D21.4:Report on Other Ongoing Research Activities 4

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EXECUTIVE SUMMARY:

One of the regular activities during each Technical Committee (TC) meeting is the reporting of ongoing activities within the scope of the TC that are being conducted by others who are not members of our NoE. Each TC member, who is aware of such activities is expected to share his/her related observations by presenting a brief oral or written report. This activity assures that the NoE is kept updated about such activities which take place outside of the NoE.

The purpose of this deliverable is to collect from each TC a brief report on such activity which took place during the TC meetings conducted during the first 11 months of 3DTV NoE operations. The function of the deliverable is twofold:

i) to provide easy access to such collection of information by any NoE member,

ii) to assure that each TC allocates time for such reporting during its meetings.

Six such reports, one from each technical WP(in 5 TCs), are provided below.

1. WP7 Report on External Activities (TC1)

3D capture technology for dynamic scene content is progressing at a breath-taking pace. It is expected to evoke a revolution in visual technology. Beyond any doubt, precise acquisition of 3-D information of dynamic scenes is crucial for 3DTV implementation. Extensive research has been conducted for capturing, processing, and analysis of 3-D scene data aimed at reliable 3-D reconstructions for more than two decades. A variety of techniques have emerged as a result of the recent advances in image sensor technologies and evolution of digital computation. Due to the diversity of WP7, the participants decided to publish a joint journal publication summarizing the state-of-the-art in the field of 3D. The article appeared as

3-D Time-Varying Scene Capture Technolgies A Survey in *IEEE Transactions on Circuits and Systems for Video Technology, Vol 17, No 11.*

It contains approximately 300 cited publications and clearly outlines the state-of-the-art up to the year 2007.

One important conclusion to be drawn from the article is that besides promising advances on the hardware side, innovative new algorithms are currently being developed that are able to achieve unprecedented 3D reconstruction results. The description of work for WP7 has been adjusted according to the findings of the journal article. The recent improvements of publications within WP7 (from 36 in 2006 to 57 in 2007), shows that the members of WP7 have now much better caught up with the recent state-of-the art and are much more competitive within High-quality conferences or journals.

The list of high-priority research areas and researchers that work in each area are:

- Multi-camera based techniques: I. Ihrke, E. de Aguiar, B. Rosenhahn (MPG), E. Çetin (Bilkent), X. Zabulis, N. Grammalidis (ITI-CERTH), M. Tekalp (KU), S. Fleck, B. Huhle (UNI-TÜBINGEN), C. Türün (Yogurt), Y. Bastanlar, Y. Yardimci, A. Temizel (METU).
- Single-camera based techniques: A. Alatan, E. Vural (METU), L. Onural (Bilkent), A. Gotchev and O. Pirinen (TUT), S. Knorr (TUB), B. Rosenhahn (MPG).
- Human face and body specific techniques: S. Piekh (UHANN), N. Grammalidis, F. Tsalakanidou (ITI-CERTH), Ç. Erdem, T. Erdem, M. Özkan (Momentum), A. Gotchev, V. Uzunov, X. Luo (TUT), L. Goldmann (TUB).
- Holographic camera techniques: W. Jüptner, M. Schulte (BIAS), J. Watson, D. Hendry, P. Benzie, T. Thevar, R. Veitch (UNIABDN), L. Ahrenberg (MPG), I. Hanak, M. Janda, V. Skala (Plzen)
- Pattern-projection and calibration: S. Malasiotis (ITI-CERTH), W. Jüptner, T. Bothe(BIAS), V. Sainov, E. Stoykova, J. Harizanova, E. Nedialkov, Z. Grancheva (CLOSPI-BAS).

- Motion analysis and tracking: Karaman (TUB), E. Çetin (Bilkent), E. de Aguiar, B. Rosenhahn (MPG), N. Grammalidis (ITI-CERTH)), M. Tekalp (KU), Ç. Türkay, E. Kalafatlar (Yogurt).
- Object-based representation and segmentation: M. Kirchner (UIL)
- Registration: Y. Yardimci Çetin (METU).

As mentioned in the technical reports, the individual subtasks are not to be seen as strictly separate fields of research since many of the attacked problems lie on the boundary between multiple subtasks. Therefore, we do not separate the research outside the NoE in the different fields to avoid multiple citations.

Several research advances outside the NoE have been presented on different conferences and journals. A list of important papers is given in the journal article. Instead, here we will concentrate on some recent publications in this years CVPR and SigGraph.

Regarding WP7 related research, different companies realized the marked potential for 3DTV, E.g. the company Organic Motion, see http://www.organicmotion.com/ gave a demo on last years SigGraph and provides a markerless real-time system for motion capture. Similar to this, the company LiberoVision, (http://www.liberovision.com/index.php) provides a virtual camera to reconstruct scenes in a football game. In-Three Inc. (http://www,in-three.com), California developed a software called "Dimensionalization" to convert the Star-Wars movies. Also the company DynamicDigitalDepth (www.ddd.com) developed software for 2D-3D conversion. RealD is currently marked leader in the field of 3D-Cinetology. 700 3D-cinemas will be build till end of the year.

Another important development is the HumanEVA-database which is provided and maintained from Michael Black at Brown University. It allows for a ground-truth comparison of markerless MoCap algorithms and will be a benchmark in the near future.
A special issue at the journal IJCV (International Journal of Computer Vision) will summarize current state-of-the art in Human Motion Capture und several members of WP7 contribute (submitted) to this issue.
Recent and related research articles:
CVPR-2008

(Download available at http://gmazars.info/conf/cvpr2008.html)

- *Learning Patch Correspondences for Improved Viewpoint Invariant Face Recognition* , Ahmed Bilal Ashraf, Simon Lucey, Tsuhan Chen

- *Human-Assisted Motion Annotation,* Ce Liu, William T. Freeman, Edward Adelson, Yair Weiss

- *Face Alignment via Boosted Ranking Models*

  Hao Wu, Xiaoming liu, Gianfranco Doretto

- *Learning realistic human actions from movie,* Ivan Laptev, Marcin Marszalek, Cordelia Schmid, Benjamin Rozenfeld

- *Global Stereo Reconstruction under Second Order Smoothness Priors*, O. J. Woodfordy, P. H. S. Torrz, I. D. Reidy, A. W. Fitzgibbon

- *People-Tracking-by-Detection and People-Detection-by-Tracking*, Mykhaylo Andriluka, Stefan Roth, Bernt Schiele

- *Recovering Consistent Video Depth Maps via Bundle Optimization*, Guofeng Zhang, Jiaya Jia, Tien-Tsin Wong, Hujun Bao

- *3D Pose Refinement from Reflections*, P. Lagger, M. Salzmann, V. Lepetit, P. Fua

- *Physical Simulation for Probabilistic Motion Tracking*, M. Vondrak, L. Sigal, O. C. Jenkins

- *Photometric stereo with non-parametric and spatially-varying reflectance,*

  Neil Alldrin, Todd Zickler, David Kriegman

- *Characterizing the Shadow Space of Camera-Light Pairs*, Daniel A. Vaquero, Rogerio S. Feris, Matthew Turk, Ramesh Raskar

- Real-Time Face Pose Estimation from Single Range Images, Michael D. Breitenstein, Daniel Kuettel, Thibaut Weise, Luc van Gool, Hanspeter Pfister

Overall there is the trend to more learnig based approaches, even in the context of scene acquisition, reconstruction, animation or tracking. On the one hand it makes perfectly sense, since we are living in a world full of rules and invariances. On the other hand it also shows that we are somehow incapable to scene analysis with plain image data and are desparate to look for other sources of information to get solvable systems. Obviously, to integrate more knowledge in scene interpretation helps to recover ambiguities or local minima which naturally occur in our current algorithms. Since members of WP7 managed to get several CVPR-papers accepted, the participants of WP7 are well aware of these trends. Further trends are higher order priors or smootheness terms which act as more sensitive regularizers.
SigGraph 2008
(Downloads available at http://kesen.huang.googlepages.com/sig2008.html)

- *Clone Attack! Perception of Crowd Variety*, Rachel McDonnell, Micheal Larkin, Simon Dobbyn, Steven Collins, Carol O'Sullivan

- *Face Swapping: Automatic Face Replacement in Photographs*, Dmitri Bitouk, Neeraj Kumar, Samreen Dhillon, Peter Belhumeur, Shree Nayar

- *Interactive Simulation of Stylized Human Locomotion*, Marco da Silva, Yeuhi Abe, Jovan Popović (Massachusetts Institute of Technology)

- *Continuation Methods for Adapting Simulated Skills*, Kangkang Yin, Stelian Coros Philippe Beaudoin, Michiel van de Panne

- *Animating Oscillatory Motion With Overlap: Wiggly Splines*
  Michael Kass, John Anderson

The current trend in computer graphics is still the demand on realistic animation or rendering of 3D World scenes, with typical applications in human animation, ray tracing or computational photography. Here members of WP7 perfomed exceptional well by also getting SigGraph papers accepted this year.

2. WP8 Report on External Activities (TC1)

2.1. Point-based Scene Representations

Related Research:

Many algorithms have been proposed in order to estimate dense depth maps that utilize stereo or multiple views. Most of these methods assign depth maps for only one image that is chosen as the reference view of the data set. However, video rendered from different viewpoints through only the reference view and its depth map, is expected to be relatively poor in quality due to occlusions, especially when the view point moves away from the reference camera. Such occlusions result with disturbing visualization at the output of any 3DTV system. In order to provide more satisfactory and realistic visualization, contribution from multiple views should be utilized during rendering process. Such an approach requires depth maps for all of the cameras in multi-view setups, which is denoted as *N-view-plus-depth* representation. This extension utilizes the maximum information belonging to multi-view video and is one of the standardization efforts to be utilized in the upcoming 3D display technologies.

The most important advance outside our NoE has occurred within MPEG standardization activities. A recent activity within MPEG has started in which N-views of the scene are being transmitted to the receiver, as well as dense depth information for each view. This effort is quite important in the sense that point-based representations are being standardized for 3D information transmission, which could be the first step for 3DTV standardization.
The following papers are interesting recent work under the scope of *N-view-plus-depth* representation:

- P. Kauff, N.Atzpadin, C.Fenn, M.Muller, O.Scheer, A.Smolic and R.Tanger, "Depth Map Creation and Image Based Rendering for Advance 3DTV Services Providing Interoperability and scalability", in Image Communication Volume 22, Issue 2 (February 2007) pages 217-234.

This paper is utilizing stereo algorithms for pairs of images among multiple views and then merging the estimated depth maps for consistency and obtaining a final representation In that manner, the depth maps for each viewpoint are estimated using the neighboring view by a pixel-based algorithm and are refined according to the extracted segment boundaries through over-segmentation. Finally, the depth maps are fused in order to provide spatial consistency. This approach is sub-optimal, since the extra information, especially for the occluded regions, from multiple views is discarded and depth maps are initially obtained with the similar problems as most stereo algorithms face. It should be noted that this paper is a leading effort in this representation type and, fortunately, the authors are mostly within our NoE. Hence, this paper shows that 3DTV NoE is one of the leading groups in point-based representations for 3DTV.

