3rd report of the state of the art of technology and standards

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MOBILE3DTV

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Abstract: In this report, we overview the RTD activities in the area of 3D video and its delivery to mobile devices for the period of June 2009 – September 2010. The report is structured in three parts: standards, devices and systems, and research. The activities of various standardization bodies relevant to the building blocks of the Mobile 3DTV value chain, are reviewed. We briefly describe the activities of: MPEG – in the area of multi-view and 3D video coding; DVB – in the area of digital video transmission to mobile devices and 3D; we overview also broadcasting standardization activities in Asia and USA. We overview the development of new embedded platforms and auto-stereoscopic displays for their applicability to handheld devices and we describe known experimental 3DTV and mobile 3DTV systems and broadcasting trials. We also briefly describe relevant ongoing research projects in Europe and Asia and review new research papers. In the conclusions, we try to identify the major trends in the overviewed technology and standards.

Keywords: 3DTV, mobile video, stereo-video, artefacts, artefact simulation, quality estimation

Executive Summary

In this report, we overview the RTD activities in the area of mobile 3D video and related fields over the period of June 2009 – September 2010. The review is structured in three parts: standards, devices and systems, and research. We logically go from the industry and community acceptance of new technologies through *standards*, to *devices and systems* where they are more or less successfully employed to arrive to the even newer ideas and developments found in *research* projects and publications.

Section 2 is devoted to recent standardization activities in the area. We focus specifically on 3D video coding and broadcasting standardization. The first field is covered by MPEG, which has developed the so-called Multi-video coding (MVC) amendment to H. 264 and is currently working toward new 3D video coding standards. The second is primary addressed within the DVB project, where we pay special attention to DVB-H and the new DVB 3D initiative. We further overview the related standardization activities in Asia and US. There have been no new relevant developments in the area of user studies and objective video quality assessment.

Section 3 is devoted to devices and systems. We overview the development of new embedded platforms and auto-stereoscopic displays for their applicability to handheld devices and we describe known experimental 3DTV and mobile 3DTV systems in Europe and Asia.

Section 4 reviews recent research activities in terms of projects and results reported in journal and conference papers. We overview both EU's FP7 projects and projects run in Asia. We also briefly review research works which support, extend or go beyond standardization activities. The same topics of interest as in our project are addressed, namely coding, error resilience, user studies and video quality enhancement and quality metrics.

In the conclusions, we try to identify the major trends in the overviewed technology and standards.

Numerous sources of information, including standards, recommendations, HW and SW references, journal articles, conference papers, research and corporate web sites, and press releases have been used in the review. The reference list includes 191 sources of information.

Table of contents

Executive Summary 2
1 Introduction 4
2 Standards 4
2.1 Coding-related standards 4
2.1.1 Multi-view Video Coding 4
2.1.2 3D Video Coding 5
2.2 Transmission-related standards 5
2.2.1 DVB-H 5
2.2.2 DVB 3DTV 6
2.2.3 Other standards related with 3D broadcast and mobile television 6
3 Devices and systems 7
3.1 Multimedia platforms 7
3.2 Displays 7
3.3 Experimental systems 8
3.3.1 3DTV systems and services in Europe 8
3.3.2 3DTV systems and services in South Korea 8
4 Research 8
4.1 Projects 9
4.1.1 FP7 projects 9
4.1.2 Other projects 10
4.2 Research publications 10
4.2.1 Coding 10
4.2.2 Error resilience 11
4.2.3 User studies 11
4.2.4 3D video quality enhancement and quality metrics 12
5 Conclusions 14

1 Introduction

The Mobile3DTV project has adopted a user-centered design of the core technologies for the value chain, namely the content creation and coding, error-resilient transmission over wireless channel, and 3D-enabled mobile device. In order to successfully develop new techniques and gather new knowledge about the respective technology and its acceptance, within the MOBILE3DTV project we have been following and comparing our efforts with the state-of-the-art in the field.

This report is third of the series of yearly reports on the mobile 3DTV technology field and update the previous reports for the period of June 2009 to September 2010. It is logically divided into three parts: standards, systems, and research. Standardization activities are quite informative indicator about what is likely to be accepted by the industrial players in the field. We review the recent standardization attempts related with the compression and broadcasting of (mobile) (3D) video. This time, we look also at the relevant developments in Asia and US. Further, we review the emerging new media-reach platforms and auto-stereoscopic displays being the core of a productive and low-power-consuming device with appropriate form factor and high-quality 3D display capabilities. Then, we describe also experimental systems and broadcasting trials all around the world. Finally, we concentrate on forefront research described through projects and academic publications. These are considering a source of novel ideas and advance solutions for further standardization and practical use. In the conclusions, we identify trends within the reviewed field.

