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Part 9:
Film grain synthesis technology for video applications

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Partie 9: Technologie de la synthèse du grain de film pour les applications vidéo

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Foreword

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This document was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 29, *Coding of audio, picture, multimedia and hypermedia information*, in collaboration with ITU-T (as ITU-T twin H.Sup-FGST).

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Introduction

Film grain synthesis technology can provide subjective quality benefits for certain video applications and can be used to effectively achieve improved video compression. The use of such technology can involve pre-processing to reduce film grain and sensor noise that is present in a video or image signal prior to compression. Metadata information can then be conveyed to a decoder and used to synthesize noise with similar characteristics as in the original content as a post-processing stage that follows the compression decoding process. This metadata can be signalled using appropriate mechanisms, such as the supplemental enhancement information messages that are supported by several video coding standards.

This document provides a referenceable overview of the end-to-end processing steps for film grain and sensor noise removal, estimation, parameterization, synthesis, and blending for consumer distribution applications. This document includes examples of encoder-side and post-decoding processing steps for grain blending for some of the currently defined technologies.

Information technology — MPEG video technologies —

Part 9:
Film grain synthesis technology for video applications

1 Scope

This document provides a description of the film grain synthesis technology in video applications, including for use with Rec. ITU-T H.264 | ISO/IEC 14496-10, Rec. ITU-T H.265 | ISO/IEC 23008-2 and Rec. ITU-T H.266 | ISO/IEC 23090-3.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Rec. ITU-T H.264 | ISO/IEC 14496-10, *Information technology — Coding of audio-visual objects — Part 10: Advanced video coding*

Rec. ITU-T H.265 | ISO/IEC 23008-2, *Information technology — High efficiency coding and media delivery in heterogeneous environments — Part 2: High efficiency video coding*

Rec. ITU-T H.266 | ISO/IEC 23090-3, *Information technology — Coded representation of immersive media — Part 3: Versatile video coding*

Rec. ITU-T H.274 | ISO/IEC 23002-7, *Information technology — MPEG video technologies — Part 7: Versatile supplemental enhancement information messages for coded video bitstreams*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in Rec. ITU-T H.264 | ISO/IEC 14496-10, Rec. ITU-T H.265 | ISO/IEC 23008-2, Rec. ITU-T H.266 | ISO/IEC 23090-3 and Rec. ITU-T H.274 | ISO/IEC 23002-7 apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 Abbreviated terms

AFGS1	AOMedia film grain synthesis 1
AVC	Advanced video coding (Rec. ITU-T H.264 | ISO/IEC 14496-10)
DCT	Discrete cosine transform
FGS	Film grain synthesis
FGC	Film grain characteristics
HD	High definition
HEVC	High efficiency video coding (Rec. ITU-T H.265 | ISO/IEC 23008-2)
IDCT	Inverse discrete cosine transform
LFS	Linear feedback shift register
LUT	Look-up table
MCTF	Motion-compensated temporal filtering
SD	Standard definition
SEI	Supplemental enhancement information
UHD	Ultra-high definition
VSEI	Versatile supplemental enhancement information (Rec. ITU-T H.274 | ISO/IEC 23002-7)
VVC	Versatile video coding (Rec. ITU-T H.266 | ISO/IEC 23090-3)

5 Conventions

5.1 General

The mathematical operators used in this document are similar to those used in the C programming language. However, the results of integer division and arithmetic shift operations are defined more precisely, and additional operations are defined, such as exponentiation and real-valued division. Numbering and counting conventions generally begin from 0, e.g. "the first" is equivalent to the 0-th, "the second" is equivalent to the 1-th, etc.

5.2 Arithmetic operators

The following arithmetic operators are defined as follows:

+	Addition
−	Subtraction (as a two-argument operator) or negation (as a unary prefix operator)
*	Multiplication, including matrix multiplication
x^y	Exponentiation. Denotes x to the power of y. In other contexts, such notation is used for superscripting not intended for interpretation as exponentiation.
/	Integer division with truncation of the result towards zero. For example, 7 / 4 and (−7) / (−4) are truncated to 1 and (−7) / 4 and 7 / (−4) are truncated to −1.