- Paul Merrell, Amir Akbarzadeh, Liang Wang, Philippos Mordohai1, Jan-Michael Frahm, Ruigang Yang, David Nister, and Marc Pollefeys, “Real-Time visibility-Based Fusion of Depth Maps”, in International Conference on Computer Vision (ICCV) 2007.

3D extraction presented in this paper utilizes a similar representation as *N-view-plus-N-depth*, however the images are captured by a video camera and consecutive frames are utilized as the multiple views. Thus, the problem is considered in the context of small base line and fusion of multiple depth maps via visibility is achieved for refining the initially estimated depth maps. In this work, Markov Random Field (MRF) models are constructed and depth assignment is achieved by belief propagation. The utilization of visibility constraint provides robustness against large occluded regions and consistent, reliable depth maps for all of the images.

- O. Stankiewicz and K. Wegner. “Depth map estimation software version 2”. ISO/IEC MPEG meeting, Archamps, France, 2008.

This work forms the initial outcome for the standardization efforts on *N-view plus N-depth* representation. In this work, depth estimation is achieved by multi-resolution belief propagation based on Potts linear and quadratic model of belief passing cost function. In addition, the number of depth levels is increased during message passing in order to increase the precision of the depth estimation as well. Based on the matching SAD values of the depth hypothesis, the reliability of the current models are determined and the message passing is provided through reliable pixels until all the assignments pass the verification of reliability.

<u>Related Conferences:</u>

Symposium on Point-Based Graphics 2008: http://graphics.ethz.ch/events/pbg/08/

2.2. Surface-based Scene Representations

<u>Related Research:</u>

Recently, several research activities have focused on building time-consistent animating mesh representations of time-varying dynamic scenes. Common approaches to infer 3D geometry rely on active stereo, shape from structured light and/or passive multi-view stereo/silhouette reconstruction. The main challenge in achieving plausable time-varying surface representations is due to several factors such as noisy real time measurements, self-occlusions and difficulty of establishing shape correspondences. Although the papers below attempt to address some of these challenges, the problem is still open for further research.

- Michael Wand, Philipp Jenke, Qixing Huang, Martin Bokeloh, Leonidas Guibas, Andreas Schilling “Reconstruction of Deforming Geometry from Time-Varying Point Clouds”, SGP '07, 2007

- Edilson de Aguiar, Carsten Stoll, Christian Theobalt, Naveed Ahmed, Hans-Peter Seidel, Sebastian Thrun, “Performance Capture from Sparse Multi-view Video”, ACM Transactions on Graphics 27(3) (Proc. of ACM SIGGRAPH'08), 2008
- Sang Il Park, Jessica K. Hodgins , “Capturing and Animating Skin Deformation in Human Motion”, ACM Transaction on Graphics (SIGGRAPH 2006),25(3),pp 881-889,July 2006.

Related Conferences:

- Eurographics 2008, http://www.ics.forth.gr/eg2008/home.php, Crete, Greece

2.3. Volume-based Scene Representations

Related Research:

The following recent papers worth examining for volume-based representations:

- Rudy Adipranata, Yun Tae Soo, “3D object reconstruction using voxel coloring with mean charts color consistency checking”, Proceedings of the third conference on IASTED International Conference: Advances in Computer Science and Technology table of contents, Phuket, Thailand, 2007, pp. 206-211

The paper deals with the area of photorealistic 3D object reconstruction. Input of this system is multiple photographs which are taken from multiple view points of scene. Then, the object in the photographs will be projected back to the 3D coordinate and applied voxel coloring method to reconstruct and view the object in 3D. Voxel coloring works by discretizing scene space into voxels, the smallest unit in 3D, then traversed and colored in specific order. The output of voxel coloring is a collection of voxels that represent the object. Those voxels can be rendered to get a new view of that object.

- Teresa C. S. Azevedo, João Manuel R. S. Tavares and Mário. A. P. Vaz, “Photo-consistent object 3D reconstruction from images using a volumetric method”, 8th. World Congress on Computational Mechanics (WCCM8), 5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008) June 30 – July 5, 2008 Venice, Italy.

The main goal of this work is to build 3D models of an object represented in a sequence of images, acquired using a turntable device and an off-the-shelf image camera. The 3D reconstruction is performed using Generalized Voxel Coloring (GVC). GVC belongs to a recent group of imagebased methods denominated volumetric methods, which are based in the visual-hull concept.

- Elmar Eisemann, Xavier D´ecoretx, “Fast Scene Voxelization and Applications”, SigGraph06.

This paper presents a novel approach that uses graphics hardware to dynamically calculate a voxel-based representation of a scene. The voxelization is obtained on run-time in the order of milliseconds, even for complex and dynamic scenes containing more than 1,000,000 polygons. The voxelization is created and stored on the GPU avoiding unnecessary data transfer. The approach can handle both regular grids and locally optimized grids that better fit the scene geometry. The paper demonstrates applications to shadow calculation, refraction simultation and shadow volume culling/clamping.

- Pau Gargallo, Peter Sturm, and Sergi Pujades, "An Occupancy–Depth Generative Model of Multi-view Images", ACCV07(II: 373-383).

This paper presents an occupancy based generative model of stereo and multi-view stereo images. In this model, the space is divided into empty and occupied regions. The depth of a pixel is naturally determined from the occupancy as the depth of the first occupied point in its viewing ray. The color of a pixel corresponds to the color of this 3D point. This model has two theoretical advantages. First, unlike other occupancy based models, it explicitly models the deterministic relationship between occupancy and depth and, thus, it correctly handles occlusions. Second, unlike depth based approaches, determining depth from the occupancy automatically ensures the coherence of the resulting depth maps. Experimental results computing the MAP of the model using message passing techniques are presented to show the applicability of the model.
There are also some projects related to volumetric representations:

- The Visualization Laboratory of Department of Computer Science at the State University of New York at Stony Brook, headed by Leading Professor and Chairperson, Dr. Arie E. Kaufman conducts research on the development of volume visualization techniques used in scientific visualization and virtual reality applications. They have projects in: architectures for volume rendering, methods for accelerating volume rendering, development of tools for visualization, volume graphics, volume modeling and manipulation, and volume visualization applications (e.g. medicine, flight simulation, scientific visualization). (http://www.cs.sunysb.edu/~vislab/)

- INRIA is working on a volumetric representation to capture and edit indirect illumination (http://ralyx.inria.fr/2007/Raweb/iparla/uid59.html)

- GEORGIA TECH RESEARCH CORP had a previous project with the goal of this research project was to investigate new methods of representing and manipulating three-dimensional geometric models using volumetric techniques. Three sub-areas were particular targets for these investigations: 1) explore ways of extending the kinds of models that can be represented volumetrically, 2) create multiresolution models using volume techniques, and 3) perform shape transformation using a volumetric framework.

  (http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA386782)

- Volume representations are used by many medical projects (e.g. projects of the Computer Graphics group in Technische Universität Wien http://www.cg.tuwien.ac.at/research/vis/vismed/)

Related Conferences:

- Eurographics 2008, http://www.ics.forth.gr/eg2008/home.php, Crete, Greece

2.4. Human Face and Body Specific Representations

Related Research:

Recognition of the emotional state of a person from the speech signal is becoming increasingly important, especially in human-computer interaction. Although extensively investigated, recognizing emotions for computers is still an open problem. Researchers mostly focus on defining a universal set of features that carry emotional clues and try to develop classifiers that efficiently model these features. The following recent research efforts on this topic propose a framework for automatic emotion recognition for facial expression animation from speech:

- F. Burkhardt, A. Paeschke, M. Rolfes, W. Sendlmeier, and B. Weiss, "A database of german emotional speech," in Proceedings of Interspeech, Lisbon, Portugal, 2005, pp. 1517–1520.

Emotional speech data sources are scarce, mostly monolingual, and small in terms of number of recordings or number of emotions. One example is the Berlin emotional speech dataset (EMO-DB) which is in German and publicly available. EMO-DB is composed of acted emotional speech recordings, which is preferred by researchers to directly compare the performances of their proposed systems with others.

- M. E. Ayadi, M. Kamel, and F. Karray, "Speech emotion recognition using gaussian mixture vector autoregressive models," in Proceedings of ICASSP, 2007, pp. 957–960.

El Ayadi et al. present results on EMO-DB by modeling the dependency between successive emotional speech vectors in addition to the multi-modality in their distribution. They claim that modeling temporal structure of speech may be beneficial for the speech emotion recognition purpose and propose Gaussian mixture autoregressive models to classify EMO-DB emotions. They compare their method with other pattern recognition techniques, such as hidden Markov models (HMM), k-nearest neighbours (k-NN), and feed-forward artificial neural networks (ANN). They parameterize EMO-DB recordings as feature vectors consisting of 12 mel-frequency cepstral coefficients (MFCC) with 12 delta (1st derivative) coefficients, 0'th cepstral coefficient, plus the speech energy. The 5-fold cross validation classification accuracy is 76% with their proposed system, versus 71% for HMM, 67% for k-NN, and 55% for ANN.

- J. Pittermann, A. Pittermann, H. Meng, and W. Minker, “Towards an emotion-sensitive spoken dialogue system classification and dialogue modeling,” in Proceedings of 3rd IET International Conference on Intelligent Environments, 2007, pp. 239–246.

In this research effort, Pittermann et al. also present a speech-based emotion recognizer trained on the EMO-DB. The emotion recognizer jointly operates with an automatic speech recognition system and allows to use textual data for the emotion recognition problem. They train HMM structures using 13 MFCC features with their delta (1st derivative) and acceleration (2nd derivative) parameters in addition to other features such as pitch in voiced speech parts, intensity, formants, jitter, and harmonicity. Their proposed system achieves a recognition rate of 71.7% for all EMO-DB emotions and speakers. However, for a reduced emotion set and a combination of multiple recognizer outputs, the recognition rate increases to 77.9% for all speakers.

- B. Vlasenko, B. Schuller, A.Wendemuth, and G. Rigoll, “Frame vs. turnlevel: emotion recognition from speech considering static and dynamic processing,” in Proceedings of Affective Computing and Intelligent Interaction, Lisbon, Portugal, Sept. 12-14 2007, pp. 139–147.

Likewise, Vlasenko et al. aim to recognize emotions using a speaker recognition engine and introduce fusion of frame and turn-level based emotion recognition. They parameterize EMO-DB recordings with 39 dimensional feature vectors composed of 12 MFCC features and log frame energy in addition to delta and acceleration coefficients. They apply cepstral mean normalization (CMN) and variance normalization for frame-level emotion analysis using GMM classifier. Turn-level analysis applies functionals to selected set of Low-Level-Descriptors (LLD) and their first-order delta coefficients. Speaker normalization and feature space optimization are applied prior to giving a final decision by SVM (support vector machines). Their overall emotion recognition rate is 89.9%.