2 Standards

2.1 Coding-related standards

Standardization of digital audio and video is investigated by the Moving Picture Experts Group (MPEG), a working group of ISO/IES and the corresponding standards are issued with ISO/IES designations [1]. The starting point of 3D video coding was the family of coding standards for classical 2D video with Advanced Video Coding (AVC/H.264), jointly developed by ISO/IEC MPEG and ITU/VCEG within the Joined Video Team (JVT). Based on that, new extensions of video coding standards for 3D video content were or are being developed, as described below.

2.1.1 Multi-view Video Coding

Multiview Video Coding (MVC, ISO/IEC 14496-10:2008 Amendment 1) is an extension of the Advanced Video Coding (AVC) standard that provides efficient coding of such multiview video. The overall structure of MVC defines the following interfaces: The encoder receives N temporally synchronized video streams and generates one bitstream. The decoder receives the bitstream, decodes and outputs the N video signals.

MVC was standardized in July 2008 in a first version [2]. The support of MVC for interlaced content has now been added. Apart form this, MVC is finalized in its current functionality.

For the Mobile3DTV project, the application of MVC to stereo formats is very important. This includes the classical case for conventional stereo, as well as extensions, where mixed-resolution stereo is investigated. For the latter, one view is sub-sampled in order to save data rate with video compression methods. The sub-sampled view is up-sampled again at the receiver after decoding and psycho-visual mechanisms provide a similar viewing experience on medium resolution mobile devices, as for full resolution stereo video. As MVC usually only supports equal image dimesnions in all N views to be coded, additional support for mixed resolution is investigated.

2.1.2 3D Video Coding

3D Video Coding (3DVC) is a standard that targets serving a variety of 3D displays, including stereoscopic displays with different sizes and baselines and multi-view displays [3]. The latter present N views (e.g. $N = 9$) simultaneously to the user, so-called multi-vied displays. For efficiency reasons only a lower number K of views ($K = 1,..,3$) shall be transmitted. For those K views additional depth data shall be provided. At the receiver side the N views to be displayed are generated from the K transmitted views with depth by depth image based rendering (DIBR).

This application scenario imposes specific constraints such as narrow angle acquisition (< 20 degrees). Also there should be no need (cost reasons) for geometric rectification at the receiver side, meaning if any rectification is needed at all it should be performed on the input views already at the encoder side.

The representation format is based on K out of N views, augmented with depth sequences. This representation related to stereo-video generalizes the possibilities of MPEG-C, Part 3 and MVC, i.e. the two separate views can be coded together or can be reduced to single view + depth with the second view to be synthesized at the receiver.

3DVC is an ongoing MPEG activity. Last year, additional test material with challenging content and depth structure has been collected in addition to the existing test data. Furthermore, reference tools for depth estimation and view synthesis have been provided. For comparison of new coding proposals, anchor coding is currently carried out, where 2 and 3 views with color and depth data of each test set is coded, using MVC for color and for depth. 4 different rate points are currently established, for which color and depth data rate are optimized for each rate point and subjective tests are carried out on pairs of synthesized views in order to judge the observed quality and guarantee, that all rate points subjectively differ from each other, as well as from the uncoded data. For the tests, glasses-based stereo as well as autostereoscopic multi-view displays are used. The vision, requirements, ongoing evaluation experiments and other documents of 3DVC can be found in [3]-[12].

2.2 Transmission-related standards

DVB-H has been deployed with mixed success. At the same time, new activities within the DVB project targeting 3D have emerged.

2.2.1 DVB-H

DVB-H is the standard of DVB related to the transmission of digital TV to handheld devices. It is based on DVB-T physical layer and includes link layer specifications addressing the challenges brought by mobility. In 2008, deployment of DVB-H across Europe has gained an increase with the EU endorsement of DVB-H as the recommended standard for mobile TV in Europe. It has acquired interest world-wide also as DVB-H services currently are on air in countries such as Vietnam, Malaysia, Indonesia, India, the Philippines, Nigeria, Kenya and Namibia. Statistical data about the deployment of DVB-H reveals that more than fifty DVB-H technical and commercial trials have taken place all over the world and further commercial launches are expected in France, Russia, Taiwan and elsewhere. According to DVB-H Fact Sheet dated September 2010, DVB-H deployment is expected to become widespread as the analogue switch-off proceeds across Europe. However the number of devices with DVB-H capability is decreasing over years. In 2009, DVB-H reception is supported only by few devices which are LG KB775 Scarlet, released in March, ZTE Raise, released in July and Nokia 5330 Mobile TV Edition, released in November. In 2010, no devices supporting DVB-H has been released by the manufacturers.

