JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Automatic Detection of 3D Quality Defects in Stereoscopic Videos Using Binocular Disparity

Sunil K, Lakshmi Narayana T.V, Raviteja P, Dinakar P
Electronics and Communication Engineering (ECE),
Narayana Engineering College,
Nellore, India

Abstract*—3D video quality issues that may disturb the human visual system and negatively impact the 3D viewing experience are well known and become more relevant as the availability of 3D video content increases, primarily through 3D cinema, but also through 3D television. In this paper, we propose four algorithms that exploit available stereo disparity information, in order to detect disturbing stereoscopic effects, namely stereoscopic window violations (SWV), bent window effects, UFO objects and depth jump cuts on stereo videos. After detecting such issues, the proposed algorithms characterize them, based on the stress they cause to the viewer's visual system. Qualitative representative examples, quantitative experimental results on a custom-made video dataset, a parameter sensitivity study and comments on the computational complexity of the algorithms are provided, in order to assess the accuracy and performance of stereoscopic quality defect detection.

Index Terms—Visual discomfort, 3D quality, stereoscopic video, binocular disparity

I. Introduction

With the rise in availability of 3D video content, especially in cinema, there has been a growing concern over certain stereoscopic effects that can negatively impact the viewing experience by causing symptoms like eye strain, headaches, and visual fatigue. To address these issues, cinematographers have established guidelines to be followed during production, but constraints like time, budget, and planning often lead to deviations from these rules. However, many problems can still be rectified in post-production if detected. In our paper, we propose algorithms that leverage stereo disparity information to identify and address stereoscopic quality issues in videos, focusing on detecting violations such as stereoscopic window violations (SWV), bent window effects, UFO objects, and depth jump cuts. Furthermore, we aim to classify these effects based on the visual stress they induce on viewers.

The structure of the paper is as follows: Section II offers an overview of current methods for disparity estimation, which is crucial for detecting stereoscopic quality issues, along with insights into comfortable stereoscopic vision and existing approaches for detecting the four issues studied. Section III outlines our proposed detection algorithms and includes qualitative examples to illustrate their functionality. Section IV presents experiments conducted on a stereo video dataset created specifically for evaluating our algorithms, along with corresponding quantitative results. Finally, Section V summarizes our conclusions.

II. Problem Setting and Justification of the Methodology

Interpreting 3D scenes relies heavily on depth information, which is captured in stereoscopic image pairs through dense disparity maps assigning depth-related values to each pixel. These maps, often processed post-production, enable objects to appear both in front of and behind the screen plane during display. Disparity estimation, or stereo matching, encompasses various algorithms categorized into local and global methods. For our experiments, we employed a state-of-the-art global variational algorithm alongside alternative methods, aiming for accurate disparity maps, crucial for subsequent analysis.

Stereoscopic 3D perception introduces a decoupling between vergence and accommodation distances, potentially causing discomfort due to the vergence-accommodation conflict. Extensive studies have explored this phenomenon, establishing comfort zones for 3D viewing based on vergence distance versus focal distance. These zones inform guidelines for stereo content creation, dictating allowable disparity ranges and informing production practices to mitigate viewer discomfort. Despite these guidelines, challenges persist in effectively detecting and addressing stereoscopic defects.

Various systems and algorithms have been proposed to detect and correct stereoscopic defects, ranging from real-time analyzers to post-production editing tools. Additionally, efforts have been made to develop quality assessment metrics considering visual discomfort in 3D videos, often correlating with subjective evaluations. While some algorithms focus on quantitatively characterizing video frames, defect detection algorithms aim to identify specific quality issues or artifacts, ensuring an enhanced viewing experience. This study presents a comprehensive set of algorithms meeting criteria for automation, integration into post-processing pipelines, accuracy, and coverage of various stereoscopic effects, provided accurate dense disparity estimation.

