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Viewer-Aware Intelligent Mobile Video System for Prolonged Battery Life

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Abstract

Mobile is increasingly going to be all about video. The major drivers in video growth are mobile devices such as smartphones, which enable people to: watch what I want, when I want, and where I want. However, due to the large data size and intensive computation, video processing consumes a large amount of power, which limits battery life and frustrates mobile users. Mobile system designers typically focus on hardware-level power optimization techniques without considering how hardware performance interfaces with viewer experience. Here we investigate how viewing context factors affect mobile viewer experience, where such factors include viewer movement, viewing distance, and ambient illumination. We connect hardware design techniques to viewer experience to develop a simple but effective decision tree model to enable video system adaption. Finally, we implement a viewer-aware intelligent mobile video system which can optimize power efficiency automatically in real-time according to the viewing context while maintaining the viewer experience. Our research has opened a door for development of future viewer-aware mobile system design, accelerating low-cost mobile devices with longer battery life.

Keywords—Viewer's experience, mobile video system, power efficiency, viewer movement, viewing distance between the user and mobile device, ambient illumination, decision tree model, battery life

INTRODUCTION

Recently, mobile devices such as smartphones have become one of the most popular media for delivering multimedia content. According to the recent Cisco Visual Networking Index, Mobile video traffic accounted for 60% of total mobile data in 2016 [1]. It is expected to increase 9-fold between 2016 and 2021 and grow to approximately 78% in 2021, with the continuous evolution of mobile networks and the proliferation of mobile devices [1]. Video streaming is one of the most power-consuming activities on mobile devices. Studies show that 69% of mobile users watch videos at work and 80% while they are performing outdoor activities [2]. Because video typically involves large data size and intensive computation, video processing requires frequent storage access and consumes a large amount of power, limiting battery life and frustrating mobile users.

There is a rich body of literature in circuit and architectural techniques for power reduction for video processing systems. However, the improvements in power efficiency are often achieved with significant design complexity, increased implementation cost, and performance penalty for voltage regulator or boosting circuits. While hardware designers try their best to support high quality videos such as keeping Peak-Signal-Noise-Ratio (*PSNR*) values above 30 dB, psychophysical researchers have conducted studies

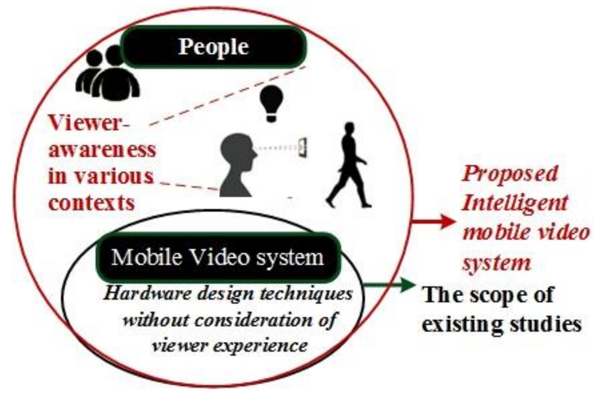

Figure 1. Proposed intelligent mobile video system with adaptation to viewer movement, viewing distance between the user and mobile device, and ambient illumination.

on the impact of visual context on the performance of the human visual system (HVS) and showed that the viewing conditions that influence the mobile video watching experience fall into three major aspects: *viewer movement*, *viewing distance between the user and mobile device*, and *ambient illumination*.

We have recently explored viewer-aware video memory design by investigating the impact of illuminance levels in different viewing surroundings on the viewer's experience [7-9]. Specifically, we used a bit truncation technique to introduce memory failures in high noise-tolerance viewing contexts with high luminance levels by adaptively disabling the least significant bits (LSB) of the video data stored in memories. Our previous studies [6-8] illustrate a new dimension of power savings for hardware design through the introduction of viewer awareness, but the impact of viewer movement and viewing distance between the user and mobile device has not been studied. In this paper, to enable viewer-aware mobile video systems, we study all key viewing context parameters and connect them to hardware design process. By connecting viewer's experience, viewing context factors, and the mobile device hardware design process, we develop a decision tree model to optimize power efficiency depending on the viewer's experience, and implement a viewer-aware intelligent mobile video system with dynamic performance management. Our proposed video system enables prolonged battery life while playing videos on mobile devices without causing perceptual video quality degradation.