- B. Schuller, D. Arsic, F. Wallhoff, and G. Rigoll, “Emotion recognition in the noise applying large acoustic feature sets,” in Speech Prosody, Dresden, Germany, May 2-5 2006.

Schuller et al. also study emotion recognition from speech using EMO-DB, yet under noise influence. They employ a large feature set including MFCC, spectral flux, and jitter features that are to be basis for a feature selection process, preferred for noisy conditions. They model features with the SVM using a 10-fold stratified cross validation (SCV) technique. Their emotional speech recognition rates on the EMO-DB are 86.7% for clean speech and 67.2% for -10 db SNR level.

- Z. Xiao, E. Dellandrea, W. Dou, and L. Chen, “Automatic hierarchical classification of emotional speech,” in Proceedings of 3rd IEEE International Workshop on Multimedia Information Processing and Retrieval, Taichung, Taiwan, May 2-5 2007, pp. 291–296.

In this work, Xiao et al. define an automatic hierarchical speech emotion classification system on the EMO-DB. They suggest that different emotions may require different features for better classification results and introduce new harmonic and Zipf based features in addition to frequency and energy based features. They use back propagation neural networks with two hidden layers to achieve recognition rates up to 79.47% for gender-dependent classification and 76.22% for the gender-independent case.

- J. Cichosz and K. Slot, "Emotion recognition in speech signal using emotion-extracting binary decision trees," in Proceedings of Affective Computing and Intelligent Interaction, Lisbon, Portugal, Sept. 12-14, 2007

Cichosz and Slot propose a binary decision tree to classify EMO-DB emotions. They parameterize speech in three-dimensional feature space that consists of frequency, energy, and temporal characteristics of speech. For speaker-dependent case they achieve a recognition rate of 74.39% whereas for the speaker-independent case the recognition rate decreases to 72.04%. In our investigations, 5-fold stratified cross validation (SCV) on EMO-DB achieves an average emotion recognition rate of 83.42% using a GMM classifier of MFCC and dynamic MFCC features. The decision fusion of this GMM classifier with an HMM classifier of the prosody features achieves an average emotion recognition rate of 84.73%. Furthermore, decision fusion of two GMM classifiers, one using MFCC and dynamic MFCC features and the other one using LSF features, yields an average recognition rate of 85.30%. Moreover, a second-stage decision fusion of this result with prosody HMM gives 86.45% average recognition accuracy.

Related Conferences:

V. Conference on Articulated Motion and Deformable Objects, AMDO 2008, Andratx, Mallorca, Spain. 9-11 July , 2008

2.5. Object-specific Representations

Related Research:

This year the hot topics and the related research in these areas can be listed as follows:

- Real Time Rendering

  1. Real-time, all-frequency shadows in dynamic scenes, Thomas Annen, Zhao Dong, Tom Mertens, Philippe Bekaert, Hans-Peter Seidel, Jan Kautz, ACM Transactions on Graphics (Proc. ACM SIGGRAPH 2008), Vol. 27, No. 3, Article No. 34.

  2. Interactive relighting of dynamic refractive objects, Xin Sun, Kun Zhou, Eric Stollnitz, Jiaoying Shi, Baining Guo, ACM Transactions on Graphics (Proc. ACM SIGGRAPH 2008), Vol. 27, No. 3, Article No. 35.

3. A meshless hierarchical representation for light transport, Jaakko Lehtinen, Matthias Zwicker, Emmanuel Turquin, Janne Kontkanen, Frédo Durand, François X. Sillion, Timo Aila,ACM Transactions on Graphics (Proc. ACM SIGGRAPH 2008), Vol. 27, No. 3, Article No. 37.

- Fluids and Their Interaction with the Environment

1. Two-way coupling of fluids to rigid and deformable solids and shells, Avi Robinson-Mosher, Tamar Shinar, Jon Gretarsson, Jonathan Su, Ronald Fedkiw, ACM Transactions on Graphics (Proc. ACM SIGGRAPH 2008), Vol. 27, No. 3, Article No. 46.

- Texture Synthesis

1. Multiscale texture synthesis, Charles Han, Eric Risser, Ravi Ramamoorthi, Eitan Grinspun, ACM Transactions on Graphics (Proc. ACM SIGGRAPH 2008), Vol. 27, No. 3, Article No. 51.

- Crowd Simulation

1. Clone attack! Perception of crowd variety, Rachel McDonnell, Michéal Larkin, Simon Dobbyn, Steven Collins, Carol O'Sullivan, ACM Transactions on Graphics (Proc. ACM SIGGRAPH 2008), Vol. 27,No. 3, Article No. 26.

- Deformable Models (including Hair, Cloth Simulation)

1. A mass spring model for hair simulation, Andrew Selle, Michael Lentine, Ronald Fedkiw, ACM Transactions on Graphics (Proc. ACM SIGGRAPH 2008), Vol. 27, No. 3, Article No. 63.

2. Simulating knitted cloth at the yarn level, Jonathan M. Kaldor, Doug L. James, Steve Marschner, ACM Transactions on Graphics (Proc. ACM SIGGRAPH 2008), Vol. 27, No. 3, Article No. 65.

3. Shape deformation with tunable stiffness, Wenwu Yang, Jieqing Feng and Xiaogang Jin, The Visual Computer, Special Issue on CGI 2008, Vol. 24, No. 7-9, pp. 495-503,

- Parallelism in Graphics Processor Unit (GPU) Programming

1. Larrabee: a many-core x86 architecture for visual computing, Larry Seiler, Doug Carmean, Eric Sprangle, Tom Forsyth, Michael Abrash, Pradeep Dubey, Stephen Junkins, Adam Lake, Jeremy Sugerman, Robert Cavin, Roger Espasa, Ed Grochowski, Toni Juan, Pat Hanrahan, ACM Transactions on Graphics (Proc. ACM SIGGRAPH 2008), Vol. 27, No. 3, Article No. 18.

2. BSGP: bulk-synchronous GPU programming, Qiming Hou, Kun Zhou, Baining Guo, ACM Transactions on Graphics (Proc. ACM SIGGRAPH 2008), Vol. 27, No. 3, Article No. 19.

3. Streaming multigrid for gradient-domain operations on large images, Michael Kazhdan, Hugues Hoppe, ACM Transactions on Graphics (Proc. ACM SIGGRAPH 2008), Vol. 27, No. 3, Article No. 21.

Related Conferences:

Most important conferences in graphics are as follows:

- The 35th International Conference and Exhibition on Computer Graphics and Interactive Techniques (ACM SIGGRAPH'08) was held on 11-15 August 2008, in Los Angeles, California, USA. (This major event contains very high quality paper sessions, courses, exhibitions, panels, computer animation festival)

- Computer Graphics International (CGI) 2008, which was held in Istanbul, Turkey, on 9-11 June 2008.

- Computer Animation and Social Agents (CASA) 2008, which will be held on Sept 1-3, 2008 in Seoul, Korea..

2.6. Pseudo 3D Representations

Related Research:

In 2008, first applications of pseudo 3D representation enter the market. Liberovision [1] enhances default 2D broadcast of soccer matches with 3D based analysis producing virtual views of the match. This technology has been used during the Euro 2008 broadcasts of the German television.

In the field of real time processing for 3D video purposes one main focus of researchers outside the NoE lies on fast processing of disparity maps. As an example the work of Gallup [2], Lu [3] or Bartczak[4] worth mentioning. These works mainly use GPU shaders or the CUDA framework for their fast implementations. In [5], a complete generic framework for image-based rendering employing the GPU is proposed. It differs from the framework developed in the NoE in that it mainly focuses on rendering of in-between views for auto-stereoscopic display.

The quality evaluation of different methods for stereoscopic of free viewpoint video still remains an open problem. Some work was conducted in [6] where objective metrics were developed and different methods were compared. The method aims at mesh-based representations. Currently, researcher focus mainly on the perceived quality of stereoscopic or auto-stereoscopic rendering which also can be seen as a pseudo-3D representation. Efforts were made to measure the quality with subjective tests [7] or new subjective methods [8].

[1] Libero Vision Website - http://www.liberovision.com

[2] D. Gallup, J.-M. Frahm, P. Mordohai, Q. Yang, M. Pollefeys, Real-Time Plane-Sweeping Stereo with Multiple Sweeping Directions, CVPR, 2007

[3] J. Lu, S. Rogmans, G. Lafruit, F. Catthoor, Real-Time Stereo Correspondence using a Truncated Separable Laplacian Kernel Approximation on Graphics Hardware, IEEE ICME, 2007

[4] B. Bartczak, D. Jung and R. Koch, Real-Time Neighborhood Based Disparity Estimation Incorporating Temporal Evidence, DAGM, 2008

[5] S. Rogmans, J. Lu, G. Lafruit, A Scalable End-To-End Optimized Real-Time Image-Based Rendering Framework on Graphics Hardware, 3DTV-CON, 2008

[6] J. Starck, J. Kilner, A. Hilton, Objective Quality Assessment in Free-Viewpoint Video Production, 3DTV-CON, 2008

[7] P. Seuntiens, I. Vogels, A. van Keersop, Visual Experience of 3D-TV with pixelated Ambilight, PRESENCE 2007

[8]J. Häkkinen, T. Kawaib, J. Takataloa, T. Leistia, J. Raduna, A. Hirsahoa, G. Nymana, Measuring Stereoscopic Image Quality Experience with Interpretation Based Quality Methodology, Proceedings of 20th Annual IS&T/SPIE Symposium on Electronic Imaging, 2008

3. WP9 Report on External Activities (TC2)

Research on 3D compression has increased significantly during the last years worldwide, partially influenced and driven from the 3DTV NoE that plays for instance a leading role in MPEG. Below is an overview of known activities for each of the high-priority research areas in WP9.

Multiview video coding (MVC):

Research in this area probably reached its climax during the last year. A Special Issue on MVC has been published in IEEE Transactions on Circuits and Systems for Video Technology with a researcher of the NoE as one of the Guest Editors. This journal includes about 10 high quality papers setting the state-of-the-art in MVC, coming mainly from the same institutions and companies that are most active in MPEG standardization of MVC as well. This includes Nagoya University, Tokyo University, NTT from Japan, GIST, ETRI from Korea, Stanford University, University of Southern California, Thomson, MERL from the US, Fraunhofer HHI, Koc University from Europe. Note that both European contributions originate from the NoE.

Besides this, numerous other papers about MVC were published in journals and conferences, mainly from academic institutions, mainly covering improvements and optimizations of specific algorithmic topics. It seems that the major grounds of MVC as research area are set under strong influence from the NoE. This includes also contributions about MVC and other 3D coding issues to Special Issues of the IEEE Signal Processing Magazine, Signal Processing: Image Communication and EURASIP Journal on Applied Signal Processing, which were all co-edited by researchers from the NoE.

