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Context-aware HDR video distribution for mobile devices

Miguel Melo · Luís Barbosa · Maximino Bessa · Kurt Debattista · Alan Chalmers

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Abstract HDR video on mobile devices is in its infancy and there are no solutions yet that can achieve full HDR video reproduction due to computational power limitations. In this paper we present a novel and versatile solution that allows the delivery of HDR video on mobile devices by taking into account contextual information and retro-compatibility for devices that do not have the computational power to decode HDR video. The proposed solution also enables the remote transmission of HDR video to mobile devices in real-time. This context-aware HDR video distribution solution for mobile devices is evaluated and discussed by considering the impact of HDR videos over conventional low dynamic range videos on mobile devices as well as the challenge of playing HDR videos directly locally or remotely.

Keywords High Dynamic Range Video · Mobile Devices · Video Delivery · Tone-mapping · Video Streaming · Context-aware

1 Introduction

Conventional imaging technology is incapable of representing the dynamic range that the Human Visual System (HVS) can perceive, leading to a loss of

M. Melo
INESC TEC, Porto, Portugal and Universidade de Trás-os-Montes e Alto Douro, Portugal
E-mail: emekapa@sapo.pt

L. Barbosa
INESC TEC, Porto, Portugal and Universidade de Trás-os-Montes e Alto Douro, Portugal

M. Bessa
INESC TEC, Porto, Portugal and Universidade de Trás-os-Montes e Alto Douro, Portugal

K. Debattista
WMG, University of Warwick, United Kingdom

A. Chalmers
WMG, University of Warwick, United Kingdom

detail in scenes with a wide dynamic range. High Dynamic Range (HDR) technology overcomes this low dynamic range (LDR) limitation as it can accurately represent the entire dynamic range that the human visual system can perceive. Since HDR reproduces the lighting perceivable by the HVS it allows an enhanced viewing experience through significantly increased physical realism, colour gamut and contrast ratio. Consequently, many applications can benefit from HDR, namely multimedia production where significantly increased physical realism can be delivered; security as it allows better surveillance in environments where the luminance can compromise the visualization; or scientific research as it provides more information about the scene and thus can lead to more accurate data visualization and understanding.

According to the OOYALA report [16] on the viewing habits of video on mobile devices, the last two years have seen an increase of 40% in mobile video requests which represents 30% of all online video views. Despite this, there is very little work addressing HDR video on mobile devices and, since mobile devices are portable, additional benefits to the mentioned applications are possible; for instance, being used for on-site evaluation and validation for content production and to allow more direct vigilance in the case of security applications. Therefore it becomes important to develop new mechanisms that can overcome this gap in order to provide a proper reproduction of HDR video on such devices.

As HDR displays for mobile devices are not available on the market yet, there is a need for adjusting the content's dynamic range to the display's dynamic range such that it can be properly displayed on mobile devices using luminance compression algorithms known as tone mapping operators (TMOs). TMOs for Small Screen Devices (SSD)s need to take into account their portability as they can be used under a wide variety of scenarios with widely differing luminance levels. In fact, recent studies indicate that TMOs' accuracy changes under different scenarios [15]. Thus, it becomes important to ensure that there are proper mechanisms capable of accounting for such differences and delivering content in an optimal manner according to each case.

Currently there are no established standards or solutions for the delivery of HDR video. Additionally, mobile devices are becoming one of the main platforms for video consumption but are subject to further constraints such as computational and battery power. This paper proposes a novel context-aware HDR video delivery architecture for mobile devices with the following contributions:

- An HDR video delivery solution for mobile devices;
- A system that enables the visualization of HDR video on mobile devices, extending the support to legacy devices that do not support native HDR decoding through an innovative remote tone-mapping approach;
- An optimization of an HDR video visualization experience based on the usage context, as mobile devices are often used "on-the-go" and exposed to environmental variables that can have impact on the visualization experience, such as different ambient luminance levels;

– An evaluation of the HDR video delivery solution that shows that it is possible to deliver HDR video to mobile devices without compromising the visualization experience.

2 Related Work

Work in the field of HDR video delivery on mobile devices is at an early stage and there are no established practices on how to deliver HDR video on mobile devices taking into account their usage scenarios. The previous research that addresses HDR video on mobile devices, is based on video capture methods, TMO evaluations, luminance retargeting methods and an HDR video player.

Castro et al. [3] proposed a method of video capture divided into two steps: capture and video creation. The first step consists of capturing the image frames using a Nokia N900 and the FrankenCamera API. As the mobile device presented computational limitations the authors decided to limit the application to capturing short videos. The second step is designated by authors as an offline step as the process does not occur on the mobile device. It consists of transferring all the frames to a desktop computer and processing them in order to generate a set of HDR images. The frames are then processed in order to generate an HDR video using pfstmo tools [12], a well-known library that allows reading, writing and manipulating HDR images and video.

