the algorithm was able to perform both a global color correction and locally improve the boat's color.

In each of these cases, the algorithm was able to decrease color discrepancies between the images, though the corrections were less than what could have been achieved with a manual procedure.

Figure 4a was considered to be a correct left-projection and 4b was the corresponding right-projection. Figure 4e is the corrected version of 4b. Figures 4c and 4f are the scatter plots associated with the uncorrected and corrected images, respectively.

Discussion and Conclusions

At this stage of development, it is not possible to implement the kinds of corrections considered herein in a fully automatic procedure. This is largely due to the inherent ambiguities in identifying corresponding regions between images – a task that is not always solvable by either computers or humans, but is much more difficult for computers. Also, because 3D shape information is reflected in subtle photometric differences in views at slightly different viewing angles, there is a limit as to how much correction is actually desirable. Issues of this type must rest on the expertise of human observers, until a more comprehensive theory of stereo vision provides guidance. But in the end, if photometric information about a scene has been degraded in one image of a stereo pair, there will not be enough information to correct unambiguously the image.

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Author Biography

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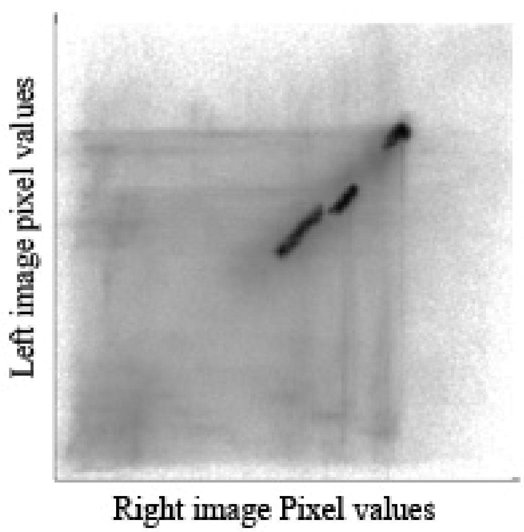

Figure1. *Scatter point derived in figure-of-merit calculation for left-eye and corrected right-eye images in figure 3.*

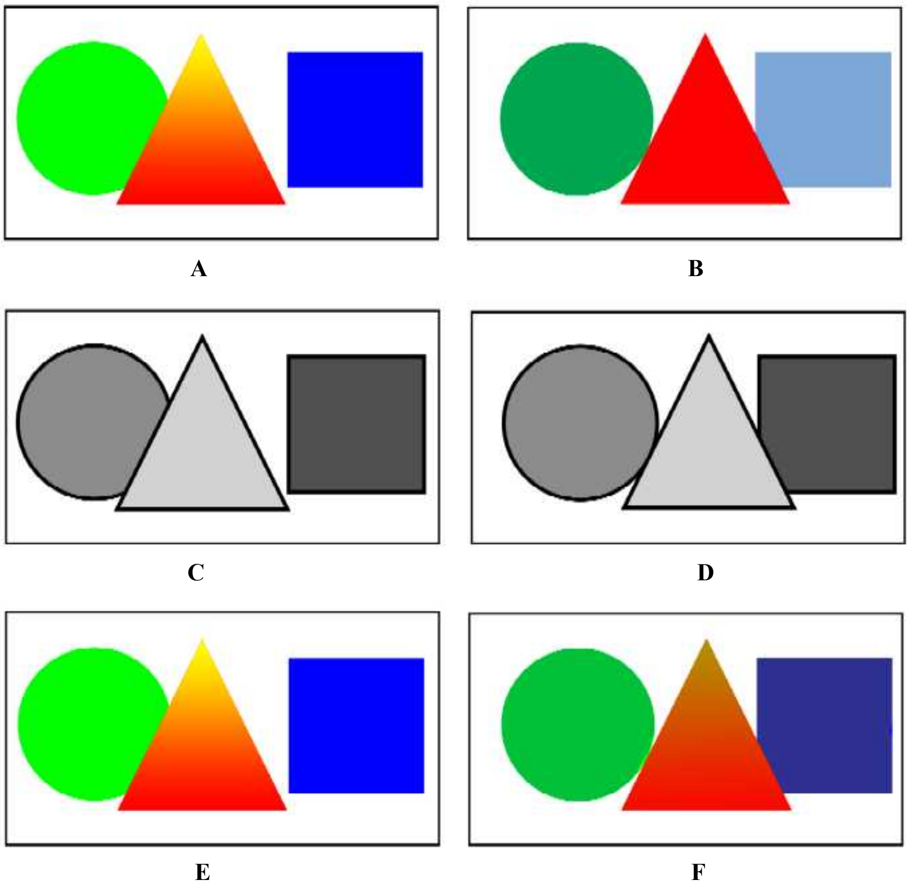

Figure2. *A synthetically generated stereo pair of three geometric forms at varying distances from the observer. A and B are the original right- and left-eye images respectively. C and D show how the regions were segmented and labeled with distance (i.e., shade of gray).*