The MVC standard is being finalized by autumn 2008 within the Joint Video Team (JVT) of ITU and MPEG in the first version. It will not include any new coding or signal processing tools, only specific high level syntax enabling efficient combined temporal/inter-view prediction, which corresponds to the initial proposal developed by Fraunhofer HHI within the NoE. The sum of improvements of all other new tools developed worldwide with respect to the Fraunhofer HHI proposal did not exceed a threshold that would justify a major redesign of the very core of the H.264/AVC codec. It is still in question whether and when work on a second version of MVC will be started which could accommodate new specific coding tools.

Research in video+depth or MPEG-C Part 3 was rather marginal. This seems to be settled and in application phase (see below). But new activities for optimized depth coding were observed recently. The reported approaches introduce so called platelets and wedglets for coding of depth data and appear to be very interesting. This was done at the Technical University of Eindhoven. Researchers from the NoE now cooperate with this group and already published a joined paper. Further publications are in preparation.

During the last year a new research area gained significant momentum in academia as well as in MPEG standardization. This is related to compression of multiview video plus depth (MVD) and layered depth video (LDV). Both can be regarded as extension and combination of MVC and MPEG-C Part 3. Both are intended for better support of free viewpoint features and wide range multiview autostereoscopic displays. Several publications about extraction, coding and rendering were published recently. MPEG is currently starting a related new standard. The Call for Proposals is expected for spring 2009.

Researchers from the NoE are again playing a leading role in academic publications as well as MPEG standardization. The corresponding group is lead by NoE members and several technical contributions were made. The importance of and interest in this new activity becomes clear from the list of registered participants to the corresponding Exploration Experiments in MPEG: Nagoya University, NTT, Univeridad Polytechnica de Madrid, Philips, GIST, ETRI, JVC, Poznan University of Technology, Thomson, Misubishi Electric Research Labs, Peking University, Tsinghua University, Huawei, Xidian University, Telefonica, Samsung, LG Electronics, Nokia/TUT, NICT, Kwangwoon University, Sharp, Fraunhofer HHI, NCTU/ITRI, Motorola, NXP, Ericsson, Logitech, Orange/France Telecom, FUB, Sony, Zhejiang University.

Finally, it shall be noted that MVC, MPEG-C Part 3 and other types of 3D video coding start to gain commercial relevance. Philips demonstrated MPEG-C Part 3 on Blue-ray at IFA 2008. Stereo video trails are reported frequently. Systems and demonstrations are under development in company labs. Consortia for commercialization of 3D video are gaining momentum. For instance the 3D@Home Consortium has been launched in spring 2008. Current member companies of the 3D@Home Consortium include: Intel, Philips, Samsung, Sigma Designs, Sony Electronics, Mitsubishi Electric, Thomson, Turner Broadcasting System, Walt Disney Studios Home Entertainment, XPAND, 3ality Digital, 3DIcon, 3Dlized, Corning, Da-Lite, DDD, Dolby, ETRI, Fraunhofer Institute for Telecommunications HHI, Holografika, IMAX, In-Three, LG Electronics, MacGillivray Freeman Films, NanoLoa, Planar Systems, QPC Lasers, Quantum Data, Sensio Technologies, Setred, SeeReal Technologies, Sim2 Multimedia, ST Microelectronics, TDVision Systems, THX, Universal Studios Home Entertainment and Volfoni.

3D mesh compression:

Research and standardization activities on compression of static and dynamic 3D meshes are continuing.

In July 2008 in the MPEG meeting in Hannover the MPEG-4 FAMC standard for compressed dynamic meshes was finalized. Partners of the 3DTV NoE together with the Artemis group significantly contributed to its successful finalization. The research group ARTEMIS (www-artemis.int-evry.fr) is very active in research and standardization in the filed of 3D mesh compression.

Currently in MPEG there are attempts to standardize a technique for low complexity compression of static meshes. This standardization activity focuses on providing a specification which will allow transmission and rendering of static geometric data on mobile devices.

Research on mesh compression in the academic sector is continuing, too. Results are presented mainly in international conferences like 3DTV-CON, ICIP, ICME, Eurographics, or Siggraph. Two of these conferences, namely 3DTV-CON08 and ICME08, were partly organized by 3DTV-NoE researchers.

MDC for 3D:

Research on MDC and, more general, on error resilience of multimedia data has been well studied. However, research on MDC for 3D visual information is quite new and within this specific topic the 3DTV NoE has done some pioneering work, namely on MDC of stereo- or multiview video and 3D geometry.

As far the external research within this field is concerned, we refer to two groups doing advanced-level research.

I. The *I-Lab Multimedia and DSP research* group led by Prof. Ahmet Kondoz in University of Surrey, UK, (http://www.ee.surrey.ac.uk/CCSR/research/ilab/).

3D image and video processing and coding is among their research topics and they focus on scalable and error-robust video 3D coding and communications (http://www.ee.surrey.ac.uk/CCSR/research/ilab/2d3d).

We refer to their latest journal publication:

1. Karim, H.A.; Hewage, C.; Worrall, S.; Kondoz, A., "Scalable multiple description video coding for stereoscopic 3D," *IEEE Trans. Consumer Electronics*, vol. 54, no.2, pp.745-752, May 2008.

II. The *Multimedia and Sensors Lab* (MSL): a research group of Dr. Ghassan AlRegib at the Electrical and Computer Engineering of Georgia Tech, USA, (http://www.ece.gatech.edu/research/labs/msl/index.html)

Among the research topics of that group, we would mention the following relevant projects:

- Progressive Streaming for Textured 3D Models
- Latency-Minimized Delivery of 3D models in Lossy Networks
- Multi-Streaming of 3D Scenes with Scalable Partial Reliability
- Parity-Object Embedded Streaming for Synthetic Graphics
- Vector Quantization for Multi-Resolution Mesh Compression

See more details at their web page
(http://www.ece.gatech.edu/research/labs/msl/research.html)

Last year we reported a list of papers on error-resilient transmission of 3D geometry, published by the same group. We extend this list as follows:

1. Dihong Tian and Ghassan AlRegib, "BaTex3: bit-allocation for progressive transmission of textured 3D models," *IEEE Transactions on Circuits and Systems for Video Technology*, Vol. 99, No. 99, pp. 1-13, Aug. 2007.

2. Dihong Tian, Junlin Li, and Ghassan AlRegib, "Joint Source and Channel Coding for 3D Scene Databases Using Vector Quantization and Embedded Parity Objects," *IEEE Trans. on Image Processing*, Vol. 16, No. 6, pp. 1675-1685, Jun. 2007.

For a more complete list of publications, see
http://www.ece.gatech.edu/research/labs/msl/publications.html

Among relevant conferences, we emphasize IEEE International Conference on Image Processing (ICIP), and IEEE International Conference on Multimedia and Expo.
We report the following papers from the latest events:

1. Sung-Bum Park; Chang-Su Kim; Sang-Uk Lee, "Multiple Description Coding of Plane-Based 3-D Surfaces," IEEE Int. conf. Image Processing, ICIP 2007, vol.5, pp.V -97-V -100, Sept. 16 2007-Oct. 19 2007.

2. Chaminda T.E.R. Hewage, Stewart T. Worrall, Safak Dogan, Ahmet M. Kondoz, "Frame Concealment Algorithm for Stereoscopic Video using Motion Vector Sharing", IEEE Int. Conf. Mutimedia and Expo, ICME 2008, P4.1, June 23-26, 2008, Hannover, Germany.

3. Hui Li, Ziying Tang, Xiaohu Guo, B. Prabhakaran, "Loss Tolerance Scheme for 3D Progressive Meshes Streaming over Networks", IEEE Int. Conf. Mutimedia and Expo, ICME 2008, P4.5, June 23-26, 2008, Hannover, Germany.

In addition, we refer to the special session on '3D Graphics Compression and Streaming: Theory, Standardization and Applications', to be held at ICIP 2008. For the list of contributions there, check at

http://www.icip08.org/Papers/PublicSessionIndex3.asp?Sessionid=1000

Watermarking for 3D:

Similar as for MDC, 3D watermarking is an active research area worldwide. The 3D watermarking technology aims protection of a representation for a 3D scene by embedding hidden data into the main components of the representation and extracting the watermark from the resulting components of a scene after any applications. A categorization of the 3D watermarking methods in the literature can be achieved regarding the main components of the 3D representations as given in Fig. 1. While the representations in the left side of this graph are in general dependent on the geometrical structure of the scene, the representation in the rightmost part is purely based on the images that are captured by the cameras appropriately located in the scene.

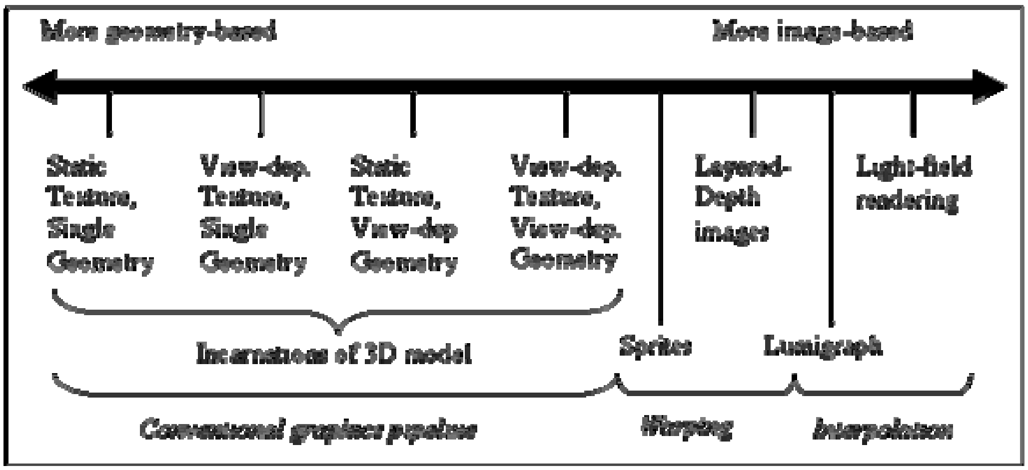

Fig. 1. *Categorization of Scene Representations*

Based on this categorization of scene representations we consider the dimensions of the main components of scene representations and the resulting components after the application of the algorithm. In this context the 3D watermarking methods can be classified into three groups, which we denote as 3D/3D, 3D/2D, and 2D/2D. The first pair of symbols identifies whether the watermark is embedded in the 3D model or a 2D rendering of it, and similarly the second pair of symbols identifies whether the watermark is detected in the 3D model or a 2D rendering.

3D/3D Watermarking

The first group, 3D/3D watermarking, mostly focuses on protection of the intellectual property rights of the 3D geometrical structure. The watermark is embedded into the 3-D geometric structure of an object used in a scene and tried to be extracted from the 3-D geometry after any attacks on the geometry

The methods on 3D geometry watermarking can be divided into two main groups based on the embedding domain of the watermark: **spatial-domain and transform-domain** methods.

