Digital Imaging and Communications in Medicine (DICOM)

Supplement 173: Wide Field Ophthalmic Photography Image Storage SOP Classes

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Scope and Field of Application

This Supplement defines Storage SOP Classes to enable anatomically correct measurements on wide field ophthalmic photography images.

Vendors have implemented new technology that enables the acquisition of OP images using wide field fundus photography. The Ophthalmic Photography IOD does not address wide fields, varied pixel spacing, and proper measurement of a stereographic projection or other methods of projection/mapping. Since the back of the eye is approximately a concave sphere, taking a very wide field image of it introduces large errors in any attempt to measure a lesion in that image (the error is very large when using a single value for the DICOM Pixel Spacing Attribute.). Therefore, DICOM WG 9 (Ophthalmology) has determined that two new Information Object Definitions (IODs) are necessary to adequately represent wide field fundus photography.

Manufacturers of ophthalmic photographic imaging devices have been developing OP images (using a narrow field) for many years in DICOM (i.e., these SOP Classes are widely supported by the DICOM ophthalmic community). Therefore, the wide field OP image storage SOP Classes are an extension to already existing narrow field DICOM SOP Classes.

Changes to NEMA Standards Publication PS 3.2

Digital Imaging and Communications in Medicine (DICOM)

Part 2: Conformance

Item: Add to table A.1-2 categorizing SOP Classes:

The SOP Classes are categorized as follows:

Table A.1-2
UID VALUES

UID Value	UID NAME	Category
…	…	…
1.2.840.10008.5.1.4.1.1.77.1.5.5	**Wide Field Ophthalmic Photography Stereographic Projection Image Storage**	**Transfer**
1.2.840.10008.5.1.4.1.1.77.1.5.6	**Wide Field Ophthalmic Photography 3D Coordinates Image Storage**	**Transfer**
…	…	…

Changes to NEMA Standards Publication PS 3.3

Digital Imaging and Communications in Medicine (DICOM)

Part 3: Information Object Definitions
Part 3 Additions

Add definition to PS3.3 3.17

Reference Coordinate System	The RCS is the spatial coordinate system in a DICOM Frame of Reference. It is the chosen origin, orientation and spatial scale of an Image IE in a Cartesian space. The RCS is a right-handed Cartesian coordinate system i.e., the vector cross product of a unit vector along the positive x-axis and a unit vector along the positive y-axis is equal to a unit vector along the positive z-axis. The unit length is one millimeter. Typically, the Image IE contains a spatial mapping that specifies the relationship of the image samples to the Cartesian spatial domains of the RCS.
Ophthalmic Coordinate System	**The Ophthalmic Coordinate System is used as the frame of reference that establishes the spatial relationship relative to the corneal vertex. The corneal vertex is the point located at the intersection of the patient's line of sight (visual axis) and the corneal surface. See section C.8.30.3.1.4 for further explanation.**

Modify PS3.3 Table A.1-1 to add new IODs for Wide Field Ophthalmic Photography Images

IODs **Modules**	…	Oph 8 bit	**Wide Field Oph SP**	**Wide Field Oph 3DC**	**…**
Patient		M	**M**	**M**	
Clinical Trial Subject		U	**U**	**U**	
General Study		M	**M**	**M**	
Patient Study		U	**U**	**U**	
Clinical Trial Study		U	**U**	**U**	
General Series		M	**M**	**M**	
Ophthalmic Series		M	**M**	**M**	
Clinical Trial Series		U	**U**	**U**	
…					
Synchronization		M	**M**	**M**	
…					
General Equipment		M	**M**	**M**	
Frame of Reference			**M**	**M**	
Enhanced General Equipment			**M**	**M**	

SC Equipment					
General Image		M	**M**	**M**	
Image Plane					
Image Pixel		M	**M**	**M**	
Enhanced Contrast/Bolus		C	**C**	**C**	
…					
Cine		C	**C**	**C**	
Multi-frame		M	**M**	**M**	
…					
Ophthalmic Photography Image		M	**M**	**M**	
Wide Field Ophthalmic Photography Stereographic Projection			**M**		
Wide Field Ophthalmic Photography 3D Coordinates				**M**	
Wide Field Ophthalmic Photography Quality Rating			**C**	**C**	
Ocular Region Imaged		M	**M**	**M**	
Ophthalmic Photography Acquisition Parameters		M	**M**	**M**	
Ophthalmic Photographic Parameters		M	**M**	**M**	
Acquisition Context		U	**U**	**U**	
ICC Profile		U	**C**	**C**	
SOP Common		M	**M**	**M**	
Common Instance Reference		U	**U**	**U**	
Frame Extraction		C	**C**	**C**	

Modify PS3.3 Annex A

A.76 Wide Field Ophthalmic Photography Stereographic Projection Image Information Object Definition

This Section defines an Information Object to be used with several types of ophthalmic photographic imaging devices that generate wide field OP images, including fundus cameras, slit lamp cameras, scanning laser ophthalmoscopes, stereoscopic cameras, video equipment and digital photographic equipment. It uses the stereographic projection method to represent on-face images of the 3D human retina in 2D on which geometric measurements can be made when the correct mathematical formulae are used.

A.76.1 Wide Field Ophthalmic Photography Stereographic Projection Image IOD Description

The Wide Field Ophthalmic Photography Stereographic Projection Image IOD specifies a multi-frame image acquired on a digital photographic DICOM modality. This IOD can be used to encode single wide field ophthalmic images and other combinations including cine sequences. This IOD captures the projection of the wide field 2D Pixel image to enable anatomically-correct geometric measurements of the retina by taking into account the curved shape of the eye using a sphere to approximate shape.

A.76.2 Wide Field Ophthalmic Photography Stereographic Projection Image IOD Entity-Relationship Model

The Wide Field Stereographic Projection Ophthalmic Photography Image IOD uses the DICOM Composite Instance IOD Entity-Relationship Information Model defined in Section A.1.2. The Series IE contains only an Image IE.”

A.76.3 Wide Field Ophthalmic Photography Stereographic Projection Image IOD Modules

Table A.76-1 specifies the Modules of the Wide Field Stereographic Projection Ophthalmic Photography Image IOD.

Table A.76-1
WIDE FIELD OPHTHALMIC PHOTOGRAPHY STEREOGRAPHIC PROJECTION IMAGE IOD MODULES

IE	Module	Reference	Usage
Patient	Patient	C.7.1.1	M
	Clinical Trial Subject	C.7.1.3	U
Study	General Study	C.7.2.1	M
	Patient Study	C.7.2.2	U
	Clinical Trial Study	C.7.2.3	U
Series	General Series	C.7.3.1	M
	Ophthalmic Photography Series	C.8.17.1	M
	Clinical Trial Series	C.7.3.2	U
Frame of Reference	Synchronization	C.7.4.2	M
	Frame of Reference	C.7.4.1	M
Equipment	General Equipment	C.7.5.1	M
	Enhanced General Equipment	C.7.5.2	M
Image	General Image	C.7.6.1	M

	Image Pixel	C.7.6.3	M
	Enhanced Contrast/Bolus	C 7.6.4.b	C – Required if contrast was administered; see A.76.4.2
	Cine	C.7.6.5	C - Required if there is a sequential temporal relationship between all frames
	Multi-frame	C.7.6.6	M
	Acquisition Context	C.7.6.14	U
	Ophthalmic Photography Image	C.8.17.2	M
	Wide Field Ophthalmic Photography Stereographic Projection	C.8.17.11	M
	Wide Field Ophthalmic Photography Quality Rating	C.8.17.13	C – Required if a quality rating value exists for this SOP Instance
	Ocular Region Imaged	C.8.17.5	M
	Ophthalmic Photography Acquisition Parameters	C.8.17.4	M
	Ophthalmic Photographic Parameters	C.8.17.3	M
	ICC Profile	C.11.15	C – Required if Photometric Interpretation (0028,0004) is not MONOCHROME2
	SOP Common	C.12.1	M
	Common Instance Reference	C.12.2	U
	Frame Extraction	C.12.3	C - Required if the SOP Instance was created in response to a Frame-Level retrieve request

A.76.4 Wide Field Ophthalmic Photography Stereographic Projection Image IOD Content Constraints

The following constraints on Series and Image attributes take precedence over the descriptions given in the Module Attribute Tables.