DIFFERENT VISUAL EXPERIENCE CAUSED BY DIFFERENT HARDWARE TECHNIQUES

(a) Original video (b) 3 bits truncated (c) 4 bits truncated

(d) Original video (e) 6 bits voltage scaling (f) 7 bits voltage scaling

Figure 2. Different impacts of hardware design techniques on video quality: voltage scaling generates shades on the frames which causes a large *PSNR* degradation with more power savings and voltage scaling generates noise dots with less *PSNR* reduction with less power savings

We first study the impact of different hardware design techniques on viewer's experience. Specifically, two popular low-power hardware techniques have been studied: voltage scaling and bit truncation. These two technologies are widely-used low-power techniques in today's mobile systems. Typical video data uses eight digit bits to contain all the pixel information and different bits consume the same amount of power in storage system, but they are representing different significance of information. Bit truncation can completely shut down least significant bits (LSBs) and lead to a lower accuracy of information with significant power savings. Voltage scaling is also a tradeoff between power savings and video quality, by reducing the power supply of hardware. Fig. 2 illustrates the video quality with bit truncation and voltage scaling techniques (with 1% memory failure rate). As shown, bit truncation and voltage scaling achieve different visual effects on the video quality: ***bit truncation generates shades on the frames which causes a large PSNR degradation with more power savings and voltage scaling generates noise dots with less PSNR reduction with less power savings***

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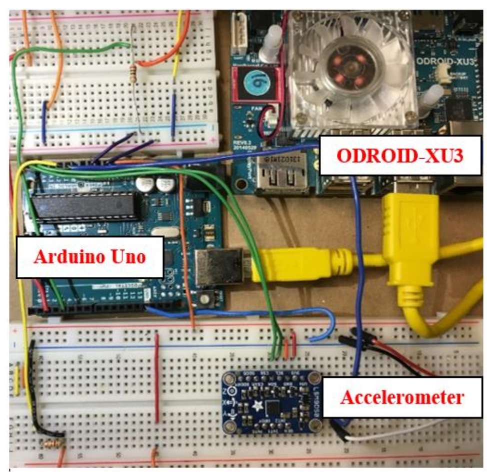
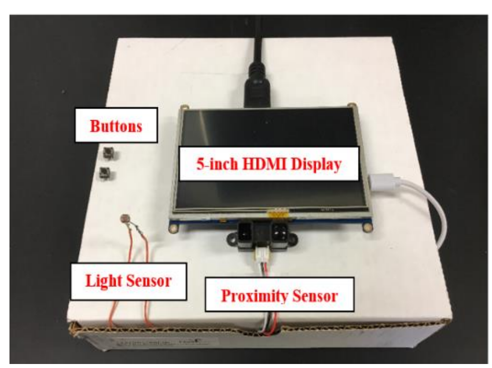
VIDEO SYSTEM DESIGN AND IMPLEMENTATION

In our experiments, an embedded system was designed using two development boards: Arduino Uno and Odroid-XU3. As shown in Fig.4, the board on the left is an Arduino Uno board which is used to collect all the context information and send the processed data to the Odroid-XU3 board using serial communication. The Odroix-XU3 board contains processed video samples for display.



(a) Inside of case



(b) Outside of the case

Figure 4. Developed video system

6 bits truncated

Figure 5. Significant video quality degradation with 6 bits truncated.

The light sensor, accelerometer and proximity sensor are connected to the Arduino Uno board. The light sensor can be used to detect luminance value, the accelerometer is used to measure the movement by collecting acceleration in X, Y and Z axis, and the proximity sensor can measure the distance between viewer and the screen. All these sensors we used are also commonly equipped on modern smartphones to bring convenient functions to users.