III. IMPLEMENTATION

In this section, we delve into four key 3D cinematography effects: Stereoscopic Window Violation (SWV), UFO objects, bent window, and depth jump cuts. These effects are critical considerations in ensuring a seamless and immersive viewing experience in stereoscopic content. Each effect is accompanied by its respective cinematographic rule and detection algorithm, with illustrative examples provided to enhance understanding and practical application. Videos initially recorded at 1920 × 1080 pixels are subsampled to 960×540 to expedite disparity estimation, facilitating efficient processing while maintaining accuracy.Stereoscopic Window Violation (SWV) stands out as a common issue impacting the perceptual integrity of stereoscopic content. It occurs when the perceived depth of objects extends beyond the defined window, leading to discomfort and visual disruption for viewers. Our proposed algorithm tackles the detection of SWV by leveraging dense disparity maps, which provide detailed depth information for each pixel in the image pair. Through meticulous analysis, regions of the scene violating the stereoscopic window are identified. To address this, a floating window technique is employed, strategically masking areas where disparities exceed acceptable thresholds. By adjusting the perceived depth of these regions, the algorithm aims to mitigate visual inconsistencies and enhance the overall viewing experience.

The algorithm further distinguishes between two types of SWV—left and right—based on the disparity patterns observed at the borders of the stereoscopic images. Detection criteria are established, considering factors such as ROI (Region of Interest) placement and object pixel density. When SWV of a specified duration is detected, the algorithm triggers the application of a floating window to mask offending regions visible to only one eye. This meticulous approach ensures that viewers are presented with a coherent and comfortable visual representation, free from disruptive disparities that may hinder their immersion in the content.The proposed algorithmic framework is rooted in extensive research and experimentation, drawing upon insights from both technical and perceptual domains. By integrating advanced disparity estimation techniques with cinematographic principles, we strive to create a robust and versatile solution capable of addressing a wide range of stereoscopic quality issues. Moreover, the algorithm's adaptability and scalability make it suitable for integration into existing post-production pipelines, enabling content creators to enhance the quality of their stereoscopic productions efficiently and effectively.

Overall, our approach to stereoscopic quality issues detection represents a significant step forward in the field of 3D cinematography. By combining cutting-edge technology with practical cinematographic expertise, we aim to empower content creators with the tools and techniques needed to deliver immersive and visually compelling stereoscopic experiences. As the demand for high-quality stereoscopic content continues to grow, our algorithmic framework serves as a valuable resource for ensuring the optimal viewing experience across various platforms and applications.

In the case of a left SWV, we first calculate a mean value $\overline{m^r_i}$ of the first three columns of right image object disparities for every object that creates a SWV, as follows:

$$\overline{m}_i^r = \left(\sum_{x=0}^{2}\sum_{y=y_{min}}^{y_{max}} d^r_{x,y}\right) / \, 3\, h_i, \quad \forall R_i^r : x^r_{i,min} = 0, \quad (1)$$

where h_i is the height of object R_i^r and $x^r_{i,min}$ is the left vertical boundary of the object. The appropriate left floating window mask width FW_l is the mean value of all $\overline{m}_i^r$:

$$FW_l = \left(\sum_{i=1}^{N} \overline{m}_i^r\right) / \, N, \quad (2)$$

where N is the number of objects that cause SWV, when detected in the right disparity map. This is done because the disparities of boundary ROI pixels, which are involved in a SWV, point at the boundary line of the region visible to only one eye (see the vertical line in Figures 1 and 2). The right floating window mask width FW_r is estimated using a similar approach. Although the floating window is a quick

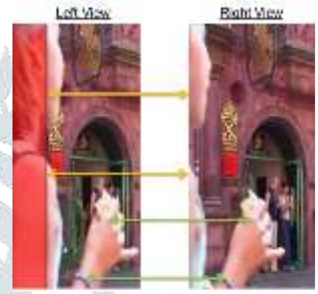


Fig. 1. Left Stereoscopic Window Violation.

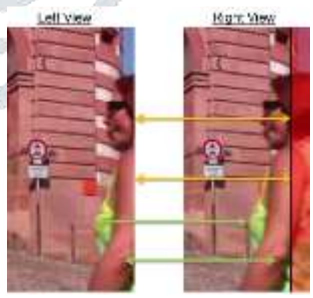


Fig. 2. Right Stereoscopic Window Violation.

Case study 1: A left SWV manifests when an object collides with the right image border, persisting for 16 frames. Despite initial detection in the first frame, the algorithm abstains from labeling it to prevent false alarms. However, as the violation spans beyond the annoyance threshold, encompassing 16 frames, it necessitates intervention. A floating window mask, with a width ranging from 28 to 30 pixels, emerges as a viable solution to rectify this persistent violation. This approach offers a targeted remedy, addressing the specific region where the SWV occurs, thereby restoring stereoscopic coherence.

