Research Statement

Gabriela Oana Cula
oanacula@caip.rutgers.edu
www.caip.rutgers.edu/∼oanacula

December 2006

The main goal of my graduate work was to develop computational methods for interpreting the visual imagery offered by the natural surroundings. Textured surfaces are an inherent constituent of real-world scenes, therefore precise computational representation of the interaction of light with real-world surfaces is of fundamental importance for developing efficient and robust real-world applications of computer vision and graphics.

More precisely, in my Ph.D. thesis research, I am concerned with measuring and modeling the complex interaction of light with real-world textured surfaces. I use bidirectional imaging to design imaging protocols to capture the appearance of real surfaces as the illumination and viewing directions are changed. By means of signal processing, statistics, machine learning and physics I have developed appearance-based surface models with applications in recognition for computer vision, and rendering for computer graphics. One interesting real-world surface to which I give special attention in my work is human skin. I have developed a unique database of skin texture [3] which captures the dependency of detailed skin texture on the imaging conditions. This database is made publicly available for further research. Moreover, I have developed computational representations for skin texture with potential use in many applications including robust face models for computer vision, realistic rendering for computer graphics, computer-assisted diagnosis for dermatology.

Currently I am working as a postdoctoral scientist with the Methods and Models Department of the Skin Research Center of $Johnson \& Johnson$, in Skillman, NJ. By means of spectroscopy, confocal microscopy, spectral and fluorescence imaging, I am exploring the physiology of the skin, for a better understanding of normal skin behavior in relation to its structure and function. It is an exciting experience for me not only because I am learning more and more about the properties of the largest human organ, but also because I am gaining experience with different imaging modalities, such as spectral imaging and microscopy.

The following is a more specific description of my graduate work in the fields of computer vision, graphics and biomedical engineering.

Previous and Current Research

Modeling Surface Appearance

In much of the computer vision literature over the of past decades the descriptions of textured surfaces suffer from oversimplification. Texture as a single image is a poor representation of the complex interaction of light with real surfaces because it cannot fully capture the complexities of real world appearance. Most real-world textured surfaces present not only variations of color or reflectance, but also local height variations. This type of surface is referred to as a 3D texture. As the lighting and viewing conditions are varied, effects such as shadowing, foreshortening and occlusions, give rise to significant changes in texture appearance. Accounting for the variation of texture appearance due to changes in imaging parameters is a key issue in developing accurate surface models. The bidirectional texture function (BTF) is observed image texture as a function of viewing and illumination directions. As reported in [1] [2], I have constructed BTF-based surface models which capture the variation of the underlying statistical distribution of local structural image features, as the viewing and illumination conditions are changed. This texture representation is called the bidirectional feature histogram (BFH). Based on the BFH, I have designed a 3D texture recognition method which employs the BFH as the surface model, and classifies surfaces based on a single novel texture image of unknown imaging parameters. Moreover, I have developed a computational method for quantitatively evaluating the relative significance of texture images within the BTF. The performance of the methods was evaluated by employing over 6200 texture images corresponding to 40 real-world surface samples from the CUReT (Columbia-Utrecht reflectance and texture) database. The experiments produce excellent classification results, which validate the strong descriptive properties of the BFH as a textured surface representation.

These methods have important implications for computer vision. For 3D texture recognition or classification, invariance to illumination or viewing direction is essential for robust performance. My approach has the key advantages that a single image can be used for recognition without the need for iterative methods and the viewing/illumination direction of the novel images need not be known. Furthermore, the images in the training set need not be registered. An additional impact of this work is the identification of a smaller subset of images from the CUReT database that can be used to sufficiently represent the texture class. The CUReT database contains over 200 images per sample and it is useful to determine which images can be considered redundant using a quantitative measure. Indeed this analysis can be used for BRDF/BTF measurement planning in subsequent experiments.

This work also has implications for computer graphics. Histograms of textural features have become an important building block for texture synthesis techniques. Compact representations of surface texture such as the one introduced here can be modified to support efficient and realistic rendering of natural objects with complex surface texture.