A.76.4.1 Bits Allocated, Bits Stored, and High Bit

These Attributes shall be determined based upon the Photometric Interpretation (0028,0004):

Photometric Interpretation (0028,0004)	Bits Allocated (0028,0100)	Bits Stored (0028,0101)	High Bit (0028,0102)
MONOCHROME2	8	8	7

	16	16	15
RGB YBR_FULL_422 YBR_PARTIAL_420 YBR_ICT YBR_RCT	8	8	7

A.76.4.2 Contrast/Bolus Agent Sequence

For Contrast/Bolus Agent Sequence (0018,0012), the defined CID 4200 shall be used.

A.76.4.3 ICC Profile Module

The ICC Profile Module shall be present for color images. If the color space to be used is not calibrated (i.e., a device-specific ICC Input Profile is not available), then an ICC Input Profile specifying a well-known space (such as sRGB) may be specified.

A.77 Wide Field Ophthalmic Photography 3D Coordinates Image Information Object Definition

This Section defines an Information Object to be used with several types of ophthalmic photographic imaging devices that generate wide field OP images, including fundus cameras, slit lamp cameras, scanning laser ophthalmoscopes, stereoscopic cameras, video equipment and digital photographic equipment.

A.77.1 Wide Field Ophthalmic Photography 3D Coordinates Image IOD Description

The Wide Field Ophthalmic Photography 3D Coordinates Image IOD specifies a multi-frame image acquired on a digital photographic DICOM modality. This IOD can be used to encode single wide field ophthalmic images and other combinations including cine sequences. This IOD includes the mapping of the wide field 2D Pixel image to 3D (x,y,z) Cartesian coordinates.

A.77.2 Wide Field Ophthalmic Photography 3D Coordinates Image IOD Entity-Relationship Model

The Wide Field Ophthalmic Photography 3D Coordinates Image IOD uses the DICOM Composite Instance IOD Entity-Relationship Information Model defined in Section A.1.2. The Series IE contains only an Image IE.

A.77.3 Wide Field Ophthalmic Photography 3D Coordinates Image IOD Modules

Table A.77-1 specifies the Modules of the Wide Field Ophthalmic Photography 3D Coordinates Image IOD.

Table A.77-1
WIDE FIELD OPHTHALMIC PHOTOGRAPHY 3D COORDINATES IMAGE IOD MODULES

IE	Module	Reference	Usage
Patient	Patient	C.7.1.1	M
	Clinical Trial Subject	C.7.1.3	U
Study	General Study	C.7.2.1	M
	Patient Study	C.7.2.2	U
	Clinical Trial Study	C.7.2.3	U

Series	General Series	C.7.3.1	M
	Ophthalmic Photography Series	C.8.17.1	M
	Clinical Trial Series	C.7.3.2	U
Frame of Reference	Synchronization	C.7.4.2	M
	Frame of Reference	C.7.4.1	M
Equipment	General Equipment	C.7.5.1	M
	Enhanced General Equipment	C.7.5.2	M
Image	General Image	C.7.6.1	M
	Image Pixel	C.7.6.3	M
	Enhanced Contrast/Bolus	C 7.6.4.b	C – Required if contrast was administered; see A.77.4.2
	Cine	C.7.6.5	C - Required if there is a sequential temporal relationship between all frames
	Multi-frame	C.7.6.6	M
	Acquisition Context	C.7.6.14	U
	Ophthalmic Photography Image	C.8.17.2	M
	Wide Field Ophthalmic Photography 3D Coordinates	C.8.17.12	M
	Wide Field Ophthalmic Photography Quality Rating	C.8.17.13	C – Required if a quality rating value exists for this SOP Instance
	Ocular Region Imaged	C.8.17.5	M
	Ophthalmic Photography Acquisition Parameters	C.8.17.4	M
	Ophthalmic Photographic Parameters	C.8.17.3	M
	ICC Profile	C.11.15	C – Required if Photometric Interpretation (0028,0004) is not MONOCHROME2
	SOP Common	C.12.1	M
	Common Instance Reference	C.12.2	U
	Frame Extraction	C.12.3	C - Required if the SOP Instance was created in response to a Frame-Level retrieve request

A.77.4 Wide Field Ophthalmic Photography 3D Coordinates Image IOD Content Constraints

The following constraints on Series and Image attributes take precedence over the descriptions given in the Module Attribute Tables.

A.77.4.1 Bits Allocated, Bits Stored, and High Bit

These Attributes shall be determined based upon the Photometric Interpretation (0028,0004):

Photometric Interpretation (0028,0004)	Bits Allocated (0028,0100)	Bits Stored (0028,0101)	High Bit (0028,0102)
MONOCHROME2	8	8	7
	16	16	15
RGB YBR_FULL_422 YBR_PARTIAL_420 YBR_ICT YBR_RCT	8	8	7

A.77.4.2 Contrast/Bolus Agent Sequence

For Contrast/Bolus Agent Sequence (0018,0012), the defined CID 4200 shall be used.

A.77.4.3 ICC Profile Module

The ICC Profile Module shall be present for color images. If the color space to be used is not calibrated (i.e., a device-specific ICC Input Profile is not available), then an ICC Input Profile specifying a well-known space (such as sRGB) may be specified.

*Add Text to Annex C section C.8.30.3.1.4 to introduce the term **Ophthalmic Coordinate System.***

Also add Figure C.8.30.3.1-6 to Annex C section C.8.30.3.1.4 (note the entire section is shown below to give context, only the figure and referencing the figure is new)

C.8.30.3.1.4 Corneal Vertex Location

The Corneal Vertex Location (0046,0202) establishes the reference point for the corneal vertex, **the origin of the Ophthalmic Coordinate System.** ~~It~~ The **Ophthalmic Coordinate System** is used as the frame of reference that establishes the spatial relationship for the corneal vertex (i.e. used within corneal topography maps) for a set of Images within a Series. It also allows Images across multiple Series to share the same ~~corneal vertex~~ Frame Of Reference.

The corneal vertex is the point located at the intersection of the patient's line of sight (visual axis) and the corneal surface. It is represented by the corneal light reflex when the cornea is illuminated coaxially with fixation.

Note: Since the criteria used to group images into a Series is application specific, it is possible for imaging applications to define multiple Series within a Study that share the same imaging space. Therefore the images with the same Frame of Reference UID (0020,0052) Attribute value share the same corneal vertex location within the patient's eye.

Figure C.8.30.3.1-3 illustrates the representation of corneal topography. The corneal vertex lies at the center of the rulers. Typical circular grids are 3, 5, 7, and 9 mm diameters centered on the vertex. The annotations in the figures are R, right; L, left; H = Head; F = Foot.

