Paper

Stereoscopic 3DTV Video Quality Metric: the Compressed Average Image Intensity

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Abstract— This paper presents a newly designed stereoscopic video quality metric. Overall insights towards the creation of mechanisms utilized within the genuine metric are presented herein. Delivery of the core information and motivation behind the features implemented, as well as functionality of the Compressed Average Image Intensity (CAII) quality metric are of utmost importance. The mechanisms created might be characterized as an objective, reliable and versatile quality evaluation tool for advanced analysis of the content delivery chain within stereoscopic video services.

Keywords*—*3D image analysis, image impairments, stereoscopy, video quality.

1. Introduction

The ever-improving performance of newly deployed multimedia content distribution networks enables customizable configuration of the end-to-end connectivity that offers even more control over the quality of the content delivered to the end-user. However, with the revenues generated by telecommunications services assigned a high priority, the last mile phenomenon implies specific behaviors concerning the content delivery scheme. Limitations regarding the available unicast bandwidth dedicated for a single user determines the overall quality over the path from the originating server towards the client's device. The study presented in [1] shows the predicted volumes of dedicated IP traffic or network capabilities required to support video-like services deployed. The fact that figures for such an application reveal an enormous rise in 3DTV and Ultra High Definition (UHD) availability (or IP traffic share) that is proclaimed to reach over 20% of the total, annual, global video IP traffic by the year 2020, may be very motivating. As a derivative of dynamic bandwidth and network management schemes, more and more multimedia services are deployed nowadays relying on adaptive bitrate streaming mechanisms, competing with different approaches, such as HTTP Live Streaming (HLS) or Motion Pictures Experts Group – Dynamic Adaptive Streaming over HTTP (MPEG-DASH) [2]. Introduction of such streaming technology mechanics implies multiple quality measurement-related considerations. From partitioning of content offered into appropriate video chunks that influence buffer saturation behavior, to stream zapping times whenever network dynamics imply a quality-wise switchover (i.e. from 1080p to 720p resolution and respective bitrate reduction), to quality restoration of the adaptive video stream whenever an updated client's manifest file is received – the overall mechanics of the quality measurement tool has to be properly designed to support reliable and codec-agnostic video analysis.

In order to prepare and implement such quality metric mechanics, it is crucial to employ appropriate evaluation of functionalities and inherent characteristics of the designed solution. As it is presented across [3], [4], assessment of basic components of the multimedia delivery chain, in terms of perceptual quality indicators within the stereoscopic 3DTV services, enables to create a cross-platform, responsive and versatile in terms of computational complexity, serving as a quality indicator for 3D, stereoscopic content. In the following sections, a detailed presentation of the objective quality metric mechanisms designed is given, along with examples of results from the CAII testing campaign.

2. Quality of 3DTV Service

Knowing the complexity of the stereoscopic content processing chain within the 3DTV service, one can analyze the problem of constructing the quality evaluation metric. Whenever key processes within such a system of service delivery are investigated, the understanding of quality factors enables to deliver a compound set of parameters and their behaviors to define how to derive and reason a coherent approach towards effective and reliable metric design. Presented in a graphical, tabular form in Fig. 1 are the fundamental elements representing crucial stages of the stereoscopic content processing flow.

As one may see, the overall composition of the quality evaluation scheme might be categorized into four baseline axes, as depicted in Fig. 1, and creates a complete definition of the phenomena defined for the stereoscopic content

Stereoscopic content processing chain within 3DTV service			
Content providers	Video service frame	Networking layer	Clients terminals
Acquisition: • stereoscopic 3D (SbS, L + R) • multi-camera rig • 2D + depth Creation (RAW): • dual stream • MVC	Asset management: • transcoding • stream forming • digital rights management • network-native encapsulation	Delivery: • push/download • streaming • adaptive streaming • unicast/multicast • single/multi stream	Reception: • decoding • filtering • display • environment clutter

Fig. 1. Anchor points in the evaluation of stereoscopic 3DTV content quality.

processing domain. Every single pillar of the positioning presented implies certain modifications of or updates to the processing scheme whenever end-to-end behavior of a 3DTV service is investigated or related to. Therefore, cross-investigation of the in-between relations is crucial in order to deliver an appropriate modeling approach towards quality definition within such a service.