2.2.2 DVB 3DTV

Cable and satellite operators have demanded a 3D transmission standard that will enable the use of existing set top boxes, in-home cabling, 2D infrastructure and compression methods. The solution came as the frame compatible 3D signal in form of Side by Side or Top & Bottom packing where the decrease in resolution is realized by row or column decimation. In June 2010, Commercial Requirements for DVB-3DTV have been approved. They include eight of all the possible combinations of field rates, picture rates, scanning algorithms, and lines/screen as follows:

- 720p@50Hz Top & Bottom
- 720p@59.94 Hz Top & Bottom
- 1080i@50Hz Side by Side
- 1080i@59.94/60Hz Side by Side
- 1080p@23.97/24Hz Top & Bottom
- 720p@50Hz Side by Side
- 720p@59.94Hz Side by Side
- 1080p@23.97/24Hz Side by Side.

All expected 3D channels will either substitute for an existing HD channel or require a separate transmission. According to DVB Scene magazine, by mid-2010, database of 3D channels includes 36 major trials or active deployments planned for this year. This includes some of the industry's best known operator names, like BSkyB, CanalSat, Comcast, DirecTV, Orange and SkyLife, along with major content brands including Discovery, ESPN and IMAX. Among the programs that these channels will provide, the most prominent one is *sports*.

2.2.3 Other standards related with 3D broadcast and mobile television

2.2.3.1 In Asia

The standardization and deployment of 3D video services have been especially active in South Korea. In January 2010, the Telecommunications Technology Association – TTA - the Standardization Body of Korea in the field, initiated a 3DTV Project into two working groups: WG1: 3DTV Broadcasting Specification and WG2: 3DTV Viewing Safety Guide. The first draft of 3DTV Broadcasting Specification is scheduled for December 2010. It shall include the service and system requirements, 3DTV video signal format, 3DTV video codec, and multiplexing and transmission. The first draft of the 3DTV Viewing Safety Guide is scheduled for September 2010 and will include the definitions of displays, content, viewing conditions, and viewer parameters [185].

3D DMB Working Group has been formed with the purpose to develop standards for stereoscopic 3D service on DMB (Digital Multimedia Broadcasting). This includes DMB Stereoscopic Video service and DMB Stereoscopic Data service. The standards suggested are to be approved by TTA.

ETRI has been active in ISO/IEC 23000-11 standardization where they suggested a very light-weight file format especially suitable for mobile phones equipped with auto-stereoscopic display and stereo camera. The activity was proposed at the 82nd MPEG meeting in Shenzhen and approved as IS at the 90th MPEG meeting (Oct. 2009) [185].

2.2.3.2 In USA

In USA, the leading standard for mobile television broadcast is MediaFLO. The abbreviation “FLO” in the name stands for Forward Link Only, which means transmission (and error correction) are implemented as forward channel without a feedback link. In US, the television broadcasted using the MediaFLO standard is branded as FLO TV, and uses frequency spectrum between 716 and 722 MHz. The bandwidth of MediaFLO is 250 kbit/s, and one transmitter has coverage of up to 40km. It is standardized by ETSI as TS 102 589 [186]. Qualcomm, which is the inventor of the standard and holds the trademark over the name “MediaFLO”, aims to expand FLO TV to markets outside US.

In October 2010, Qualcomm announced that it is suspending sales of new FLO TV devices, while keeping the network running [187], [188]. It stated current Flo TV customers would be able continue to receive the service into the spring [187], but did not clarify future plans. The reasons for the decision are said to be slow take-off of the service, and the competition from web-based services, such as US-based iTunes, Hulu and Netflix [188].

3 Devices and systems

3.1 Multimedia platforms

Modern mobile application platforms are becoming more and more powerful systems-on-chip maintaining a good balance between power efficiency and high performance. Examples are the Texas instruments’ OMAP 4 [179], NXP’s LH7A400 [180], Marvell’s PXA320 [181], NVIDIA. Tegra APX 2500/2600 Series, Next Generation NVIDIA Tegra [182], [183], and Qualcomm Snapdragon Series [184]. The aim in designing such processors is to achieve high system clock rate and to provide functionality for new rich multimedia applications by more powerful graphical accelerators and digital signal processors. Support of 3D graphics for 3D user interfaces and 3D gaming as well as existing and future multimedia codecs is targeted. The support of high-end operating systems, such as MS Windows Phone, Symbian, Linux (including Android and MeeGo) is essential for fast development and integration of new applications.

3.2 Displays

Among the wide range of 3D display technologies being developed there are quite few appropriate for mobile use. The screen size, CPU power and battery life of a mobile device limit the choice of a suitable 3D display technology. As wearing glasses is considered inappropriate for mobile devices, the auto-stereoscopic technology continues to be the most mature one for handhelds. Either lenticular sheet or parallax barrier is placed in front of a LCD or OLED display to create the 3D effect by refracting the light to the two eyes.