÷ Used to denote division in mathematical formulae where no truncation or rounding is intended.

$\frac{x}{y}$ Used to denote division in mathematical formulae where no truncation or rounding is intended.

$\sum_{i=x}^{y} f(i)$ The summation of f(i) with i taking all integer values from x up to and including y.

x % y Modulus. Remainder of x divided by y, defined only for integers x and y with x >= 0 and y > 0.

5.3 Bit-wise operators

The following bit-wise operators are defined as follows:

& Bit-wise "and". When operating on integer arguments, operates on a two's complement representation of the integer value. When operating on a binary argument that contains fewer bits than another argument, the shorter argument is extended by adding more significant bits equal to 0.

| Bit-wise "or". When operating on integer arguments, operates on a two's complement representation of the integer value. When operating on a binary argument that contains fewer bits than another argument, the shorter argument is extended by adding more significant bits equal to 0.

^ Bit-wise "exclusive or". When operating on integer arguments, operates on a two's complement representation of the integer value. When operating on a binary argument that contains fewer bits than another argument, the shorter argument is extended by adding more significant bits equal to 0.

x >> y Arithmetic right shift of a two's complement integer representation of x by y binary digits. This function is defined only for non-negative integer values of y. Bits shifted into the MSBs as a result of the right shift have a value equal to the MSB of x prior to the shift operation.

x << y Arithmetic left shift of a two's complement integer representation of x by y binary digits. This function is defined only for non-negative integer values of y. Bits shifted into the LSBs as a result of the left shift have a value equal to 0.

5.4 Assignment operators

The following assignment operators are defined as follows:

= Assignment operator

++ Increment, i.e. x++ is equivalent to x = x + 1; when used in an array index, evaluates to the value of the variable prior to the increment operation.

− − Decrement, i.e. x− − is equivalent to x = x − 1; when used in an array index, evaluates to the value of the variable prior to the decrement operation.

+= Increment by amount given, i.e. x += 3 is equivalent to x = x + 3, and x += (−3) is equivalent to x = x + (−3).

−= Decrement by amount given, i.e. x −= 3 is equivalent to x = x − 3, and x −= (−3) is equivalent to x = x − (−3).

5.5 Relational, logical and other operators

The following operators are defined as follows:

== Equality operator

!= Not equal to operator

!x Logical negation "not"

> Larger than operator

< Smaller than operator

>= Larger than or equal to operator

<= Smaller than or equal to operator

&& Conditional/logical "and" operator. Performs a logical "and" of its Boolean operators, but only evaluates the second operand if necessary.

|| Conditional/logical "or" operator. Performs a logical "or" of its Boolean operators, but only evaluates the second operand if necessary.

a ? b : c Ternary conditional. If condition a is true, then the result is equal to b; otherwise the result is equal to c.

5.6 Range notation

y..z range operator/notation.
This function is defined only for integer values of y and z. When z is larger than or equal to y, it defines an ordered set of values from y to z in increments of 1. Otherwise, when z is smaller than y, the output of this function is an empty set. If this operator is used within the context of a loop, it specifies that any subsequent operations defined are performed using each element of this set, unless this set is empty.

5.7 Mathematical functions

The following mathematical functions are defined as follows:

$$\text{Abs}(\,x\,) = \begin{cases} x & ; \quad x >= 0 \\ -x & ; \quad x < 0 \end{cases}$$

Ceil(x) the smallest integer greater than or equal to x.

$$\text{Clip3}(\,x, y, z\,) = \begin{cases} x & ; \quad z < x \\ y & ; \quad z > y \\ z & ; \quad \text{otherwise} \end{cases}$$

Floor(x) the smallest integer lower than or equal to x.

$$\text{Min}(\,x, y\,) = \begin{cases} x & ; \quad x <= y \\ y & ; \quad x > y \end{cases}$$

5.8 Order of operations

When order of precedence in an expression is not indicated explicitly by use of parentheses, the following rules apply:

— Operations of a higher precedence are evaluated before any operation of a lower precedence.

— Operations of the same precedence are evaluated sequentially from left to right.

