Artefacts in Image and Video Systems: Classification and Mitigation

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Abstract

This paper reviews a range of image and video artefacts, their causes, and mitigation techniques. Due to processing and distortions in transmission, the final display of visual data may contain artefacts. These can be classified into four types based on their origin: capture, processing (coding and decoding), delivery and display.

The most significant cause of artefacts is the limited availability of bandwidth, and the tradeoffs associated with using this optimally.

Often objective measures of image quality are poorly correlated with perceived image quality. This makes the effectiveness of various mitigation techniques harder to quantify.

Keywords: image, video, artefacts, classification, coding, multipath, mitigation

1 Introduction

For the purpose of communication we need to acquire, process and deliver information, visual data, including images and video. In a multimedia environment, an image can be described as a two-dimensional representation of a scene or other visual data. Video can simply be treated as a sequence of images but often contains additional information such as timing or synchronization signals. Video also implies correlated audio, which is often included in the video stream. Audio artefacts are beyond the scope of this paper.

Images and video are strong forms of information in comparison to other forms of information such as text, sound and signs. When an item of visual data is used for a given medium, it is processed based on the constraints of the medium. Since each image and video contains a large quantity of data, delivery generally requires a high bandwidth. A common model for this process is shown in Figure 1. Fortunately, most image data contains significant redundancy in the form of high correlation of adjacent pixel values, and between adjacent frames of video.

2 Artefacts

When visual information is captured, processed and delivered to the final recipient, the displayed picture may differ from the original. Artefacts are any visible differences that are a direct result of some technical limitation at any stage of the communication process.

Image and video artefacts can be broadly classified into four types based on their origin. They are due to capture, processing (coding and decoding), delivery and display. They occur in both analogue and digital systems however some artefacts may be more prevalent or visible in one type of system.

2.1 Capture

Images and video are captured using cameras that comprise of an optical system and a sensor with processing circuitry. Artefacts based on capture will affect both analogue and digital systems as this is at the front end of the image acquisition. Reflected light from the object or scene forms an image on the sensor.

Optical imperfections distort the image captured; limited depth of field can make parts of the image appear defocused; non-uniform magnification leads to barrel or pincushion distortion; chromatic aberrations introduces colour fringing; and vignetting-decreasing intensity towards image corners due to lenses being faster in centre than periphery.

Capture artefacts may include visible effects due to interlaced scanning (see for example Figure 2), aliasing (both temporal and spatial), or distortion due to perspective. Area sampling on the sensor limits the resolution and can give rise to contrast inversions. With digital image capture, quantisation introduces additional noise, and can give contouring. Study of these artefacts and their mitigation is very important to avoid the propagation of artefacts.

Figure 2: Interlace artefact from panning camera

2.2 Processing

Once image or video data is captured it needs to be processed before delivery through the communication medium. This processing is required to meet constraints such as bandwidth limitations imposed by the medium and to provide immunity against medium noise.

There are many coding techniques for removing the redundancies in images and video. Coding can introduce artefacts

Figure 1. Image/Video processing model for communication

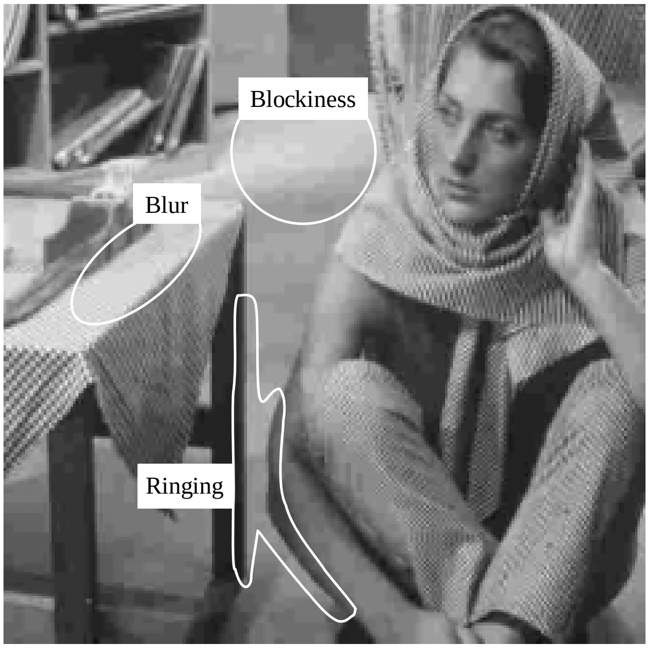

Figure 3. Blockiness, ringing and blur artefacts

such as reduced spatial and temporal resolution, and they are the common and dominant undesirable visible effects.