Studies have also been undertaken in order to evaluate video TMOs. For instance, Eilertsen et al. [5] conducted a TMO evaluation for HDR video that considered 11 TMOs using camera-captured and computer generated videos. A total of 36 participants were asked to conduct pairwise comparisons between the TMOs and the HDR content. It was observed that many TMOs can introduce artefacts such as flickering, ghosting or over-saturated colours and the major conclusions of this work were that less sophisticated global TMOs could perform better than more recent and complex TMOs.

Another example of HDR video tone mapping evaluation addressing mobile devices is the study conducted by Melo et. al [14]. This study used an HDR display as reference to compare TMOs between a 9" tablet and 37" LDR display under medium lighting levels (quantified at approximately 55 cd/m^2, the equivalent of a regular indoors environment). The 60 participants ranked a set of six TMOs applied to seven videos and the results demonstrated that there was a statistically significant difference between the choice of TMOs preferred on the mobile device and the LDR display; however, the difference was subtle and the ordering accuracy of the TMOs remained constant across the two displays. The studies were further extended by Melo et al. [15] to address different viewing conditions, in particular different lighting levels. These new studies extended the first study with two different sets of luminance and an increase in the number of participants from 60 to 180. The results showed that the TMOsâĂŹ accuracy ranking obtained differed from bright lighting levels to dark and dim ambient lighting levels. The conclusion was that the lighting levels have a significant impact on the TMOs' accuracy.

Another study that considers HDR video on mobile devices is the method proposed by Wanat and Mantiuk [18] that investigated the luminance retargeting that alters the perceived contrast and colours of the image to match the appearance under different luminance levels. This method is appropriate for mobile devices as it compensates for appearance changes and the retargeting of bright scenes for dark displays implies a reduction of the display luminance, resulting in a significant power consumption saving that is one important limitation to take into account when dealing with mobile devices.

The first HDR video player for mobile devices was only recently proposed by Meira et. al. [13]. The first step for HDR video reproduction was to load a frame and decode all the information associated with it such as average luminance, minimum and maximum luminance etc. Tone-mapping was applied to each frame and rendered onto the SSD. Additionally, an evaluation of mobile devicesâĂŹ performance when reproducing HDR content was conducted and the results demonstrated that it was possible to display HDR video on mobile devices with satisfactory battery consumption rates. Also, a difference in performance between the older devices and the most recent ones was noted suggesting, as expected, that the evolution of the mobile device specifications will produce better performance.

3 Context-aware HDR video delivery system for mobile devices

HDR is a demanding technology and running it on mobile devices requires the need to overcome significant challenges, ranging from the device computational power to the environment under which HDR content is viewed. Currently, there are no solutions that ensure a proper delivery of HDR video that take into account the specifics of mobile devices. This system aims to deal with those constraints, giving an important contribution to the state-of-the-art of HDR video delivery on mobile devices. In this work, a context-aware HDR video architecture for mobile devices is presented.

3.1 System Description

Due to the particularities of mobile devices, the proposed context-aware HDR video distribution system takes into account both device specifics and the context in which it is used. In regards to mobile devices' computational limitations, previous work shows that not all devices have computational power to locally decode HDR video [13]. Thus, it is important to provide mechanisms that enable the HDR video visualization on mobile devices and the solution presented in this paper overcomes such limitation via a client-server solution that enables the upload of the HDR video for a remote server in order to be transcoded and transmitted back in the form of a tone-mapped stream.

Previous work has also shown that context has impact on TMO performance [15] so systems should be designed to take this into account and deliver

HDR content in an optimal manner. The presented system is designed to continuously read the usage context and apply the best TMO in real-time. The TMO selection criteria is based on the research by Melo et al. [15].

3.2 Architecture

The system supports the playing of HDR video locally (stored on the mobile device) and remotely, stored on a server. Furthermore, the proposed system is built around a flexible solution that leverages the same system server for those legacy mobile devices that are not powerful enough to decode HDR video data locally. Legacy devices is our chosen term to refer to mobile devices that were released over two years ago; this corresponds to the typical average time for handset replacement cycle [6]. When needing to play a recently recorded local file on legacy mobile devices, the HDR video on the mobile device is uploaded to the server in order to be processed, tone-mapped and encoded as a tone-mapped LDR. This work focuses particularly on the delivery process which is important to establish mechanisms that can allow HDR videos to reach the largest number of devices as possible, so capturing HDR videos on mobile devices and network performance for uploading HDR videos to the servers will not be considered extensively. The context-aware HDR video delivery system for mobile devices consists essentially of two parts: the HDR video player for mobile devices and the HDR video streaming server (Fig. 1).