Table 1 specifies the precedence of operations from highest to lowest; a higher position in the table indicates a higher precedence.

NOTE For those operators that are also used in the C programming language, the order of precedence used in this document is the same as that used in the C programming language.

Table 1 — Operation precedence from highest (at top of table) to lowest (at bottom of table)

operations (with operands x, y, and z)
"x++", "x−−"
"!x", "−x" (as a unary prefix operator)
x^y
"x * y", "x / y", "x ÷ y", "$\frac{x}{y}$", "x % y"
"x + y", "x − y" (as a two-argument operator), "$\sum_{i=x}^{y} f(i)$"
"x << y", "x >> y"
"x < y", "x <= y", "x > y", "x >= y"
"x == y", "x != y"
"x & y"
"x | y"
"x && y"
"x || y"
"x ? y : z"
"x..y"
"x = y", "x += y", "x −= y"

6 Overview of film grain technologies

6.1 General

This clause provides an overview of film grain technologies in the context of video/image compression and distribution. It includes historical information on the development of such technologies in subclause 6.2, information on some of the use cases and applications in subclause 6.3, and a high-level description of film grain modelling in subclause 6.3. More details are provided in subsequent clauses as follows:

— Clause 7 describes some of the already defined film grain synthesis technologies, and in particular the frequency filtering and autoregressive models.

— Clause 8 provides examples of technologies that can be used for film grain analysis, including techniques for video denoising, edge and complex texture detection, film grain characteristic analysis, and model parameter estimation.

— Clause 9 describes some of the film grain metadata that have already been defined in current image/video coding standards and specifications, and how each metadata is interpreted, if appropriate, in the context of the frequency filtering and autoregressive models.

— Example implementations of such technologies are then described in Annex A and Annex B.

6.2 Film grain technical characteristics

The multimedia distribution industry began using celluloid (analogue) film as the medium for capture, editing and distribution. Content distribution evolved to analogue technology and then digital technologies. During this evolution, the attraction to the visual characteristics of analogue film did not fade. Due to its physical nature, analogue film produced a visual experience that was appreciated by many. Film grain is one of the characteristics of analogue film and is considered a primary contributor to the visual appearance of analogue film, e.g. film look or also known as the cinematic look. Film grain is a product of the physical characteristics of analogue film. It refers to the spatiotemporal variations in optical density of processed film that resulted from photographically developing the light-exposed silver-halide crystals dispersed in photographic emulsion.[1] Images are thus formed by exposure and the development of these crystals. In colour images, where the silver is chemically removed after development, dye clouds (like soft, tiny grains) are formed on the sites where the silver crystals have been exposed. Grains are randomly distributed in the resulting image because of the random formation of silver crystals in the original emulsion. The naked eye cannot distinguish individual grains, which are about 2 microns down to about a tenth of that in size. Instead, the eye resolves groups of grains in an image, that an observer identifies as a grainy look that is commonly called “film grain”. This is illustrated in Figure 1. Another example is shown in Figure 2, with a different colour image formation process called “autochrome”. This was one of the first colour image techniques invented by Auguste and Louis Lumière in 1903, where a classical black and white photo emulsion was exposed through a colour filter made of a fine dust of potato starch dyed with different colours.

In general, the higher the image resolution, the higher likelihood for perception of film grain. Film grain can be clearly noticeable in cinema and high definition (HD) images; although it progressively loses importance in standard definition (SD) images and becomes imperceptible in smaller formats as described in Reference [2].