Case study 2: Figure 4 shows a right stereoscopic window violation, signaled by a left disparity map. The algorithm starts signaling SWV at the second video frame, as the size thresholds and ThSWV are not exceeded. The SWV duration is lower than the duration threshold of 13 frames, making it not annoying. However, the violation width ranges from 36 to 44 pixels, making it mild but significant. A floating window mask can fix the problem by addressing every right image involved in the SWV.

B. The Bent Window effect

Stereoscopically distorted (SWV) windows can occur at any of the four video frame borders, including the top or bottom ones. Top or bottom window violations cause less discomfort to the human brain but can ruin the 3D effect and change depth perception. In cases where a car and street pole appear behind the screen plane, the viewer's brain must decide whether to bend the stereoscopic window towards the viewer due to the top and bottom window violation locking the tree behind the screen plane. Top screen edge violations have more significant impact on creating the bent window effect than bottom screen edge violations

The proposed bent window effect detection algorithm takes the left disparity map of a stereo video frame as input and detects objects with significantly negative disparity. It performs connected component analysis on pixels with negative disparity lower than a threshold and encloses each object in a rectangular ROI. The algorithm checks if any objects in contact with the upper and lower video frame boundary are marked as the cause of a bent window effect.

The computational complexity of the algorithm is linear to the number of detected connected components having significant negative left disparity, dominated by the connected component analysis process. A representative example of bent window detection is provided, where the camera is located behind a thin pole with a strong negative left disparity of about -35 pixels.

C. UFO object detection

In 3D cinematography, a UFO is an object that is improperly displayed within a theater space, requiring proper movement and justified position. UFOs can cause visual discomfort and fatigue due to rapid eye convergence changes. To be considered a UFO, an object must appear and disappear suddenly, have significant negative left disparity, and not be justified by the image structure. Identifying and addressing UFOs is crucial for post-production to ensure a safe and enjoyable experience for viewers.

The detection of UFOs in 3D cinematography is challenging due to the need for prior knowledge about 3D set construction and object placement. An algorithm has been developed to detect UFOs by analyzing object motion along the depth axis. A UFO appears and disappears suddenly near the viewer, while a non-UFO object either never moves close to the viewer or begins its motion away from the viewer, approaches the viewer, and returns on or behind the screen. Examples of non-UFOs include a bird flying from its nest towards the viewer and then returning to its nest. Non-UFO objects may follow half the trajectory described above, such as a knife flying from the screen to the viewer and then disappearing or a ball appearing in front of the viewer and falling to the ground. In summary, a non-UFO object with transiently negative left disparity must either move from the screen to the viewer or from the viewer to the screen at a sustainable speed.

D. Depth Jump Cuts

The editing process in 3D cinematography is more complex than 2D cinematography due to the depth continuity rule, which states that two shots should not be cut if their depth does not match. This rule is not objectively defined, but it can be used to create a depth jump cut, where the viewer loses 3D perception when the eye convergence point in the close-up shot is too far away from the one in the long shot. This is called a depth jump cut.

Another type of depth cut in 3D cinematography is the active depth cut, which is used when a cut between two shots with "non-matching" depth is absolutely necessary, such as in a live music band concert. In an active depth cut, the eye vergence point of the long shot is moved to the screen plane, and the cut to the close-up shot is performed, with the close-up shot vergence point moving towards the viewer until it takes its correct position.

Other transitions, such as cross fades, wipes, and split screens, can be adapted to fit 3D cinematography, but their use is limited due to their implementation being more difficult than in the 2D case. Overall, the editing process in 3D cinematography is more complex and requires careful consideration of various factors.

The algorithm proposed for the detection of depth jump cuts begins by calculating the mean positive and negative disparity values for the entire disparity map for every video frame $n = 1,..,N_t$. Given a set of disparity maps $\mathbf{d} = \{d_1, d_2, ..., d_{N_t}\}$, for every disparity map d_i, two subsets are defined, $A^+_i = \{(x,y) | d_i(x,y) > 0\}$ and $A^-_i = \{(x,y) | d_i(x,y) < 0\}$ and the average positive and negative disparity values are calculated as:

$$\overline{d_i^+} = \frac{1}{|A_i^+|} \sum_{(j,k)\in A_i^+} d_i(j,k) \quad (3)$$

and

$$\overline{d_i^-} = \frac{1}{|A_i^-|} \sum_{(j,k)\in A_i^-} d_i(j,k) \quad (4)$$