In order to determine how best to save power and prolong battery life by deliberately introducing hardware noise in various viewing contexts, we prepared three different short mobile video clips using bit truncation and voltage scaling techniques. On each trial observers (N=15) sequentially viewed two short clips (lasting 6 seconds), one of which was rendered in original high quality and the other processed using either bit truncation or voltage scaling. On each trial observers indicated which clip possessed the highest video quality. Specifically, we tested all the bit truncation methods from one bit truncation to seven bits truncation and conducted the video quality testing. It shows that viewers cannot tell the difference between original video and truncated video less when fewer than three bits are truncated. For truncation of more than five bits, the video becomes completely unacceptable (see Fig. 5), and viewers can easily distinguish the degraded video under most viewing conditions. Accordingly, in our study, *we use videos with truncation of three, four, and five bits. Considering the higher power efficiency enabled by bit truncation, voltage scaling technique is applied after bit truncation to enable additional power savings.*

CONNECTING VIEWER'S EXPERIENCE, VIEWING CONTEXT FACTORS, AND HARDWARE DESIGN

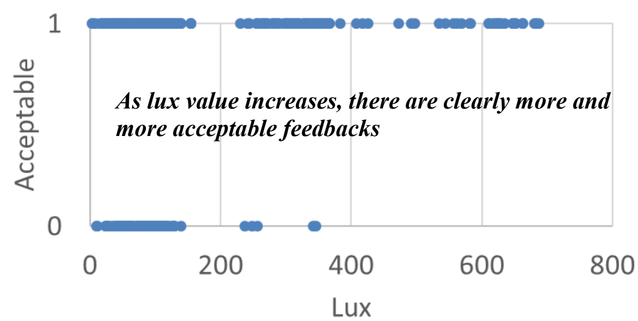
A. Impact of Viewing context factors on Viewer's experience

We further study the impact of viewing context factors on viewer's experience. Fig.6 shows the video testing results. The y-axis represents whether the video quality is acceptable or not and x-axis represents ambient illumination, viewer distance and viewer movement (acceleration), respectively. Each point on the graph represents one feedback we collected. As shown, as ambient illumination level (lux value) increases, the video degradation caused by bit truncation becomes invisible. Alternatively, for distance and acceleration, the acceptance of video quality does not have a very obvious change when their values increase. Accordingly, *ambient illumination is the dominant viewing context factor for viewer experience.*

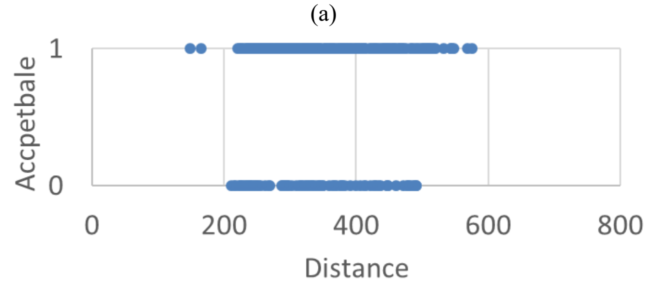
B. Decision Tree Model To connect ambient illumination and bit truncation

To connect the ambient illumination and number of truncated bits, we develop a decision tree model for decision making. As compared to other machine learning algorithms, the simplicity and fast speed of decision tree can bring a huge performance benefit in our system to achieve real time hardware adaptation. Our goal of training the model is to make each one of the processed videos able to be matched up with one viewing environment for maximum power saving.

We collected data by asking viewers to watch video samples with different numbers of bits truncated under different light conditions. The viewers will choose whether the quality of the video sample is acceptable or not. In the data collection process, 15 participants from North Dakota State University were invited. All the participants have normal vision, 4 of them are video processing experts. Three CIF video samples were used for this experiment, including *Akiyo*, *Coast* and *Foreman*, each one of these videos



(a)



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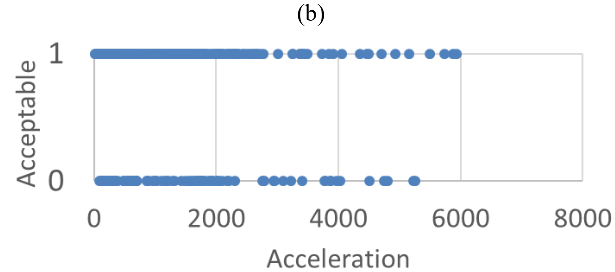

(c)

Figure 6. Video testing results. Each point on the graph represents one feedback we collected.