The client-side application is composed of seven modules:

– **HDR Mode Tester:** Tests if the mobile device is capable of locally decoding HDR video and saves the information to the application settings;

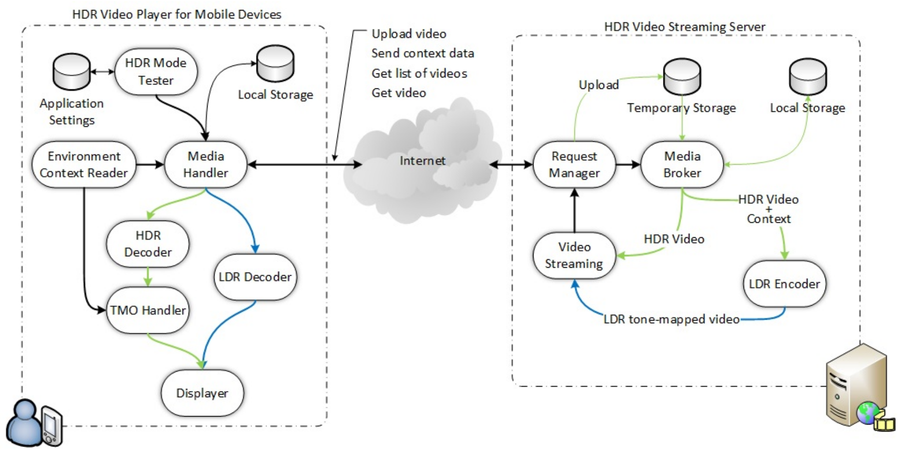

Fig. 1 Context-aware HDR video delivery system for mobile devices. The green data flows represents HDR-related activities and the blue data flows represent LDR-related activities. Orange data flows represent activities where HDR and LDR-related activities can occur.

- **Media Handler:** Processes information related to HDR support, the HDR videos available, the selected video, and the environment context in case the mobile device does not support local HDR video decoding. If the selected video is remote, this module communicates with the HDR video streaming server in order to request the corresponding video stream. This module permits the uploading of HDR video to the server in order for it to be transcoded and then transmitted back as an option for legacy mobile devices;
- **HDR Decoder:** Decodes the video by receiving a video handler provided by the "Media Handler". Each decoded frame is forwarded to the "TMO Handler";
- **Context Reader:** Continuously collects data regarding the environment's lighting level. If the mobile device supports HDR decoding locally, this information is passed on to the "TMO Handler" module, otherwise it is forwarded to the "Media Handler" module;
- **TMO Handler:** After receiving an HDR frame, this module renders it by analysing the context information gathered by the "Environment Context Reader" and applying the most adequate TMO in real-time. The TMO selection criteria is based on the psychophysical studies conducted by Melo et al. [15]. The rendered frame is then forwarded to the "Displayer";
- **LDR Decoder:** This module is used on legacy mobile devices that do not support local HDR video decoding. It receives a video stream from the "Media Handler", decodes the video stream, renders and finally forwards each frame to the "Displayer";
- **Displayer:** Presents each frame on the screen.

The context-aware feature of the proposed architecture is based on the ambient lighting levels and this feature considers two levels: dark and medium environments (typical of indoor scenarios) and bright environments (typical of outdoor scenarios). The dark and medium scenarios were combined into one condition as between those two scenarios no significant difference in the tone-mapping performance was found [15]. The criteria for selecting and evaluating the architecture with Man and Pat was that it was shown that Pat is most suitable for dark and medium lighting levels and Man is more suited for bright ambient levels [15]. These TMOs were used to showcase the system but other the TMOs could be used under specific context variables.

The server-side of the HDR video delivery system for mobile devices is important for two main reasons: to make HDR video available to mobile devices that are not capable of locally decoding such content, as well as to allow the existence of an HDR video repository. The server-side is composed of the following four modules:

- **Request Manager:** Handles the requests made by the HDR video player and dispatches them accordingly. In the case of having an HDR video uploaded, the "Request Manager" is also responsible for storing it on temporary storage;

- **Media Broker:** If the mobile device supports HDR video, the module establishes a communication between the selected video on the database and the "Video Streaming" module. If the mobile device does not support HDR video, the "Media Broker" forwards the HDR video to the "HDR Decoder" module along with the context data;
- **LDR Encoder:** For the legacy mobile devices this process is conducted at the server on this module. First, the HDR video is transcoded to LDR taking into account the context data provided. Then, the video is forwarded to the "Video Streaming" module in order to be streamed to the client;
- **Video Streaming:** This module has a video as input and handles it in order to create a stream to the HDR video player.

3.3 Workflow

The workflow of the HDR video player for mobile devices is presented in Fig. 2. On initialising the application for the first time the application will run the test to evaluate if the device is capable of reproducing HDR video locally (this runs only once per installation). This test consists of running a small HDR clip and analysing the frame rate. If the device is not capable of achieving a minimum of 25 fps for HD at full HD resolution then it is not capable of running HDR videos locally.