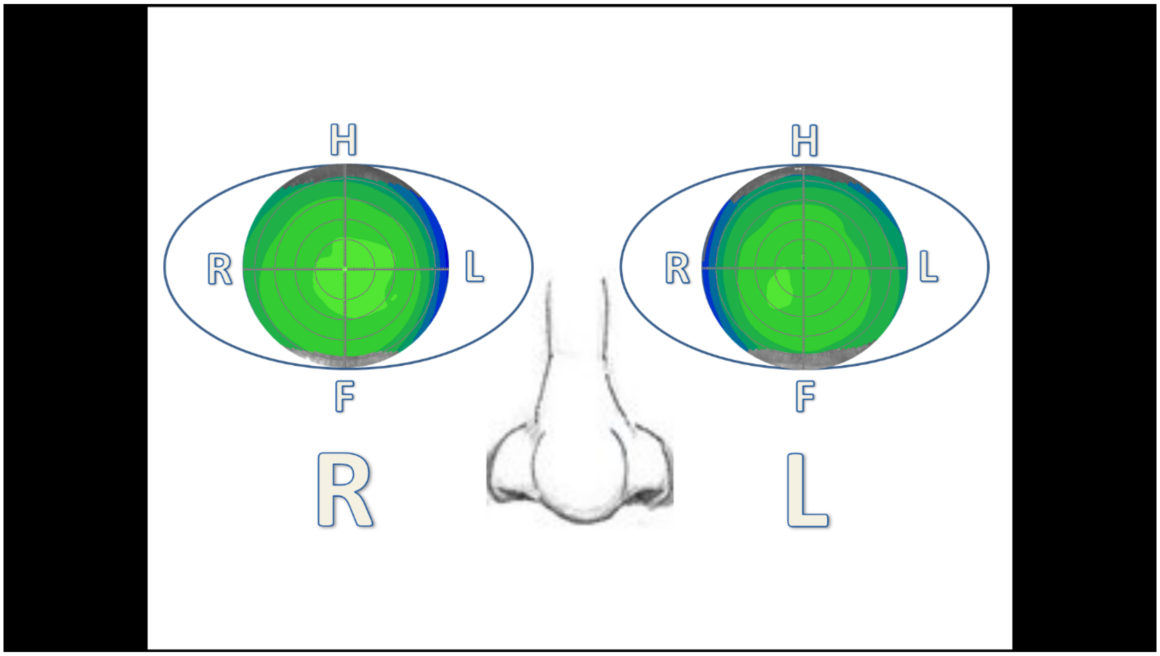

Figure C.8.30.3.1-3. Representation of Corneal Topography

Numerical position data shall use the Cartesian (i.e. two dimensional rectangular) coordinate system. The direction of the axes are determined by the Patient Orientation (0020,0020), see C.7.6.1.1.1 for further explanation.

Devices that internally capture data in polar coordinates will need to convert to Cartesian coordinates, see Figure C.8.30.3.1-4.

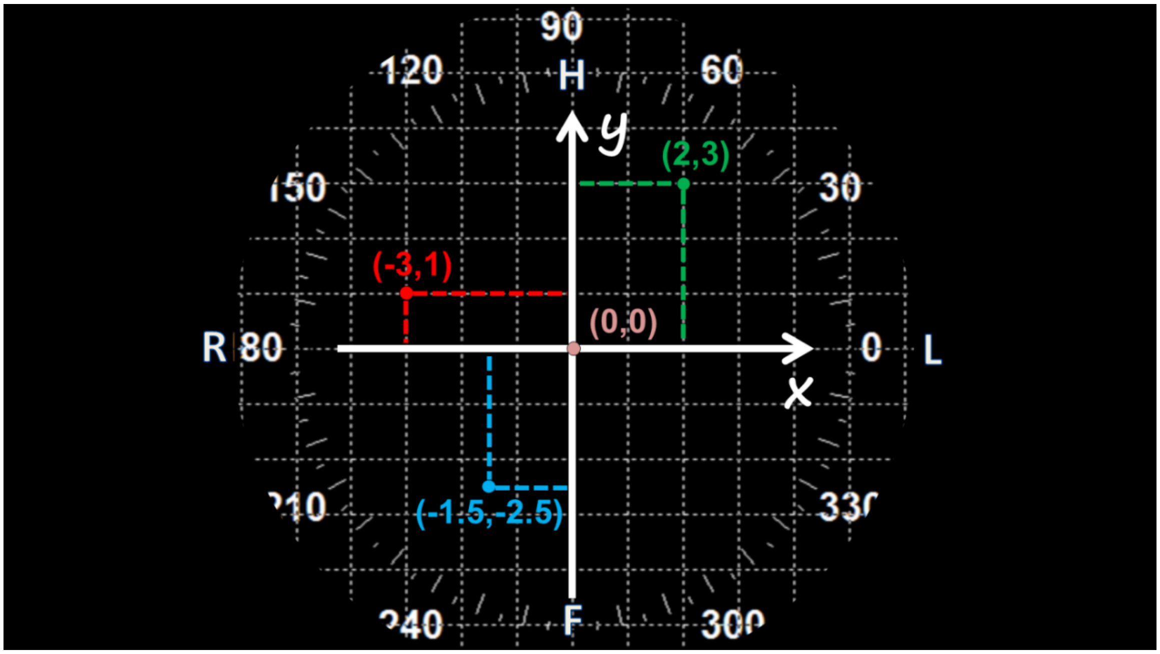

Figure C.8.30.3.1-4. Sample Coordinate Data Points

When using the 3 dimensional coordinates (X, Y, Z), the Z axis shall represent corneal elevation. Z shall be measured from the length of a vector normal to the plane that is normal to and intersects the corneal vertex at the intersection of the x, y, z, axes. It is shown in the diagram as "+" (0.0, 0.0, 0.0). The Z axis shall be positive towards the anterior direction of the eye; (i.e., it is a right-hand rule coordinate system. Thus the Z values (see Figure**s** C.8.30.3.1-5 **and C.8.30.3.1-6**) will be predominantly negative, as they are posterior to the plane of the corneal vertex.