(a) *Akiyo* (b) *Coast* (c) *Foreman*

Figure 7. Three video samples used for data collection

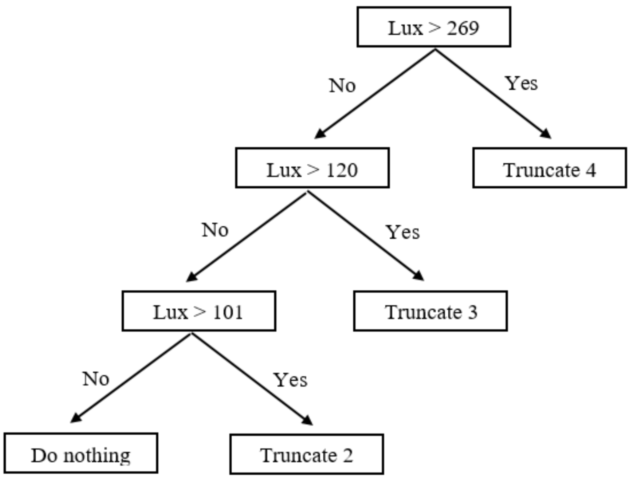

Figure 8. Decision tree for luminance and bit truncation

were processed to have 2, 3 and 4 bits truncated. We chose these three videos as our test samples due to the fact that they have different types of characteristics and they are widely used in video processing researches. *Akiyo* has very small motion vector change, *Foreman* has higher motion vector change and much brighter scene, and *Coast* has very high motion vector (Fig. 7).

The decision tree model was then built using MATLAB's machine learning toolbox. As shown in Fig. 8, each level of the tree represents a different luminance level. As the luminance level increases, additional LSBs can be truncated and viewers can tolerate a much lower video quality with power savings.

C. Impact of Body Movement and Viewing Distance on Viewer's experience with introduction of hardware noise

We further study the relationship between voltage scaling technique and the other two viewing context factors: viewing distance and body movement. We conducted another experiment to collect more data. In this experiment, participants were asked to watch videos with different body movements and different viewing distances. During this process, the video system randomly displays video samples with different voltage scaling levels from 3 bits scaled to 6 bits scaled, and viewers choose whether the video sample has noticeable error/noise under the current viewing context or not.

Fig. 9 shows the results with different viewing distances. As viewing distance increases, the number of unacceptable samples decreases. When the viewing distance is higher than 50cm, viewers can no longer notice any quality degradation.

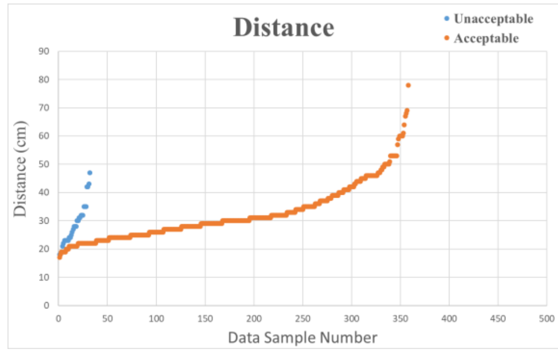

Figure 9. Acceptability and viewing distance

Our collected data shows that the body movement does not pose clear impact on viewer's experience in the presence of hardware noise (induced by voltage scaling). Viewers mentioned that if the noise dots generated by voltage scaling are spotted, then they can still be easily spotted even when the viewer is walking at a relatively high speed.

CONCLUSIONS AND FUTURE WORKS

Current mobile system designers are focusing on hardware-level power optimization techniques (device/circuit/system), but without consideration of how hardware performance interfaces with viewer experience. Such isolation significantly increases implementation overhead. In this paper, we break this isolation by introducing mobile viewer-awareness and hardware flexibility to achieve power optimization. We have studied the impact of viewer contexts on viewer experience and connected it to hardware design techniques. Based on that, we developed a decision-tree based model to enable run-time adaption and implemented the proposed system based on embedded system platform. Our future investigations would include incorporating the motions of videos in the viewer's experience study as well as combining the video characteristics to further enable energy-quality adaption adaptation across a wide variety of mobile videos.

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