2.1. Content Providers

The aforementioned core axes of the stereoscopic 3DTV service quality plane are as follows: content provider's side, video service frame, networking layer part, client's terminal zone. To start with, let one perform an evaluation of the content provider's side with respect to content manipulation flow. In this area, the greatest importance might be assigned to the process of acquiring stereoscopic visual data. At that point, the initial forming and shaping of quality, or further – the final quality of experience [5] of the actual video takes place. Thus, enabling possibly the highest, richest and undistorted imaging of the composition or logical scene is necessary.

To quantify the range of elements impacting the quality of the content acquisition stage, one may employ the following set of variables determining the overall quality-varying factors:

- formatting of stereoscopic pair (in a side-by-side composition or continuous left-and-right imaging) implies the overall resolution of the image, whenever the pixel stacking approach is available (i.e. limitation in vertical representation or capabilities in frame compression, given by selected standard of targeted format);
- discrepancies in the physical build of lenses and sensors used, causing deteriorating effects, such as fringing, vignetting, aspherical distortions and flaring alongside the sensors' dynamic range of captured luminance scale, sub-sampling of color space and noise footprint whenever a low light situation is captured.

Another aspect of multi-rig camera stacking involves pairing and synchronization of visual cue cameras used. However, there is still a vast range of stream reassembling methods that make it possible to achieve the desired result at the post production stage of content creation. Next, in the latter case of creation stage in the content provider's pillar, the forming part of the resulting video stream is kept. Delivering video content implies a certain composition of stereoscopic data streams. Therefore, several approaches exist towards assembling (and coding) the general video queue. The most frequently used ones are Multi-view Video Coding (MVC) [6] and dual stream aggregation. Both of the aforementioned approaches implement temporal and spatial image sampling (i.e. master-stream and slave-residual channel), thus guaranteeing a strong compression ratio and relatively direct investigation possibilities during video stream analysis.

2.2. Video Service Frame

The next stage of the stereoscopic content propagation chain is the video service frame axis. Here, the content is altered and manipulated in a number of manners, especially related to transcoding aspects of video stream compression. Management of 3DTV assets is closely connected with the type of media distribution or delivery relied upon. Thus, the main aim of the video service frame is to deliver a network native set of video streams. The asset management block is responsible for the creation of independent, quality-scaled stereoscopic video content to meet various adaptive streaming techniques (i.e. stream forming).

At this stage, the highest factor or compression ratio is observed, as the regular, straight-render movie assets are transcoded into low-weight multimedia files. In addition to this procedure, a complementary file, also referred to as a manifest file, is created. It contains a certain playlist-like network-native addressing scheme of where to find appropriate streams, or – in more sophisticated streaming systems – the list of chunk locations for network distribution. It may be also observed that such partitioning of the original video stream might be based upon actual network congestion parameters, upon the reported workload of the certain network node or upon the given computing core (especially in modern day implementations of distributed cloud streaming services [7]). As for the consecutive activities, the Video Service Frame stands also for the digital rights management application. There, the appropriate certification and digital signing of video content is delivered, offering the final customer the selected media access methods (i.e. temporal, cyclic, per view, etc.).

2.3. Networking Layer

In the case of the third pillar of the stereoscopic 3DTV service core, namely the networking layer, as it was previously mentioned, whenever a certain approach towards media transmission is selected, appropriate mechanisms towards delivery technique are chosen. To support inherent functionalities of the transport mechanisms available, like the download/push technique or, more contemporarily, convenient streaming approaches, the difference in network-native phenomena determines the behavior of the selected mechanism and, as follows, its imminent impact upon the quality of distributed content. For instance, in the basic delivery scheme of a plain 3DTV video streaming service, one can enumerate four basic network phenomena causing instant QoE deterioration, specifically: bandwidth limitation, jitter, packet delay and stream synchronization.

