Grid Distortion in Raspberry pi Microcomputer Based 3-by-3 Video Wall

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Abstract- Grid Distortion due to screen bezels is a major problem in LCD-based video walls. The evaluation of distortion based on subjective assessment has resulted in difficulty and inconsistency. This paper proposes an objective approach using Structural Similarity Measure (SSIM) to evaluate grid distortion in Raspberry pi microcomputers based on 3-by-3 video wall with offset and overlay bezel enhancement techniques. Forty (48) videos with varying frame rates and resolutions were processed and recorded in a dark room (0 Lux light condition), using camera approach. Analyses of results at 95% confidence level using one-way Analysis of Variance (ANOVA) revealed the existence of bezels impacts negatively on video quality irrespective of the resolution, frame rate or bezel compensation used. However, resolution changes show significant differences in performance, with the overlay having a better performance of up to 9.96% when using 1080p videos. Results also revealed that this proposed evaluation model is an important tool for making a definite conclusion on the grid distortion in a video wall.

Indexed Terms- Grid Distortion, Screen Bezel, Video wall; Raspberry pi; Offset; Overlay.

I. INTRODUCTION

A video wall is an assemblage of several monitors (displays) designed and capable of showing content in a synchronized fashion, resulting in a single larger screen [1]-[3]. Video walls are employed for educational, commercial, informational, command, control, and scientific visualization [4]-[6]. They have also been used for collaboration and or tele-immersion scenarios [7] and monitoring in smart cities [8]. Liquid crystal displays (LCDs) in video walls are more common than video projectors because they are cost-effective, use less physical space, have better colour correction and monitor alignment. Additionally, they are adaptable for patterns and orientations that fit available space with more pixel density per unit cost [9]-[13]. Screen bezels limit the closeness of putting monitors together as tiled displays, hence leading to distractions and visual discontinuity [12, 15, 16]. Screen bezels vary in size, typically as shown in Fig 1.

The use of monitors of similar sizes and orientations forms a uniform distribution (Fig 2a), while the use of different sizes forms non-uniform distribution (Fig. 2b) video walls. Also, the number of grids or bezels formed in a row or column is less than the number of monitors, by N-1 for N columns and M-1 for M rows of the large display [1].

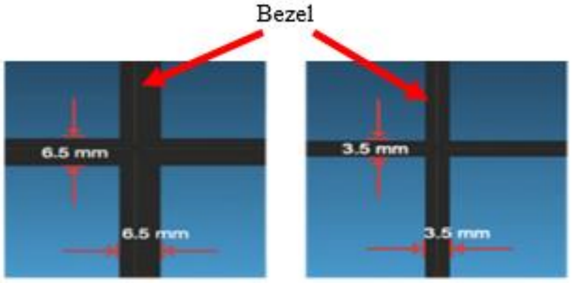


Fig 1: LCD Video Wall Screen Bezel

(a) Uniform

(b) None-Uniform

Fig 2: LCD Based Video Wall Distribution [1]

In video wall, the size of screen bezels, display alignment, processing hardware, and algorithms influence grid distortion and visual image discontinuity (Fig. 3) particularly during scene transitions or fast movements in videos.

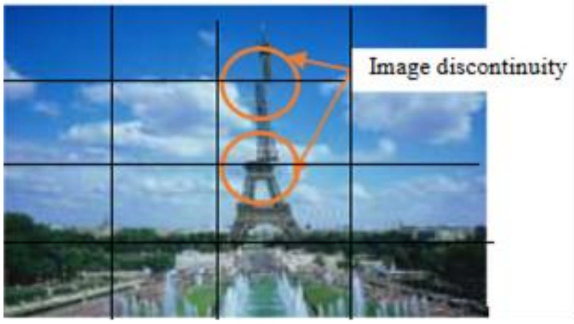


Fig. 3: Video Distortion

Uniform distributed video wall are more popular, and several studies in this field have investigated the impact of bezels and bezel compensation algorithms in Uniform distributed video walls. Unfortunately, these efforts are based on subjective assessments, leading to persistent inconsistency and inconclusiveness [16] - [19].

This inconsistency and inconclusiveness include; insignificant impact of screen bezels, as well as negative and positive impacts [20], positive effects [21, 22], and negative impacts [23]. The inconsistency and inconclusiveness necessitated further controlled investigations [15, 24] employing subjective assessment.