a) 4000 dots per inch (2.54 cm) scan of 2 mm × 2 mm area

b) raw negative 500× microscope view of 0.1 mm × 0.1 mm area

Figure 1 — Fuji Superia™[1)] 400 film

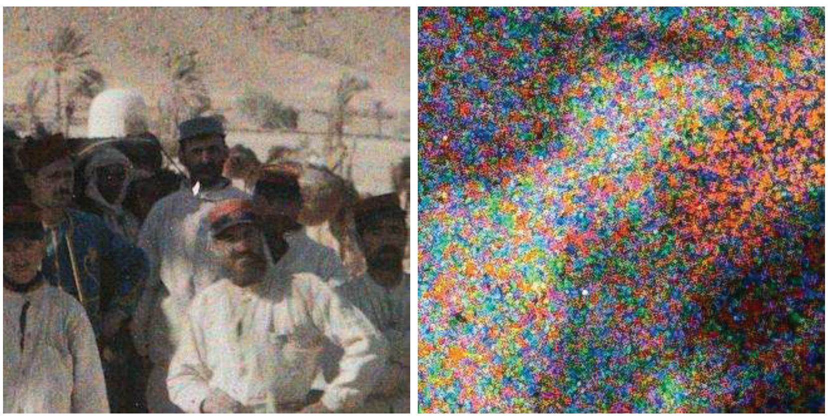

Figure 2 — 24 mm × 24 mm and 2.2×2.2 mm crops of a 1916 autochrome picture (13 cm × 18 cm glass plate) photograph by Albert Samama Chikly, scan courtesy of Ministère de la Culture / RMN-GP (France)

1) Fuji Superia™ 400 is an example of film product available commercially. This information is given to describe examples used in this document and does not constitute an endorsement by ISO or IEC of the use of this product.

Film grain appearance is therefore inevitable because of the physical nature of the process embedded in the film design itself. However, historically, it was considered as noise, and as such, technological advances have gone in the direction of its elimination.

The silver-halide crystals were engineered to be smaller and less visible, however due to the physical design and characteristics of analogue film, it was not possible to completely eliminate the grainy look. With the advancements of digital camera sensors and their widespread utilization, the grainy look has been mostly eliminated. Although digital sensors have brought many possibilities in terms of visual quality and visual processing, the "film look" lives on among professionals and film enthusiasts. Within the new era, film grain has turned into a visual tool and not just a by-product of chemical processing as in the case of analogue film stock.

Note that the term film grain also includes synthetic film grain that can be added in post-production to digitally captured high-value content for artistic effect or to mask imperfections in digital footage, which can otherwise look too sharp and unnatural. The term "film grain" can sometimes be used informally to refer to image sensor noise, particularly in low light and high-speed captures.

Therefore, perception of moderate grain texture is a desirable, often sought after, characteristic in motion picture and video productions. Although the exact effect of the grain is not clear, it is considered a requirement in the motion picture industry to preserve the grainy appearance of images throughout the image processing and delivery chain. Intuitively, in this context, the presence of film grain can help to differentiate 'real-world' images from 'computer-generated' material, which are commonly created with no film grain. Furthermore, it is possible that film grain provides some visual cues that facilitate the correct perception of depth in two-dimensional pictures.[2] Even when movies are captured with digital cameras, artificial film grain can be added at a post-processing stage to create a specific look, which artists qualify as "soft", "organic", or "living". Synthetic film grain is also used to harmonize capture from different cameras, potentially mixing film and digital capture and different lighting conditions.

Film grain preservation during video distribution, and especially when targeting low bitrate applications, can be challenging for two reasons. First, compression gains related to temporal prediction cannot be fully leveraged because of the random nature of the grain. Film grain noise is temporally independent, and as a result, motion compensation cannot be efficiently used for its prediction. Second, the grain commonly appears at high spatial frequencies, and it is typically filtered with other noise by in-loop filters, such as deblocking filters, or due to the quantization process.[2] This challenge is more severe with recent coding formats, as bitrate gains have come along with noise elimination. In addition, introduction of pre-filtering in the video distribution chain can potentially remove film grain prior to compression. The use of quantization matrices[3],[4] could potentially assist in the preservation of some of the film grain within the video content, however this also can have severe limitations, especially at lower bitrates, and for streaming applications.

This report focuses on film grain technology from the video compression and distribution point of view. It includes encoder-side and decoder-side aspects. On the encoder side, film grain technology provides means to denoise and/or analyse source video to improve compression and to determine statistical characteristics of the film grain to be synthesized at the decoder. At the decoder side, film grain technology provides the means to synthesize and blend film grain with the decoded video.