Spatial domain methods embed the watermark directly into the values of the geometric primitives. In general, most of the methods in this group first extract perceptually significant geometric primitives from the model and then embed a watermark into those primitives by using a specially proposed method.

[1] S. Zafeiriou, A. Tefas, and I. Pitas, “Blind watermarking schemes for copyright protection of 3-D mesh objects,” *IEEE TVCG*, vol. 11, no. 5, Sep./Oct. 2005.

[2] Ki-ryong Kwon, Jae-sik Sohn, Young Huh, Suk-hwan Lee, "The Watermarking for 3D CAD Drawing using Line, ARC, 3DFACE Components," icme, pp. 1361-1364, 2006 IEEE International Conference on Multimedia and Expo, 2006.

[3] A. G. Bors, “Watermarking mesh-based representations of 3-D objects using local moments,” IEEE Trans. Image Process., vol. 15, no. 3, pp. 687–701, Mar. 2006.

[4] Wang Liu, Sheng-he Sun, "Rotation, Scaling and Translation Invariant Blind Digital Watermarking for 3D Mesh Models," icicic, pp. 463-466, First International Conference on Innovative Computing, Information and Control - Volume III (ICICIC'06), 2006.

[5] Yu-Ping Wang, Shi-Min Hu, "A New Watermarking Method for 3D Models Based on Integral Invariants," IEEE Transactions on Visualization and Computer Graphics, 15 Aug 2008. IEEE Computer Society Digital Library. IEEE Computer Society, Sept. 2008.

[6] Xiaoqing Feng, Li li, Zhigen Pan, Shusen Sun, Daxing Zhang, "A Robust Double Watermarking 3D Mesh Model Based On Feature," iih-msp, pp. 1109-1112, 2008 International Conference on Intelligent Information Hiding and Multimedia Signal Processing, 2008.

[7] Jihane Bennour, Jean-Luc Dugelay, Emmanuel Garcia, Nikos Nikolaidis, “3D Object Watermarking”, in *3D Object Processing: Compression, Indexing and Watermarking.* Edited by J.-L. Dugelay, A. Baskurt and M. Daoudi, 2008 John Wiley & Sons, Ltd. ISBN: 978-0-470-06542-6, 2008.

The other group contains **transform domain methods**, where a 3-D object is decomposed into sub-signals by applying a 3-D geometry based transformation, such as WL transform or mesh spectral analysis. In this group of methods, after applying the transformation to the mesh model, watermark is embedded to the resulting transform coefficients. Compared to the spatial domain methods, transform domain methods generally satisfy the trade off between imperceptibility and robustness in a more reliable manner, since the applied transformation mostly separates the perceptually significant and insignificant part of a 3-D model.

[1] S. Kanai, H. Date, and T. Kishinami, “Digital watermarking for 3-D polygons using multiresolution wavelet decomposition,” in *6h IFIP WG 5.2 GEO-6*, Tokyo, Japan, pp. 296–307, 1998.

[2] R. Ohbuchi, S. Takahashi, T. Miyazawa, and A. Mukaiyama, “Watermarking 3-D polygonal meshes in the mesh spectral domain,” in *Proc. Graph. Interface 2001*, pp. 9–17, 2001.

[3] K. Yin, Z. Pan, J. Shi, and D. Zhang, “Robust mesh watermarking based on multiresolution processing,” *Comput. Graph.*, vol. 25, pp. 409–420, 2001.

[4] Bors AG, “Watermarking mesh-based representations of 3-D objects using local moments”, *IEEE Transactions on Image Processing* **15**(3), 687 – 701, 2006

[5] K. Anusudha, Kalyan Vaddagiri, "Generation of Secured 3D Polygonal Models Using Lazy Wavelet Transforms," icetet, pp. 38-43, First International Conference on Emerging Trends in Engineering and Technology, 2008

3D/2D Watermarking

The second group, 3D/2D watermarking, aims to extract the watermark that was originally hidden in the 3D object, from the resulting images or videos (obtained after projection of 3D object into 2D image planes), thus protecting any visual representation of the object. The watermark can be both embedded to the geometry or the texture of the object

[1] E. Garcia and J.-L. Dugelay, “Texture-based watermarking of 3-D video objects,” *IEEE Trans. Circuits Syst. Video Technol.*, vol. 13, no. 8, pp. 853–866, Aug. 2003.

[2] J. Bennour and J.-L. Dugelay, “Protection of 3-D object through silhoutte watermarking,” in *IEEE ICASSP*, Toulouse, France, May 14–19, 2007.

[3] Suk-Hwan Lee and Ki-Ryong Kwon, “Mesh watermarking based projection onto two convex sets”, Multimedia Systems, Springer Berlin / Heidelberg, Volume 13, Numbers 5-6 / February, 2008.

2D/2D Watermarking

The final group, 2D/2D watermarking, try to protect the image-based representation of a 3D scene. While the first two groups try to protect the intellectual property rights for the two important components of a traditional representation of a 3D scene, geometry and texture, the third group approaches to this problem, by watermarking sequences of images, which represent the 2D projections of the same 3D scene, and extracting the watermark from any 2D rendered image, generated for an arbitrary angle of the scene via these sequences. An application of this category should be expected in the copyright protection of multiview video content in emerging new technologies such as free view televisions (FTV) where the TV-viewers freely select the viewing position and angle for the transmitted multiview video.

[1] Mitrea M, Duta S, Preteux F. “Approaches to 3D watermarking : state-of-the-art and perspectives”, Proceedings of SPIE, Image processing : algorithms and systems, neural networks, and machine learning, 16-18 January 2006, San Jose, California, USA.

Some research projects in the area of 3D watermarking are as follows:

- GEOMARK

The Geomark-system is realized as a 3D Studio MAX-plugin and currently offers the following functionality:

– Labeling, integrity check and authentication of polygonal 3D models through public readable fragile watermarks.

– Local secret and public readable watermarks for polygonal models and NURBS control nets surviving affine transformations (semi-robust watermarks).

– Secret watermarks robust against more complex transformations, e.g. free form deformation or polygon-reduction, for the purpose of tracing copies (robust watermarks).

- CERTIMARK project

Within the CERTIMARK project, the problem was to design a benchmarking utility for image watermarking algorithms. The platform had to be flexible enough to address different kinds of attacks with various parameter ranges and so on.

- EPFL 3D watermarking

A 3D watermarking algorithm over polygonal meshes has been developed and it is available at display the error values on the surface itself. This new technique that embeds the information in the geometry of the model allows its extraction without the original model, it is robust towards attacks such as translation and rotation and besides it is fast extracted. In order to evaluate the performance of 3D watermarking techniques, a new tool has been created by EPFL. Its name is MESH which stands for Measuring Error between Surfaces using the Hausdorff distance. MESH is a tool that measures distortions (maximum, mean and root-mean square errors) between two discrete surfaces (triangular meshes). The tool aims at having quantitative measurements of the distortions introduced by the watermarking algorithm.

- MIT Shape Intrinsic Watermarks for 3D Solids

The objective of this project is to develop an intrinsic watermark technique for solids bounded by Non-Uniform Rational B-Spline surfaces. The key idea is to extract intrinsic properties of solids, which are not affected by coordinate transformations, random noise and malicious action of the user. This watermark can be destroyed only if the digital model describing the shape is changed so much that the newly represented object cannot any longer be considered approximately identical to the original solid in the database.

- French Institut National des Telecommunications - ARTEMIS Project Unit

This study presents a watermarking method for 3D models represented by NURBS surfaces. The method features obliviousness, transparency and robustness with respect to the common attacks. There was no need for error correcting codes or other ready-to-use solutions which are known as increasing the watermarking method performances.

The following major conferences this year contains sessions on watermarking including papers on 3D watermarking as well:

- 3DTV-CON 2008
- 7th international workshop on digital watermarking, IWDW 2008
- Workshop on Information Security Applications (WISA2008)
- International Conferences on Information Security and Cryptology (ICISC 2008)
- International Conference on Image Processing 2008
- 2008 International Conference on Intelligent Information Hiding and Multimedia Signal Processing
- Image Analysis and Recognition, 5th International Conference, ICIAR 2008
- ACM Multimedia and Security Workshop 2008
- Information Hiding 2008

Some well known research groups in companies working on watermarking are:

- Philips Research
- IBM-Watermarking Research
- Microsoft's Security Research
- Digimarc Corporation
- Alpvision

The following groups on watermarking in Universities are also attractable:

- Multimedia Lab at University of Texas
- Korea Institute of Information Security and Cryptology
- Dept. of Computer Science, University of York
- National Research Lab of 3D Media, Department of Electronic Engineering, Kwangwoon University
- Artificial Intelligence Information Analysis Lab, Dept of Informatics, Univ of Thessaloniki

- Computer Vision Group, University of Genova
- Grenoble INP/GIPSA-Lab
- EPFL, Signal Processing Laboratory
- EURECOM - IMAGE and VIDEO Group for MultiMedia Communications and Applications
- University College London, Adastral Park Postgraduate Research Group
- Lyon Research Center for Images and Intelligent Information Systems, Lyon University
- Information and Communication Theory Group, Technical University of Delft
- Video and Image Processing Laboratory, Purdue University

A special non profit forum dedicated to digital watermarking where scientists, researchers and companies in digital watermarking meet:

www.watermarkingworld.org

The upcoming events on watermarking including conferences, workshops, special issues on watermarking in the journals can be found in the mentioned site.

Although the watermarking is an active research area for the last decade, the research on 3D watermarking is still an unoccupied and attractive area for the researchers on watermarking. There are some detailed researches on the watermarking of 3D objects represented by meshes in the literature as given in the Figure. However, the copy and copyright problems for the 3D objects represented by points and voxels, for the texture and for the 3D scenes represented by images are not handled yet to the best knowledge of NoE participants. Here, 3DTV NoE is also doing a pioneer work with its focus on the mentioned problems.

4. WP10 Report on External Activities (TC3)

Recent review of state of the art by others can be found in [1]. In addition to those references, we know the following groups outside ofthe NoE who work on this same problem:

Mitsubishi Electric Research Laboratories (MERL)

http://www.merl.com/projects/3dtv/ MERL group is one of the earliest who published an article on end-to-end 3DTV streaming system [2]. However, their streaming system is quite elementary.

Electronics and Telecommunications Research Institute (ETRI) – Korea ETRI has concentrated on HDTV compatible 3DTV [3] and development of 3D video services over T-DMB [4]. They have a demo, including transmitter, receiver connected to Sony UMPC, equipped with parallax barrier stereoscopic display. Their system employs MVC coding of two-channel (stereoscopic) video, and direct encapsulation within T-DMB with no special error resilience scheme. In addition, their system support 3D data object transmission (using MPEG-4 BIPS) combined with 3D video for advertising applications.