Depending on the form of the buffer implemented, dropping packets in a form of bandwidth limitation may cause an influent multimedia playback, stuttering of an image or, if adaptive streaming is concerned, switchover to a lower bandwidth video stream.

In the case of the jitter phenomenon, whenever fluctuation in the ordering of a packet stream is observed, some plain mechanisms may not recover from rearrangements in the delivered data package, thus leading to discrepancies in the decoded video stream.

As far as the third and fourth of the aforementioned network phenomena are considered, the overall problem generated by their existence is the inability to synchronize the playback with the actual timing of the video stream data. Packet delay causes a vast buffer drainage, which implies either single stream corruption (i.e. only audio data) or more likely stereoscopic (i.e. MVC stream composite) video data line discontinuity [8]. Such phenomena might be concealed with encapsulated or expanded transport protocols that allow to reorder or recover packet arrangement with an appropriate stream synchronization, in order to avoid data discarding whenever the logical structure of the movie being played back is outdated (in fact, receiving video data afterwards its scheduled display timing makes the playback routine irrelevant).

2.4. Client's Terminal

The last, fourth axis of the stereoscopic content chain delivery scheme depicted on the graphical representation in Fig. 1 discovers the service customer domain. In that area there exist several aspects defining the final, overall quality of stereoscopic video content. To start with, the decoding process is a crucial and most important stage. Based on the data received throughout the previous axes of the content propagation scheme, whenever the logical structure of the content is incoherent, appropriate decomposition of the video stream is inaccessible. Thus, the QoE is not proclaimed, and the visual, perceptual outcome of the service is also limited [9]. In terms of further, quality impacting features, apart from the decoding process, the displaying technique and the accompanying stereovision filtering type generate complexity in recovering the originally captured scene. However, those two processes are mainly interfered by environmental clutter which is strictly dependent on the hardware setup used or the display technology itself.

2.5. Quality Evaluation

Having defined the pivot points of the quality domain within the stereoscopic content distribution chain, the consecutive step is to focus on the aspects of monitoring or evaluation of the quality of content, especially the one being perceived at the user's end. Basic organization of the quality evaluation domain is defined, with respect to video services, based on the following areas: objective quality metrics, subjective quality measurements and reference-type metrics, where a certain set of inherent parameters is considered, i.e. full reference information, reduced/limited or no-reference models where quality is evaluated strictly over the decoded stream outcome.

In the first video quality assessment method, the emphasis is placed on the reliability of measurement procedures and their outcome, their responsiveness and reproducibility or repeatability. The objective approach is widely acclaimed and highly demanded whenever digital video services are to be benchmarked, in terms of the quality offered. Nonetheless, the domain of the objective quality metrics, especially with respect to 3DTV, stereoscopic content, is barely initialized. As presented by the International Telecommunication Union (ITU) and its J-series recommendation found in [10], the domain is still under development. Proposals concerned with construction of the objective quality metric are funneled into a trilateral model of quality evaluation fundamentals.

The first one spans the analysis of actual, decoded image and pixel information conveyed alongside, i.e. image structure, optical composition, blurriness, etc. The next one is based upon network abstraction layer analysis, mainly in a form of packet investigation (so called bit-stream methodology). The third approach defines coding parameters as the basis for quality evaluation, thus the internal analysis of the codec configuration stream is assessed. Therefore, as one can observe, an objective methodology of video quality evaluation scheme delivers multiple resourceful indicators that can precisely and independently describe the actual quality of the stereoscopic, 3DTV content service rendered.

