International Standard

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Information technology — Plenoptic image coding system (JPEG Pleno) —

Part 5: **Holography**

Technologies de l'information — Système de codage d'images plénoptiques (JPEG Pleno) —

Partie 5: Holographie

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Contents

Foreword

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A list of all parts in the ISO/IEC 21794 series can be found on the ISO and IEC websites.

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Introduction

This document is part of a series of standards for a system known as JPEG Pleno and defines JPEG Pleno Holography. It specifies a codec mechanism for holographic modalities and associated codestream syntax and file format elements. JPEG Pleno Holography allows for efficient compression of holograms for a wide range of applications such as holographic microscopy, tomography, interferometry, printing and display and their associated hologram types. Key functionalities include support for both lossy and lossless coding, scalability, random access, and integration within the system architecture of the JPEG Pleno framework.

Information technology — Plenoptic image coding system (JPEG Pleno) —

Part 5:
Holography

1 Scope

This document defines the syntax and an accompanying decompression process that is capable of representing binary and continuous-tone holograms while supporting one or multiple color/spectral components. The supported compression mechanisms are lossless for binary holograms and lossy for continuous-tone holograms. Additional information on the encoding tools is provided as well. The document also defines extensions to the JPEG Pleno File Format and associated metadata descriptors specific to holographic modalities.

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.

ISO/IEC 21794-1:2020, *Information technology — Plenoptic image coding system (JPEG Pleno) — Part 1: Framework*

ISO/IEC 21794-2:2021, *Information technology — Plenoptic image coding system (JPEG Pleno) — Part 2: Light field coding*

ISO/IEC 21794-3, *Information technology — Plenoptic image coding system (JPEG Pleno) — Part 3: Conformance testing*

ISO/IEC 21794-4, *Information technology — Plenoptic image coding system (JPEG Pleno) — Part 4: Reference software*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 21794-1, ISO/IEC 21794-2, ISO/IEC 21794-3, ISO/IEC 21794-4 and the following 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/ui

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

3.1
holography
technique based on coherent light allowing for the recording and reconstruction of a wavefront, thereby encoding three-dimensional information about objects

Note 1 to entry: This has many applications, including 3D display technology, microscopy, tomography, interferometry, telecommunications, data storage, and non-destructive testing.

3.2
hologram
two-dimensional representation of the complex-valued coherent wavefield of light encoding an interference pattern describing the amplitude and phase of the scalar wavefield

Note 1 to entry: This pattern may be encoded directly in the spatial domain or indirectly using optical transformations such as Fourier-transforming lens systems, magnification, or modulation.

3.3
digital hologram
one or more two-dimensional arrays of coefficients representing the sampled coherent wavefield of light

3.4
tile
a spatial segment of a digital hologram, each coded independently

3.5
window block
unit of a series of 2D windows over the propagated hologram's input coefficients, corresponding to 2D contiguous subsets of input coefficients and serving as input for the STFT

3.6
transform block
coefficient set resulting from applying a transform to a tile

3.7
code block
input coefficient set of the arithmetic coding within a transform block, where each code block is independently arithmetically encoded

3.8
quantization block
unit of quantization within a code block

3.9
transform size
4-tuple of positive integers, describing the number of elements along each dimension of the entire set of coefficients after applying the transform step, which is represented by a 4D array

3.10
source hologram
uncompressed input hologram

3.11
decoded hologram
output decompressed hologram decoded back into raw hologram samples

4 Symbols and abbreviated terms

4.1 Symbols

H	Digital hologram
λ_i	The wavelength of the ith colour channel at which the hologram was recorded or generated
$\odot$	Hadamard product
$\mathcal{F}$, $\mathcal{F}^{-1}$	Forward and reverse two-dimensional Fourier transform