Video Coding and Architectures (VCA) group at the Eindhoven University of Technology: VCA group has proposed a streaming architecture for 3D-IPTV. They have designed and implemented of a stereoscopic and multiple-perspective video streaming system [5]. This work is also elementary.

Recently, researchers have also started working on P2P streaming for 3DTV transport [6][7]. Standardization of 3DTV specific issues in IETF has been considered in [8].

There are also three related FP7 projects that are known to us. Research towards delivery of 3DTV over DVB-H system is addressed in the FP7 MOBILE3DTV project [9]. The project aims at developing the optimal representation and coding formats for stereo video and its robust transmission over DVB-H utilizing novel, stereo-video dedicated, UEP

schemes. 3DTV broadcast solutions are studies in the 3D4YOU project [10]. It favors the “video+depth” representation format as the most broadcast-friendly one and aims at developing format conversion tools and carrying out broadcast demonstrations. P2P-Next [11] project addresses standard (2D) IPTV over P2P networks.

[1] A. Kubota, A. Smolic, M. Magnor, M. Tanimoto, T. Chen, and C. Zhang, “Multiview Imaging and 3DTV,” Special issue of IEEE Signal Processing Magazine., vol. 24, no. 6, pp. 10-21, Nov. 2007.

[2] W. Matusik and H. Pfister, “3D TV: A scalable system for real-time acquisition, transmission, and autostereoscopic display of dynamic scenes,” SIGGPRAPH 2004; ACM Trans. on Graphics (TOG) , vol. 23, no. 3, pp. 814-824, August 2004.

[3] N. Hur, G. Lee, W. You, J. Lee, and C. Ahn,.”An HDTV-compatible 3DTV broadcasting system,” ETRI Journal, vol.. 26, no..2, pp..71-82, Apr. 2004.

[4] S. Cho, N. Hur, J. Kim, K. Yun, and S.-I. Lee, “Carriage of 3D audio-visual services by T-DMB,” Proc. IEEE Int. Conf. Multimedia and Expo (ICME), pp. 1881-1884, Toronto, Canada, July 2006.

[5] G. Petrovic and P. H. N. de With, “Near-future streaming framework for 3D TV applications,” Proc. IEEE Int. Conf. Multimedia and Expo (ICME), pp. 1881-1884, Toronto, Canada, July 2006.

[6] S.-Y. Hu, “A case for 3D streaming on peer-to-peer networks,” Proc. ACM Web3D, pp. 57-64, Columbia, Maryland, USA, April 2006.

[7] W.-L. Sung, S.-Y. Hu, J.-R. Jiang, “Selection strategies for peer-to-peer 3D streaming,” Proc. ACM NOSSDAV, pp. 15-20, Braunschweig, Germany, 2008.

[8] Y.-K. Wang and T. Schierl, RTP Payload Format for MVC Video, Feb. 2008 http://www.ietf.org/internet-drafts/draft-wang-avt-rtp-mvc-01.txt

[9] Mobile3DTV Project, http://sp.cs.tut.fi/mobile3dtv

[10] 3D4YOU Project, http://www.3d4you.eu/index.php

[11] P2P-NEXT Project, http://www.p2p-next.org/

5. WP11 Report on External Activities (TC4)

The TC4 teams have been constantly monitoring the research carried outside the 3DTV NoE through monitoring relevant conferences, journals (especially special issues), and web pages of research groups. In addition, personal contacts with recognized experts in the field have been constantly maintained.

The results of this monitoring have been used to steer our own research as well as to compare our results with the state of the art.

This report summarises the outside research activities monitoring and related it with our own research topics within TC4.

I. Outside research by topics

Within the TC4 technical report #3 we have made a detailed analysis of the state of the art related with the results of our research work. Here, we present the main conclusions out of this analysis and extend it with more recent observations, made after the TC4 TR3 was completed.

The research on signal processing problems in holography and diffraction science has been driven by the following drivers:

- New 3D display technologies
- Implementation of theoretical results and expanding the theory where needed
- Efficient computations

1. New 3D display technologies

Among the new 3D display technologies, influencing the research on related signal processing issues, we recognize the *quasi-holographic techniques* [1, 2]; *integral imaging* [3-8], *holographic imaging techniques utilizing SLMs* [42, 43, 67], and *auto-stereoscopic displays* [52-59]. While we have been following the results in the first two fields, TC4 has been particularly active in the last two fields. Our works on holographic imaging using SLMs and on corrective filtering for auto-stereoscopic displays compete successfully with the state of the art.

In the area of hologram reconstruction by SLMs, the efforts have been focused on the suitable choice of the modulation mode (amplitude or phase) [42, 43, 80, 81] as well as on full-color and full-parallax display [67]. To achieve both full-color and full-parallax modes, in the work [67] the authors have considered image holograms where the object is assumed close to the hologram, therefore for calculation of each hologram pixel only a few points in the close vicinity have to be engaged, contrary to Fresnel holography where for each hologram pixel all object points have to be taken into account. This choice significantly reduced the computational effort. The spatial light modulators used are three LCoS in a conventional video projector, one for each of three colours, thus producing full-colour reconstructions. However, the scenes to be displayed are not recorded in real world, but synthetic artificial objects calculated by computer.

There is a close relation between the researches in the area of *computer-generated holograms* (CGH) with that on SLMs. The main problem investigated in CGH is the determination of the optimum configuration for some static or dynamic light modulating device such that a desired light field is synthesized in some region of space. Static devices are usually named diffractive optical elements (DOE) while dynamic devices are usually called spatial light modulators (SLM). In most cases, there are harsh constraints on the device (such as quantization of pixel values) that need to be taken into consideration while determining the optimum configuration thus leading to *constrained optimization approaches* [82-86].

An approach dealing with synthesized phase objects instead of real ones for optical-digital recognition systems is described in a series of papers [68-74]. It utilizes iterative Fourier Transforms [69] to calculate object-dependent phase distributions and leads to phase-only spatial light modulators [70]. Modifications based on combinations of two object-dependent filters (amplitude and phase) [71, 72] or on encoding of many intensity distributions into a single phase-only hologram [73] have been developed as well. An interesting iterative technique for phase determination is developed in [74].

Our work on *hologram synthesis by SLMs*, effectively combines computationally attractive techniques for diffraction field computation, in the fashion of [10], with thorough analysis of the structure of the liquid crystal SLMs and their effects on the reconstructed images. In our view, in order to achieve a good reconstruction quality, the artifacts of the practical SLMs should be incorporated into the used models and they should be compensated for via appropriate signal processing algorithms as much as possible.

We have built also a nice overview of the area of SLM-based synthesis. In this area, the research has been focused on improving the techniques for amplitude or phase modulation as well as on analysing the effects of sampling and quantization [42-51].

Our work on *corrective filtering for auto-stereoscopic displays* is well in line with the state of the art. The outside activities in this area have been focused on designing anti-aliasing filters on non-rectangular grids in order to cope with the individual-view and interperspective resampling problem in multi-view displays [58, 59, 64, 65]. MPEG community has also recognized the importance of that topic as related with efficient encoding of multi-view imagery for particular 3D displays [66]. Our research extends these activities toward combined anti-aliasing and cross-talk mitigation schemes. We have demonstrated that the inter-channel crosstalk plays a major role in creating ghosting artifacts in multi-view displays and in fact is more pronounced than the aliasing caused by non-rectangular resampling. Therefore, we have designed cross-talk mitigation schemes employing depth-adaptive filtering. Based on the knowledge of the sampling geometry, we have designed optimal single-user view rendering utilizing face and eye position tracking.

2. Advances in diffraction theory and practice

Research activities under this topic are thorough and diverse. The very general problem is how to represent, model and compute the diffraction field in different scenarios. Various forms of diffraction integral, such as *Rayleigh-Sommerfeld*, *plane wave decomposition* and it approximations such as *Fresnel* and *Fraunhofer* have been investigated and fast algorithms developed [10 – 26]. Fundamental relations with *linear canonical transforms* have been studied [22-25]. Within TC4, we have addressed the same problems through our general framework of finding *plane wave decomposition for arbitrary surfaces*, which turns to be related with the problem of *non-uniform sampling and reconstruction of the diffraction field*. In our work, we analysed approaches based on discrete modelling of continuous functions and developed fast techniques utilizing iterative algorithms, such as Projections onto Convex Sets (POCS) and Conjugate Gradient (CG). Our sampling and reconstruction framework compares with the framework developed in [26].

One of the high-priority research tasks within TC4 has been *phase-retrieval* based approaches to holography. In particular, two main topics have been indicated within this task: i) *phase shifting* digital holography and its relation to problems in interpolation; ii) *phase retrieval* from multiple images distributed in space or time. As it should be expected, these topics, being in the main stream of research in the vast area of digital holography, attract also many other research groups all over the world. The recently published papers show that the research efforts are focused on

i) Development of new or improvement of the already established algorithms for phase retrieval;

ii) Analysis of accuracy of phase-measuring techniques;

iii) Development of methods for numerical wavefront reconstruction from 2D data arrays digitally recorded by a 2D photo-sensor (CCD or CMOS);

iv) Implementation of phase-shifting technique in real time for 3D capture of objects and scenes or monitoring of fast processes. We give below a brief review of the results obtained in these areas.