where |A| denotes the cardinality of set A. This way, two mean disparity signals $\overline{d^+_i}$ and $\overline{d^-_i}$, $i = 1,..,N_t$ are created, as shown in Figure 7b. Since disparity maps are generally noisy, a median filter is applied on both the positive and negative mean disparity signals. Positive disparities suffer from noise more severely than negative ones, since they usually refer to the background, which is customarily displayed behind the screen, is often blurred and covers a much bigger region than foreground. Thus, disparity estimation is harder on the background than on the foreground. Taking the above into account, we use median filter masks of length $M^- = 5$ and $M^+ = 15$ to filter the negative/positive mean disparity signals, respectively.

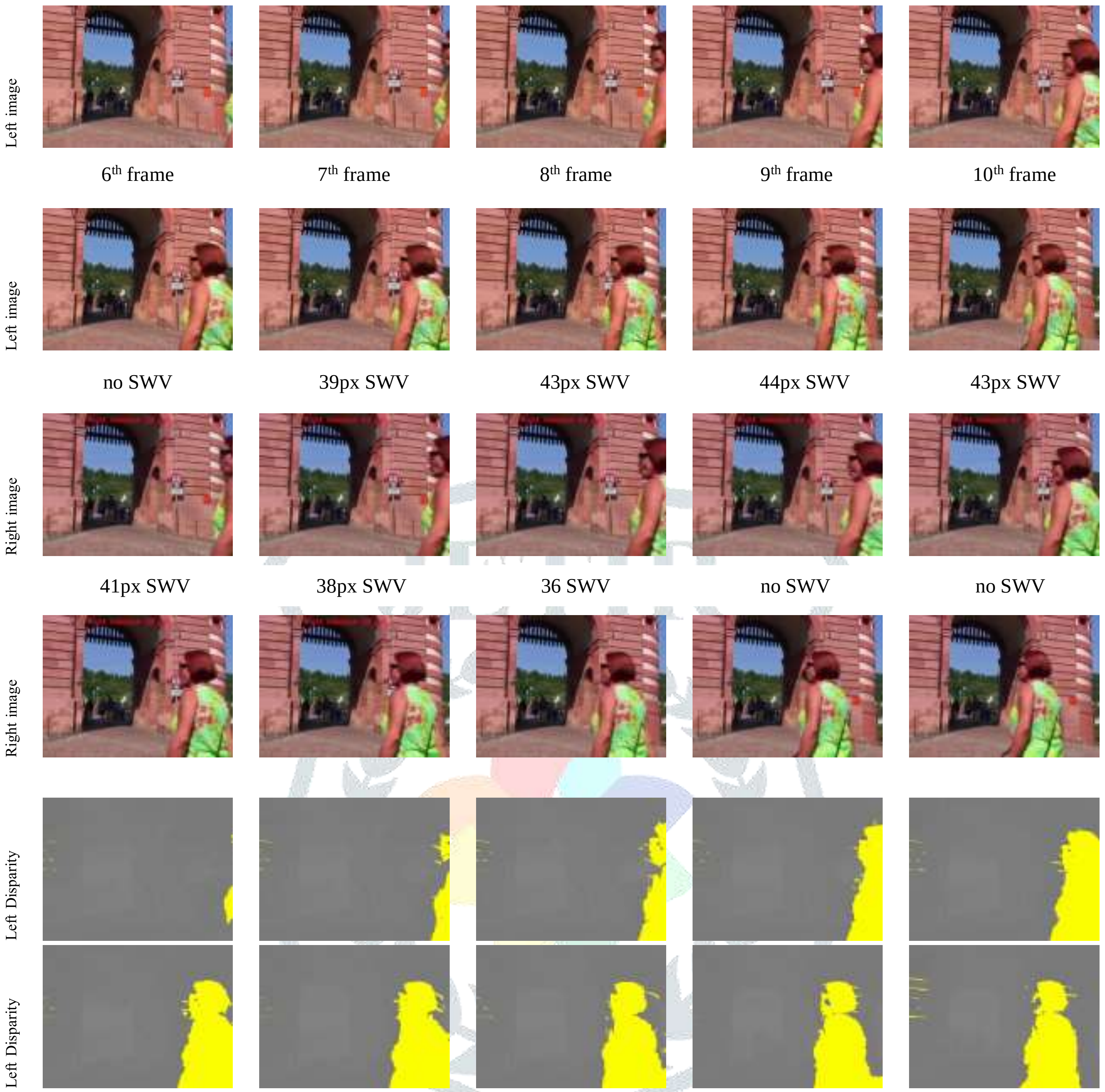


Fig. 3. Example of right stereoscopic violation: a) left video frames, and corresponding b) right video frames, c) left disparity maps.