As far as subjective methodologies utilized for evaluation of quality within stereoscopic video services are concerned, a trending approach exists leaning towards objective methodologies. However, there is still a strong movement towards subjective judging regimes. Foremost, the undeniably requested feature of this kind is to evaluate quality of the perceived content with respect to the Human Visual System (HVS). That feature offers additional advantages of the subjective quality evaluation approach, namely delivers the measurement results in a conformed layout of Mean Opinion Score (MOS). Therefore, it is recognized in international academic research (for instance in [11]) as well as in the standardization activities of the ITU-R [12]. The vast workload presented in the aforementioned publications reveals the complexity of evaluation of the subjective quality of stereoscopic 3DTV content, involving appropriate procedures accompanying the standardization workflow. Nonetheless, in recent works presented in [13], there exists a strong aim to deliver a reasonable, reliable and effective methodology for the subjective metrics. Its outcome might greatly improve not only the subjective methodology domain, but may also expand the common field for comparative and benchmarking routines concerned with objective quality metrics.

3. CAII Metric

This section delivers insights towards the designed, genuine Compressed Average Image Intensity (CAII) metric. As the theoretical and engineering aspects of the quality metric creation were discussed in previous sections of the article, the aim of the design process was to implement an objective methodology scheme. The analysis performed by the mechanisms deployed is based on the assumptions presented strictly for the purpose of HVS. This implies that perceptive cues of the stereoscopic imagery need to be followed, thus realizing a resourceful algorithmic path – inquiry and analysis of 3D compound pairs of frames under the assumption of luminance stream investigation. Therefore, the criterion of perception of the HVS system, also referred to as the naturalness criterion, is proclaimed and fully supported. Processes that are present when stereoscopic information is perceived and ingested by HVS are based upon the dynamic range of the luma channel. As a result, outcomes produced by the CAII mechanism guarantee a direct representation of the actual perceptive sensitivity of the service's customer, and reflect what the HVS system may portray as a seemingly native image. The detailed algorithmic path of the designed objective quality metric is depicted in the graph presented in Fig. 2.

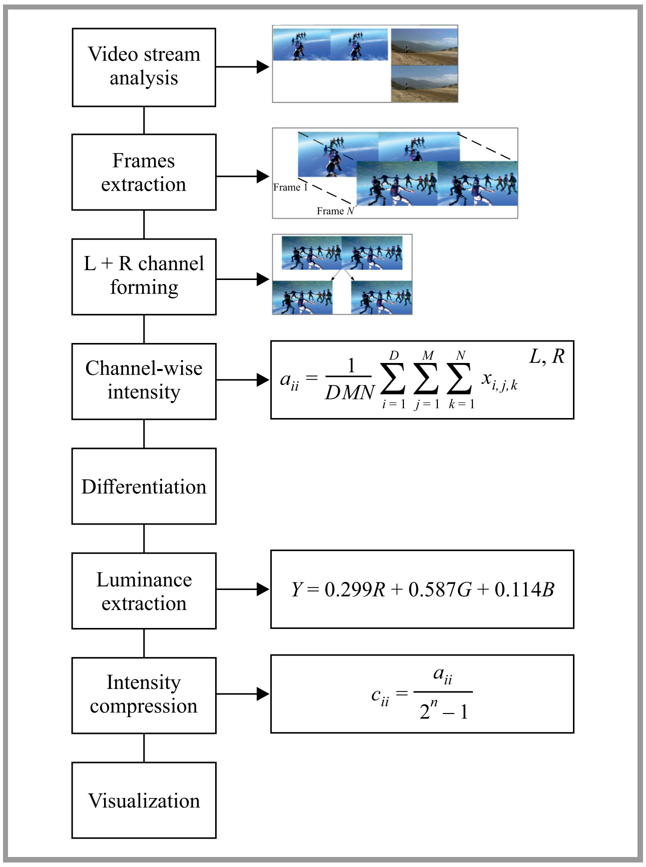

Fig. 2. Layout of the CAII quality metric core mechanism.