Accuracy of phase retrieval continues to be attractive topic among the holographic and interferometric community. It is inevitably connected with development of more sophisticated and efficient algorithms for raw data processing. Accurate measurement of the phase in phase-shifting interferometry in the presence of linear and non-linear errors in the introduced phase-steps as well as in the presence of higher harmonics in the projected fringes is addressed in several papers [87-92] of the group of Prof. P. Rastogi from Applied Computing and Mechanics Laboratory, Ecole Polytechnique Fédérale de Lausanne. The signal processing methods which have been discussed in their research are annihilation filter, state space, multiple-signal classification, minimum norm, estimation of signal parameter via rotational invariance, and maximum-likelihood estimator. These methods enable the estimation of phase in an interferogram in the presence of harmonics and noise. A comprehensive analysis of the influence of systematic errors (spatial carrier miscalibration, nonuniform average intensity profile, and nonlinear recording) in the spatial carrier phase shifting interferometry as well as of calibration error of unequal phase changes across the interferogram field is made in the works of Prof. K. Patorski and co-authors [93, 94] from the Institute of Micromechanics and Photonics, Warsaw University of Technology. The group of M. Atlan, M. Gross, and E. Absil from Université Pierre et Marie Curie proposed to remove most of the phase-shift error by a frequency-shifting method. This approach can be applied to both holography and interferometry. From analysis of holograms they compared respective efficiencies of off-axis and phase-shifting holography in terms of noise and aliases removal. A variant of the heterodyne holography scheme that combines the properties of off-axis and phase-shifting holography has been also proposed. The results were published in [95-97]. The group of L. Cai, Q. Liu, Y. Wang, X. Meng, and M. He from Department of Optics, Shandong University, Jinan, proposed a digital method of correcting both amplitude and phase distortions caused by arbitrary phase-shift errors in standard four-frame phase-shifting interferometry; their last results are published in [98]. A spectrally resolved white-light interferometer is used for experimental study of the phase error due to the phase-shift error in the phase-shifting technique in [99]. A compensation algorithm is proposed and verified in [100] for correction of nonsinusoidal phase error in DMD pattern projection profilometry. The research on generalized phase-shifting interferometry with arbitrary phase steps is addressed by many authors. In [101] indirect reduction of the phase-shifting errors by elimination of the twin-image noise in the reconstructed image is proposed. Minimization of a half-quadratic (robust) regularized cost function for simultaneously computing phase maps and arbitrary phase shifts is chosen in [102] as a phase shifting method which is robust for irregular and unknown phase steps. An advanced iterative algorithm for phase extraction from interferograms with random and spatially nonuniform phase shifts is presented in [103]. The group of P. Jia, J. Kofman, and C. English from Canada developed an intensity-ratio error-compensation method to decrease the measurement error caused by projector gamma nonlinearity and image defocus in triangular-pattern phase-shifting profilometry [104,105]. A novel fast convergent algorithm to extract arbitrary unknown phase shifts in generalized phase-shifting interferometry is proposed and verified by a series of computer simulations in [106]. A blind phase shift estimation algorithm that allows simultaneous calculation of phases and phase shifts from three or more interferograms is presented in [107]. The actual phase shifts are estimated by minimization of an objective function based on a cross-power spectrum of specific correlations between the calculated background intensity distribution and the fringe component. In [108] in order to minimize the phase shifting error, a special pixelated spatial carrier phase shifting technique is developed through grouping of phase shifted pixels around a single point in two dimensions, minimizing the phase shift change due to the spatial variation in the test wavefront.

Intensive research efforts are unceasingly dedicated to phase-shifting digital holography, proposed by Prof. I. Yamaguchi from Department of Electronic Engineering, Faculty of Engineering, Gunma University. His group demonstrated experimentally that an image of a diffusely reflecting object can be reconstructed only by phase data of the derived complex amplitude [109]. They also proposed a surface contouring by phase-shifting digital holography with a wavelength shift [110]. To perform an instantaneous phase shifting measurement beyond the limitations of off-axis digital holography a parallel phase-shifting digital holography was proposed and realized in [11-113] by spatial segmentation of the reference wavefront using an array of cells consisting of 3 or 4 different phase retarders in front of the image sensor. The main drawback of the proposed approach is the decreased number of pixels which contribute to image reconstruction. A two-step simultaneous phase-shifting detection has been also introduced as a further improvement of this method by utilization of a 2x1 cell configuration array of polarizers [114, 115] or retarders. In this case only two holograms are recorded, but some conditions have to be set on the intensities of the reference/object waves. A novel approach for numerical suppression the zero-order images in digital holography on the basis of a single hologram is described in [116] where satisfactory reconstructed image is obtained even if the distribution of the object wave is not uniform. In-line digital holography based on two-intensity measurements [Zhang et al. Opt. Lett. 29, 1787 (2004)], is modified in [117] by introducing a π shifting in the reference phase. Thus the restriction that the object beam must be much weaker than the reference beam is avoided. In [118] it is shown that by combining a white light source and a spectral tunable filter a speckle-free white light on-axis digital holographic microscopy can be realized. Phase-shifting interferometry is used in [119] to retrieve amplitude and phase information from an interferometric near-field scattering system with nanoscale resolution. A technique for phase-shifting digital in-line holography which compensates for lateral object motion is proposed in [120] as well as phase-shifting holographic reconstruction which minimizes additive white Gaussian noise for an arbitrary set of reference field amplitudes and phases.

The work in the field of phase retrieval for 3D shape measurement continues to be very active. The currently used algorithms are modified and new algorithms are developed. In [121] a new two-step phase-shifting fringe projection profilometry by removal of the background intensity of fringe patterns through high-resolution differential algorithm based on global interpolation of fringe gray level on a subpixel scale. A new very fast three-step phase-shifting algorithm is proposed in [122] that relies on an intensity ratio function to replace the arctangent function in the traditional algorithm. The phase error caused by this new algorithm is compensated for by use of a lookup table. A novel algorithm for the phase extraction from a single interferogram based on the spatial processing of interference patterns without the introduction of a linear carrier as in Fourier transform techniques is proposed by the group of Prof. W. Osten [123] from the Institute of Technical Optics, Stuttgart University. The algorithm relies on the spatial application of a temporal phase-shifting algorithm and an iterative correction process to obtain an accurate reconstruction of the wavefront. Another method developed in the same group is a single-beam multiple-intensity wavefront reconstruction without reference wave [124]. Optical phase extraction from a one-shot phase-shifting technique realized by a common-path interferometer consisting of two windows in the input plane and a phase grating in Fourier plane as its pupil is described in [125]. Each window has a birefringent wave plate which makes nearly circular polarization of opposite rotations after being illuminated with a 45° linear polarized beam. Four phased-shifted at pi/2 interferograms are obtained simultaneously. Another type of phase-shifting interferometer is described in [126], which utilizes a polarizing prism to form quadrature phase-shifted fringe patterns onto a single imaging sensor. Four phase-shifted fringe patterns in quadrature are obtained by taking images twice. A rapid phase-shifting algorithm for phase and amplitude reconstruction from a single spatial-carrier interferogram that reconstructs through direct estimation and integrating of the phase real-value derivatives is proposed in [127]. The algorithm permits to avoid a phase unwrapping process. The group of S. Zhang and S. Yau from the Mathematics Department, Harvard University continues its work for development of a system for real-time 3D absolute coordinate measurement [128, 129]. By implementing the GPU into the system, they realized simultaneous absolute coordinate acquisition, reconstruction and display at 30 frames per second with a resolution of approximately 266K points per frame. A three-dimensional (3D) digital holographic display system based on phase-shifting digital holography for recording of 3D objects is presented in [130]. Reconstruction of scenes that include multiple objects is performed in [131] with phase-shifting synthetic aperture digital holography. The synthetic aperture technique is used to enlarge the effective sensor size and to make it possible to widen the range of changing perspective in the numerical reconstruction. A change of viewpoint is realized by a double numerical propagation and by clipping the wave field by a given pupil. A novel color fringe projection system for simultaneous determination of absolute 3D shape and color of objects is presented in [132]. The system operation is based on encoding three fringe sets of different pitch into the primary colors of a digital light projector and recording the information on a 3-chip color CCD camera. An algorithm for estimating the color demixing matrix based on the color fringe patterns captured from the reference plane or the surface of the object is proposed in [133]. The calculating the demixing matrix makes unnecessary extra images for color calibration before performing profile measurement thus improving the measurement accuracy of the color-channel-based phase-shifting profilometry. A compression method of phase-shifting digital holographic data is presented in [134]. The compression of phase-shifting digital holograms has been also addressed in [135,136] interferogram domain-, hologram domain-, and reconstruction domain-based strategies are considered.

In our work, we have focused on *phase unwrapping* combined with efficient *denoising of the fringe patterns*. The state of the art of that field is represented by the works [30, 31]. Our developments, based on careful denoising of the fringe patterns before phase unwrapping and using local phase approximations, are superior to the above cited works.

Yet another fundamental area of research is the *pattern projection profilometry* aimed at capturing 3D scenes based on high-resolution structured light [32-34]. For this type of approaches, advanced signal processing techniques are a must [35-41]. Our contribution to the field is the development and study of a novel projection element, i.e. sinusoidal phase grating. Its properties in a multi-source and multi-camera profilometric system have been studied in a pioneering work. In addition, careful error analysis has been accomplished.

3. Efficient computations

It is all about the huge amount of data. Anything that can help in fast calculations of diffraction fields and holographic patterns has been well appreciated and thoroughly studied. Parallel techniques and techniques utilizing graphical processing units (GPU) are particularly fashionable [27, 28, 29]. In our work, we have combined expertise on the usage of GPUs with deep knowledge of the diffraction field features in terms of signal theory (space-frequency representations, sampling schemes).

Highly-efficient GPU based techniques are also appreciated for rendering of multiple views in auto-stereoscopic display systems [61-63]. We have contributed to that field by developing methods for efficient GPU-based rendering, incorporating crosstalk-suppressing filtering and single-user view adaptation.

II. Outside research by names

It is difficult to overview the activities of all prominent individual researchers and leaders of research groups working in the area. In this section, we just mention some of them, as we have been constantly checking their achievements. The list is incomplete, though.

Bahram Javidi, University of Connecticut (http://www.ee.uconn.edu/javidi.php). He has been active in the area of integral imaging [4,6,7,8], hologram reconstruction and related signal processing issues (sampling, time-frequency distributions) [26]. See the full list of his papers on his web page. Prof. Javidi was a plenary speaker at the 3DTV-CON 2008 in Istanbul.

John T. Sheridan, Optoelectronics Research Centre, University College Dublin (http://ee.ucd.ie/~jsheridan/). He and his group have been active in TC4-related fields, such as theory of diffraction, applications of the Wigner Distributions and Fractional Fourier and Linear Canonical Transforms [22, 23, 79]. For full list of his publications , check http://ee.ucd.ie/~jsheridan/pubjs.htm and for projects of his lab, check http://eleceng.ucd.ie/research_areas/optoelectronics.html. Dr. Sheridan has been collaborator with T. J. Naughton (http://www.cs.nuim.ie/~tnaughton/index.html), who is now the coordinator of the new FP7 project 'Real 3D' (one of the new projects formed partly by 3DTV NoE partners).

Kyoji Matsushima, Optical Information Systems lab, Kansai University (http://www.laser.ee.kansai-u.ac.jp/matsu/). We have been following his works on computer-generated holograms. He mainly focuses on plane-wave decomposition with rotational transformations in order to efficiently calculate diffraction fields between tilted planes. Then, the diffraction field relationship between tilted planes can be used to compute diffraction field due to an object which is formed by planar patches [16-19].

Martin Bastiaans, Signal Processing Systems, Eindhoven University of Technology, Nederland and *Tatiana Alieva*, Department of Optics, Complutense University of Madrid, Spain. We have been following their works on fractional and canonical transforms in optics [75-78], for full list of their publications see http://www.sps.ele.tue.nl/members/M.J.Bastiaans/abstracts/index.asp and http://www.ucm.es/info/giboucm/TAlievapub.html.

In the area of interferometry and phase unwrapping, we have been comparing our work with the work of *Jose M. Bioucas Dias*, Technical University of Lisbon, Portugal (http://www.lx.it.pt/~bioucas/).