Bidirectional Imaging and Modeling of Skin Texture

One very interesting textured surface is the human skin. The skin surface is a detailed landscape, with complex geometry and local optical properties. In addition, skin features depend on many variables such as body location (e.g. forehead, cheek), subject parameters (age, gender) and imaging parameters (lighting, camera). As with many real world surfaces, skin appearance is strongly affected by the direction from which it is viewed and illuminated. I have developed a skin imaging protocol for clinical environment, called bidirectional imaging, that captures the dependency of skin appearance on the angle of incident illumination and the angle of observation. This imaging protocol has been used to create the Rutgers Skin Texture Database [3], which is made publicly available for further research. The construction of the database is a collaborative effort with Dr. Frank P. Murphy and Dr. Babar K. Rao, from the Department of Dermatology, University of Medicine and Dentistry of New Jersey.

Rutgers Skin Texture Database has two main components: (I) normal skin surface appearance for computer vision and graphics, and (II) skin conditions and disorders for dermatology.

For the first component of the database I have focused on facial skin [5]. The database contains more than 2400 images corresponding to 20 human faces, 4 locations on each face (forehead, cheek, chin and nose) and 32 combinations of imaging angles. The images in the database are acquired from both female and male subjects (7 females and 13 males), while the subjects age ranges from 24 to 53. Inspired by this data, I have developed two models for use in skin texture recognition. Both models are image-based representations of skin appearance that are suitably descriptive without the need for prohibitively complex physics-based skin models. These models take into account the varied appearance of the skin with changes in illumination and viewing direction. I have employed these texture representations for skin classification in two contexts: to discriminate between different facial regions, and to classify human subjects based on detailed facial skin images. The experimental results show high classification rates, confirming that the proposed texture representations capture well the characteristics of skin texture. The results are even more encouraging when one considers that I attempt and succeed in discriminating skin vs. skin. The visual differences in appearance of various skin areas are rather subtle, while the usual texture recognition scenario employs textures of different nature, e.g. tree bark vs. concrete.

Some interesting conclusions for both computer vision and graphics can be drawn from the outcome of the experiments. Specifically, I observed that forehead skin and cheek skin corresponding to a certain subject presents similar characteristics, and one implication of this observation is that a skin texture renderer would not need two different skin texture models for the forehead and the cheek of the same subject. Also, the nose skin has generic characteristics for different subjects, and this observation could lead to one unique skin model for rendering the nose skin of different subjects. On the other hand, the forehead skin varies significantly from one subject to another, and this observation suggests that human identification can be aided by including skin texture recognition as a biometric subtask.

The clinical component of the database is the first of its kind in the dermatology community [4]. This unique database contains 75 cases of skin disorders with multiple images per case. Unlike existing databases, skin images of several disorders are obtained under multiple controlled illumination and viewing directions. The database serves as a valuable research and education tool. It sets an example of public dissemination of data that would be of great value to the biomedical research community. In addition, the database clearly demonstrates the advantages of bidirectional imaging. Geometric structure such as wrinkles and bumps can literally disappear and reappear as the illumination and/or viewing directions are changed. The series of images obtained with bidirectional imaging is more representative of overall skin appearance. In a real clinical visit, physicians can tilt their head or reposition their patients to get a complete impression of the skin surface. Bidirectional imaging provides this information using an image series and is superior to a single digital image.

The complete database is made publicly available and it will constitute an effective teaching tool for medical students, residents and practicing dermatologists, as well as an informative reference for patients. The database shows the utility of standardized bidirectional imaging for clinical and research purposes.

Polarization Multiplexing for Bidirectional Imaging

Polarization of reflected light provides a wealth of information not available in scalar intensity images. My goal is to incorporate polarization in appearance-based modeling in an efficient and meaningful way. It is well known that polarization of light is a useful quantity for separating surface reflectance from body reflectance because surface reflectance maintains the polarization of the source, while body reflectance becomes depolarized. In this work I show that polarization can also be used to separate surface reflectance contributions from individual light sources. My approach is called *polarization multiplexing* and it has significant impact in appearance modeling and bidirectional imaging where the image as a function of illumination direction is needed. Multiple unknown light sources can illuminate the scene simultaneously, and the individual contributions to the overall surface reflectance can be estimated. To develop the method of polarization multiplexing, I use a relationship between light source direction and intensity modulation. Inverting this transformation enables the individual intensity contributions to be estimated. In addition to polarization multiplexing, I show that phase histograms from the intensity modulations can be used to estimate scene properties including the number of light sources. This work is reported in [6].