For mobile devices that are HDR enabled (Fig. 2(a)), the device decodes the HDR videos directly from storage. For each HDR frame received, the device applies a TMO based on the context and generates a texture that will be posteriorly drawn and displayed on the screen. The TMO selection criteria is based on the evaluation study conducted by Melo et. al [15] as discussed above. The process is repeated until the video ends or the user stops the reproduction. If the videos are located at the HDR video delivery server, the player requests the HDR video stream from the server and processes it similarly to the local HDR video decoding process. For legacy mobile devices (Fig. 2(b)), the proposed system has a feature that enables the HDR video to upload to a temporary storage located at the server and have it transcoded to LDR in real-time. If the environment context changes, the transcoding parameters can be updated on-the-fly in order to generate an adequate LDR stream. There is also the possibility for reproducing HDR videos that are made available on the HDR video delivery server through a proper LDR stream.

Fig. 3 describes the server workflow. If the device is responsible for HDR video-enabled devices, the process is straightforward: the streaming server loads the video from its storage and provides an HDR video stream. When the video finishes or the user stops the playback, the HDR video stream process is ended.

For legacy mobile devices the video is stored locally on the mobile device, the server receives the HDR video from the client application and locates it into temporary storage. Then, the video is processed together with the environmental data and the proper LDR stream is made available. Similarly, if the

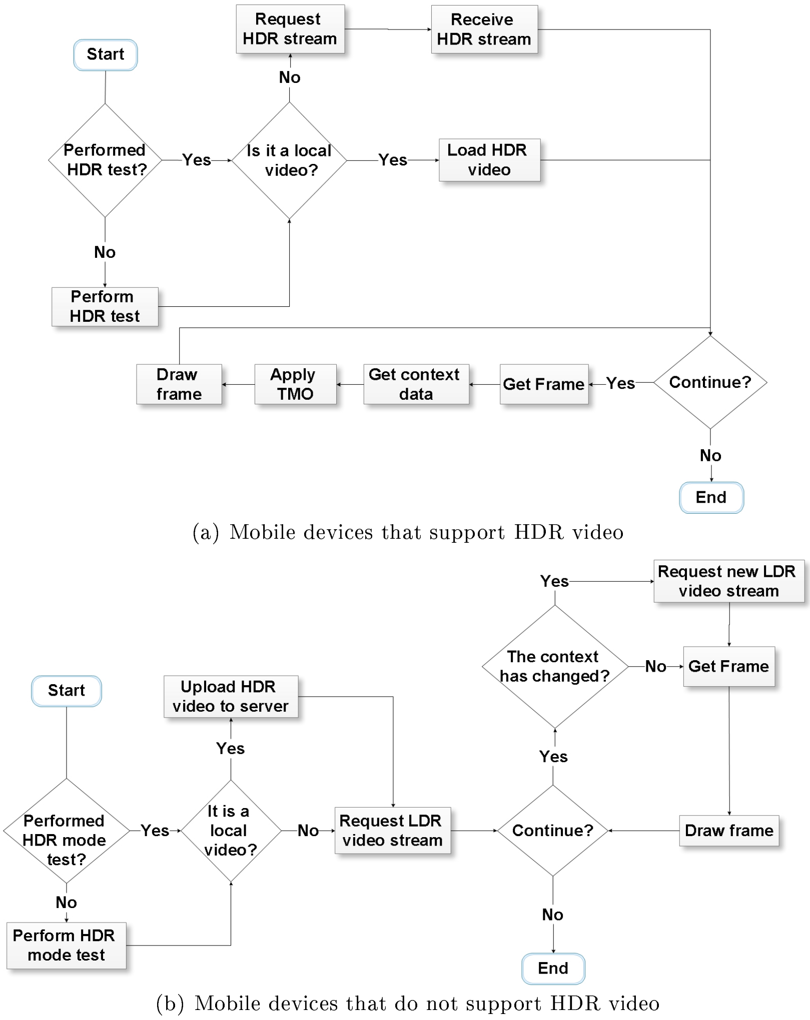

Fig. 2 Flowcharts of the HDR video player for mobile devices.

requested video is on the server, the server processes it directly with the environmental data sent from the mobile client and provides the converted LDR stream. In any case, if the context data changes, the transcoding parameters are updated and a new video stream is transmitted to the client. When the video finishes or the user interrupts the operation, the video stream process is ended.