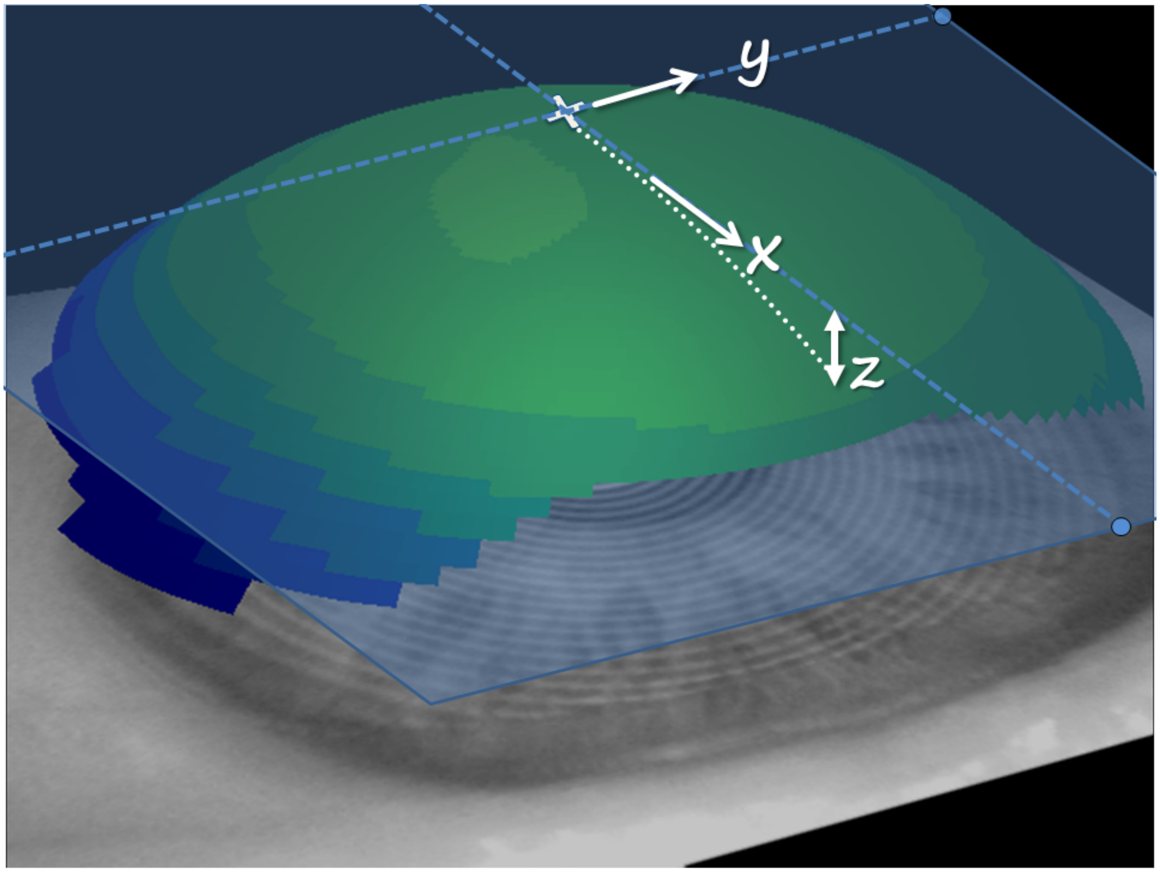

Figure C.8.30.3.1-5 Schematic of the 3-Dimensional Representation of Corneal Elevation

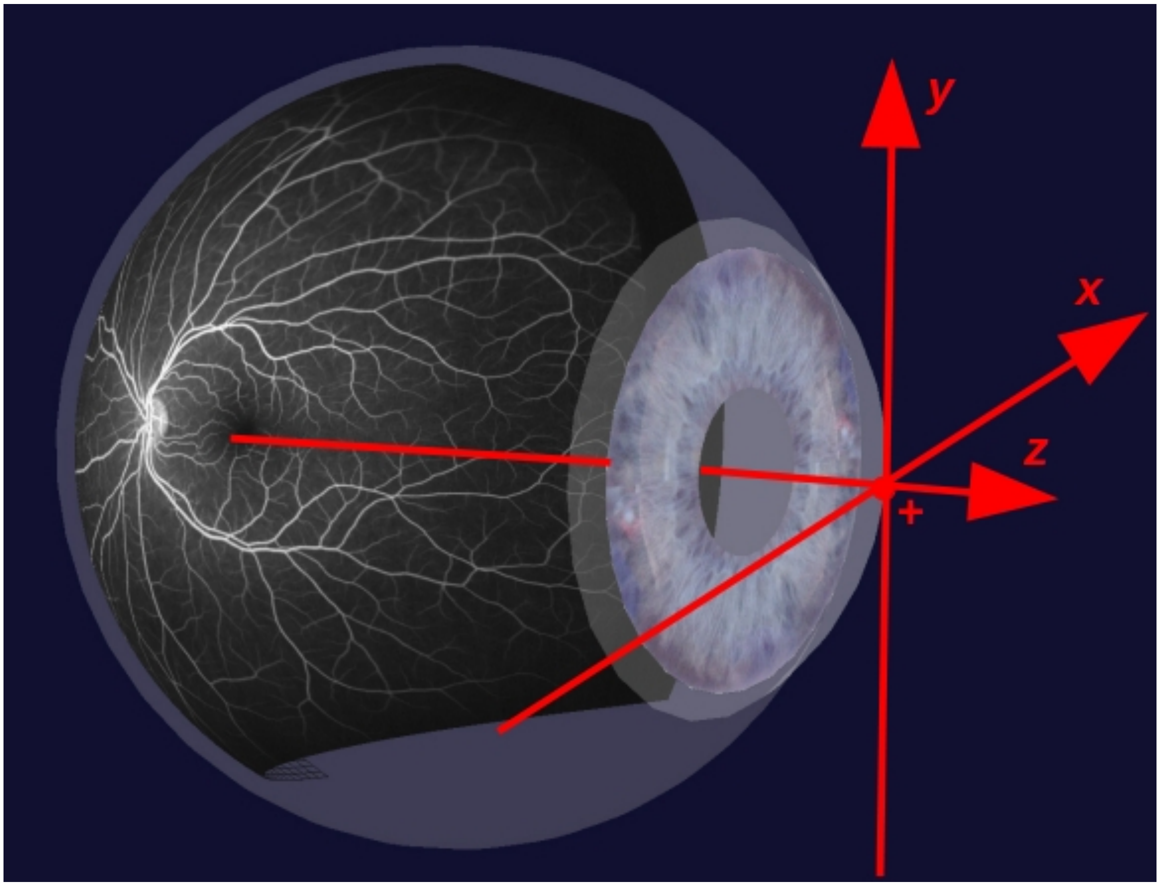

Figure C.8.30.3.1-6 Schematic of the Ophthalmic Coordinate System of the 3-Dimensional Representation used in Wide Field Measurements

Modify text to C.7.4.1.1.2 to specify that Ophthalmic Coordinate System is based upon the corneal vertex.

C.7.4.1.1.2 Position Reference Indicator

…………..

For **an Ophthalmic Coordinate System, the Frame of Reference is based upon the corneal vertex.** ~~**corneal vertex based Frame of Reference, this is t**~~ The corneal vertex **is** determined by the measuring instrument and shall be identified in this attribute with the value CORNEAL_VERTEX_R (for the right eye) or CORNEAL_VERTEX_L (for the left eye). The **Ophthalmic Coordinate System** ~~**corneal vertex based coordinate system**~~ is described in C.8.30.3.1.4.

Modify PS3.3 Annex C

C.8.17.11 Wide Field Ophthalmic Photography Stereographic Projection Module

Table C.8.17.11-1 specifies the Attributes that describe the Wide Field Photography Stereographic Projection Module.

Table C.8.17.11-1
WIDE FIELD OPHTHALMIC PHOTOGRAPHY STEREOGRAPHIC PROJECTION MODULE ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
Include ‘General Anatomy Mandatory Macro’ Table 10-5			*The concept code for Anatomic Region Sequence (0008,2218) shall be (T-AA000, SRT, “Eye”), and Defined Context ID 244 shall be used for Anatomic Region Modifier Sequence (0008,2220).* *Only a single Item shall be included in Anatomic Region Modifier Sequence (0008,2220).*
Transformation Algorithm Sequence	(0022,1513)	1	Software algorithm used for stereographic projection. Only a single Item shall be included in this sequence.
>Include ‘Algorithm Identification Macro’ Table 10-19			
Ophthalmic Axial Length	(0022,1019)	1	The axial length measurement used for the stereographic projection, in mm.
Ophthalmic Axial Length Method	(0022,1515)	1	The method used to obtain the Ophthalmic Axial Length. Enumerated values: MEASURED = Measured axial length. ESTIMATED = An estimated value based upon performing the examination (i.e. based upon surrogate markers of axial length). POPULATION = A length that represents a population norm (i.e. not based upon a measured axial length or surrogate markers

			of axial length).
X Coordinates Center Pixel View Angle	(0022,1528)	1	The horizontal angle covered on the sphere by the center pixel of the projected image, as measured from the center of the sphere, in degrees. See section C.8.17.11.1.1 for further explanation.
Y Coordinates Center Pixel View Angle	(0022,1529)	1	The vertical angle covered on the sphere by the center pixel of the projected image, as measured from the center of the sphere, in degrees. See section C.8.17.11.1.1 for further explanation.
Ophthalmic FOV	(0022,1517)	3	The field of view used to capture the ophthalmic image, in degrees. The field of view is the maximum image size displayed on the image plane, expressed as the angle subtended at the exit pupil of the eye by the maximum dimension 2r (where r equals the radius).