6.3 Film grain modelling

To synthesize grain, use of light-dependent film grain model parameters can be useful, particularly for the simulation of photographic film grain, as photographic film grain is intrinsically light intensity (exposure) dependent. First, variation of film opacity is the result of a variation of grain density, as seen in Figure 1, which has an impact on the perceived grain. Also, film is organized in several layers (usually 3) for each colour component, with various light sensitivities to reach to its full dynamic range. Light-sensitive crystals have a distribution of sizes. Larger crystals capture more photons and are more likely to be exposed than smaller crystals, particularly in darker regions. This results in a dependency of the noise characteristics on brightness. An example with both grain size and strength variation is shown in Figure 3.

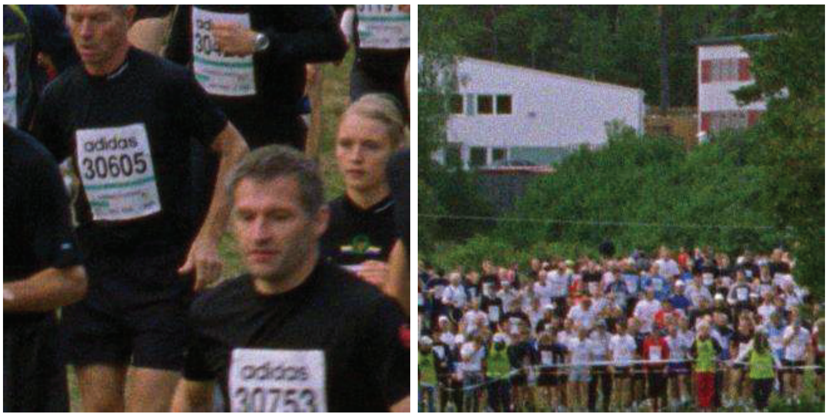

Figure 3 — Kodak Vision™[2)] 250D film and 3063 dots per inch (2.54 cm) scan of 2.7×2.7 mm areas of the same picture

6.4 Film grain use cases and applications

Two main film grain use cases are presented below:

a) The first use case of film grain synthesis is artistic intent: recreate the film grain at the decoder side, which was unavoidably lost by compression involved in content distribution at practical bitrates. In this case, the film grain is considered to be a significant aspect of the video, and the content provider wants it to be part of the user experience. Preserving film grain through video compression would require too high bit rates for applications such as adaptive streaming and broadcasting. On the other hand, removing film grain allows using the full potential of video compression technologies, while requiring film grain synthesis after decoding.

b) The second use case, which can also complement the first one, is the masking of compression impairments, like blocking, banding, "mosquito" noise, etc., including impairments due to quantization. If there is no artistic intent, then the constraints on film grain model accuracy can be relaxed. For this use case, the encoder can adjust film grain parameters to fit the coding parameters, so that the intended defect masking is effective (e.g. by adjusting noise amplitude based on quantization step sizes).

It was determined that removing the film grain by filtering the content, compressing, and providing information that enables the regeneration of the film grain, even if that is just an approximation, can result in more efficient coding performance and a better visual outcome. This is called film grain modelling. The use of film grain modelling technologies can be beneficial for image and video compression by providing improved subjective quality at a lower bitrate for certain types of video content. For example, these technologies can potentially provide benefits to video content that contains noise, such as film grain or image sensor noise.

Thus, film grain modelling technologies provide a means of optionally removing noise prior to or during the encoding process to improve compression efficiency and, subsequently, to reconstruct an approximation of the film grain during or after the decoding process. It can also be used to add visual noise to decoded video to mask or attenuate the visibility of compression artefacts. Note here that visually pleasant noise can be added to the decoded video even if the source video had no visible noise/film grain to fulfil the masking task mentioned above.

6.5 Film grain workflow

Use of film grain modelling technologies to denoise a source video by using a pre-processor is illustrated in Figure 4. Source video is input to a denoising process that outputs a video sequence from which noise or film grain is attenuated or removed. A film grain parameterization process then compares the source and denoised videos to determine film grain model parameter values, which relate to the variance, spatial frequency characteristics, colour correlation, and other statistical characteristics of the film grain. The

2) Kodak Vision™ 250D is an example of film product available commercially. This information is given to describe examples used in this document and does not constitute an endorsement by ISO or IEC of the use of this product.