$\boldsymbol{S}$, $\boldsymbol{S}^{-1}$	Forward and reverse two-dimensional FFTSHIFT operator. This operation rearranges Fourier transform coefficients by shifting the zero-frequency component to the centre of the array, matching its conventional mathematical representation.
H_i	Ith monochrome component of the digital hologram *H;* Corresponds to λ_I.
p	Hologram pixel pitch sampled on a square lattice
d	Distance parameter for propagation operator
x, y	Symbols for the first and second spatial dimensions
f_x , f_y	Symbols for the first and second frequency dimensions
NT	Number of tiles
NCB	Number of code blocks per tile
NQB	Number of quantization blocks per tile
$XThoc$, $YThoc$	Tile x and y dimensions
$XTcod$, $YTcod$, $UTcod$, $VTcod$	Power of 2 exponents of the four-dimensional transform block dimensions
$XCBcod$, $YCBcod$, $UCBcod$, $VCBcod$	Power of 2 exponents of the four-dimensional code block dimensions
$XQBcod$, $YQBcod$, $UQBcod$, $VQBcod$	Power of 2 exponents of the four-dimensional quantization block dimensions
$\mathcal{Q}$, $\mathcal{Q}^{-1}$	Mid-rise quantizer and dequantizer
Λ_1 , Λ_2	Lagrangian multipliers for systems 1 and 2, respectively

4.2 Abbreviated terms

2D	Two-dimensional
4D	Four-dimensional
CB	Code block
CBP	Code block payload
DFT	Discrete Fourier transform
FFTSHIFT	Fourier transform coefficient shifting operator
L2	Euclidean norm
MRQ	Mid-rise quantizer
MRDQ	Mid-rise dequantizer
QB	Quantization block
QBP	Quantization block payload
RDO	Rate-distortion optimization

SNR Signal-to-noise ratio

STFT Short-time Fourier transform

TB Transform block

5 Conventions

5.1 Naming conventions for numerical values

Integer numbers are expressed as bit patterns, hexadecimal values, or decimal numbers. Bit patterns and hexadecimal values have both a numerical value and an associated length in bits.

Hexadecimal notation, indicated by prefixing the hexadecimal number with "0x", may be used instead of binary notation to denote a bit pattern having a length that is an integer multiple of 4. For example, 0x41 represents an eight-bit pattern with only its second most significant bit and its least significant bit equal to 1. Numerical values that are specified under a "Code" heading in tables that are referred to as "code tables" are bit pattern values (specified as a string of digits equal to 0 or 1 in which the left-most bit is considered the most significant bit). Other numerical values not prefixed by "0x" are decimal values. When used in expressions, a hexadecimal value is interpreted as having a value equal to the value of the corresponding bit pattern evaluated as a binary representation of an unsigned integer (i.e. as the value of the number formed by prefixing the bit pattern with a sign bit equal to 0 and interpreting the result as a two's complement representation of an integer value). For example, the hexadecimal value 0xF is equivalent to the 4-bit pattern '1111' and is interpreted in expressions as being equal to the decimal number 15.

5.2 Operators

NOTE Many of the operators in this document are similar to those in the C programming language.

5.2.1 Arithmetic operators

\+ Addition

− subtraction (as a binary operator) or negation (as a unary prefix operator)

× Multiplication

/ division without truncation or rounding

<< left shift; `x<<s` is defined as $x \times 2^s$

>> right shift; `x>>s` is defined as $\lfloor x/2^s \rfloor$

++ increment with 1

-- decrement with 1

umod Unsigned modulo operator; x umod a is the unique value y between 0 and a–1 for which y+Na = x with a suitable integer N

& bitwise AND operator; compares each bit of the first operand to the corresponding bit of the second operand
If both bits are 1, the corresponding result bit is set to 1. Otherwise, the corresponding result bit is set to 0.

^ bitwise XOR operator; compares each bit of the first operand to the corresponding bit of the second operand
If both bits are equal, the corresponding result bit is set to 0. Otherwise, the corresponding result bit is set to 1.

5.2.2 Logical operators

|| logical OR

&& logical AND

! logical NOT

5.2.3 Relational operators

> greater than

>= greater than or equal to

< less than

<= less than or equal to

== equal to

!= not equal to

5.2.4 Precedence order of operators

Operators are listed in descending order of precedence. If several operators appear in the same line, they have equal precedence. When several operators of equal precedence appear at the same level in an expression, evaluation proceeds according to the associativity of the operator, either from right to left or from left to right.