In the area of resampling and anti-aliasing filtering for auto-stereoscopic displays, we have been following the works of *Matthias Zwicker*, Computer Graphics Laboratory at the University of California in San Diego and his co-authors [64] and *Janusz Konrad* and his Visual Information Processing Lab at Boston University [58, 59, 65]. For more info see also their respective web pages: http://graphics.ucsd.edu/~matthias/index.htm ; http://iss.bu.edu/jkonrad/.

See also the part reviewing the activities in the field of phase-shifting holography and phase retrieval for several other research groups being within the scope of our locator.

III. Outside research by events

SPIE conferences and symposiums have tracks related with the research activities of TC4. Among these, we mention the following:

- The conference '*Three-Dimensional Imaging, Visualization, and Display*'. Earlier, it was part of PIE Optics East, while since 2009 it will be part of SPIE Defence, Security and Sensing Symposium to be held on 13 - 17 April 2009, in Orlando, FL, USA.
- The conferences '*Stereoscopic Displays and Applications*' and '*Practical Holography: Materials and Applications*', part of the *Electronic Imaging Symposium*, held annually at the end of January in San Jose, CA, USA.

- The whole *Optics and Photonics Symposium*, held annually in San Diego, CA, USA

- *SPIE Photonics Europe*, held biannually in April, in Strasbourg, France.

International Commission for Optics (ISO) has been organizing biannual topical meetings on *Optoinformatics* and *Information Photonics*. The last such meeting was held in 2006 in St. Petersburg, Russia and the next meetings are scheduled for September 2008 in St. Petersburg (Optoinformatics) and for November in Awaji, Hyogo, Japan.
Similar topical meetings have been organized by the *Optical Society of America*. We refer to the '*Digital Holography and Three-Dimensional Imaging*' topical meeting of OSA, held in March 2008 in St. Petersburg, FL, USA.

In addition to conference events, we have been following all prestigious journals in the field, and in particular their special issues representing activities relevant to TC4 topics. Among these we mention the July issue of *Applied Optics* (vol. 47, issue 19, pp. 3406-3542) devoted to digital holography and 3D imaging,
http://ao.osa.org/issue.cfm?volume=47&issue=19

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6. WP12 Report on External Activities (TC5)

In the four years since the initiation of our Network of Excellence in 3DTV, worldwide activity in 3D displays, vision and associated applications has increased dramatically. The prospect of 3DTV in the home and the associated development of a host of related commercial and industrial applications grow ever closer. New implementations of displays have appeared, new techniques have been pioneered and a wide range of applications has been generated to exploit this technology. However, it is still true to say that no particular technique or technology has yet stamped its dominance on the market place: autostereo methods still vie with the embryo holographic techniques for a market share. Although several displays carry the "holography" name, none of them is a true implementation of 3D as envisaged by this NoE. It is still the case that in the short to medium term, displays based on stereoscopy (with glasses) and auto-stereoscopy are still likely to dominate for several years to come. A true interactive, full colour holographic TV in the home or workplace is still a long way away. At the recent 3DTV Conference in Istanbul (May 2008) [1], it was significant that many of the "big-players" in display technology discussed their plans for displays based upon stereo and autostereo; holography was barely mentioned! However, work on holography is gathering pace especially for niche applications.

We have seen the arrival in the marketplace of stereo and pseudo-holographic displays from, fro example, *Philips* [2], *SeeReal* [3], *Holografika* [4] and *Sharp* [5]. In particular, *Philips* screened a Jean Michel Jarre concert to a private audience in 3D without glasses using their stereo-3D conversion tool "Bluebox" in conjunction with their "WOWvx3D" display. The *SeeReal* display is holography-based and utilises a limited "viewing window technology" to transmit a reduced numerical aperture to the eye (again without glasses). *SeeReal* also offer a range of autostereo displays [6]. The *Holografika* display also purports to be holographic in nature; images are replayed from a series of 3D arrayed voxels to give the illusion depth. Engineers at *Stanford University* are developing a 3D camera [7] incorporating 12,616 lenses which is itself a development of an earlier "light-field" camera.

Three-dimensional movies using a variety of vision-assists are becoming commonplace: the *BBC* screened a live Rugby International in 3D-stereo using glasses to a limited audience [8]; other related news items from the *BBC* include a U2 concert recorded in 3D. This was produced by *3DFirm* [9], a consortium of companies involved in the production of 3D movies and TV productions. Versions of *Bugs*, *Jaws*, *Shrek*, and *Beowulf* were released in stereovision. *Beowulf* was screened to the 3DTV-CON delegates in Istanbul in May 2008. The *Disney Corporation* announced the creation of six new animated 3D movies by 2012 [10].

Representatives from *Philips*, *Texas Instruments*, *Mitsubishi* and *Holografika* displayed or talked about their latest developments and their hopes for the future of 3DTV at the aforementioned 3DTV-CON in 2008. It is clear that these companies believe in the future of 3D and are putting significant resources into its development. Mitsubishi talked about their particular 3DTV to be released later this year (2008). The same company are also planning the release of a 3D blu-ray gaming module [11]. What was particularly significant was that these companies (with the exception of *Holografika*) are currently basing their designs on stereo and autostereo. For autostereo and some implementations of holography, headtracking is a vital element of the display and available techniques are becoming more user-friendly, less intrusive and cheaper [e.g. 12].

Holography, though, is not standing still. Much activity is going on worldwide to further the development of holographic systems. Without mentioning members of our NoE, groups that are particularly active include, the *University of Connecticut* [13] and the *Media Lab MIT* [14] in USA; the *Electronics and Telecommunications Research Institute* (*ETRI*) [15] and the *Korea University of Science and Technology* [16] in the Republic of Korea, and the *Advanced Telecommunications Research Institute International* (*ATR*) [17] in Japan. Companies active in utilisation of holography include, as mentioned earlier, *Holografika* and *SeeReal*. Clearly, though, for holography to become a real prospect, the underlying technologies need to be developed to a higher level than at present. SLMs and LCD panels need to be developed to higher pixel density and smaller pixel size. VLSI technologies continue to grow at a rate consistent with the so-called "Moore's Law" and spatial light modulators (SLMs) are improving in resolution and overall dimensions [18].

There has been significant growth in the associated technologies required for 3D to make its impact. Through the mechanisms of the network, two well-developed laboratories were established at *Aberdeen* and *Bilkent Universities* for the development of SLM applications and several papers (*Aberdeen University*, *Bilkent University* and *MPG*) were published on the use of SLMs in computer generated holography and 3D displays. *CLOSPI-BAS* have taken another approach by advancing our knowledge of photopolymer materials for SLMs. Implementation of head tracking technology is an area our Network partners have been particularly influential in: the *Heinrich Hertz Institute* and *deMontfort University* have co-operated in the development of a new interactive autostereo display and have made significant contributions to head-tracking techniques. *BIAS* are leaders in the world of optical metrology and laser development and have led our look at the evaluation of RGB sources needed for a 3D colour display.

FogScreen, has seen their "immaterial" display appear in the *Eurovison Song Contest* and used by many companies around the world such as *Disney*, *Nokia*, *Procter & Gamble*, *Motorola*, *Sony*, *Siemens* and *Microsoft*. *Tampere University of Technology* and the *University of Ilmenau* are studying aspects of human factors and perception which is a vital aspect if 3D is to gain widespread acceptance.

The rate of growth of available applications is no less impressive and again our own partners are in the vanguard here. *ITI-CERTH*, *Koc University*, *METU* and *Yogurt* have all been influential. *Aberdeen University* has been involved in the development of subsea holographic cameras for plankton measurements. We have been instrumental in pursuing several unique applications of 3D technology from football-related visualisation through forest fire simulation to subsea holography of plankton. Although some of these applications had begun before the onset of the network and are outwith its remit, they are again a testament to the ingenuity and forward-thinking capacity of the group as a whole.

Another point of note is the preparation, by *Momentum*, of a market survey of users' expectations for a 3D display.

At the last General Research Meeting of the network [20], consideration was given to what a 3D display requires in terms of scene capture, coding, transmission and the like. In Figure ES-3, we explore the inter-relationships in more detail and outline what is required from these other technical areas if 3DTV is to reach its goal. For true, realistic implementations of 3D many factors, such as human perception, price and reliability of the equipment, image resolution, broadcast standards, and availability of material to be broadcast have to be taken into account.

An important aspect is how the public will perceive and relate to 3DTV; what form will a display take; will it require vision aids; how will human factors such as comfort and accommodation affect our perception. These aspects need answered over the next few years. Will 3D capture be holographic or some combination of 2D cameras? Certainly, holography has some significant barriers that may be insurmountable such as laser safety and laser parameters. For scene representation, what is the exact form of the data structure, can correct angular views be created with the correct angles for accurate parallax information? In coding and compression, standardisation needs addressing and how holographic data is to be handled. Finally for data transmission, how can intelligent packaging of data be handled. These questions and more have been posed but most, as yet, remain unanswered.

Over the course of the NoE, members of WP12 have been instrumental in generating some significant achievements in displays and applications. The roadmap concept is one. Our input in areas of SLM application, photopolymers, novel autostereo and head-tracking; implications of human factors and means of evaluating them; have all helped to progress the science and technology of 3D displays. Several of our participants have formed groups (sometimes with outside partners) that have applied for, and received, prestigious funding awards from national or international bodies.

[1] Conference Proceeding 3DTV-CON (Istanbul 2008)

[2] Philips 3D Solutions, http://www.business-sites.philips.com/3dsolutions

[3] SeeReal Technologies, http://www.seereal.com.seereal.com

[4] Holografika, http://www.holografika.com

[5] Sharp, http://www.sle.sharp.co.uk.research/optical_imaging/3d_research.php

[6] SeeReal Technologies, Autostereo, http://www.seereal.com.seereal.com

[7] Stanford 3D camera, http://news-service.stanford.edu/news/2008/march19/camera%20-031908.html

[8] BBC News, http://news.bbc.co.uk/1/hi/technology/7213534.stm and http://news.bbc.co.uk/1/hi/technology/7286852.stm

[9] 3DFirm, http://www.inition.co.uk/wowlab_3dfilm.htm

[10] Disney, http://news.bbc.co.uk/1/hi/entertainment/7338320.stm

[11] Mitsubishi: http://www.mitsubishi.com; http://crave.cnet.com/8301-1_105-9764622-1.html; http://www.tvpredictions.com/mitsu3d092507.htm; http://www.engadget.com/2008/01/04/mitsubishi-shows-off-3d-tv-technology-no-glasses-needed/

[12] Johnny Chung Lee, Head tracking using Wii Remote, http://www.cs.cmu.edu/~johnny/projects/wii

[13] Univ. of Connecticut, Bahram Javidi, http://www.ee.uconn.edu/javidi.php

[14] MIT Media Lab, http://www.media.mit.edu/

[15] ETRI, Korea, http://www.etri.re.kr/eng/

[16] Korea University of Science and Technology, http://www.ust.ac.kr/eng/index.html

[17] ATR Japan, http://www.atr.jp/index_e.html

[18] Holoeye, http://www.holoeye.com