While analyzing the structure of the core mechanism of the CAII quality metric designed, one can distinguish eight independent but complementary, functional blocks within the processing scheme flow. Another characteristic features of the genuine mechanism might be noticed in Fig. 2, namely its modular, flexible construction and, most importantly, structural complexity minimized to create an independent measurement tool, performing a quality analysis in spite of various types and formats of the video content injected. To elaborate on the functional blocks of the algorithm, the following list presents insights towards the designed stages of the algorithm:

- **Video stream analysis**: initialization of the algorithmic flow starts with investigation and identification of the ingested video stream parameters. Appropriate structures of information are created here – resolution, frame rate, duration, dynamic range of pixel information and other relevant data is directed into the object determining the further processing path (i.e. vertical or horizontal scanning of a structure).

- **Frames extraction**: this step is based upon the previously recovered information (for instance from the header of the multimedia file) that determines the extraction of the pixel structures of stereoscopic imagery into a selected stream or structure of frames given in a logical (i.e. display) order.

- **Channel forming**: while the unprocessed data structures are created over the previous steps in this particular stage of the algorithm, defined structures of visual cues (delivered for both, left and right HVS sensors) are being formed. Synchronization of such pairs is to be performed to avoid erroneous propagation.

- **Intensity calculation**: as presented in the diagram in Fig. 2, a special formula designed to appropriately calculate the image intensity is being deployed. The whole processing part is performed in the parallel regime, thus computational effectiveness might be achieved.

- **Differentiation**: it is a stage within which a base, residual image is constructed, thus delivering crucial data for the pair-wise disparity analysis. As far as the designed mechanism's workflow is considered, this stage delivers the most important data for further identification and investigation of core quality parameters (by means of the disparity measure) processed to evaluate the overall and actual quality of the decoded image.

- **Luminance extraction**: in this part of the algorithmic approach, image processing is performed by the implementation of the formula for Y parameter (also presented in Fig. 2), applied over the scope of pixel information to regain the luminance envelope of the input signal. A formula is therefore recommended to create a luminosity map of the analyzed pair of stereoscopic images, enabling further utilization of HVS-compatible measures to assess the achievement of the objective quality metric.

- **Intensity compression**: this step is realized in accordance with the set of parameters recovered at the initial stage of the algorithm. With respect to the depth of the pixel information or its dynamic range, appropriate scaling and therefore compression of the information is obtained. That enables to compare different realizations of the same original, logical 3DTV footage whenever its first-grade package is transcoded into a major set of resampled and highly compressed content.

- **Results visualization**: as far as the final stage of the algorithmic path is concerned, its aim is to deliver a graphical representation alongside live plotting of the results of the actual metric performance. Further investigation of the generated outcomes might be achieved by performing a detailed analysis with use of bundled tools available to the user.

To sum up, the insights concerned with the creation and delivery of the objective quality metric mechanism, as presented above, indicate its modular and flexible design. Whenever the need of special adjustments is present, the structural composition of the algorithm enables to set newly determined parameters, therefore meeting the range of features requested. Moreover, thanks to the ability to assess the algorithm presented, using parallel computing and efficient data structures, maximized efficiency may be achieved along with minimized complexity of the data processing performed. Furthermore, in the following sections, an in-depth description of the experimental testing stage and its results related to the CAII metric are presented.

4. Experimental CAII Testing

Deployment of the experimental testing stage for the CAII objective metric designed focused on the investigation of the behavior and responsiveness of the metric in the presence of simulated impairments. In order to prepare such a multipurpose testing scheme, the selected, initial conditions for the testing environment were defined as follows.

To start with, the test-bed of choice was utilizing the programming environment of the widely popular Mathworks Matlab solution (2013a release) installed on a mid-class PC workstation. In terms of the stereoscopic video content selected, a logical scene containing highly dynamic action with dense motion flows was chosen. As far as its technical parameters are concerned, the source video stream was constructed with the use of 152 images on a side-by-side frame stacking and with the display rate of 30 FPS. Furthermore, vertical resolution of the image reached 1080 pixels in a progressive mode, with half resolution within the horizontal orientation of the frame. The bitrate level evaluated was averaging 9 Mbps, while the pixel depth indicated information channel resolution of 8-bit.