Bezel compensation algorithms reduce grid distortion resulting from use of cheaper monitors with larger bezels [25]. These algorithms include the offset and overlay techniques, described in [2, 3], for dealing with distortion in video walls.

Research, such as [3, 14, 15, 24], investigated features of picture distortion (user distraction) with bezels compensation and uniformly distributed model using commercially available LCD monitors. Specifically, [14, 24] demonstrate the overlay approach outperformed the offset for static and dynamic scenes. Unfortunately, [24] stated that there are minimal differences in the use of bezel compensation and surprisingly the overlay approach performed better at 4 cm bezel than 1 cm bezel. Authors could not make clear conclusion on the impact of bezel size variation with the two algorithms.

The inconclusive and inconsistent in video wall performance evaluation is due to the use of subjective assessment, which are affected by human emotion, cost and time required. However, according to [26], several recent research studies now use objective quality models to evaluate video quality.

Research related to characterizing image quality of electronic devices are drifting towards automated data collection and evaluation. To achieve good data collection and evaluation, reducing motion blur, hand jittering, ghosting artifacts, image misalignment and capturing is critical. The use of camera on a tripod stand with full-reference image quality metrics for evaluation are demonstrated as quite suitable [27, 28, 29].

In [29] optical data collection method was used for image capturing with a camera on tripod stand, wired to a computer interface for control while full-reference image quality metrics was used for evaluation. The camera-based image quality assessment framework, eliminated the use of humans in video quality evaluation of displays.

Other recent applications of camera-based approaches in include [30, 31]. [30] Demonstrated the application of smartphones to evaluate structural deformation of images, offer very similar results at lower cost and power required by traditional sensors. [31], showed camera-based approaches when used as a pre-recognition rejection method, produces stable positive predictive value of 86.7% and a negative predictive value of 64.1% on the synthetic dataset.

The fast electronic shutters speed and frame rate of smartphone place them ahead of digital single lens reflex (DSLRs) cameras. In addition, the large RAM, and powerful processors found in modern smartphones provides computational resources to compensate for the limitations of optical system in image processing [28].

In [2], camera method with objective assessment was simulated to evaluate effect of bezel compensation with varying bezel sizes in 3-by-3 video wall. Results showed a negative effect of bezel size increases. The overlay outperformed the offset algorithm with up to 30% with a static video and 24% with a dynamic video. Also, in, [3] camera method with objective assessment was implemented to evaluate video impairments as a result of bezel compensation with varying bezel sizes in 3-by-3 video wall. Result showed insignificant differences in video impairments as a result of bezel compensation and varying bezel sizes but negative impact compares to a bezel-less display.

In this work we propose a video wall grid distortion evaluation model with optical data collection method. Ghosting artefacts caused by local motion due to moving objects in a scene across screens are avoided by use of smartphone in a dark room condition, while motion bur and hand jitter during capture are handled using a tripod and contactless (Bluetooth) control Interface.

Literature, show applying optical data collection and full reference metrics, image deformation associated with the model in [3], can be objectively evaluated. This research, therefore, focuses on an objective approach to examine video distortions for uniform tiled LCDs with a large interior bezel. 10 Raspberry Pi (R-Pi) microcomputers, with 10 LCD monitor, and a 10/100 Mbit switch were used in the research. Experiments were conducted in a controlled environment, with the two bezel compensation algorithms and a smartphone camera to collect data.

The experimental strategy explores grid distortions related to video frame rate and resolution changes, with Similarity Structural Index Measures (SSIM) and one-way Analysis of Variance (ANOVA) as for analysis.

A. *Raspberry pi (R-pi) Microcomputer*

R-pi is a portable, inexpensive microcomputer designed to operate with several interfaces and capable of performing the function of desktop computers [32]. Some supported interfaces include USB, card readers, power supply terminal and ethernet ports, as shown in Fig 4. The R-pi model 3B+ has a low power consumption of 15 W, processor capacity of 64 bit, 1.4GHz, static random-access memory (SRAM) of 1GB, with an Ethernet speed of up to 300Mbps.

Attempt to reduce the cost, energy and space of video walls, [1, 3, 33, 34, 35] used R-pi to develop video walls yet, none evaluated possible grid distortion.