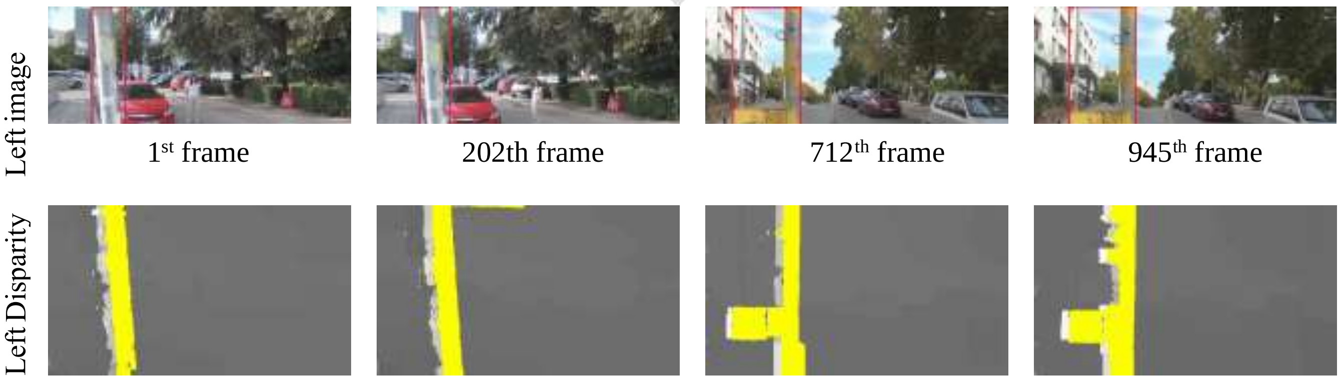


Fig. 4. Bent window effect caused by a thin object (road pole).

IV. EXPERIMENTAL EVALUATION

A video database was created to quantitatively evaluate the proposed algorithms for detecting four quality defects in stereo video. The database consists of four videos, one for each defect type, with each video consisting of multiple consecutive shots. A percentage of these shots exhibit the corresponding defect, while others are defectless. The videos were subjectively evaluated using the Single Stimulus Continuous Quality Evaluation method, conforming to Recommendation ITU-R BT.1438, a standard protocol for subjective stereoscopic video quality assessment. Each video frame score was thresholded to become compatible with a binary quality defect ground truth, with Si ≥ 4.5 indicating no defect and Si < 4.5 signaling a defect. Visual inspection was then conducted to rule out cases where viewer discomfort is not caused by the defect type, such as in the "SWV" video, where discomfort can be solely attributed to excessive disparities without any SWV present.

(a)

Fig. 5. Example of the video dataset used for the experimental evaluation: a

The study analyzed various video formats, including SWV, BW, DJC, and UFO, to identify stereoscopic window violations, bent window effects, depth jump cuts, and UFO effects. The original videos were recorded at 1920 x 1080 pixels but sub-sampled to 960x540 pixels to reduce disparity estimation time. The stereo matching method was used to obtain accurate disparity maps. The algorithms were implemented in C++ and executed in real-time on a high-end desktop PC with a Quad Core i7 @ 3.4 GHz and 16 GB RAM. The proposed algorithms achieved a processing rate of over 25 frames per second on a high-end desktop PC. The original videos were recorded at a resolution of 1920 x 1080 pixels, but sub-sampled to 960x540 pixels to reduce execution time.

With the exception of depth jump cuts, all of the examined quality defect instances are characterized by a specific duration (typically 15 frames or more). Therefore the temporal overlap between the detected defects and the actual defects known from the ground truth is of high importance. In order to account for this overlap, the experimental results were evaluated on a per-frame basis and each frame was deemed as a true positive, a true negative, a false positive or a false negative, based on the ground truth. Given these characterizations, a set of popular metrics were evaluated for the results of each algorithm, i.e., precision, recall, F-Measure, specificity (true negative rate) and accuracy.