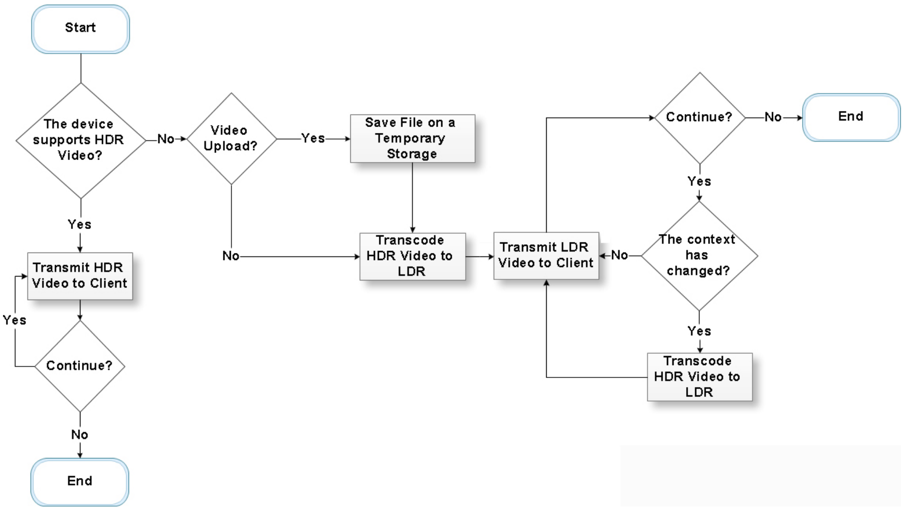

Fig. 3 HDR video delivery server workflow.

4 Prototype

The prototype was developed from the starting point of previous work, namely the modules TMO Handler and Displayer developed by Meira et. al ([13]). As for the server, it was a setup in collaboration with goHDR Ltd., a spinoff of the University of Warwick [8]. When compared to previous work, the developed prototype is a new solution with a number of new features:

- A complete solution ranging from the client to the server;
- An optimized HDR video decoding process;
- Support for both conventional and HDR video;
- Access to an online HDR video repository;
- Support for both state-of-the art and legacy devices; and
- The context-aware features.

The player is based on six blocks (Fig. 4). The block "Decoder" loads the HDR video from storage and it is responsible for decoding the frames and reading the relevant metadata for the video reproduction. The HDR processing itself is done at the "HDR Model" block that manages and processes all the information gathered by the "Decoder" and enables the tone-mapping process taking into account the context data that is made available by the "Context Reader" block. As previously mentioned, the display adaptive TMO is applied under environments with dark or medium luminance levels and the time-dependent visual adaptation TMO is applied under high luminance level environments.

The system's hardware consists of an Apple Macbook Pro laptop, the goHDR encoder [7], a Canon 5D Mark III digital single-lens reflex camera and a BlackMagic UltraStudio Mini Recorder [4]. The Apple laptop acted as the server whereby the goHDR encoder was running in order to process all the

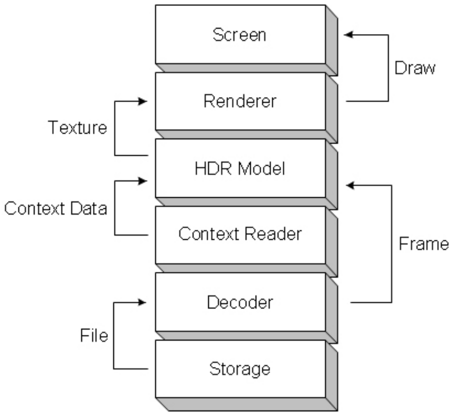

Fig. 4 General scheme of the HDR video player for mobile devices with HDR support.

Fig. 5 Full HDR system encoding and delivering contents in real time.

tasks associated with the HDR information such as video encoding, video transcoding, or video streaming. For live streaming, the Canon 5D Mark III digital camera was used in combination with the Magic Lantern software. Magic Lantern runs on the original Canon firmware and makes more features available to the original firmware [10], in particular the ability of capturing alternating frames at different exposures. This is useful for generating HDR content. The entire HDR system is shown in Fig. 5.

5 Evaluation of the Proposed System

To evaluate this solution a prototype based on the proposed architecture was developed and a set of performance tests was undertaken. The evaluation consisted of reproducing a set of HDR videos as well as a set of tone-mapped versions of the selected HDR videos and measuring the performance based on the average number of Frames Per Second (fps), the battery drain, and the average CPU usage. Measuring these variables provides an understanding of the impact of HDR videos on mobile devices and validates whether the

Table 1 Technical specifications of the mobile devices evaluated.

				CPU		Display
Brand/Mobel	Release Date (month/year)	Operating System	RAM (GB)	Cores No.	Clock (MHz)	
Google Nexus 4	11/2012	Android	2	4	1.5	4.7”
LG G3	04/2014	Android	3	4	2.5	5.5”
Apple iPhone 6	09/2014	iOS	1	2	1.4	4.7”
Google Nexus 7	07/2012	Android	1	4	1.3	7”
Apple iPad 4	11/2012	iOS	1	2	1.4	9.7”
Apple iPad Air	11/2013	iOS	1	2	1.4	9.7”

architecture can manage to deliver HDR content without causing a substantial overhead on the mobile devices.