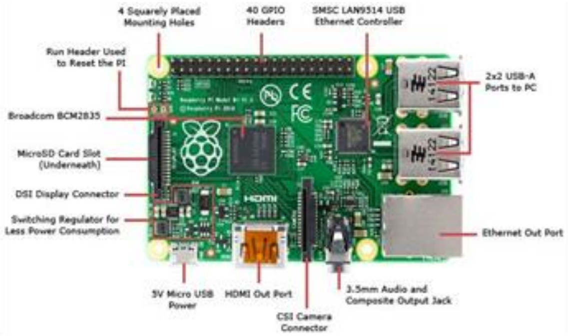


Fig 4: R-pi Microcomputer Board

B. *Video Quality Assessment (VQA)*

Video quality is the level of closeness of a processed video relative to other processed video or an original video. It is the result of a comparison and an evaluation of a video, this includes observing, considering, and the explanation of the result [36]. VQA are either subjective or objective; the former present actual video quality but it is inconsistent because is dependent on human nature. The latter is designed based on mathematical algorithms to mimic human judgment. it is consistent, verifiable and applicable in; system monitoring, optimization and adjustment, as well as system parameter settings and benchmarking [22].

Structural Similarity Index Measure (SSIM) is an objective metric useful for comparing image elements observed by human eyes rather than pixel values. The difference in luminance values determines the perceptual distortion. SSIM measures luminance, contrast, and texture distortions, it adds these distortions together to estimate the final SSIM index. Acceptable values range from -1 (highest difference) to 1 (no difference); a higher value indicates a greater level of quality. Mathematical evaluation by this metric is presented in [37,38].

In [39] the author show that video quality assessments mapping applied to SSIM create generic mapping on 5-point MOS scale for Structural Similarity Index (SSIM) in Table 1.

Table 1: SSIM and MOS Mapping

MOS level	MOS level (0-100)	SSIM
5 Execellent (A)	$80 \le A \le 100$	$A \ge 0.93$
4 Good (B)	$60 \le B < 80$	$0.85 \le B < 0.93$
3 Fair (C)	$40 \le C < 60$	$0.76 \le C < 0.85$
2 Poor (D)	$20 \le D < 40$	$0.62 \le D < 0.76$
1 Bad (E)	$0 \le E < 20$	$E < 0.62$

Source: Moldovan *et al.,* (2016)

C. *Analysis of Variance (ANOVA)*

ANOVA is a statistical tool suitable for verifying the level of disparity between the means of two or more groups. Typically, the impact of one or more mean(s) of samples are compared for the null hypothesis (H0) or the alternative hypothesis (H1). The null applies when all means are equal and if for the test criteria quantile of F-distribution is greater than the critical value of F-distribution (F_{crit}) within and between degrees of freedom [40, 41]. The null hypothesis also holds, for a chosen significance level (α), the probability of rejection (p-value) $p < \alpha$, otherwise the null hypothesis is rejected with probability greater than $(1-\alpha)100\%$.

II. METHODOLOGY

A. *Testbed Model*

The testbed (as in Fig 5) developed in our previous study [3] (monitor parameters in Table 2) was used.

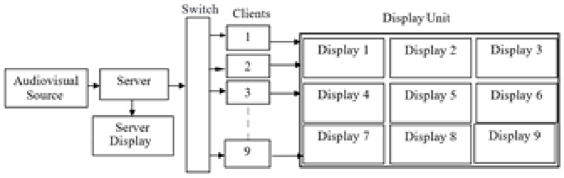


Fig 5: Testbed Model

Table 2: Monitor Parameter

Parameters	Abbreviation	Dimension(mm)
Height	H	230
Width	W	305
Bezel	B	10

To reduce the effect of ageing, misalignments, and colour variation, all monitors are from the same source, manufacturer, with same specifications and all monitors were tightly aligned, with parameters set as in Table 3.

Table 3: Monitor Parameter and Settings

Parameters	Value (%)
Brightness	100
Horizontal Position	64
Vertical Position	55
Clock	0
Phase	25
Contrast	50

B. *Bezel Compensation Algorithms*

1. Offset model

In this model, each client crops its portion of the video without considering the bezel areas, then tiled to form the wall.

2. Overlay model

In this model, each client crops its portion of the video removing the bezel areas, then the videos are tiled to form the wall.