Figures 10a-d show the experimental results for the case of stereoscopic window violation, bent window, UFO and depth jump cut detection, respectively, using the aforementioned metrics. As can be seen, the corresponding F-Measures are 94.05%, 90.40%, 96.15% and 84.54%, while the respective specificity rates (*SPC*) are 79.00%, 98.31%, 98.79% and 99.89%. Therefore, the algorithms successfully detect the majority of the defects in all cases, while the false positive rate ($FPR = 1 - SPC$) is negligible in all cases, except for the stereoscopic window violations. Note, however, that the specificity and accuracy metrics are not very informative in the case of depth jump cuts, since their computation is dominated by the number of true negatives *TN*. Due to depth jump cuts being of momentary duration, only 46 out of 9798 frames contain depth jump cuts and *TN* is unavoidably very large, resulting in values near 100% for both specificity and accuracy.

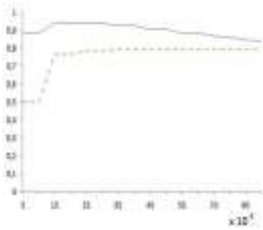
TABLE I

.

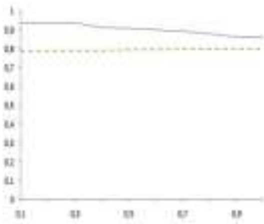
Parameter	Value	Parameter	Value
T_1^{SWV}	$0.0030W$	T_{minUFO}	$0.0100W$
T_{hSWV}	$0.2000H$	T_{maxUFO}	$0.0030W$
T_{wSWV}	$0.0100W$	T_{vUFO}	$0.0010W$
T_{2SWV}	$0.3000h_{ROI}$	T_{dsnDJC}	$0.0009W$
T_1^{BW}	$0.0045W$	T_{dspDJC}	$0.0016W$

The proposed algorithms for stereoscopic quality defect detection were tested on a dataset of 960 pixels. The parameters were derived through a sensitivity analysis, with the highest F-Measure value being the most sensitive parameter, hROI. The algorithms were robust in parameter values, with an extended range of possible values leading to high quality defect detection performance. The most sensitive parameter was hROI, with a very specific parameter value providing the best performance in terms of the F-Measure metric.

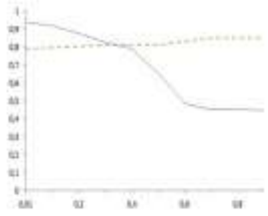
To compare the proposed methods against rival algorithms, the best obtained F-Measures were 78.79% and 63.16% for SWV and DJC, respectively, and 81.26% and 99.51% for SPC. The proposed methods outperformed these competing algorithms by 15.26% (SWV) and 21.38% (DJC) in terms of the F-Measure metric, while achieving comparable specificity/false positive rate. Additionally, the proposed methods rate the detected defects according to the visual stress they cause.

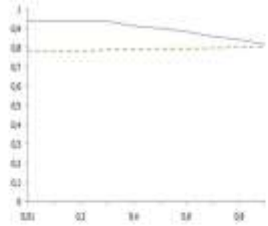


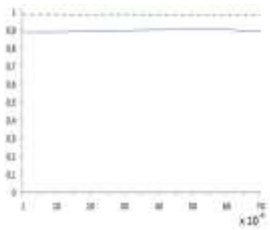
(a)

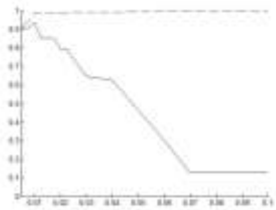


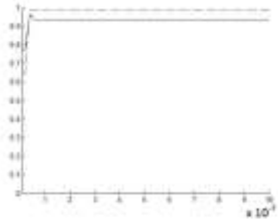
(b)

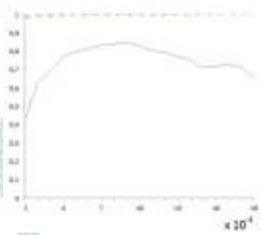

(c)


(d)


(e)


(f)


(g)


(h)

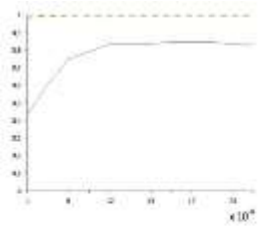

(i)

Fig. 6. Sensitivity analysis results

The method implementation parameter, initially considered secondary, was modified after initial testing, resulting in slight performance improvements. In the initial SWV detection software, two different left and right SWVs were considered the same SWV, with less than 5 frames separating them. The entire video duration was marked as suffering from left or right SWV. In the final software, the parameter was changed from 5 frames to 2 frames, resulting in improved results.