In 2010, NEC LCD delivered the nHD version of their HDDP (Horizontal Double-Density Pixel) based display. The HDDP structure is composed of horizontally striped RGB colour sub-pixels; each pixel consists of three sub-pixels that are striped horizontally and split in half lengthwise. As a result, horizontal resolution is double that of 3D LCD modules constructed with vertically striped pixels, and 3D images are produced through data for the right eye and data for the left eye being alternately displayed horizontally by pixel. 2D images may also be displayed when the same data is presented for adjacent pixels. The new display has been procured by the Mobile3DTV project and embedded to the fourth version of the prototype device demonstrated at the ICT Event in September in Brussels.

Other examples of marketed 3D-enabled handheld and portable devices include the Hitachi Wooo H001 mobile phone with a 3.1 inch parallax barrier based display [175], Samsung SCH-W960 and

SPH-W9500 3D stereoscopic mobile phones with 3.2 inch parallax barrier displays, the light-guiding film based 3D display of the Fuji FinePix Real 3D W1, Fuji FinePix REAL 3D V1 photo frame, the I-Tec portable Blu-ray player [176][177][178].

3.3 Experimental systems

3.3.1 3DTV systems and services in Europe

In 2009, Eutelsat launched satellite 3D TV channel in order to showcase 3D content in the home. Currently the channel transmits short stereoscopic 3D clips for demonstration of the technology. The content is transmitted as stereoscopic side-by-side, MPEG4 encoded stream with a bandwidth of 8Mb/s [189].

On October, 1, Sky TV launched a 3D TV channel, which it claims to be Europe's first. It is available to Sky HD subscribers without additional fee, and requires that the subscriber has a 3D-ready television set channel. The transmission format is stereoscopic side-by-side, compressed into 1080i25 using "horizontal line"-based encoding (HDMI 1.4 annex H compatible) [191]. The transmission started with live broadcast of a soccer match. The launch film line-up includes Bolt. Monsters vs. Aliens, Alice in Wonderland 3D, Ice Age 3D with more 3D titles expected soon [190].

3.3.2 3DTV systems and services in South Korea

On May 19th, the Korean company KBS started trial terrestrial 3DTV broadcasting. The used channel is Channel 66, 1kW @ Kwanak Mt. Transmission station. The video format is side-by-side. The service included live 3D broadcasting of 2010 Daegu Pre-Championships. Six 3DTV camera rigs (5 from 3ality, 1 from KBS/3 parallel, 3 orthogonal) captured the event, and a 620 inch 3D Display placed at Yeouido Square, Seoul was part of the show. In addition, several football matches from the World Championship in South Africa, as well as drama and entertainment programs have been broadcast.

Goals have been set in South Korea to test backward compatible high quality terrestrial 3DTV broadcasting by October 2010. The initiative has been driven by Korea Communications Commission (KCC). The first trial service has been planned for Seoul (100 places) with subsequent demonstration of the 3DTV system at the G20 summit meeting in November 2010. The system aims at providing backward compatibility in terrestrial broadcasting. The video format is Stereoscopic video (L+R) squeezed into 18 Mbps with unnoticeable quality degradation from the current HDTV service where both L and R channels are in full HDTV resolution, 1920x1080 interlaced 30 fps. The coding approach assumes dual Stream coding (L with MPEG-2, R with AVC/H.264), thus generating 2 Elementary Streams and one Transport Stream.

What is important to be emphasized about 3DTV activities in South Korea, is that a complete 3D ecosystem has been growing, including *broadcasters* such as KBS (terrestrial), Skylife, TU-Media (satellite), MSO (cable); *research institutes and academia* such as ETRI, KIST, KETI, and GIST, *manufactures* such as Samsung, LG Electronics, Hyundai IT, Pavonine, Master Image, Redrover, V3I; *content producers and telcos*, such as BigIEntertainment, SKT, KT, and LGT. The activities have been steered by two organizations: Association for Realistic Media Industry (ARMI) – www.armi.me, and 3D Fusion Industry Consortium – www.3dfic.org.

4 Research

Research work and project relevant to the scope of the MOBILE3DTV project to be described here.

4.1 Projects

4.1.1 FP7 projects

A number of FP7 3D-related projects are related to the research and technology being developed within the Mobile3DTV project. At the beginning of 2010, also a number of new projects started, which develop technology in the area of 3D media technology. These projects have been meeting to exchange ideas, to form a vision and to find areas of join collaboration under the umbrella of 3D, Interactive, immersive Media Cluster. We briefly review some of the projects for their relevance to the Mobile3DTV research topics.