Using the layout in Fig 6, Python codes with Piwall codecs, ffmpeg, and pwomxplayer multimedia installed on server and clients.

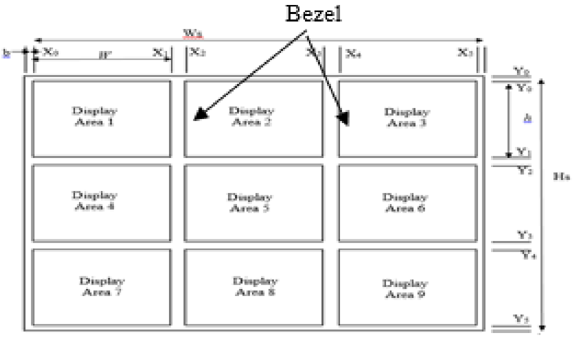


Fig 6: 3 x 3 Video Wall Display Layout

C. *Optical Data Collection Model and Setup*

Tiled screen was configured in a 25°C air-conditioned room (380 by 400 cm) while a light meter (HS1019A), fixed at the center of the room and perpendicular to the screen (90°), was used to set luminance at 0 Lux. A 10-minute period between experimental sections was observed to maximize illuminant temporal stability. A similar-sized television (LG 47LB671V-ZB) was also mounted in same room with same setup and used to displays the content of all bezel-less videos.

A 64-megapixel camera (Samsung Galaxy A32) placed on a tripod stand (VCT-1688) was set 2 m in front of the screen. His camera capture videos and transfers the same to a Core i7 Laptop for processing, as shown in Figs 7 and 8. To reduce sensitivity to noise, the camera's exposure setting was set as; aperture f/2.2, ISO 200, and shutter speed of 0.4 s [42].

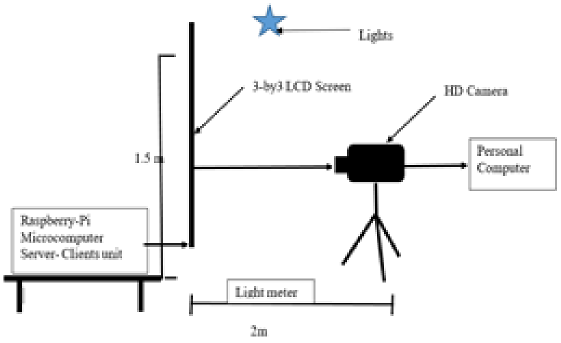


Fig. 7: Optical Data Collection Model

Fig. 8: Optical Data Collection Setup

D. *Objective Evaluation Model and Setup*

Four (4) YouTube videos referred to as video 1, video 2, video 3, and video 4 [43-46] used by [3] were downloaded to cover various sources; 360p for smartphones, 480p; for DVD, computers, 720p; for high definition (HD) television broadcast, and 1080p; for full high-definition video (Full HD) in television stations, social media, larger screens and TVs. Each of these videos were obtained at frame rates of 10fps, 25fps, 30fps, and 60fps using [47].

To reduce the influence of surrounding, unwanted surrounding background and frames were remove. The cropped version contains only the actual video content without background and frames recorded before or after the actual content of the video. Finally, the resulting videos (video wall and television) were compared for video grid distortion using SSIM in Moscow State University (MSU) VQMT [48] and analyzed with ANOVA see Fig. 9.

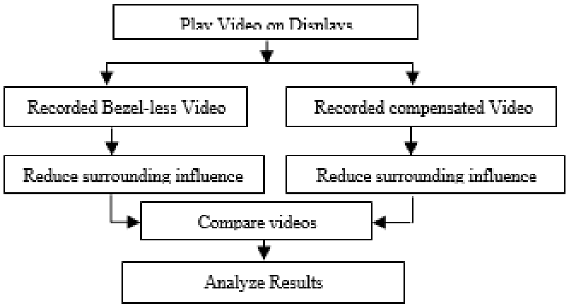


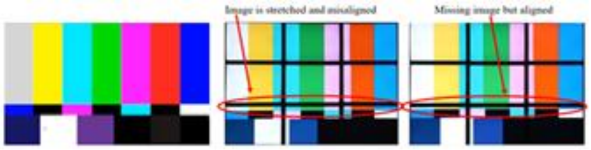
Fig. 9: Video Quality Evaluation Model

III. RESULTS AND ANALYSIS

The implemented algorithms on the R-pi based wall displayed the four videos. Screenshots of the videos were taken for observation while, grid distortions are evaluated based on resolution and frame rate changes.