Blocking artefacts are the result of the independent processing of each block in block-based signal processing. Staircase noise is one form of blocking artefact, which appears when a block includes image edges; the edge is degraded such that the block bands looks like the edge. Grid noise is other form of artefact where slight change of image intensity along the block boundary becomes noticeable in areas with slowly varying intensity with position. Corner outliers are visible at the corner points of blocks, where the corner point is either much larger or much smaller than neighbouring pixels. Blockiness can be observed in low bit rate images, JPEG images, DCT coded images, MPEG video, multimedia and transform coded video.

Blur and ringing are artefacts that result from truncation or quantisation of coefficients in the frequency domain. Ringing artefacts typically appear as sharp oscillations along the edges of an object against a relatively uniform background. Any motion of the object in a video results in these oscillations flickering, giving mosquito noise.

The compression algorithms used, the picture content, and the origin of the source material influence the coding artefacts. The greatest technical limitation is the available bandwidth, which affects the compression ratio and data rate. In general, artefacts will become more visible as the compression ratio is increased.

Colour images have three independent variables to represent the colour information. They can be processed as red, green and blue components or some combination of them depending on the colour space used. In normal or standard definition analogue video, each of three primary colour signals requires a channel having 5MHz bandwidth. Early analogue television standards used a technique of frequency interleaving for backward compatibility with existing black and white systems. When colour information is frequency interleaved to the same luminance frequency band, it resulted in a composite signal, which could be delivered over a single channel. This resulted in cross-colour artefacts for high detailed video signals and cross-luminance artefacts with saturated colours.

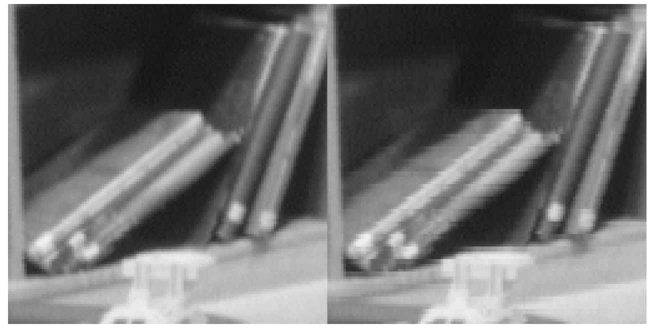

Figure 4: Line replication artefact from scan conversion

Scan conversion introduces artefacts when converting from one format to another [Lee et al. 2000; Ojo and Schoemaker 2000]. An example of these is line replication artefacts such as those shown in Figure 4. State-of-the-art field rate conversion uses motion-compensated up-conversion, which will avoid judder artifacts [Ojo and Schoemaker 2000].

2.3 Delivery

When data is transmitted through a medium, some of the data may be lost, distorted or may result in multiple data due to reflections. When data arrives through many paths in addition to the direct path, the distortion is known as multipath distortion and affects both analogue and digital communications. Multipath distortion or ghosting is the common form of artefact as depicted in Figure 5 in analogue television due to propagation [Williams 2001] and is the most severe form of artefact in analogue communication. In digital systems, multipath intersymbol interference is a common propagation distortion and robust modulation schemes such as orthogonal frequency division multiplexing (OFDM) are used to minimise ill effects [Lei et al. 1998; Chini et al. 1998; Negi et al. 1998]. Channel estimation is needed to recover the symbols when the reflections are severe. In digital communication systems, data recovery can be done without loss when the signal strength is over

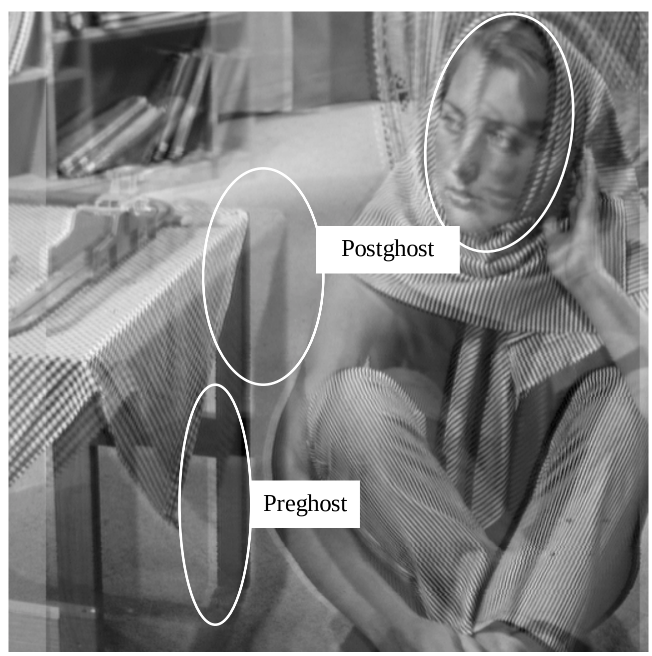

Figure 5. Ghosting artefacts

the threshold of the receiver. Noise and distortions can result in missing data blocks or data packets in digital systems. These errors are often propagated by subsequent processing when predictive coding is used. Motion compensation data is particularly vulnerable to this sort of error propagation.