C.8.17.11.1 Wide Field Ophthalmic Photography Stereographic Projection Attribute Descriptions

C.8.17.11.1.1 Center Pixel View Angle

The Center Pixel View Angle (0022,1528) comprises two real numbers XCENTERPIXELVIEWANGLE and YCENTERPIXELVIEWANGLE that represent in degrees the angle along the horizontal axis and the vertical axis respectively covered by the center pixel in the image, where this angle is measured from the center of the sphere. These are used to convert pixel locations in the image to their corresponding locations on a sphere. x and y are pixel locations (may be sub pixels) in the image, x running from 0 to XPIXELS from the left-hand side of the image to the right-hand side, and y running from 0 to YPIXELS from top to bottom, and if λ denotes the azimuth or longitude on the sphere and ϕ the elevation or latitude on the sphere, both in degrees, then,

$$\lambda = -\tan 2^{-1}\left(\frac{x'}{\rho}, \frac{1}{\tan(c)}\right)$$

$$\phi = \sin^{-1}\left(\frac{y' \sin(c)}{\rho}\right)$$

$\tan2^{-1}$ used to define λ represents the two-argument inverse tangent function.

$$\tan2^{-1}(y,x) = \begin{cases} \tan^{-1}\frac{y}{x} & x > 0 \\ \tan^{-1}\frac{y}{x} + 180^\circ & y \geq 0, x < 0 \\ \tan^{-1}\frac{y}{x} - 180^\circ & y < 0, x < 0 \\ +90^\circ & y > 0, x = 0 \\ -90^\circ & y < 0, x = 0 \\ \text{undefined} & y = 0, x = 0 \end{cases}$$

Where

$$x' = \left(x - \frac{XPIXELS}{2}\right) XCENTERPIXELVIEWANGLE$$
$$\mathrm{y'}=\left(-y + \frac{YPIXELS}{2}\right) YCENTERPIXELVIEWANGLE$$

And

$$\rho = \sqrt{x'^2 + y'^2}$$
$$c = 2\tan^{-1}\left(\frac{\rho}{2}\frac{\pi}{180}\right)$$

The above equations assume the use of degrees throughout. Radians can be used, if XCENTERPIXELVIEWANGLE and YCENTERPIXELVIEWANGLE are given in radians, if all trigonometric functions are switched to their radian-equivalent, and if the factor $\frac{\pi}{180}$ is removed from the definition of c.

C.8.17.12 Wide Field Ophthalmic Photography 3D Coordinates Module

Table C.8.17.12-1 specifies the Attributes that describe the Wide Field Ophthalmic Photography 3D Coordinates Module.

Table C.8.17.12-1
WIDE FIELD OPHTHALMIC PHOTOGRAPHY 3D COORDINATES MODULE ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
Include 'General Anatomy Mandatory Macro' Table 10-5			*The concept code for Anatomic Region Sequence (0008,2218) shall be (T-AA000, SRT, "Eye"), and Defined Context ID 244 shall be used for Anatomic Region Modifier Sequence (0008,2220).* *Only a single Item shall be included in Anatomic Region Modifier Sequence (0008,2220).*
Transformation Method Code Sequence	(0022,1512)	1	Method used to map the 2D Pixel Image data in this SOP Instance to the 3D Cartesian coordinates in the Dimensional to Two Three Dimensional Map Sequence (0022,1518). Only a single Item shall be included in this

			sequence. See Section C.8.17.12.1.1 for further explanation.
>Include 'Code Sequence Macro' Table 8.8 1. Defined Context ID is 4245			
Transformation Algorithm Sequence	(0022,1513)	1	Software algorithm that performed the mapping. Only a single Item shall be included in this sequence.
>Include 'Algorithm Identification Macro' Table 10-19			
Ophthalmic Axial Length	(0022,1019)	1	The axial length measurement used when performing the 2D pixel image mapping into 3D Cartesian coordinates, in mm.
Ophthalmic Axial Length Method	(0022,1515)	1	The method used to obtain the Ophthalmic Axial Length. Enumerated values: MEASURED = Measured axial length. ESTIMATED = An estimated value based upon performing the examination (i.e. based upon surrogate markers of axial length). POPULATION = A length that represents a population norm (i.e. not based upon a measured axial length or surrogate markers of axial length).
Ophthalmic FOV	(0022,1517)	3	The field of view used to capture the ophthalmic image, in degrees. The field of view is the maximum image size displayed on the image plane, expressed as the angle subtended at the exit pupil of the eye by the maximum dimension 2r (where r equals the radius).
Two Dimensional to Three Dimensional Map Sequence	(0022,1518)	1	A sparsely sampled map of 2D image pixels (with sub pixel resolution) to 3D coordinates. Each frame shall be referenced once and only once in this sequence in Referenced Frame Numbers (0040,A136). One or more Items shall be included in this sequence.
>Referenced Frame Numbers	(0040,A136)	1	References one or more frames within this SOP Instance to which this sequence item applies. The first frame shall be denoted as frame number one.
>Number of Map Points	(0022,1530)	1	The number of points in the map. Shall include one or more points.
>Two Dimensional to Three Dimensional Map Data	(0022,1531)	1	See C.8.17.12.1.2 for further explanation.

C.8.17.12.1 Wide Field Ophthalmic Photography 3D Coordinates Attribute Descriptions

C.8.17.12.1.1 Transformation Method Code Sequence

If Transformation Method Code Sequence (0022,1512) is (DCM, 111791, “Spherical projection”) all the coordinates in the Two Dimensional to Three Dimensional Map Data (0022,1531) shall lie on a sphere with a diameter that shall be equal to Ophthalmic Axial Length (0022,1019).

If Transformation Method Code Sequence (0022,1512) is (DCM, 111792, “Surface contour mapping”) the coordinates in the Two Dimensional to Three Dimensional Map Data (0022,1531) are based upon the contour of the eye, therefore it cannot be assumed to be a spherical surface.

C.8.17.12.1.2 Two Dimensional to Three Dimensional Map Data

Two Dimensional to Three Dimensional Map Data (0022,1531) is used to convey a sparsely sampled map of 2D image pixels (with sub pixel resolution) to 3D coordinates.

The origin of the 3D points shall be the Ophthalmic Coordinate System which is based upon the corneal vertex (i.e. the x, y and z coordinates of 0.0, 0.0, 0.0, in mm). See section C.8.30.3.1.4.

All data points are encoded as a floating point 5-tuple where the values are:

1st value = 2D horizontal location (a sub pixel location between 0 and number of columns)
2nd value = 2D vertical location (a sub pixel location between 0 and number of rows)
3rd value = x 3D-coordinate
4th value = y 3D-coordinate
5th value = z 3D-coordinate

The ordering is 2D horizontal location$_1$,2D vertical location$_1$,3Dx$_1$,3Dy$_1$,3Dz$_1$,…2D horizontal location$_n$, 2D vertical location$_n$, 3Dx$_n$,3Dy$_n$,3Dz$_n$.