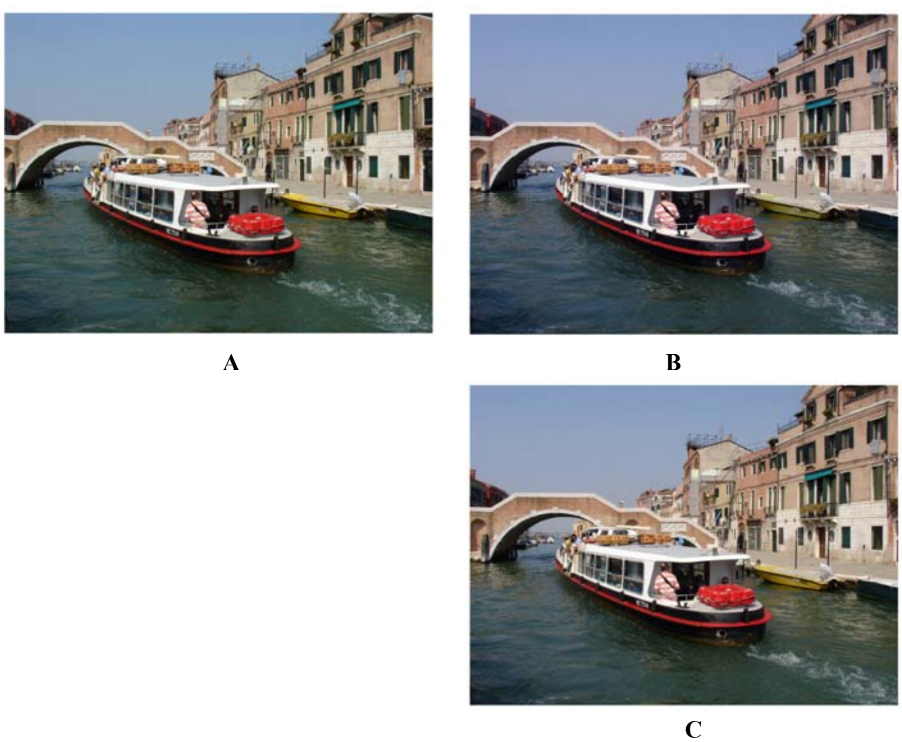

Figure3. *A and B represent the left-eye and right-eye images in a stereo pair. Image C is the result of correcting B to match A.*

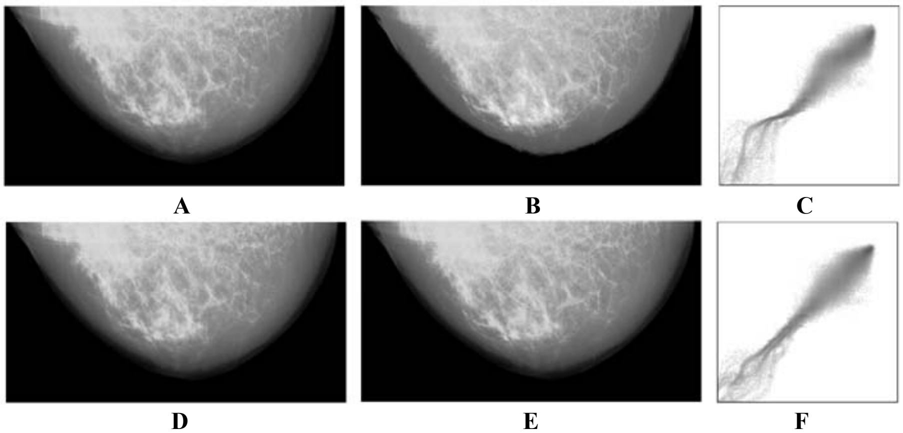

Figure4. *A and B are a left- and right-view of breast projections acquired by X-ray tomography. E is the result of correcting B to match A. C and F are the scatter plots generated by the uncorrected and corrected pairs respectively.*