One project, targeting 3D technology on mobile devices is *3DPHONE.* It develops an *all-3D* phone, which means that all menus, applications and programs interfaces will have a 3D appearance and shall be perceived in 3D via stereo display technology. Two target platforms will be used to present a broad spectrum of 3D-based Computer Graphics and Vision technologies: one platform is the OMAP device with less processing power and limited display technology, which will boil down to stereoscopic displays. The second platform is the UMPC, which has more processing power and allows for high level graphics rendering, like practical engines and complex shading. In the past year, the video coding and decoding GStreamer plugins for the OMAP platform have been developed, which can now be integrated into the multimedia framework and are generic enough to be used in other platforms as well. Also, performance tests have been carried out in order to estimate processing times.

In the *3D4YOU* project, the main focus is the development of the 3D transmission chain for home entertainment environments. It targets camera capturing, format conversion from production to transmission/coding format, coding of multiview data and rendering/display. In the area of format description and coding, the layered depth video format was investigated, which consists of one main view with color and depth data, as well as one or more occlusion layers with color and depth data, which include information that is occluded in the main view. Here, compression has been optimized by developing methods for blockwise alignment of residual data in the occlusion layer and temporal sub-sampling with information accumulation [63]. These methods are of higher-complexity compared to the encoding methods for mobile devices where the low complexity at the decoder is of primary importance and imposes a major restriction. The developed stereo coding methods in Mobile3DTV represent a simplified subset of the set of multi-view coding methods and will be followed. Investigation of human factors and usability is also targeted by 3D4YOU and will be followed as well.

In *3DPresence* project, a multi-party, high-end 3D videoconferencing concept is developed. In the past year, the demonstration system was built up and already shown at certain eximitions, like the 3D Media Event in 2009. Regarding 3D video coding, existing technology is used mainly for head-and-shoulder-sequences. Similar to 3D4YOU, also human factors and usability studies are planned with special emphasis on video conferencing scenarios. In general, the technology developed in 3DPresence has limited relevance for Mobile3DTV.

The *2020 3DMedia* project researches and develops technologies for 3D Digital cinema in the areas of capturing, production, networked distribution and display of sounds and images in 3D. Thus, it targets even larger and more complex systems in comparison to 3D4YOU. In addition to the pure data handling, also metadata descriptions, like annotations or content-based media descriptors as in MPEG-7 are developed. Though large in scale, compared to the 3D video transmission chain for mobile devices being investigated within Mobile3DTV projects, the technologies for capture and content creation and 3D video representation addressed by 2020 3DMedia are followed.

The *DIOMEDES* project is a new FP7 project and aims to develop live DVB-T broadcast of multi-view content as near-term solution, as well as peer-to-peer delivery of multi-view video, including 3D video coding and transportation methods, scalable multi-view solutions with rate allocation due to human perception, multiple description coding, as well as 3D audio coding. Again, the project will focus on more complex processing, such that the obtained solutions cannot be directly used for Mobile3DTV, however will be monitored.

Another new FP7 project is *FINE*, which targets robust and accurate methods for capturing calibrated and synchronized multi-viewpoint video, free-viewpoint video representation of a 3D scene at real-time performance from the captured data, robust marker-less motion capture techniques to generate accurate multiple character 3D animation streams from video/film sources. For this, efficient free-viewpoint video coding algorithms suitable for real-time delivery are developed and strategies and specifications for next generation networks are defined. Furthermore, the project will investigate image-based algorithms for photorealistic rendering of 3D characters, synchronized with live-action video feeds, new user centered and multi platform framework to integrate and exploit free-viewpoint technologies in experimental productions. Mobile3DTV will monitor the advances, however only little overlap in joint technology exists.

The third new project is *MUSCADE*, which looks into scalable and generic 3DTV representation format, develop advanced multi-view video coding algorithms and propose them to standardization bodies. Also, intelligent audio-visual capture and production assistance system performing multi-view configuration and providing calibration and metadata, advanced versions of specialized sound, techniques for the scalable & robust transmission of 3DTV is investigated. This represents an extension of the functionality in the 3D4YOU project. The developed technology for coding and transmission is closer to Mobile3DTV that the other two new FP7 projects. However, *MUSCADE* just started, such that only limited technology usage for Mobile3DTV is possible.

4.1.2 Other projects

The *3D DMB Broadcasting Project* by ETRI, Korea has aimed at providing mobile users with realistic 3D services based on T-DMB system. Backward-compatible 3D data and video services are developed to be delivered to mobile phone, PMP, or UMPC equipped with auto-stereoscopic displays (no glasses). The transmitter side contains 3D Data Service Contents Authoring tool, 3D Data Service Broadcasting Server and Commercial Transmission System. The receiver is based on a UMPC equipped with parallax barrier LCD and a USB DAB Receiver. The device includes a 3D DMV SW decoder.