C.8.17.13 Wide Field Ophthalmic Photography Quality Rating Module

Table C.8.17.13-1 specifies the Attributes that evaluate the quality of the projection or mapping used for a wide field ophthalmic photography image.

Table C.8.17.13-1
WIDE FIELD OPHTHALMIC PHOTOGRAPHY QUALITY RATING MODULE ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
Wide Field Ophthalmic Photography Quality Rating Sequence	(0022,1525)	1	Type of metric and metric value used to evaluate the quality of the projection or mapping used for the wide field ophthalmic photography image for this SOP Instance. Only a single Item shall be included in this sequence.
>Include 'Numeric Value Macro' Table 10-26			*Defined Context ID 4243 shall be used for Concept Name Code Sequence (0040,A043)*
>Wide Field Ophthalmic Photography Quality Threshold Sequence	(0022,1526)	1	Quality threshold value and software algorithm used to provide the wide field ophthalmic photography projection or mapping quality rating for this SOP Instance. Only a single Item shall be included in this sequence.
>>Wide Field Ophthalmic	(0022,1527)	1	Quality rating threshold value for acceptable wide

Photography Threshold Quality Rating			field ophthalmic photography projection or mapping. Note: The units of this Attribute is the same as defined in Measurement Units Code Sequence (0040,08EA) of the Wide Field Ophthalmic Photography Quality Rating Sequence (0022,1525). The threshold value is not the same as the attribute Numeric Value (0049,A30A) of the Wide Field Ophthalmic Photography Quality Rating Sequence (0022,1525). Therefore, it conveys the least stringent value that is acceptable, not the actual rating for this SOP Instance.
>>Include 'Algorithm Identification Macro' Table 10-19			

Modify PS3.3, C.8.17.2, Ophthalmic Photography Image Module for Attribute Pixel Spacing

C.8.17.2 Ophthalmic Photography Image Module

Table C.8.17.2-1 specifies the Attributes that describe an Ophthalmic Photography Image produced by Ophthalmic Photography equipment (OP) imaging Modalities.

Table C.8.17.2-1
OPHTHALMIC PHOTOGRAPHY IMAGE MODULE ATTRIBUTES

Attribute Name	Tag	Type	Attribute Description
…….	……	……	……
Pixel Spacing	(0028,0030)	1C	Nominal physical distance at the focal plane (in the retina) between the center of each pixel, specified by a numeric pair - adjacent row spacing (delimiter) adjacent column spacing in mm. See 10.7.1.3 for further explanation of the value order. Note: These values are specified as nominal because the physical distance may vary across the field of the images and the lens correction is likely to be imperfect. **Shall not be sent when Two Dimensional to Three Dimensional Map Sequence (0022,1518) or X Coordinates Center Pixel View Angle (0022,1528) and Y Coordinates Center Pixel View Angle (0022,1529) are present. Otherwise,** required when Acquisition Device Type Code Sequence (0022,0015) contains an item with the value (SRT, R-1021A,"Fundus Camera"). May be present otherwise.
…	…	….	……

Modify the name of Content ID 4243 to be more generic in tables C.8.28.3-1 and C.8.25.14.5 – delete Axial Length

C.8.28.3 Ophthalmic Thickness Map Quality Rating Module

Table C.8.28.3-1 specifies the Attributes that describe the quality rating for the ophthalmic mapping.

Table C.8.28.3-1. Ophthalmic Thickness Map Quality Rating Module Attributes

Attribute Name	Tag	Type	Attribute Description
Ophthalmic Thickness Map Quality Rating Sequence	(0022,1470)	1	Type of metric and metric value used to evaluate the quality of the ophthalmic mapping for grading and diagnostic purposes for this SOP Instance. Only a single Item shall be included in this sequence.
>Include Table 10-26 "Numeric Value Macro Attributes"			Defined CID 4243 "Ophthalmic ~~Axial Length~~ Quality Metric Type" shall be used for Concept Name Code Sequence (0040,A043)
……	….	…	…

C.8.25.14.5 Ophthalmic Axial Measurements Quality Metric Macro

Table C.8.25.14-6 describes the attributes for the Ophthalmic Axial Length Quality Metric Macro.

Table C.8.25.14-6. Ophthalmic Axial Length Quality Metric Macro Attributes

Attribute Name	Tag	Type	Attribute Description
Concept Name Code Sequence	(0040,A043)	1	Type of metric used to evaluate the quality of the ophthalmic axial length. Only a single Item shall be included in this sequence.
>Include Table 8.8-1 "Code Sequence Macro Attributes"			Defined CID 4243 "Ophthalmic ~~Axial Length~~ Quality Metric Type"
…..	….	…	….

Changes to NEMA Standards Publication PS 3.4

Digital Imaging and Communications in Medicine (DICOM)

Part 4: Service Class Specifications

Add to PS3.4 Annex B.5.

B.5 Standard SOP Classes

Table B.5-1
STANDARD SOP CLASSES

SOP Class Name	SOP Class UID	IOD (See PS 3.3)
…		
Wide Field Ophthalmic Photography Stereographic Projection Image Storage	**1.2.840.10008.5.1.4.1.1.77.1.5.5**	**Wide Field Ophthalmic Photography Stereographic Projection Image Storage**
Wide Field Ophthalmic Photography 3D Coordinates Image Storage	**1.2.840.10008.5.1.4.1.1.77.1.5.6**	**Wide Field Ophthalmic Photography 3D Coordinates Image Storage**

Add to PS3.4 Annex I.4.

I.4 Media Standard Storage SOP Classes

Table I.4-1
Media Storage Standard SOP Classes

SOP Class Name	SOP Class UID	IOD (See PS 3.3)
…		
Wide Field Ophthalmic Photography Stereographic Projection Image Storage	**1.2.840.10008.5.1.4.1.1.77.1.5.5**	**Wide Field Ophthalmic Photography Stereographic Projection Image Storage**
Wide Field Ophthalmic Photography 3D Coordinates Image Storage	**1.2.840.10008.5.1.4.1.1.77.1.5.6**	**Wide Field Ophthalmic Photography 3D Coordinates Image Storage**

Changes to NEMA Standards Publication PS 3.6

Digital Imaging and Communications in Medicine (DICOM)

Part 6: Data Dictionary

Add to PS3.6 Annex A

UID Value	UID NAME	UID TYPE	Part
…			
1.2.840.10008.5.1.4.1.1.77.1.5.5	**Wide Field Ophthalmic Photography Stereographic Projection Image Storage**	**SOP Class**	**PS 3.4**
1.2.840.10008.5.1.4.1.1.77.1.5.6	**Wide Field Ophthalmic Photography 3D Coordinates Image Storage**	**SOP Class**	**PS 3.4**

Add to PS3.6 the following Data Elements to Section 6, Registry of DICOM data elements:

Tag	Name	Keyword	VR	VM
(0022,1512)	Transformation Method Code Sequence	TransformationMethodCodeSequence	SQ	1
(0022,1513)	Transformation Algorithm Sequence	TransformationAlgorithmSequence	SQ	1
(0022,1515)	Ophthalmic Axial Length Method	OphthalmicAxialLengthMethod	CS	1
(0022,1517)	Ophthalmic FOV	OphthalmicFOV	FL	1
(0022,1518)	Two Dimensional to Three Dimensional Map Sequence	TwoDimensionalToThreeDimensionalMapSequence	SQ	1
(0022,1525)	Wide Field Ophthalmic Photography Quality Rating Sequence	WideFieldOphthalmicPhotographyQualityRatingSequence	SQ	1
(0022,1526)	Wide Field Ophthalmic Photography Quality Threshold Sequence	WideFieldOphthalmicPhotographyQualityThresholdSequence	SQ	1
(0022,1527)	Wide Field Ophthalmic Photography Threshold Quality Rating	WideFieldOphthalmicPhotographyThresholdQualityRating	FL	1
(0022,1528)	X Coordinates Center Pixel View Angle	XCoordinatesCenterPixelViewAngle	FL	1
(0022,1529)	Y Coordinates Center Pixel View Angle	YCoordinatesCenterPixelViewAngle	FL	1
(0022,1530)	Number of Map Points	NumberOfMapPoints	UL	1
(0022,1531)	Two Dimensional to Three Dimensional Map Data	TwoDimensionalToThreeDimensionalMapData	OF	1