5.1 Metrics

A measure of success will be determined according to the solution’s capabilities to reproduce HDR videos at the encoded rate (with a tolerance of 5% as error margin), and the impact of HDR video on battery drain when compared to LDR videos. Average CPU usage was measured to understand the impact of HDR video on this resource but it is not considered crucial to the evaluation success as it can be fully utilised without compromising the viewing experience as long as the frame rate is upheld and the battery does not run out.

5.2 Material and Methods

The study was carried out using the HDR videos generated with the goHDR encoder [2]. In total, seven mobile devices (LG G3 is counted as twice as it was evaluated using two different operating systems âĂŞ Android Kit Kat (KK) and Android Lollipop (L)) were considered and their technical specifications are presented in Table 1. The main criteria for selecting these devices was to understand the impact of the HDR videos on devices released over the two years prior to the running of the experiment and to find out if they are HDR compatible. Three different videos encoded at 30 fps that were chosen carefully to address different content (indoors, outdoors and computer-generated) were used in the evaluation. The characteristics of the selected videos are presented in Table 2 where the average dynamic range is expressed in logarithmic units. The measurement of the average dynamic range was obtained by disregarding the top 1% and bottom 1% of the values in each frame and averaging across frames - this was performed to avoid possible error introduced by noise in the frames.

To broaden the study, the evaluation considered four scenarios:

– local decoding of the HDR video;

Table 2 Features of the HDR videos used on the evaluations.

Video	Length (seconds)	Average Dynamic Range	Capture Method
Kalabsha (K)	11	18.5	CG
Explosion (E)	8	12.0	Canon 5D
Medical (M)	14	15.2	Spheron HDRv

– streaming of the HDR video and local decoding;
– local decoding of an LDR encoding of the HDR video; and,
– stream of the LDR encoding of the HDR video and local decoding.

As the HDR videos available were relatively brief, the HDR videos were played in a loop during the experiment. For the remote condition, the videos were streamed in a concatenated loop rather than having only one loop streamed to better simulate a real situation. Additionally, in order to guarantee that the ambient lighting levels do not have impact on the performance tests (especially on battery drain), the auto-brightness feature was disabled on all devices and it was manually set to half.

Each run duration was set to 90 minutes. This value was based on the values provided by IMDB [9] that indicates that 90 minutes is the approximate duration of a feature film (this value was determined by calculating the average feature film length of all movies registered on the IMDB database).

Regarding the TMOs, this work considers the display adaptive TMO [11] (that will be referred in this paper as Man) and the time-dependent visual adaptation TMO [17] (that will be referred to as Pat). This choice was made based on previous work by Melo et. al. [15] discussed above.

Both TMOs were evaluated across all scenarios and across all videos for a total of 24 runs for each device. In order to ensure uniformity of the lighting levels across each run, the information was directly manipulated on the device sensor in order to simulate the effect.

5.3 Procedure

The first step of the evaluation consisted in charging the battery completely so that at the beginning of each test the mobile device was fully charged. The next step was to select the video to be reproduced. Note that for ensuring uniformity across the evaluation, all videos were tested in the same order on all devices. Each video was played for 90 minutes and in the end, play was automatically stopped and a log file with all values of the identified variables was generated.

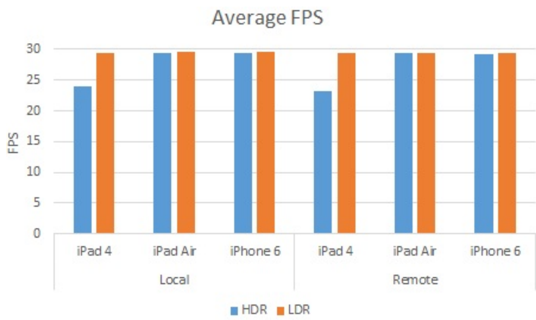

Fig. 6 Average fps for iOS devices.

5.4 Results

Due to the large amount of data retrieved from the evaluation of the HDR video delivery system, the results presented were subdivided into three sections where each represented the measured variables (average number of fps, battery drain and average CPU usage). In each section the results are subdivided by operating system as well as grouped by mobile devices, as there were no significant differences found between videos and between TMOs.

5.4.1 Average fps

For the average fps, the results for the iOS operating system are presented in Fig. 6. Apart from the iPad 4, all the devices managed to playback at close to the encoding rate (30 fps) for all scenarios.