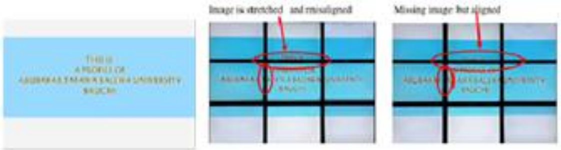
A. Subjective Results of Approaches

The screenshots of processed video for bezel-less and two bezel compensation approaches are shown in Figs 10 to 13.



(a)Bezel-less (b) Offset (c) Overlay

Fig. 10: Video 1



(a)Bezel-less (b) Offset (c) Overlay

Fig. 11: Video 2

(a)Bezel-less (b) Offset (c) Overlay

Fig. 12: Video 3

(a)Bezel-less (b) Offset (c) Overlay

Fig. 13: Video 4

B. Grid Distortions

Average metric values (Avg) from experiments are recorded and plotted in Figs 14 and 15. Videos at fixed frame rates but varying resolutions are “10 fps (OL), 25 fps (OL), 30 fps (OL) and 60 fps (OL)” for overlay and “10 fps (OS), 25 fps (OS), 30 fps (OS) and 60 fps (OS)” for offset (Fig. 14). Videos with varying frame rates are “360p (OL), 480p (OL), 720p (OL), and 1080p (OL)” for overlay and “360p (OS), 480p (OS), 720p (OS), and 1080p (OS)” for offset (Fig. 15).

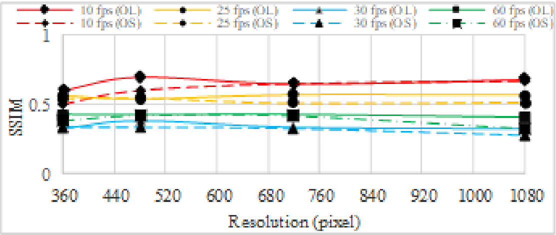


Fig. 14: Grid Distortions for Resolution

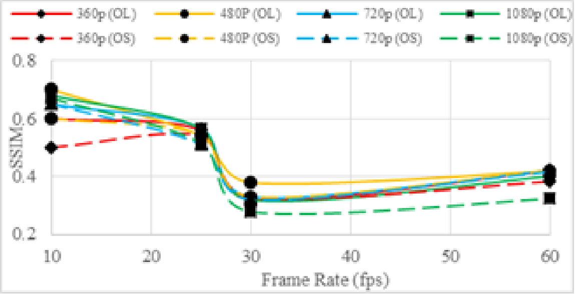


Fig. 15: Grid Distortions for Frame Rate

C. Bezel Compensation Techniques

For comparison, all recorded videos are in mp .4 file format and the performance of each algorithm is plotted in Figs 16 and 17. While for analysis, the best quality is valued as 1, other referenced values of the SSIM metrics based on human mean opinion scores (MOS) are values within the range of; ≥ 0.93 is excellent, 0.85 ≥ good < 0.93, 0.76 ≥ fair < 0.86, also any value 0.62 ≥Poor < 0.76 and any value below 0.62 is bad.

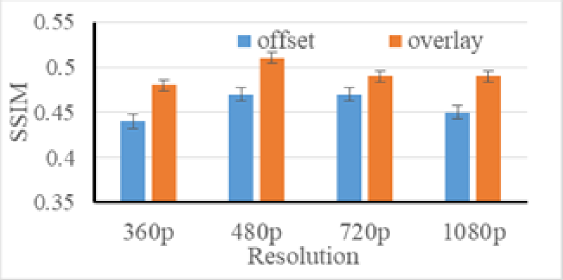


Fig 16: Comparison of Resolution

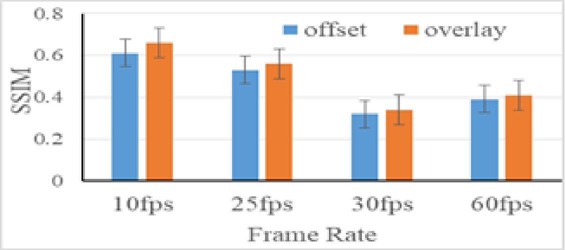


Fig. 17: Comparison of Frame Rate

IV. DISCUSSION OF RESULTS

Figs 10 to 13 show videos split into nine non-overlapping segments using bezel compensation techniques. Figs 10(a) to 13(a) show the bezel-less video, Figs 10(b) to 13(b) are the offset approach while, Figs 10(c) to 13(c) are the overlay approach. The tiled display shows video are stretched and misaligned for an offset approach. In Figs 10(c) to 13(c), images are not stretched and are aligned, but information under the bezel area missing.