Image and video delivery on mobile systems is creating demand on industrial and consumer applications. In low bit-rate video telephony service for mobile third generation systems, channel errors could introduce distortions to the video and audio resulting highly annoying artefacts [Dubec et al. 2001].

The conventional synchronous model of digital video, in which video is reconstructed synchronously at the decoder on a frame-by-frame basis, assumes its transport is delay-jitter-free. However in modern integrated service packet networks such as the Internet, network delay jitter varies widely [Chang et al. 1998].

If the delivery is via videotape or other analogue storage medium, there can be synchronisation jitter due to tape stretch or wear, or poor calibration of tape and drum speeds. These artefacts appear as a tearing of the lines in the image, as shown in Figure 6.

Figure 6: Synchronisation jitter.

2.4 Display

Display artefacts are due to poor contrast range, limited ability to reproduce colour, persistence in display devices and flicker resulting from interlaced scanning, resolution limitations, aspect ratio distortions, and blur and judder resulted from scan rate conversions. Haan and Klompenhouwer [2001] published an overview of flaws in emerging television displays and remedial processing.

In analogue television large area flicker due to low display frequencies and line flicker due to interlaced scanning are visible if the television is not equipped with a video up conversion. Though motion-compensated up-conversion is used to reduce flicker artefacts, incorrect motion vectors may introduces objectionable artefacts [Ojo and Schoemaker 2000]. With large displays, edge flicker is inevitable when the scanning is done in interlaced scheme.

3 Mitigation Techniques

Researchers have developed many techniques and algorithms to mitigate image and video artefacts. Artefacts can be reduced by system design. One of the examples is a colour component signal. In analogue television, when transmission is based on a composite base-band signal, which share the same transmission band for three pieces of information give rise to cross-colour and cross-luminance interference or artefact. Having three separate components for video information where bandwidth allows prevent these artefacts. Depending on the colour space used the three signals are RGB, YUV or Y(R-Y)(B-Y). However cross-colour, cross-luminance artefact mitigation is at the cost of other processing artefacts such as blockiness from increased compression needed to compensate for the wider input bandwidth.

Some researchers have proposed algorithms to define a metric for blockiness and then minimise that metric for the given blocky image.

3.1 Analogue systems

Multipath distortion can be mitigated by post processing at the terminal device by transmitting a reference signal [Greenberg 1993]. Analogue television broadcast systems can be equipped with a very robust ghost mitigation mechanism where broadcasters need to transmit a reference signal on one of the blanking lines during vertical retrace. This signal is used at the receiver to characterise the channel and to perform adaptive filtering. A world standard ghost cancellation signal was defined in the mid nineties and now high-end receivers in the consumer market are equipped with circuitry conforming to this standard [Greenberg 1993; Chini et al. 1998; Jeong et al. 2000; Huang 1993]. This mechanism enables ghosting to be almost completely eliminated. Appelhans and Schroder [1995] have researched on ghost cancellation for mobile television, which has greater problems because of the physical motion of the receiver. Many researchers have proposed new ghost cancellation reference signals [Al-saud et al. 1996; Fiallos et al. 1994; Yang et al. 1994]

In analogue video, early equipment had only composite interfaces. When colour signals to be processed for recording in professional or higher standard formats, luminance and chrominance signals need to be separated. Comb-filters have been used for many years and even expensive consumer models of televisions are equipped with comb-filters for cleaner luminance and chrominance signal separation.

For consumer television, field repetition and progressive scanning with field stores would mitigate large area flicker and line flicker. This may result in motion blur or motion judder. To reduce the introduction of motion artefacts, motion compensated up-conversion techniques are being developed for high-quality consumer display products. Error concealment or fallback in which the level depends on the estimated global image degradation can suppress the image degradation due to motion compensation artefacts. The fallback levels are based on the human perception properties [Ojo and Schoemaker 2000]. Edge directional line averaging interpolation technique reduces edge flicker in interlaced large displays [Lee et al. 2000].

3.2 Digital systems

Many researchers have developed algorithms and techniques to mitigate blocking artefacts. They can be broadly classified into pre-processing [Johnson 1998; Min 1998], post-processing, or some combination of the two [Mancuso 1998].