V. CONCLUSIONS

The popularity of 3D movies makes the investigation of stereo quality issues all the more important. Certain stereoscopic effects found in the 3D video content may confuse the human visual system, affect viewing experience in a negative way and eventually cause unpleasant symptoms, such as eye strain, visual fatigue and headaches. In this paper, new algorithms are presented that detect four such stereoscopic effects, namely, stereoscopic window violations (SWV), bent window effects, UFO objects and depth jump cuts automatically, by exploiting disparity information. The algorithms also try to characterize these stereoscopic effects according to the stress they cause to the viewer. Representative qualitative examples, quantitative experimental results on a custom-made video dataset, a parameter sensitivity study and comments on the computational complexity of the algorithms are provided, proving effectiveness of the proposed methods in detecting the four above mentioned stereo quality defects.

The assembled video dataset may be useful in future stereo quality studies, by providing positive and negative examples of the four quality defects under examination.

VI. ACKNOWLEDGEMENT

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement number 287674 (3DTVS). This publication reflects only the author's views. The European Union is not liable for any use that may be made of the information contained herein. The authors would like to thank the Fraunhofer Heinrich Hertz Institute for providing stereo videos used as case studies.

REFERENCES

[1] B. Mendiburu, *3D movie making. Stereoscopic digital cinema from script to screen*. Focal Press, 2009.

[2] D. Scharstein and R. Szeleiski, "A taxonomy and evaluation of dense two frame stereo correspondence algorithm," *IEEE International Journal of Computer Vision*, vol. 47, no. 1/2/3, pp. 7–42, 2002.

[3] J. Ralli, J. Daz, and E. Ros, "Spatial and temporal constraints in variational correspondence methods," *Machine Vision and Applications*, vol. 24, no. 2, pp. 275–287, 2013.

[4] V. Kolmogorov and R. Zabih, "Computing visual correspondence with occlusions using graph cuts," in *Proceedings of IEEE Conference of Computer Vision*, vol. 1, 2001, pp. 508–515.

[5] N. Atzpadin, P. Kauff, and O. Schreer, "Stereo analysis by hybrid recursive matching for real-time immersive video conferencing," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 14, no. 3, pp. 321–334, March 2004.

[6] M. Lambooij, W. IJsselsteijn, M. Fortuin, and I. Heynderickx, "Visual discomfort and visual fatigue of stereoscopic displays: A review," *A review. Journal of Imaging Science and Technology*, vol. 53, pp. 1–14, 2009.

[7] D. M. Hoffman, A. R. Girshick, K. Akeley, and M. S. Banks, "Vergence – accommodation conflicts hinder visual performance and cause visual fatigue," *Journal of Vision*, 2008.

[8] A. S. Percival, "The relation of convergence to accommodation and its practical bearing," *Ophthalmological Review*, vol. 11, pp. 131–328, 1892.

[9] C. Sheard, "The prescription of prisms," *American Journal of Optometry*, vol. 11, pp. 364–378, 1934.

[10] T. Shibata, J. Kim, D. M. Hoffman, and M. S. Banks, "The zone of comfort: Predicting visual discomfort with stereo displays," *Journal of Vision*, vol. 11, pp. 1–29, August 2011.

[11] F. Zilly, M. Mller, P. Eisert, and P. Kauff, "The stereoscopic analyzer an image-based assistance tool for stereo shooting and 3d production," in *Proceedings of 2010 IEEE 17th International Conference on Image Processing*, September 2010.

[12] S. Heinzle, P. Greisen, D. Gallup, C. Chen, D. Saner, A. Smolic, A. Burg, W. Matusik, and M. Gross, "Computational stereo camera system with programmable control loop," *ACM Transactions on Graphics*, vol. 30, no. 4, 2011.

[13] M. Lang, A. Hornung, O. Wang, S. Poulakos, A. Smolic, and M. Gross, "Nonlinear disparity mapping for stereoscopic 3d," *ACM Transactions on Graphics*, vol. 29, no. 3, p. 10, 2010.