4.2 Research publications

4.2.1 Coding

In the field of classical 2D as well as 3D video coding, numerous papers have been published during the last year. The most important sources are the IEEE Transaction journal series, with the IEEE Transactions on Circuits and Systems for Video Technology as the major representative. Here, a number of comprehensive articles can be found, however since it takes some time for publication, the presented technology is from the year before. Therefore, newer research on these issues can be found in the recent conferences, dedicated to this, which include the IEEE International Conference on Image Processing (ICIP), and the IEEE 3DTV Conference as mayor events in the field. We list here most interesting papers and refer to the proceedings of these conferences for details.

For 2D video, a number of improvements and investigations have been published, mainly for advanced and scalable video coding. These improvements usually target all blocks of the classical hybrid coding structure, like transformation, motion estimation, mode decisions and arithmetic coding, as shown in the paper list in [85]-[140].

In the area of 3D and multi-view video processing, papers can be mainly assigned to the different blocks of the 3D media processing chain, which are Capturing/depth provision [15]-[45], coding [46]-[66] and view synthesis for display [67]-[84]. In the area of content capturing, better calibration methods for stereo or multi-view camera settings were introduced, as well as the use of special sensors, like time-of-flight-cameras. Coding technologies include 3D format descriptions from stereo formats, like mixed-resolution and video plus depth, which are also highly relevant for the Mobile3DTV project, depth-enhanced multi-view formats, like MVD or LDV and 3D CG animation formats. On the other hand, coding methods include compression technology, based on classical compression methods, like MVC, however with improvements towards preprocessing for higher coding efficiency and inclusion of intermediate view synthesis quality for optimization of bit rate distribution between depth and color components. Also, different methods for quality measures, like structure similarity are investigated. For intermediate view synthesis and rendering, improved methods were introduced, which provide better temporal consistency and flicker reduction and are able to suppress some of the coding errors form classical video compression.

4.2.2 Error resilience

An error resilience scheme based on data partitioning of depth data and multiple description coding has been developed in [143]. The work refers to the unavailability of error resilience tools for depth data in the standard transmission of 2D video plus depth format in ISO/IEC 23002-3 (MPEG-C part 3) and offers to use MDC in 2D plus depth approach. In the paper, 2D data is partitioned as motion and texture. Depth data is appended at the end of these two partitions as a third partiton of the stereoscopic sequence.

The study presented in [144] is also about the error resilience of 2D plus depth format. It is based on the correlation between motion vectors of color and depth sequences. A joint encoding method is proposed in order to remove the redundancy in the motion vector data.

A study addressing specifally the DVB-H channel is presented in [145], where a new FEC scheme aware of intra-burst layers, has been developed.

4.2.3 User studies

Related to the User-centered Quality of Experience approach that has been established in the Mobile3DTV research, an interesting paper was published by Wu et al. [146]. In their publication, Wu et al. present an approach towards a theoretical framework for the relation between Quality of Experience and the Quality of Service. Their framework is adapted for Distributed Interactive Multimedia Environments and so applicable for 3D-related applications like 3D-videoconferencing [146]. As a remarkable part of the framework, Wu et al. provide a holistic definition of the term Quality of Experience being "*a multi-dimensional construct of perceptions and behaviors of a user, which represents his/her emotional, cognitive, and behavioral responses, both subjective and objective, while using a system."* [146]

The definition outlines the importance of understanding QoE as a multidimensional construct of users' perceptions and behaviours. Current approaches in multimedia quality evaluations have started to extend existing research approaches towards an evaluation of quality beyond quantitative methods. During the last year, some interesting research approaches have been published in the domain of multimedia quality evaluation related to descriptive analysis. In the area of mobile 3DTV research, the developments of the Open Profiling of Quality approach (OPQ) [149] and a hybrid method for Quality Evaluation in the context of use [151] are two remarkable steps towards combining current standardized research approaches with additional descriptive tasks to be able to study experienced quality factors. Both methods were successfully applied in the system optimization of mobile 3D television and video systems [150][147][152][153][149][151]. Another approach to study quality of 3D beyond Mean Opinion scores has been published by Häkkinen et al. [154]. The study targeted the differences in the perception of 2D and 3D movies. Häkkinen et al. applied eye-tracking to study how content is watched in both cases. The results reveal that there is difference in 3D vs. 2D in a way that there is more eye movement in 3D case. Häkkinen et al. suggest that the exploration of 3D content is an important quality aspect for users which is an important finding for the production of 3D movies.