Modify Table A3 to PS3.6 for new CIDs and CID 4243 name change, delete "Axial Length"

Table A-3. Context Group UID Values

Context UID	Context Identifier	Context Group Name
1.2.840.10008.6.1.1029	**CID 4245**	**Wide Field Ophthalmic Photography Transformation Method**
1.2.840.10008.6.1.889	**CID 4243**	**Ophthalmic ~~Axial Length~~ Quality Metric Type**

Changes to NEMA Standards Publication PS 3.16

Digital Imaging and Communications in Medicine (DICOM)

Part 16: Content Mapping Resource

Add the following definitions to Part 16 Annex B DCMR Context Groups (Normative)

CID 4245 Wide Field Ophthalmic Photography Transformation Method

Context ID 4245
Wide Field Ophthalmic Photography Transformation Method
Type: Extensible Version: 20150326

Coding Scheme Designator (0008,0102)	Code Value (0008,0100)	Code Meaning (0008,0104)
DCM	111791	Spherical projection
DCM	111792	Surface contour mapping

Modify the name of Content ID 4243 to be more generic – delete Axial Length

CID 4243 Ophthalmic ~~Axial Length~~ Quality Metric Type

Type: **Extensible**
Version: **20100623**

Table CID 4243. Ophthalmic ~~Axial Length~~ Quality Metric Type

Coding Scheme Designator	Code Value	Code Meaning
DCM	111786	Standard Deviation of measurements used
DCM	111787	Signal to Noise Ratio

Add the following definitions to Part 16 Annex D DICOM Controlled Terminology Definitions (Normative)

Annex D DICOM Controlled Terminology Definitions (Normative)

Code Value	Code Meaning	Definition	Notes
111791	Spherical projection	Projection from 2D image pixels to 3D Cartesian coordinates based on a spherical mathematical model.	
111792	Surface contour mapping	Mapping from 2D image pixels to 3D Cartesian coordinates based on measurements of the retinal surface. E.g., of the retina, derived via a measurement technology such as Optical Coherence Tomography, Ultrasound etc.	

Changes to NEMA Standards Publication PS 3.17 Digital Imaging and Communications in Medicine (DICOM)

Part 17: Explanatory Information

Add to PS3.17 Annex UUU

Annex UUU Ophthalmology Use Cases (Informative)

UUU.1 Wide Field Ophthalmic Use Cases

Any 2-dimensional representation of a 3-dimensional object must undergo some kind of projection or mapping to form the planar image. Within the context of imaging of the retina, the eye can be approximated as a sphere and mathematical cartography can be used to understand the impact of projecting a spherical retina on to a planar image. When projecting a spherical geometry on a planar geometry, not all metric properties can be retained at the same time; some distortion will be introduced. However, if the projection is known it may be possible to perform calculations "in the background" that can compensate for these distortions.

The example in Figure UUU.1-1 shows an ultra-wide field image of the human retina. The original image has been remapped to a stereographic projection according to an optical model of the scanning laser ophthalmoscope it was captured on. Two circles have been annotated with an identical pixel count. The circle focused on the fovea (A) has an area of 4.08 mm^2 whereas the circle nasally in the periphery (B) has an area of 0.97 3mm^2, both as measured with the Area Measurement using the Stereographic Projection method. The difference in measurement is more than 400 %, which indicates how measurements on large views of the retina can be deceiving.

The fact that correct measurement on the retina in physical units is difficult to do is acknowledged in the original DICOM OP SOP Classes in the description of the Pixel Spacing (0028,0030) tag.

Note: These values are specified as nominal because the physical distance may vary across the field of the images and the lens correction is likely to be imperfect.

Figure UUU.1-1: Ultra-wide field image of a human retina in stereographic projection

The following use cases are examples of how the DICOM Wide Field Ophthalmology Photography objects may be used.

UUU.1.1 Clinical Use Cases

UUU.1.1.1 Routine Wide Field Image for Surveillance for Diabetic Retinopathy

On routine wide-field imaging for annual surveillance for diabetic retinopathy a patient is noted to have no retinopathy, but demonstrates a pigmented lesion of the mid-periphery of the right eye. Clinically this appears flat or minimally elevated, irregularly pigmented without lacunae, indistinct margins on two borders, and has a surface that is stippled with orange flecks. The lesion is approximately 3 X 5 DD. This lesion appears clinically benign, but requires serial comparison to r/o progression requiring further evaluation. Careful measurements are obtained in 8 cardinal positions using a standard measurement tool in the reading software that calculates the shortest distance in mm between these points. The patient was advised to return in 6 months for repeat imaging and serial comparison for growth or other evidence of malignant progression.

UUU.1.1.2 Patient with Myopia

A patient with a history of high myopia has noted recent difficulties descending stairs. She believes this to be associated with a new onset blind spot in her inferior visual field of both eyes, right eye greater than left. On examination she shows a bullous elevation of the retina in the superior periphery of both eyes due to retinoschisis, OD>OS. There is no evidence of inner or outer layer breaks, and the maculae are not threatened, so a decision is made to follow closely for progression suggesting a need for intervention. Wide field imaging of both fundi is obtained, with clear depiction of the posterior extension of the retinoschisis. Careful measurements of the shortest distance in mm between the posterior edge of the retinal splitting and the fovea is made using the diagnostic display measurement tool, and the patient was advised to return in 4 months for repeat imaging and serial comparison of the posterior location of the retinoschisis.

UUU.1.1.3 Patient with Diabetes

Patients with diabetes are enrolled in a randomized clinical trial to prospectively test the impact of disco music on the progression of capillary drop out in the retinal periphery. The retinal capillary drop-out is demonstrated using wide-field angiography with expanse of this drop-out determined serially using diagnostic display measurement tools, and the area of the drop-out reported in mm^2. Regional areas of capillary drop out are imaged such that the full expanse of the defect is captured. In some cases this involves eccentric viewing with the fovea positioned in other than the center of the image. Exclusion criteria for patient enrollment include refractive errors greater than 8D of Myopia and 4D of hyperopia.

UUU.1.1.4 Patient with Age Related Macular Degeneration (ARMD)

Patients with ARMD and subfoveal subretinal neovascular membranes but refusing intravitreal injections are enrolled in a randomized clinical trial to test the efficacy of topical anti-VEGF eye drops on progression of their disease. The patients are selected such that there is a wide range of lesion size (area measured in mm^2) and retinal thickening. This includes patients with significant elevation of the macula due to subretinal fluid.

UUU.1.2 Stereographic Projection (SP)

Every 2-dimensional image that represents the back of the eye is a projection of a 3-dimensional object (the retina) into a 2-dimensional space (the image). Therefore, every image acquired with a fundus camera or scanning laser ophthalmoscope is a particular projection. In ophthalmoscopy, part of the spherical retina (the back of the eye can be approximated by a sphere) is projected to a plane, i.e., a 2-dimensional image.

