Graduate Course on Three-Dimensional Television Introduction and Overview

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This effort was coordinated by Haldun M. Ozaktas with contributions by Levent Onural on shaping the outline and content of the course and determining appropriate contributors. The material was first prepared between September 2004 and August 2005. The course was subsequently offered or the material used at a number of institutions.

1 Introduction

The term "three-dimensional television" (3DTV) is understood by many as a natural extension of "two-dimensional television" which produces an image on a screen. In the past, 3DTV was usually understood to mean stereoscopic imaging, which many people are familiar in the form of the "old" 3D cinema that involved viewing with special glasses. The modern vision of 3DTV, occasionally depicted in science-fiction films, involves the perception of objects in three-dimensional space.

Until now, this vision of 3DTV has remained a long-time goal that was too difficult to realize. However, advances in optical technology and computing power have now brought us to the point where we can seriously consider making this technology a reality. This technology has immense consumer potential not only for network television but also for an array of entertainment, commercial, industrial, and medical applications.

Three-dimensional photography and video are not new. However, as already noted, most systems to date are not "true" 3D but rather involve stereo viewing, often with special glasses. This is far from what current research is trying to achieve. Research on holography has been continuing for several decades, but only with recently available computing power has it been possible to contemplate moving 3D images. Many of the constituent parts of 3DTV technology are starting to fall into place. In 5–10 years, specialized applications may begin to emerge. Beyond 10 years, consumer applications may be expected, although this is difficult to predict.

Although the final form 3DTV will take is not certain, current visions involve ghost-like but crisp moving video images floating in space or standing on a tabletop-like display. Viewers will be able to peek or walk around the images to see them from different angles and from behind. Undoubtedly this will be of immense interest for consumer TV, games, virtual reality and entertainment in general. Non-consumer applications are also diverse. In medicine, 3DTV images may aid diagnosis as well as surgery. In industry, they may aid design and prototyping of machines or products involving moving parts. In education and science, they may allow unmatched visualization capability. The possibilities are endless.

Advances in this area will also be closely related to advances in the area of *interactive* multimedia technologies in general. While interactivity is a different concept from three-dimensionality, since both are strong trends, it is likely they will overlap and it will not be surprising if the first 3DTV products also feature a measure of interactivity. Indeed, since interactivity may also involve *immersion* into the scene and three-dimensionality is an important aspect of the perception of being immersed in a scene, the connections between the two trends is greater than might be thought at first.

While the end result is deceptively simple to visualize, the diversity of the technologies involved is very great. Successful realization of such products will require significant interdisciplinary work. Few if any researchers can claim to be experts in all of the areas involved. The purpose of this course is to both aid the training of new researchers in this area and to serve as self-study material for those wishing to enter the field. It will also help experienced researchers fill in the gaps in their knowledge in those aspects they are less familiar with.

2 General Features

The course lasts 15 weeks of 3 lecture hours each. It is split into 1 or 2 week modules by subject. Some of the modules are further split into parts by contributing author. Each contribution consists of several materials which have been designed with the purpose of self-containment:

1. References and/or course notes: This is meant to be the primary reading material for students. Either a clear indication of what the students are responsible for reading or a set of course notes may fulfill this purpose.
2. Course presentation slides/transparencies: These are the presentation slides to be used by the instructor in class.
3. Speaker notes and/or references (unless embedded in course presentation): Some contributors have embedded speaker notes in the course presentation. Others have listed these separately or provided a clear indication of the references which the instructor should consult in preparing for the lecture.
4. Additional study materials (optional): Some contributors have provided additional exercises or other materials.

While a degree of uniformity has been sought, all contributors have provided these in somewhat different ways. The purpose has been to allow an instructor who is not especially an expert in all of these topics to be able to still teach the course without undue difficulty. That is why we have insisted on the items other than the presentation slides also to be provided.

Most contributors have also provided examination questions. These have not been posted to maintain confidentiality, and will be available from the project management office for the duration of the project.

The prerequisites for each module have been indicated separately to allow selective use in different contexts to serve different purposes.

3 Course contents

In what follows we give a weekly description of the course contents and their contributing authors. Some modules are one week and others are two weeks long. Some modules are split into submodules since different authors have independently contributed different parts. Some modules or submodules have joint authors.

Week 1 Vaclav Skala, Libor Vasa, Ivo Hanak, and Martin Janda (3 hours). Contents: Fundamentals of algebra, vector and matrix operations. Implicit, explicit and parametric description of geometric primitives (points, lines, triangles etc.). Euclidian, affine and projective spaces, Cartesian, barycentric and homogeneous coordinates, coordinate systems (world coordinates, camera coordinates, device coordinates). Principle of duality. Points, vectors and frames. Geometric transformations in E2 and E3. Projective transformations. Stereo projection. Camera parameters and camera settings.