[14] S. J. Koppal, C. L. Zitnick, M. F. Cohen, S. B. Kang, B. Ressler, and A. Colburn, "A viewer-centric editor for stereoscopic cinema," *IEEE Computer Graphics and Applications*, vol. 31, no. 1, 2011.

[15] K. L. Tseng, W. J. Huang, A. C. Luo, W. H. Huang, Y. C. Yeh, and W. C. Chen, "Automatically optimizing stereo camera system based on 3d cinematography principles," *3DTV-Conference: The True Vision Capture, Transmission and Display of 3D Video (3DTV-CON)*, 2012.

[16] J. P. Lpez, J. A. Rodrigo, D. Jimnez, and J. M. Menndez, "Stereoscopic 3d video quality assessment based on depth maps and video motion," *EURASIP Journal on Image and Video Processing*, no. 1, pp. 1–14, 2013.

[17] K. Ha and M. Kim, "A perceptual quality assessment metric using temporal complexity and disparity information for stereoscopic video." in *ICIP*. IEEE, 2011, pp. 2525–2528.

[18] M. Sohl, G. AlRegib, and J. M. Bauza, "3vqm: A vision-based quality measure for dibr-based 3d videos," ser. International Conference on Multimedia and Expo. IEEE, 2011, pp. 1–6.

[19] A. Voronov, D. Vatolin, D. Sumin, V. Napadovsky, and A. Borisov, "Towards automatic stereo-video quality assessment and detection of color and sharpness mismatch," in *International Conference on 3D Imaging*. IEEE, 2012.

[20] B. Mendiburu, Y. Pupulin, and S. Schklair, *3D TV and 3D cinema. Tools and processes for creative stereoscopy*. Focal Press, 2012.

[21] K. Suzuki, I. Horiba, and N. Sugie, "Linear-time connected-component labeling based on sequential local operations," *Computer Vision and Image Understanding*, vol. 89, no. 1, pp. 1–23, Jan. 2003.

[22] O. Zoidi, A. Tefas, and I. Pitas, "Visual object tracking based on local steering kernels and color histograms," *IEEE Transactions on Circuits and Systems for Video Technology*, 2012.

[23] O. Zoidi, N. Nikolaidis, A. Tefas, and I. Pitas, "Stereo object tracking with fusion of texture, color and disparity information," *Signal Processing: Image Communication*, 2014.

[24] I. Pitas and A. N. Venetsanopulos, *Nonlinear Digital Filters: Principles and Applications*. Boston:Kluwer, 1990.

[25] S. Gu, Y. Zheng, and C. Tomasi, "Linear time offline tracking and lower envelope algorithms," in *International Conference on Computer Vision*. IEEE, 2011, pp. 1840–1846.

[26] S. Perreault and P. Hbert, "Median filtering in constant time," *IEEE Transactions on Image Processing*, vol. 16, no. 9, pp. 2389–2394, 2007.

[27] S. Yanoa, M. Emotoa, and T. Mitsuhashia, "Two factors in visual fatigue caused by stereoscopic HDTV images," *Displays*, vol. 25, no. 4, pp. 141–150, November 2004.

[28] S. Yanoa, S. Idea, T. Mitsuhashib, and H. Thwaitesc, "A study of visual fatigue and visual comfort for 3d HDTV/HDTV images," *Displays*, vol. 23, pp. 191–201, October 2002.

[29] K. Ukai and P. A. Howarth, "Visual fatigue caused by viewing stereoscopic motion images: Background, theories and observations," *Displays*, vol. 29, pp. 106–116, October 2007.

[30] Y. Niu, Y. Geng, X. Li, and F. Liu, "Leveraging stereopsis for saliency analysis," *IEEE Conference on Computer Vision and Pattern Recognition*, 2012.

[31] J. Wang, M. P. D. Silva, P. L. Callet, and V. Ricordel, "Computational model of stereoscopic 3d visual saliency," *IEEE Transactions on Image Processing*, vol. 22, no. 6, pp. 2151–2165, 2013.

[32] L. Goldman, F. De Simone, and T. Ebrahimi, "A comprehensive database and subjective evaluation methodology for quality of experience in stereoscopic video," ser. Three-Dimensional Image Processing (3DIP) and Applications. SPIE, 2010.

[33] ITU, "Subjective assessment of stereoscope television pictures," 2000. [34] C. C. Lin˜an, "cvBlob," http://cvblob.googlecode.com.´