Having stated the initial conditions, both for the environment and the content selected, the experimental tests are concerned with the core mechanism of the metric designed. In order to properly investigate its performance and the designed HVS or luminosity responsiveness (which proper objective metric should be characterized by), the next objective was to design an appropriate set of testing routines. The guidelines for synthetic benchmarking assumed following three independent test case scenarios, delivering multiple reactions of the CAII metric. An instant approach was selected: creation of synthetic image impairments, generated on-the-fly, simulating typical stereoscopic image deteriorations within the selected networking scheme.

The aforementioned content delivery approaches clearly state that the contemporarily deployed network solutions are based upon the adaptive streaming technology. Thus, one of the outcomes in the event of a network impairment is to switch the actual video stream over to a lower bitrate or a lower resolution. Therefore, to simulate such a behavior, a desirable approach was to implement the following set of impairments reflecting a real-life scenario of a networking environment:

- Scaling distortion – is realized by a function defined over the bilinear transform (with a set parameter k). It ensures scaling distortion by executing a cyclic action of step-down/step-up image transform. First, the original image is shrinking by a factor of 4 (i.e. $k = 0.25$) and is then scaled up by the same factor. The result is a blurry image, simulating a full screen boost of an 270p image to the 1080p format.

- Gaussian filtering – delivers similar impairment as the previous one, but is realized with use of the 2D filtering functionality, based on the Gaussian filter with the following parameter set: size $N = 11$ and generator variable $s = 2.0$. The video frame processed is rotationally and symmetrically blurred with the designed filter action. Thus, the image also resembles adaptive streaming impairment.

- Salt-and-pepper impairment – is realized by native, random saturation of pixel levels (in an 8-bit mode, with parameter $d = 0.2$). Therefore, a distortion similar to a pixellate scheme is created. It boosts a randomly selected picture element once it reaches its saturated state, but in one sub-channel (i.e. green component of an image).

All of the abovementioned impairments were morphed into the original video stream. The result of merging those image deteriorations, and the original frame, are presented in Fig. 3. In order to underline the image impairments, a local cropping of the same frame section was performed (Fig. 3).

Presented in Fig. 4 are synchronized test case scenario passes that indicate the behavior of the CAII metric in the presence of specifically designed impairments. The subplots included are constructed in the following manner. Out of the two main parts of each subplot, the section to the left depicts a stack of three frames representing the actual left and right channels, and the bottom one states the resid-

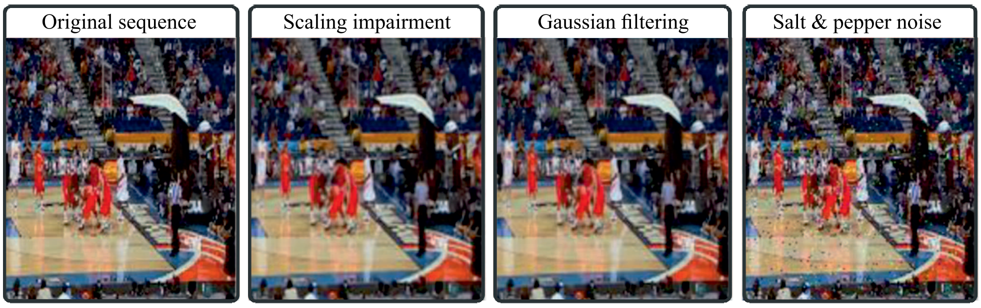

Fig. 3. Experimental impairments injection over the original image.