On Android (Fig. 7), the LG G3 was the device that achieved the best frame rate on average, followed by Nexus 4 and Nexus 7. It is clear that Nexus 7 performed poorly, only nearing on average 26 fps on LDR videos and hardly reaching half of the encoded fps on HDR videos. One interesting fact is that there is a noticeable difference between the performances of two different operating systems on the same device (LG G3). This result suggests that the reason for a poor performance by the Nexus 7 can be software related as the worst performance obtained by the LG G3 was obtained with the same operating system as the Nexus 7.

5.4.2 Battery Drain

The battery drain on iOS devices (Fig. 8) indicates that, on average, HDR videos have an impact of approximately 50%. The results also show that more recent devices have lower battery consumption. As expected, the results show that when reproducing remote videos there is a larger impact on the battery drain, as a consequence of having an active wi-fi connection.

On Android devices the results, Fig. 9, also show a bigger battery drain when reproducing HDR videos. In particular, the LG G3 demonstrated a larger

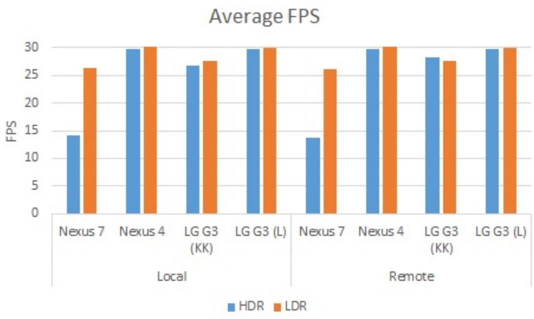

Fig. 7 Average fps for Android devices.

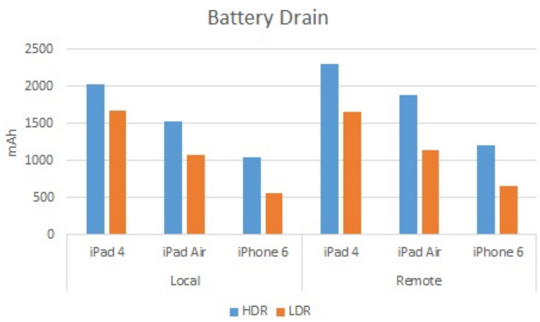

Fig. 8 Average battery drain for iOS devices.

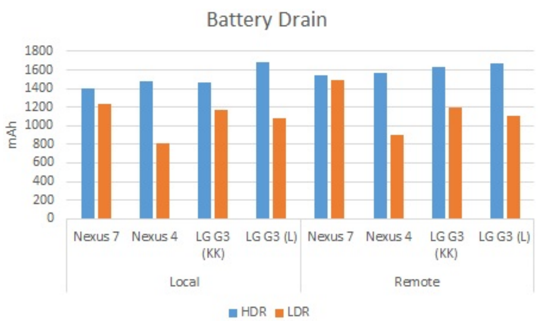

Fig. 9 Average battery drain for Android devices.

drain with Android Lollipop than with Android Kit Kat. Results show that only Nexus 7 reported more similarity between the battery drain for HDR and LDR videos.

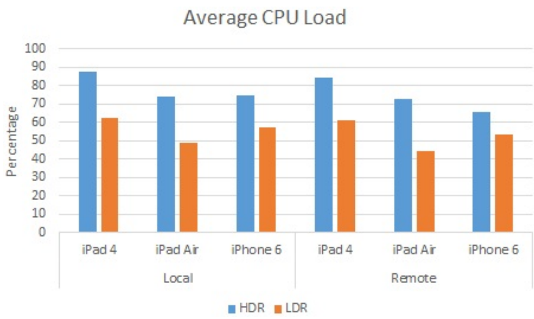

Fig. 10 Average CPU usage for iOS devices.

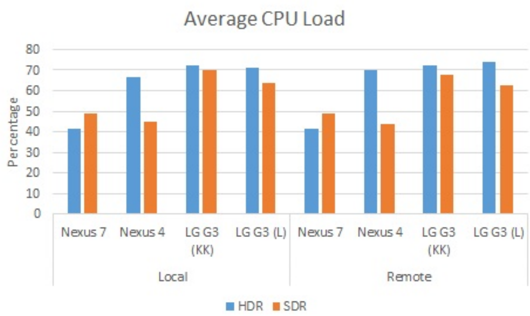

Fig. 11 Average CPU usage for Android devices.

5.4.3 Average CPU usage

With regards to the average CPU usage, as expected the oldest device was the one that presented the highest values since the computational power is lower. Fig. 10 presents the results for iOS.

The average CPU usage results for the Android devices (Fig. 11) curiously do not follow chronological ordering with the older devices presenting higher values since LG G3 presented higher CPU load than Nexus 4 (on LDR videos only) and Nexus 7. The Nexus 7 results are contradictory since they show a higher CPU load for decoding LDR videos than HDR videos.