Fig 14, ANOVA analysis of SSIM at 95% confidence level (α =0.05 and F_{crit} = 3.490295) revels insignificant variation in videos quality, as resolution varies, ($F_{3,\,12}$ = 0.07026, p= 0.974741); with best SSIM ($\bar{x}$ = 0.5095, σ^2 = 0.020895), at 480p, worst of ($\bar{x}$ = 0.47525, σ^2 = 0.01653) at 360p for overlay. Similarly, for offset ($F_{3,\,12}$ = 0.037075, p= 0.989957), with best SSIM ($\bar{x}$ = 0.4745, σ^2 = 0.01958), at 720p, worst of ($\bar{x}$ = 0.43825, σ^2 = 0.009786) at 360p. This shows increases in resolution has little or no variation in grid distortion. The low average values of SSIM (<0.62) indicate the existence bezel impact negatively on video quality, irrespective of resolution or bezel compensation.

Fig. 15 shows significant effect for frame rate variation with SSIM; for overlay ($F_{3,\,12}$ = 112.4589, p= 4.74E-09) with average SSIM ($\bar{x}$ = 0.6575, σ^2 = 0.001892) for 10 fps and $\bar{x}$ = 0.5585, σ^2 =0 0.000146 for 25 fps while, the 30 fps and 60 fps videos have SSIM ($\bar{x}$ = 0.33725, σ^2 = 0.000798), and ($\bar{x}$ = 0.4145, σ^2= 9.43E-05) respectively. For offset ($F_{3,\,12}$ = 32.25638, p= 5.03E-06) with 10 fps video having best SSIM ($\bar{x}$ = 0.605, σ^2 = 0.005767), while 25 fps, 30 fps, and 60fps videos had ($\bar{x}$ = 0.5275, σ^2 = 0.000306), ($\bar{x}$ = 0.31475, σ^2 = 0.000579), and ($\bar{x}$ = 0.38525, σ^2= 0.001988) conditions. This shows that as the frame rate increases, grid distortion increases. The generally low average SSIM values (<0.62) imply that the presence of a bezel has a detrimental effect, this agrees with the findings in [23] but with best performances of up to 0.6575 at lower frame rates.

Comparing the performances of the two bezel compensation algorithms, using ANOVA analysis (F_{crit} = 5.987378) at 95% confidence level (α =0.05) for variation in resolution (Fig. 16) shows significant differences, ($F_{1,\,6}$ = 8.568029, p= 0.026386) with offset having SSIM ($\bar{x}$ = 0.458125, σ^2 = 0.017417), while overlay had ($\bar{x}$ = 0.491938, σ^2 = 0.020589) for while variation in frame rate (Fig.17) shows insignificant differences, $F < F_{crit}$ and $p > \alpha$, ($F_{1,\,6}$ = 0.120326, p= 0.740523).

CONCLUSION

This paper has proposed a new method of evaluating grid distortions in video walls using smartphone camera approach and objective metric. The paper has used bezel compensation algorithms on R-pi microcomputers-based video wall with 15-inch, 1 cm bezel displays. SSIM objective metrics has been used to experimentally investigate structural deformation as a result of grid lines formed by bezels. Results analyze with ANOVA affirm significant differences between the two compensation algorithms, with up to 9.96% differences when using 1080p videos.

Results also show it is difficult to notice differences in grid distortions between algorithms with frame rate variation and that lower frame rate video generates less grid distortion. The proposed method of using smartphone camera approach and SSIM to evaluate grid distortions in video walls, eliminate the use of humans and an alternative to the use of subjective assessment. The low average values of SSIM (<0.62) indicate the existence bezel impact negatively on video quality, irrespective of resolutions, frame rates or bezel compensation used. This approach has shown that the inconsistency and inconclusiveness in performance of video wall as a result of using subjective assessment can be eliminated.

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