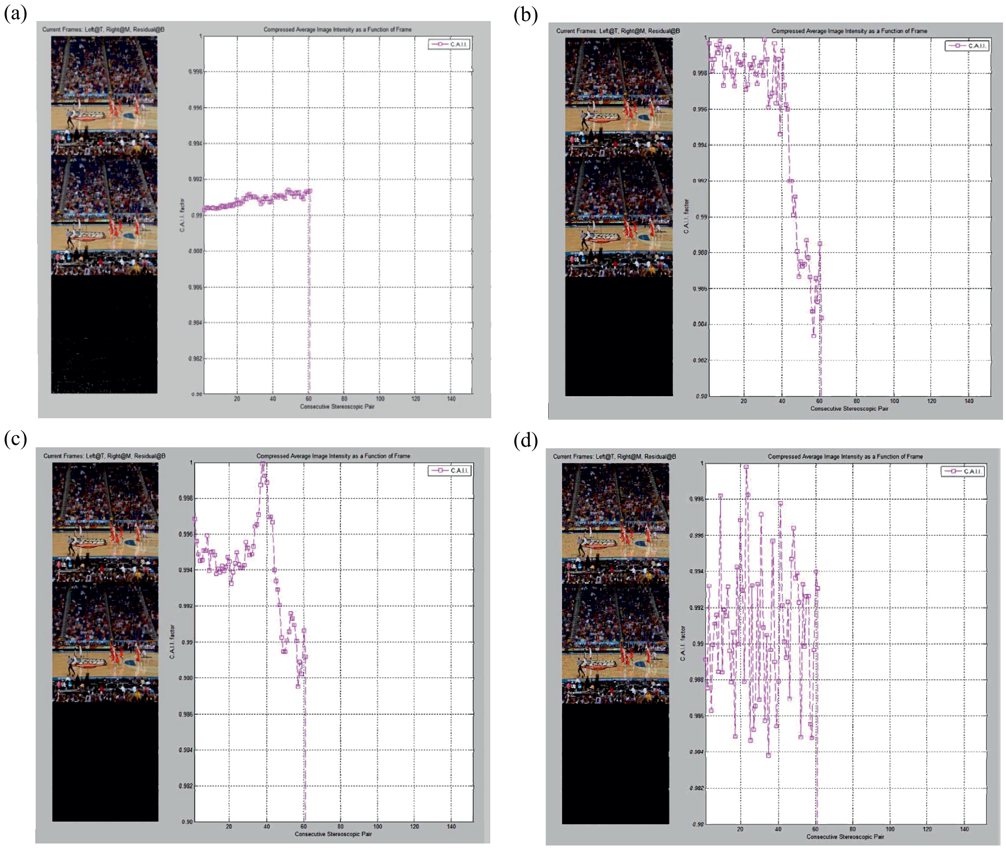

Fig. 4. Visualization of the results of the benchmarking routines to test the CAII quality metric.

ual frame (recall contents of the schematic diagram from Fig. 2). To the right of that stack is the synchronized, updated graph of the CAII metric plot indicating the present quality factor level.

Considering the experimental results obtained, as shown in the compound representation in Fig. 4 (partitions a–d) the CAII metric might be successfully stated to be a selective network probe, as it has identified video distortions amongst the infected structures of stereoscopic frames. The performance of the CAII mechanism shall be further characterized by its capability of indicating specific distortions (i.e. scaling outcomes against salt-and-pepper impairment). Fig. 4a reveals the reference, undistorted playback, which in fact is characterized by a steadily plotted line revealing the image of the stereoscopic pair is of the original quality. What is more, in Fig. 4b, at the exact, synchronized frame order, but imposed with the scaling impairment, the plotted characteristic shows the deterioration in video quality. The disrupted imagery (as depicted in Fig. 3) results in CAII metric value instability. Therefore, one can infer that fluent playback of an undistorted video cannot be achieved. Followed by the results shown in Fig. 4c, the Gaussian filtering process generates similar plots as the one with the scaling procedure invoked. Such a similarity in behavior might be based upon the effective algorithms used to simulate certain impairments, and in this particular case, it is due to the blurring effect procedures (comparable outcomes in the form of plotted graphs reveal similar distortions being generated). In terms of the last section, Fig. 4d, the oscillating plot line reflects the nature of the salt-and-pepper image distortion – clearly visible randomness. Analysis of the behavior of the plotted graphs might deliver multiple parameters, in the form of delivered information and overall characteristics, crucial for identification of the image distortion introduced; it enables the users of the designed tool to classify the impairment by means of the figure observed.