Research Agenda

My intention is to continue working in the fields of computer vision, graphics and biomedical engineering. More specificaly, my future research plans are comprised of two major directions. First, due to my current involvement in exploring the appearance and the physiology of human skin, I am interested in working in the area of medical imaging. Given the significant interest for precise skin texture models across various fields (e.g. computer vision, graphics, medical imaging) I would like to continue to explore the visual properties of skin texture, as they are determined by the physiological attributes. I plan to further develop my skin texture model to accurately capture all properties of skin: the fine scale geometry of pores, the pigment variations of skin markings, the translucency due to subsurface scattering of light, the undelying layer of structural proteins, collagen and elastin. All these properties together determine the specific appearance of skin, and an accurate skin texture model needs to capture all these properties simultaneously. Current models suffer from simplification, and do not yield realistic renderings of detailed skin texture.

I will work towards developing imaging techniques not only for normal skin, but also for damaged skin, i.e. skin affected by psoriasis, acne, melanoma, and other disorders. I will continue my collaboration with my colleagues at the Skin Research Center at $Johnson\&Johnson$, because our combined expertise about skin appearance and skin physiology will lead to a better understanding of skin structure and function. Moreover, I plan to extrapolate my learnings about skin imaging and modeling towards other exciting directions of medical imaging, such as breast and chest imaging, or computerized analysis of radiographic hard tissue (bone) patterns and texture models applied for detection and characterization of various lesions in radiologic images.

Second, my work is driven by the desire to continue to develop modeling and measurement methods, to accurately capture the complex appearance of the surrounding world. I intend to pursue the integration of real-world surface models into synthesis and recognition algorithms, as well as the augmentation of surface models to provide object and scene representations that employ a large range of visual cues such as depth, motion and shape.

The list of research topics which raise my interest could continue, but a common theme can be identified: measurements and models of the rich visual imagery offered by the natural surroundings. With the significant advances of camera technology, we have the capability of acquiring good quality and high resolution image data, in an economical and convenient way. The great improvement in processor and hardware memory allows us to process and store this data without significant effort. We are compelled to take advantage of these technical capabilities and to endow computers with the ability of understandanding the rich visual world surrounding us. This is a fascinating mission, and I am excited to be able to contribute to its advancement.

Pursuing continuous support will be an integral part of my research agenda. Aside from offering technical challenges, this research topic also is an important building block of commercial and medical applications, or applications related to national security. For instance, precise models for real-world surface appearance can greatly improve the realism of renderred scenes for computer graphics applications, while robust face models are essential for successful human identification. Also, accurate skin texture models are fundamental for computer-assisted diagnosis systems and remote consultation applications. Moreover, the quantification of skin appearance has implications in evaluating treatment efficacy, and it can aid development, evaluation and testing of pharmaceuticals and cosmetics. Given the large range of applications for which precise surface models are of great importance, I believe I will be able to obtain funding for my research by applying for grants from the National Science Foundation (NSF), the Defense Advanced Research Projects Agency (DARPA), and the National Institute of Health (NIH).

As an important part of my research agenda, I look forward to collaborations within and outside the department, with other insightful faculty members and fellow researchers. I am open to new ideas and methodologies that arise from collaborative efforts. I am especially stimulated by the prospect of working jointly with graduate and undergraduate students. Research is a fascinating and satisfying experience, which helps develop independent thinking and build confidence. For this reason, the research experience should start as early in a career as during undergraduate studies.

References

[1] O. G. Cula and K. J. Dana. Compact representation of bidirectional texture functions. *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, I:1041–1047, December 2001.

[2] O. G. Cula and K. J. Dana. 3D texture recognition using bidirectional feature histograms. *International Journal of Computer Vision*, 59(1):33–60, August 2004.

[3] O. G. Cula, K. J. Dana, F. P. Murphy, and B. K. Rao. http://www.caip.rutgers.edu/rutgers_texture/. 2003.

[4] O. G. Cula, K. J. Dana, F. P. Murphy, and B. K. Rao. Bidirectional imaging and modeling of skin texture. *IEEE Transactions on Biomedical Engineering*, 51(12):2148–2159, December 2004.

[5] O. G. Cula, K. J. Dana, F. P. Murphy, and B. K. Rao. Skin texture modeling. *International Journal of Computer Vision*, 62(1/2):97–119, April/May 2005.

[6] O. G. Cula, K. J. Dana, D. K. Pai, and D. Wang. Polarization multiplexing and demultiplexing for appearance-based modeling. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 29(2):362–367, February 2007.