6 Discussion

Overall, the performance tests conducted to evaluate the proposed solution's capability of viewing LDR and HDR content on mobile devices were successful. LDR content was always played without causing much impact on the devices and the videos were always decoded as expected with the exception of the average fps on the Nexus 7. In terms of HDR decoding the obtained results are good as each device was capable of delivering HDR video with satisfactory resource consumption. Apart from the Nexus 7's average fps, all devices performed well since they reached, on average, the target of 30 fps at which the videos were encoded. Nexus 7 was the only one that did not perform as well and that could be software-related, as the Nexus 7, has a similar feature set to the Nexus 4 and they had significant differences in terms of performance. An explanation for this case may be based on the OS installed (Kit Kat versus Lollipop). Unfortunately, at the time of the experiments Android Lollipop was not yet available for Nexus 7 so it was not possible to test it. Although it was not possible to test this aspect with Nexus 7, this was tested on an LG G3. On LG G3 there was a noticeable difference in terms of performance between two different OSâĂŹs. With Kit Kat the LG G3 achieved an average of 28 fps for LDR videos and 27 fps for HDR videos while under Lollipop it achieved an average of 30 fps for both cases. The difference in performance between devices may be related directly to software on the Lollipop version of the Android Runtime since this was changed from Dalvik to ART, which is optimised for better performance [1].

Despite the fact that most of the mobile devices used on the evaluation succeeded at decoding locally HDR video, other legacy devices might fail to do so. In such cases, the nature of the novel architecture which allows computational effort to be made at the server would be used.

The average battery drain results have shown that HDR videos have, on average, an impact of 50% on the battery on iOS devices and 40% on Android devices when compared to running LDR videos, and newer devices need less battery to decode videos. Battery efficiency may be explained by the natural evolution and optimisation of devices. When streaming HDR videos a larger battery drain is expected since the application is streaming content from a remote server and requires more features such as the Wi-Fi connection to deliver the HDR content leading to higher battery drain.

The average CPU usage results are similar to the battery drain results as they show that HDR video requires more CPU usage than LDR videos and that older devices may struggle more than most recent devices.

6.1 Study limitations

There are a number of limitations within this current work. In particular, network performance and file upload features are not considered. This is because, at this stage, the proposed solution is a first step for HDR video delivery systems on mobile devices and the priority was to establish that it was possible to have such a solution rather than verifying the impact of these additional variables. Therefore, ideal network conditions and file upload features were assumed in order to evaluate the feasibility of the approach. However, it should be expected that with reasonable resources, the process of uploading the HDR video to the server for decoding, tone-mapping, subsequent encoding and streaming would cause overhead and possible lag when compared to the direct playback from the mobile device. For feature-length video sequences this would be ineffective so such a feature would be limited to shorter video clips. However, a contribution is the ability to directly host HDR videos on the server-side and making them available to less powerful devices.

Another limitation that can be identified is that the presented prototype is based on existing HDR video decoding and encoding methods as well as on current TMOs. To overcome this limitation, the system was developed based on a modular structure allowing new HDR video methods and TMOs to be included when they become available. The TMOs used in this work were examples but there is always the possibility to extend the TMOs available on the architecture and to redefine the default TMOs used under specific context variables. The same applies to the context variables themselves, allowing for the addition of new context variables.

The architecture evaluation only considers the featured mobile devices released over the last two years, however, this period was considered to minimize threats to the validity of the study: the average time for a handset replacement cycle is typically two years [6]. Our method could be used as a framework for future work taking into account other devices and formats.

Despite these limitations, our proposed context-aware HDR video delivery system for mobile devices provides a novel contribution to the field. Particularly, when considering mobile devices' usage and multimedia consumption is growing significantly and there are no current solutions that cater for HDR video adoption specifically on mobile devices.

7 Conclusion

HDR technology on mobile devices can bring many advantages for a number of applications, thus it is important to ensure that there are mechanisms that allow the delivery of HDR content to such devices which take into account the variety of devices, and way in which they are employed. The solution presented in this paper intends to provide a step forward towards the delivery of HDR content on mobile devices and encourage future work in the field.

The HDR video delivery solution proposed supports both the latest and legacy mobile devices and exploits results from experimental studies that demonstrate that TMO accuracy changes according to the environment lighting levels. This context-aware feature is achieved by determining the current lighting levels and applying the most appropriate TMO. Real-time tone mapping ensures that the system can cope with changing environmental conditions.

The high volume of data associated with HDR video could affect the decoding capability of mobile devices. This study has proven that current mobile devices are technologically able to play HDR video. Results show the proposed system is viable and that it is possible to deliver HDR video without compromising the viewing experience. Future work will evaluate the impact of all the possible factors on the HDR video delivery system and further improve the system.

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