5. Conclusions

Insights towards the following stages: design, implementation, deployment and testing of the CAII metric revealed its effectiveness and reliability as an objective quality measure. The depicted mechanics perform accordingly to the HVS requirements, presenting perceptive quality aspects in parallel with responsiveness and multiple utilization aspects the CAII is capable of. To mention a few applications, it can be utilized as a network probe, as a system performance benchmarking routine and, most importantly, it might assess picture parameters concerning the luminance signal channel. The plotted outcomes deliver a rich set of indicators helpful in recognizing image distortion and identifying the significant deteriorations. Therefore, as far as the overall view of the topic of QoS and QoE is concerned, the genuine CAII designed reveals its comprehensive and versatile performance within stereoscopic 3DTV content distribution systems.

References

[1] Cisco Systems, "Cisco Visual Networking Index: Forecast and Methodology, 2015—2020", Jun 2016 [Online]. Available: http://bit.ly/295yXfL

[2] N. Fimic, S. Tanackovic, J. Kovacevic, and M. Temerinac, "Implementation of Multi-Format Adaptive Streaming Server", in *Proc. 5th IEEE ICCE Berlin Conference*, Berlin, Germany, 2015, pp. 218–220 (doi: 10.1109/ICCE-Berlin.2015.7391239).

[3] G. Wilczewski, "Analysis of Content Quality Evaluation within 3DTV Service Distribution Systems", *J. of Telecommun. and Inform. Technol.*, no. 1, pp. 16–20, 2014.

[4] G. Wilczewski: "An objective method for a video quality evaluation a 3DTV service", *Proc. Symp. on Photonics Applic. in Astr., Commun., and High-Energy Physics Exper. Wilga 2015*, Wilga, Poland, 2015, pp. 231–237 (doi: 10.1117/12.2205197).

[5] D. Minoli, *3DTV Content Capture, Encoding and Transmission*, New York: Wiley, 2010.

[6] A. Vetro, T. Wiegand, and G. J. Sullivan, "Overview of the Stereo and Multiview Video Coding Extensions of the H.264/MPEG-4 AVC Standard", *Proc. of the IEEE*, vol. 99, no. 4, pp. 626–642, 2011 (doi: 10.1109/IPROC.2010.2098830).

[7] G. Wilczewski, R. Mielowski, K. Perlicki, M. Siergiejczyk, and E. Kowalczyk, "Data Center resources monitoring for resilient telecommunication services", *Przegląd Elektrotechniczny*, no. 91, pp. 225–228, 2015 [in Polish] (doi: 10.15199/48.2015.10.47).

[8] T. H. Luan, L. X. Cai, and X. S. Shen, "Impact of Network Dynamics on User's Video Quality: Analytical Framework and QoS Provision", *IEEE Transact. on Multimedia*, vol. 12, no. 1, pp. 64–78, 2010 (doi: 10.1109.TMM.2009.2036294).

[9] R. A. Farrugia and C. J. Debono, "A Hybrid Error Control and Artifact Detection Mechanism for Robust Decoding of H.264/AVC Video Sequences", *IEEE Transact. on Circuits and Systems for Video Technol.*, vol. 20, no. 5, pp. 756–762, 2010 (doi: 10.1109/TCSVT.2010).

[10] "Objective perceptual multimedia video quality measurement of HDTV for digital cable television in the presence of a full reference", ITU-T J.341 Recommendation, 2016.

[11] T. Tian, X. Jiang, and X. Du, "Subjective quality assessment of compressed 3D video", in *Proc. 7th Int. Congress on Image and Signal Proces. CISP*, Dalian, Liaoning, China, 2014, pp. 606–611 (doi: 10.1109/CISP.2014.7003851).

[12] "Methodology for the subjective assessment of the quality of television pictures", ITU-R BT.500-13 Recommendation, 2012.

[13] "Subjective Assessment Methods for 3D Video Quality", ITU-T P.915 Recommendation, 2016.

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