Week 2–3 Aydın Alatan (6 hours). Contents: Extracting 3D structure from multi-view 2D images. Determining correpondences between images: feature extraction, robust feature matching, finding dense correspondences. Determining 3D structure from image pairs: epipolar Geometry, solving for F-matrix, E-matrix and 3D parameters, triangulation for depth estimation. Determining 3D structure from multi-frames (video): bundle adjustment for multi-frames, factorization approaches, recursive methods based on Kalman filters.

Week 4–5 A Uğur Güdükbay (3 hours). Contents: Introduction to computer graphics. Geometric modeling: curves, surfaces, and solids. Usage of implicit and parametric surfaces for modeling and rendering (collision detection for animation purposes, ray-surface intersections for rendering, generating geometric primitives). Polygon mesh representations. Cubic curves and surfaces (Hermite, Bezier B-Spline, etc.). Introduction to animation.

Week 4–5 B Bülent Özgüç (3 hours). Contents: Radiance, irradiance, image formation, BRDF, Lambert's cosine law. Object space rendering techniques (Gouraud shading, Phong shading etc.). Image space rendering techniques (ray tracing). Texture mapping, bump mapping, environment mapping.

Week 6–7 A Enis Çetin (3 hours). Contents: Basic principles of digital coding of waveforms, basic entropy, fundamentals of lossless and lossy compression. Transform domain data coding: discrete cosine transform (DCT), integer arithmetic based implementation of DCT, integer transform, KLT and wavelet transforms. Lifting implementation of the wavelet transform. Geometric coding. JPEG algorithm.

Week 6–7 B Gözde Bozdağı Akar (3 hours). Contents: Basics of video compression. Popular video standards: H.263, H.264, MPEG-1, MPEG-2, MPEG-4. 3D video coding techniques (multichannel video coding, stereo video coding, mesh based coding etc.).

Week 8 M. Reha Civanlar (3 hours). Contents: Internet protocol stack overview. Basics of data transport. IP reliable transport, flow and congestion control. Multicast. Wireless networking issues. Multimedia transport over IP. Packet loss (resilience, recovery). Delay (buffer management). Review of the existing protocols and techniques. 3D video models and their transport over IP. Left/right views. Views and depth. Views and 3D models. Lightfields.

Week 9 Haldun M. Ozaktas (3 hours). Contents: Introduction to elementary ray and wave optics from a signals and systems viewpoint, plane-wave decompositions, diffraction, Fourier optics.

Week 10-11 Atanas Gotchev, Karen Egiazarian, Moncef Gabbouj, and Levent Onural (6 hours). Contents: Sampling higher dimensional signals. Sampling rate and geometry conversions (up-down sampling, conversion between rectangular and other periodic sampling geometries, conversion between rectangular and circular grids). Non-uniform sampling basics. Sinc, spline and polynomial based decimators and interpolators and their efficient realization. Plane-wave decomposition of propagating waves. 4D Fourier transform and its fast computation. Fast algorithms for multi-dimensional Hartley transforms, Fresnel transform, etc. Atomic decomposition and wavelets. Gabor waveletes, complex wavelets, ridgelets, curvelets, beamlets, brushlets, chirplets, fresnelets, etc. Multidimensional subband decomposition.

Week 12 A Ian Sexton (1.5 hours) Contents: Directional basics of stereoscopic vision and an analytical view of stereoscopy.

Week 12 B Andreas Schilling (1.5 hours) Contents: Depth perception, 3D displays: color multiplex, polarization multiplex, time multiplex, location multiplex, direction multiplex, multiple focal distances.

Week 13-14 Ventseslav Sainov and Elena Stoykova (6 hours). Contents: Fundamentals of holography and holographic 3DTV techniques. Brief Introduction to the theoretical basis and experimental techniques of the holographic process. Techniques for dynamic holographic recording. Digital methods in holography, hybrid and synthesized holograms for dynamic holographic displays. SLMs and DMDs for holographic displays. Applications of holographic 3D displays.

Week 15 A Ventseslav Sainov and Elena Stoykova (1 hour). Contents: Integral imaging.

Week 15 B Ismo Rakkolainen (1 hour). Contents: Volumetric imaging.

Week 15 C Andreas Schilling (1 hour). Contents: LIDAR, principles, different types of operation, time-of-flight range imaging, photonic mixing devices.