Operators	Type of operation	Associativity
()	Expression	left to right
[]	indexing of arrays	left to right
++, --	increment, decrement	left to right
!, –	logical not, unary negation	
×, /	multiplication, division	left to right
umod	unsigned modulo (remainder)	left to right
+, –	addition and subtraction	left to right
&	bitwise AND	left to right
^	bitwise XOR	left to right
&&	logical AND	left to right
||	logical OR	left to right
<<, >>	left shift and right shift	left to right

< , >, <=, >=	Relational	left to right

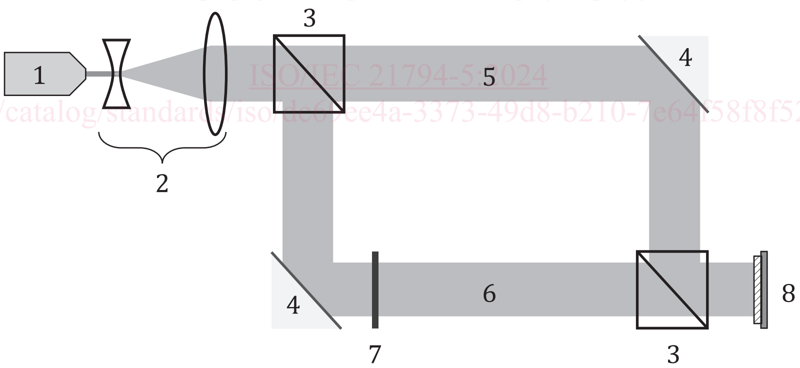
5.2.5 Mathematical functions

$\lvert x \rvert$	absolute value, is $-x$ for $x < 0$, otherwise x
sign(x)	sign of x, zero if x is zero, +1 if x is positive, -1 if x is negative
clamp(x,min,max)	clamps x to the range [min,max]: returns min if $x < min$, max if $x > max$ or otherwise x
$\lceil x \rceil$	ceiling of x; returns the smallest integer that is greater than or equal to x
$\lfloor x \rfloor$	floor of x; returns the largest integer that is less than or equal to x
$\lfloor x \rceil$	rounding of x to the nearest integer, equivalent to

6 Representation of digital holograms

6.1 Digital holograms and their signal properties

Like conventional images, holograms can be optically recorded, computer-generated, or some hybrid thereof. A classic holographic recording setup utilizes interferometry, where a coherent, monochromatic light beam is split into a reference beam and an object beam. Only the object beam will illuminate the sample to be imaged, after which both beams are recombined, forming an interference pattern (cf. Figure 1). This pattern encodes the complex-valued amplitudes of the object wavefront, thus describing both the wavefront amplitude and phase. Alternatively, one can utilize numerical diffraction simulations in virtual objects and scenes to compute the hologram pattern, called computer-generated holography. Although this approach is not limited by the physics of an optical setup, such as geometrical constraints or optical component nonidealities, it tends to require significant computational resources to calculate.



Key

1 laser
2 beam expander
3 beam splitter
4 mirror
5 reference beam
6 object beam
7 sample
8 image sensor

Figure 1 — Simplified diagram of a holographic recording setup, in case of a transparent sample, with corresponding legend.