In related fields of quality evaluations, other interesting approaches of user-centered evaluation methods have been published during the last year. In the domain of image quality evaluation, descriptive quality evaluation has been applied to study different processing pipes. Nyman et al. applied a hybrid qualitative/quantitative methodology [155] and found out that there is a significant difference between the description of good and bad quality. Radun et al. have published a study on evaluating multivariate image quality [156]. In this study they applied the research method of Interpretation-based Quality (IBQ) [159]. IBQ is a related method to OPQ and aims at a mixed evaluation of quality preferences and descriptive quality factors. As a key finding of their study, Radun et al. conclude that especially in high image quality evaluations existing objective measures at not useful anymore as quality experience is related to high-level criteria of human perception. The findings of Nyman et al. [155] and Radun et al. [156] might be relevant for a deeper understanding of the OPQ results in Mobile3DTV evaluation.

Beyond visual quality evaluation, descriptive studies have also been conducted in the domain of perceptual audio quality [157][158]. Especially the work of Lokki and Puolamäki [157] applies an interesting approach. They compared objective measures with sensory profiles by applying Canonical Analysis (CA). They showed that, with the help of CA, it is possible to analyze how much information of the sensory profiles is represented by the objective measures. In addition, it is possible to model the information that is not covered by the objective measures. The approach chosen by Lokki and Puolamäki [157] can be a useful approach when designing new objective quality metrics.

4.2.4 3D video quality enhancement and quality metrics

Akhter et al [163] say that perceived distortion and disparity of a stereoscopic display is dependent of local features. They proposed a non-reference method that uses segmented image features and disparity in order to estimate the quality of JPEG coded stereoscopic images.

A similar approach to the previous one is a no-reference quality assessment model for JPEG coded stereoscopic images by Sazzad et al [164]. In the method, information from segmented local features such as edges, textured areas, blockiness and zero crossing rate within the block of the images are evaluated for artefacts and disparity. In their method, a temporal segmentation approach is considered [165]. Different weighting factors were applied to measure the spatial artefacts, disparity, and temporal features.

Wang et al [166] concluded that the perceived quality depends on the content and the distortion type. Based on the stereoscopic images used on the subjective experiments, an extensive database was build in order to gain understanding on perception of stereoscopic images, and provide data for designing objective metrics.

Zhu and Wang [167] proposed a perceptual model for stereo video quality evaluation, consisting of three steps: wavelet-based perceptual decomposition, contrast conversion and masking, and pooling and quality mapping. The proposed objective metric takes the stereoscopic human visual system into consideration better than traditional objective metrics such as PSNR or MSE, and is more consistent with the subjective quality assessment than the traditional ones. The model requires still further refinement.

Ozbek [168] proposed a PSNR-based quality method that can be used for multi-resolution coded video. It uses a weighted combination of the two PSNR values given for the left and right views, and a jerkiness measure. The optimal weights are sought from correlations between subjective quality test results and the objective measure scores on a set of test videos.

Zhao and Yu [169] propose a full-reference metric, *Peak Signal to Perceptible Temporal Noise Ratio*. The metric is used for measuring perceptible temporal noise in synthesized stereo sequences.

Yasakethu et al [170] studied the relationship between perceptual attributes of 3D video and overall 3D quality. These attributes were analyzed for correlations with several objective quality measures for 3D video content. The study indicates that Gaussian and linear polynomial models can be used to approximate the relationship between perceived depth or quality and overall 3D quality. Moreover, the average PSNR, VQM and SSIM quality measures of individual left and right views can be used in predicting the image quality and depth perception, respectively.

Joveluro et al [172] propose *Perceptual Quality Metric* (PQM), in which the 3D quality is evaluated using 2D objective metrics. It quantifies the distortion of the luminance and contrast, using an approximation weighted by the mean of each pixel block to obtain the distortion in an image. From this, a quality score is obtained.

Chen et al [171] have summarized some novel conditions of 3DTV which need to be addressed. These are presented in Table 1, and are based on recommendations of ITU_R BT.500 [173] and ITU-R BT.1438 [174].

Table 1 Requirement of subjective video quality assessment methodologies for 3DTV