The simplest post-processing approach is low pass filtering to blur block boundaries. Statistical estimation and set-theoretic reconstruction methods improve on this by making use of the underlying image statistics. Statistical estimation methods use probabilistic models and maximum a priori probabilities to mitigate blocking artefacts. Set-theoretic reconstruction methods uses convex constraint set or the smoothness constraint set to reconstruct the original image by projection on to the convex set. The key idea in POCS is to represent every known property of the original image by a closed convex set. The solution is an image that is an element in all sets and can be found by alternating projections onto each set, starting from the blocky image itself [Gunturk et al. 2002; Patti and Altunbasak 2001; Jeong et al. 2000; Liu et al. 1998]. The post-processing algorithms include: the principle of POCS-Projection onto convex sets [Jeon and Jeong 2000; Paek et al. 1998; Kim et al. 2001], MRF (Markov random fields) [Meier et al. 1999], multi-frame constraint sets, maximum-likelihood parameter estimation [Yang et al. 2001], MAP-maximum a posteriori probability [Robertson and Stevenson 2001; Wang and Zhang 1998; Yang et al. 2000], entropy maximisation [Cao 1999], bayesian approaches [Mateos 2000], spatio-temporal concealment using boundary matching algorithm and mesh-based warping [Atzori et al. 2001], multilayer perception for adaptive processing [Qui 2000] and spatio-temporal adaptive filtering [Lee et al. 1998; Kim et al. 1999; Apostolopoulos and Jayant 1999; Chen et al. 2001; Paek et al. 2000; Park and Lee 1999; Castagno 1998; Kaup 1998]. One drawback of all of these algorithms is their high computational complexity. Any postprocessing should be able to efficiently remove blocking artefacts while preserving dominant edges, retaining the sharpness of the image and not introducing any new artefacts [Mextream 2001].

Carli et al. [2002] developed an error concealment technique by data hiding to mitigate blockiness appearing due to loss data packets in transmission. Data hiding techniques can be used to control errors and conceal them by transmitting the redundant information necessary at least to partially recover data lost during transmission.

The wavelet transform embedded data act as a reference signal for both error detection and concealment. Atzori et al. [2001] have developed a spatio-temporal concealment technique using boundary matching algorithm and mesh-based warping to conceal errors due to lost data packets in transmission.

Other techniques such as overlap coding, adaptive filtering, application of singularity detection and wavelet transform [Hsung and Lun 1998; Kim et al. 1998], wavelet-based sub-band decomposition [Choi and Kim 2000], adaptive lapped transform [Malvar 1998], a modified uniform quantisation scheme that constrains local regularity [Carey et al. 1999], and wavelet transform modulus maxima can be used to mitigate above coding artefacts.

Source coding and channel coding are used in communication to minimise the effects of transmission errors. Source coding techniques are efficient only if the error rate is below an acceptable level (usually in the order of 10^{-6}~10^{-7}). Unequal error protection schemes reduce significantly the occurrence of highly annoying audio and video artefacts [Dubec et al. 2001].

Experimental results of Chang et al. [1998] indicate that introducing temporal jitter in video rendering without degrading video quality can be managed with a technique called delay cognizant video coding (DCVC). DCVC segments an incoming video into two video flows with different delay attributes. The DCVC decoder operates in an asynchronous reconstruction mode that attempts to maintain image quality in the presence of network delay jitter [Chang 1998].

4 Quality metrics

Often objective measures such as Mean Square Error, Root Mean Square, Signal to Noise Ratio and Peak Signal to Noise Ratio are only poorly correlated with perceived image quality. For example, dithering, the process of adding quantizing or spatial noise to reduce contouring or other alias artefacts will make the objective measures such as mean square error worse but improve the subjective appearance of the image.

Due to limitations in the quality metrics, it is important to develop quality metrics that are tied to the human visual system. Impairment metrics have been developed based on Human Visual System model and an extension of such a vision model. Researchers have presented extensions to the vision model by introducing a segmentation tool to partition the areas of the sequence into classes. A particular metric is then run on each class to estimate how the particular features of each class are rendered.

Yang et al. [2000] have done research on noise estimation for blocking artefacts. Researchers have developed metrics to estimate the level of blockiness and have used that indicator to assess the performance of some blockiness reduction algorithms [Bailey et al. 2002; Chang et al. 1998]. Fenimore et al. [2000] developed test patterns and metrics for MPEG compressed video.

Different coding schemes introduce different artefacts to the decoded pictures, making it difficult to design an objective quality model capable of measuring all of them. Tan and Ghanbari [2000] proposed a multi-metric model comprising of a perceptual model and a blockiness detector. This approach combines a picture quality model for each kind of known distortion according to the perceptual impact of each type of impairment.

5 Conclusions

In this review paper, we have presented an overview of artefacts, their causes, and their mitigation in image and video systems. Artefacts are classified into four types based on origin as per the simple model presented.

While the volume of data and processing power are being increased, usable spectrum per user is diminishing. Hence it is important that modern digital communication systems are able to handle the spectrum efficiently. With increasing processing power available at terminal equipment, it is possible to improve the quality of images and video to be displayed by mitigating the artefacts. However most existing techniques focus only on single types of artefact. There is a need for more comprehensive and systematic approach to artefact reduction.

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