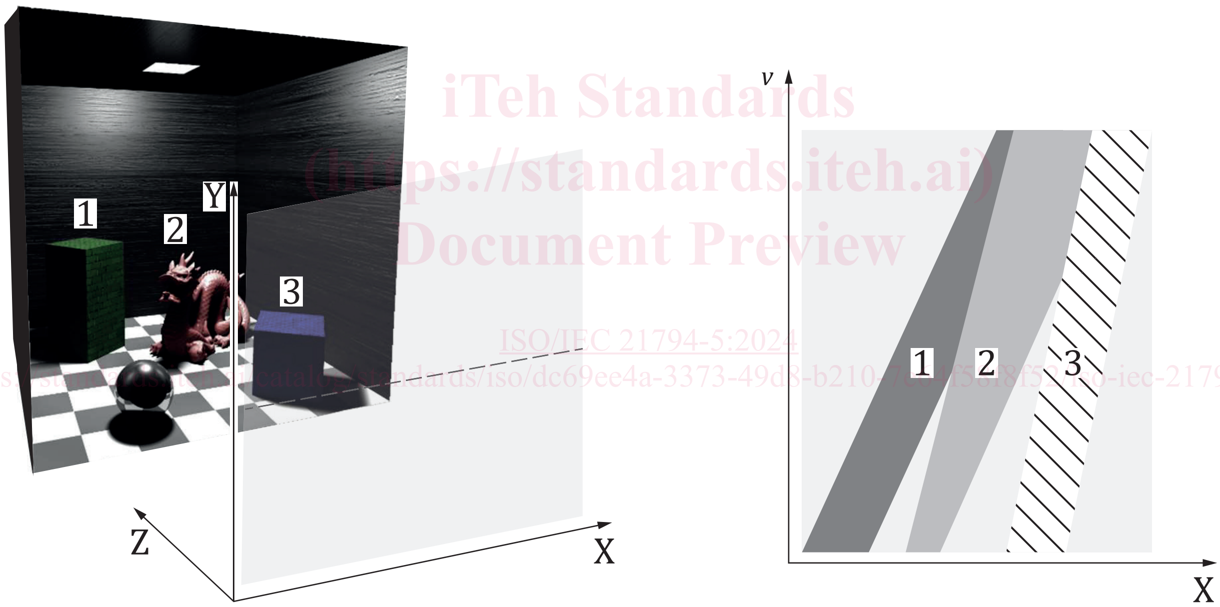
However, holography is often confused with other display techniques that do not involve interference. Many systems that claim to be "holographic" consist of various projection systems that display flat images in mid-air, using, for example, semi-transparent screens. These "false holograms" are produced by technologies such as Pepper's ghost illusion (or its modern variants), lenticular printing, and volumetric displays. These technologies are not addressed in this standard.

Holograms and discrete light fields (hereupon just called "light fields") are closely related, as both representations encode spatial and angular information. A full-parallax light field can be represented by a 4D array of rectilinear samples with two spatial and two angular dimensions, as specified in ISO/IEC 21794-2.

Because of the discrete sampling, light fields will have a discretized motion parallax and limited depth cues, but they will have fewer samples than a hologram to cover the same spatio-angular range and work with incoherent light. In contrast, holograms can account for all human visual cues, including continuous motion parallax and exact eye-focusing cues.

In holography, frequency components correspond to plane waves whose propagation angle is proportional to the frequency magnitude. Thus, one can characterize the relationship to light fields by looking at phase space, jointly representing space and frequency data using, e.g., a spectrogram. (cf. Figure 2). This matches closely with the spatio-angular phase space of 4D light fields.

This relationship was the primary rationale for utilizing the short-time Fourier transform for hologram compression in this specification. The size of the transform window will dictate the trade-off between spatial and angular resolution.



a) 3D scene with numbered (coloured) objects, creating a hologram in the x-y plane, analyzing the signal along the dashed horizontal line

b) corresponding spatio-frequency phase diagram, with matching numbered (coloured) footprints in phase space

Key

X space

v frequency

Figure 2 — Relationship between objects in 3D space and the phase space representation.

The hologram sample values are represented by discretized two-dimensional arrays of coefficients. These coefficients may encode the complex-valued amplitudes in whole or in part, for example, by only encoding the phase, the real part, or the amplitude of the complex coefficients. Moreover, the hologram coefficients may have different levels of precision, ranging from floating-point numbers down to 1 bit per pixel, denoted as "binary holograms."

A hologram consists of one or more arrays with the same dimensions, denoted "channels," representing different colour components. Every channel may have different wavelengths and pixel pitches.

6.2 Functional overview of the decoding process

This document specifies the JPEG Pleno Holography superbox and the JPEG Pleno Holography decoding algorithm. These are detailed in the annexes; the status of Annexes A to I is normative, while the status of Annex J is informative. The generic JPEG Pleno Holography superbox syntax is specified in Annex A.

The overall architecture of JPEG Pleno Holography (Figure 3) provides the flexibility to configure the encoding and decoding system depending on the requirements of the addressed use case.