Feature	Condition	New elements
General Viewing Conditions	Luminance and contrast ratio	*Luminance reduction caused by additional optical instrument, minimum luminance necessary to sustain Depth Of Focus, crosstalk affects contrast ratio*
	Background and room illumination	*Minimum distance between display and background necessary, technology of room illumination critical*
	Monitor resolution	*Recommendation of minimum values for spatial and temporal per view resolution and stereoscopic resolution*
	Viewing distance	Designed Viewing Distance *(DVD) sometimes fixed by display manufacturer and adding depth perception factor into* Preferred Viewing distance (*PVD)*
	Viewing position	*Avoidance of 3D geometry distortion, luminance reduction, suboptimal viewing position for autostereoscopic displays*
	Depth rendering	*Upper bounds for Depth Of Focus and binocular disparity*
Source signals	Video format	*Requirements for depth representation formats*
	Video format conversion	*Specification of accuracy for conversion*
Selection of test materials	Video content complexity	*Measurement tools for depth complexity of content*
Test method	Visual discomfort	*Questionnaires for visual discomfort and objective measurement of visual fatigue*
	Subjectively measured quality indicator	*Additional indicator besides image quality, e.g. Naturalness, Presence, Visual Experience*
Observers	Number	*Reevaluation necessary to guarantee stability and reliability of results*
	Viewer's stereopsis performance	*measurement of stereopsis, accuracy, ocular differences, etc.*
The test session	Viewing duration	*Re-evaluation of duration for presentation, voting, session length*
Test Results analysis	Viewer factors	*Rejection criteria, detection of bimodal distributions*
	Multi-dimension indicators analysis	*Statistical methods fro analysis, e.g. relation, interaction and combination of subjectively measured quality indicators*

5 Conclusions

In this report, we have overviewed the state-of-the-art in the area of mobile 3D video and its delivery over wireless channels to mobile users.

The standardization activities related with 3D video coding have been concentrated around the MPEG, where new standards, denoted as 3DV, have been targeted with quite active work during the last year. The broadcast of 3D video has been addressed within the DVB project, where special 3D interest group has been working actively over the year to specify the commercial requirements for DVB-3DTV. However, no new developments in the field of objective video quality metrics and user studies have been observed.

In the area of embedded platforms, the trend has continued toward more powerful devices supporting reach media. Decoding of high resolution and high frame rate video seem no problem with the new emerging platforms equipped also with advanced 3D graphics engines. Support of DVB and DMB has been also available. As far as the portable 3D auto-stereoscopic displays are concerned, the trend is to seek commercialization of the cheaper parallax-barrier technology. Devices equipped with such displays have been announced in Japan and Korea and new display modules of that type have appeared. The superior display technology delivered by NEC has been demonstrated by the Mobile3DTV project at a series of exhibitions culminating at the ICT Event in Brussels in September. We still cannot tell more about the new OMB technology developed by Toshiba-Matsushita.

We especially emphasize the 3DTV and mobile 3DTV activities in Korea. A national-wise standard about the 3D DMB data service has been proposed. Nation-wide 3DTV broadcast trial simultaneously over terrestrial, satellite and cable channels has been scheduled to start on 29 of October with the aim to demonstrate a full-functional 3DTV at the time of the G20 Summit in Korea in November. We note the different approach taken within DVB and the Korean trial. While the former considers a frame compatible 3D signal in form of side-by-side or top-bottom packing of reduced resolution views, the latter considers dual-stream coding (L view with MPEG-2, R view with H.264/AVC), thus generating two elementary streams with higher quality into one transport stream. Samsung has constructed the corresponding compatible TV set. It seems the future is bright for the 3D Blu-ray players and glasses-enabled TV sets. Not so clear is the situation with mobile broadcasting channels. While T-DMB has been doing fine in South Korea, the penetration of DVB-H has continued with mixed success, and MediaFLO in US has been simply shut down.

The research in the area has been busted by dedicated funding as the 3D Immersive and Interactive Media research topic has been given a priority in the ICT Specific theme of FP7. Group of projects dealing with different aspects of 3D Media have been gathered together within the respective 3D Immersive, Interactive Media Cluster. This activity is pretty in line with the worldwide trend, clearly seen, i.e. in Korea and Japan, where 3D standardization and commercialization attempts has been progressing quite a bit. Major conferences such as IEEE’s ICIP and SPIE’s Electronic Imaging have programmed more sessions on related topics where new interesting works have been reported. New scientific events, such as 3DTV-Con and 3DSA have also taken place to provide forum for presenting and discussing novel research results in the field.

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Mobile 3DTV Content Delivery Optimization over DVB-H System

MOBILE3DTV

MOBILE3DTV - Mobile 3DTV Content Delivery Optimization over DVB-H System - is a three-year project which started in January 2008. The project is partly funded by the European Union 7th RTD Framework Programme in the context of the Information & Communication Technology (ICT) Cooperation Theme.

The main objective of MOBILE3DTV is to demonstrate the viability of the new technology of mobile 3DTV. The project develops a technology demonstration system for the creation and coding of 3D video content, its delivery over DVB-H and display on a mobile device, equipped with an auto-stereoscopic display.

The MOBILE3DTV consortium is formed by three universities, a public research institute and two SMEs from Finland, Germany, Turkey, and Bulgaria. Partners span diverse yet complementary expertise in the areas of 3D content creation and coding, error resilient transmission, user studies, visual quality enhancement and project management.

For further information about the project, please visit **www.mobile3dtv.eu**.

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SEVENTH FRAMEWORK PROGRAMME

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