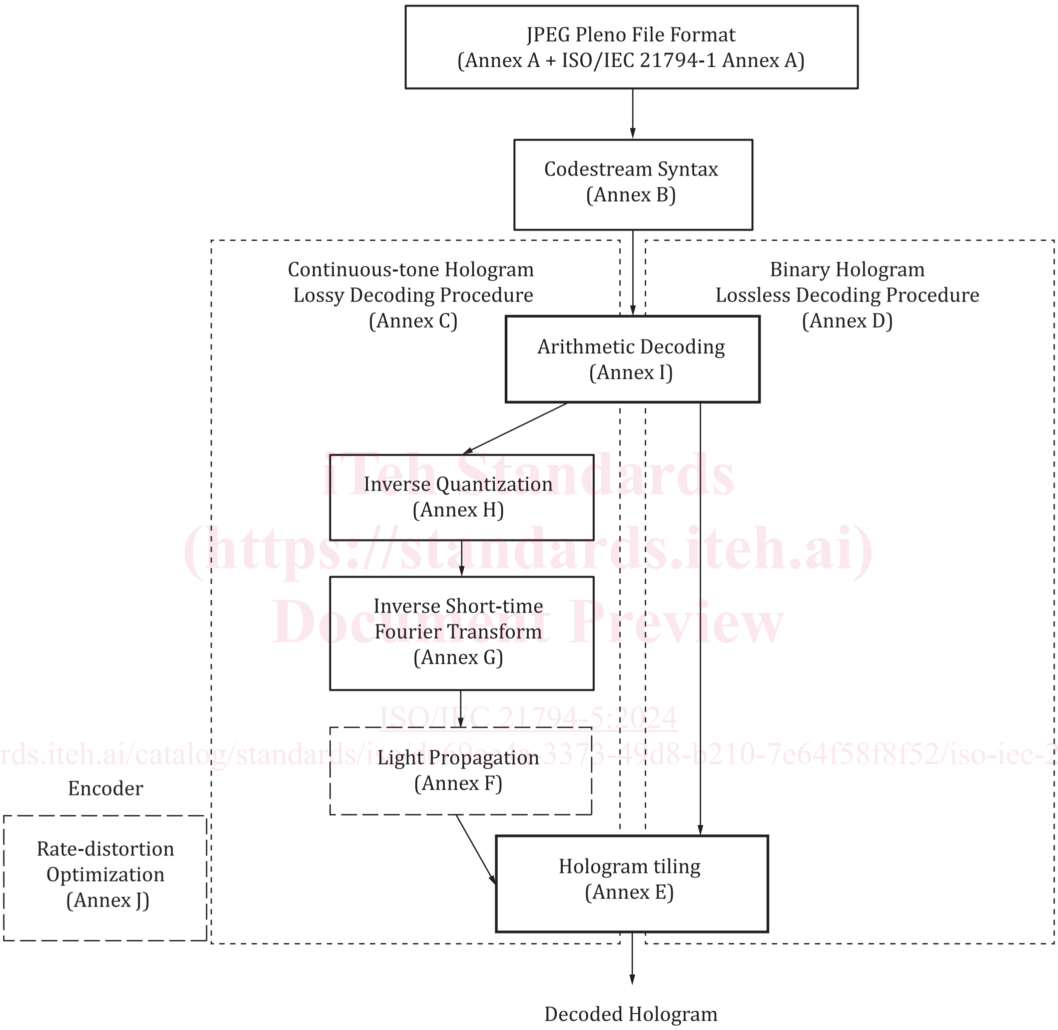


Figure 3 — General JPEG Pleno Holography decoder architecture

As can be seen in Figure 3, each annex provides information about the individual components of the codec architecture. Annex A provides a description of the JPEG Pleno Holography superbox and its composing boxes. The codestream syntax issued in this specification is specified in Annex B. Subsequently, Annex E describes the tiling mechanism issued to handle potentially large binary and non-binary holograms.

The annexes specific to the encoding/decoding of non-binary holograms are:

— Annex C gives a general overview of the non-binary lossy coding pipeline

— To enable the propagation of the hologram to a more suitable plane for compression Annex F specifies several supported propagation models.