The projection used for a specific retinal image depends on the ophthalmoscope; its optical system comprising lenses, mirrors and other optical elements, dictates how the image is formed. These projections are not well-characterized mathematical projections, but they can be reversed to return to a sphere. Once in spherical geometry, the image can then be projected once more. This time any mathematical projection can be used, preferably one that enables correct measurements. Many projections are described in the literature, so which one should be choosen?

Certain projections are more suitable for a particular task than others. Conformal projections preserve angle, which is a property that applies to points in the plane of projection that are locally distortion-free. Practically speaking, this means that the projected meridian and parallel intersect through a point at right angles and are equiscaled. Therefore, measuring angles on the 2-dimensional image yields the same results as measuring these on the spherical representation, i.e., the retina. Conformal projections are particularly suitable for tasks where the preservation of shapes is important. Therefore, the stereographic projection explained in Figure UUU.1.2-1 can be used for images on which to perform anatomically-correct measurements. The stereographic projection has the projection plane intersect with the equator of the eye where the fovea and cornea are poles. The points Fovea, p and q on the sphere (retina) are projected onto the projection plane (image in stereographic projection) along lines through the cornea where they intersect with the project plane creating points *F'*, *p'* and *q'* respectively.

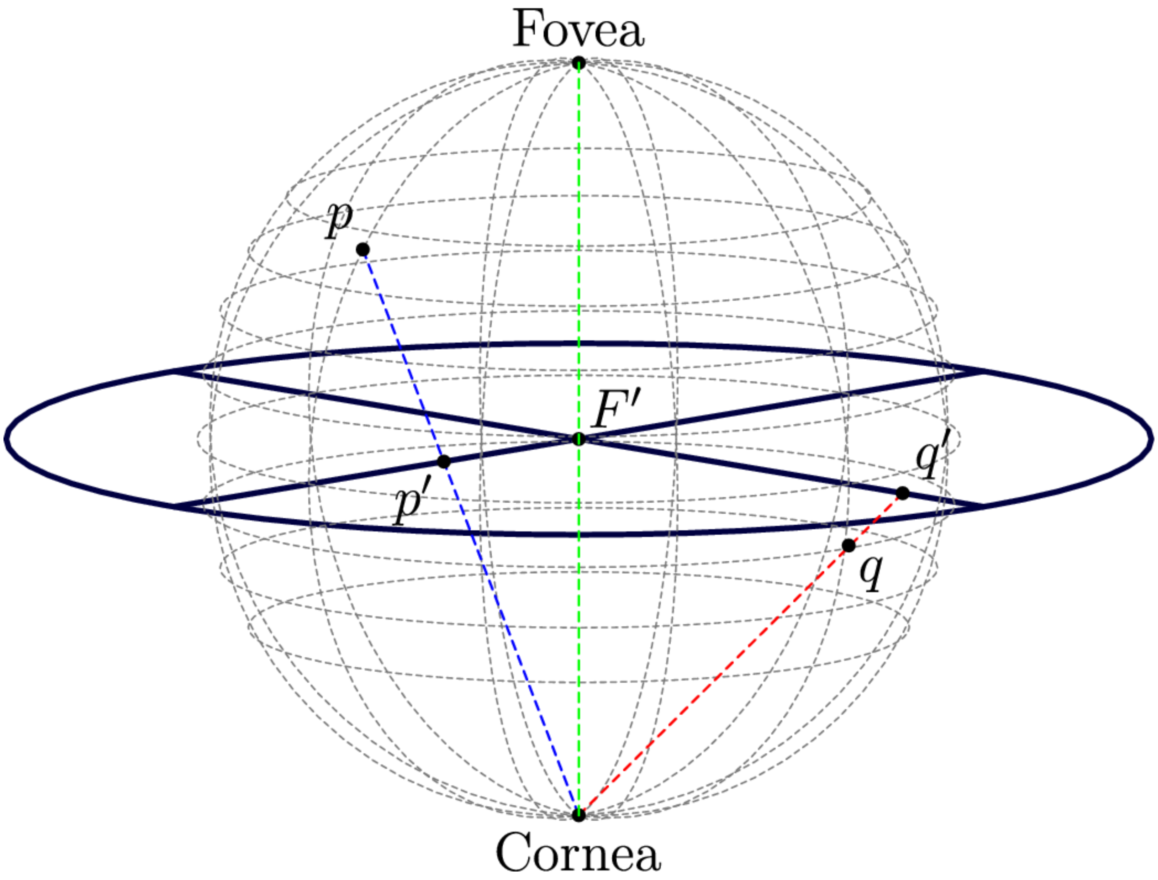

Figure UUU.1.2-1: Stereographic projection example

Note that in the definition of stereographic projection the fovea is conceptually in the center of the image. For the mathematics below to work correctly, it is critical that each image is projected such that conceptually the fovea is in the center, even if the fovea is not in the image. This is not difficult to achieve as a similar result is achieved when creating a montage of fundus images; each image is re-projected relative to the area it covers on the retina. Most montages place the fovea in the center. An example of two images of the same eye in Figures UUU.1.2-2 and UUU.1.2-3 taken from different angles and then transformed to adhere to this principle are in Figures UUU.1.2-4 and UUU.1.2-5 respectively.

455 **Figure UUU.1.2-2: Image taken on-axis, i.e., centered on the fovea**

Figure UUU.1.2-3: Image acquired superiorly-patient looking up

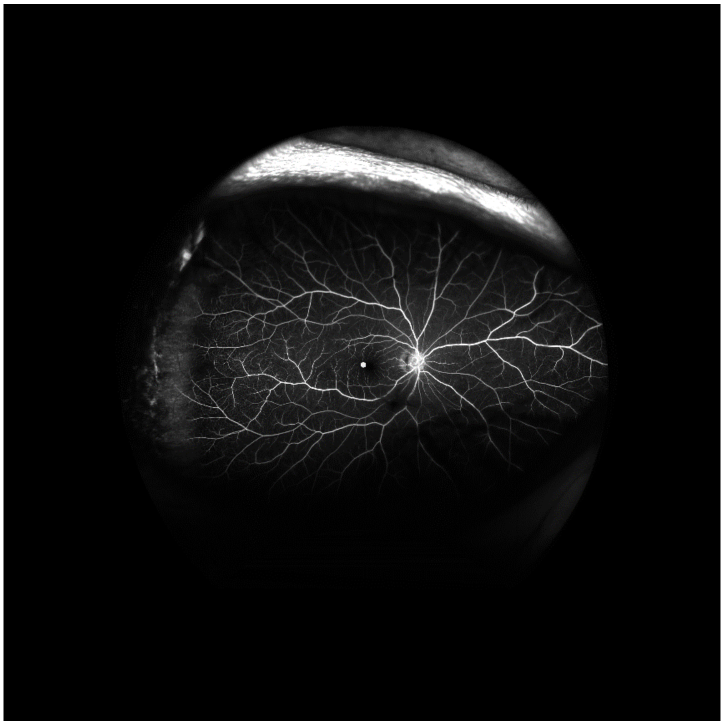

Figure UUU.1.2-4: Fovea in the center and clearly visible

Figure UUU.1.2-5: Fovea barely visible, but the transformation ensures it is still in the center

Furthermore the mathematical "background calculations" are well known for images in stereographic projection. Given points (pixels) on a retinal image, these can be directly located as points on the sphere and geometric measurements, i.e., area and distance measurements, performed on the sphere to obtain the correct values. The mathematical details behind the calculations for locating points on a sphere are presented in PS3.3 Section C.8.17.11.1.1.

UUU.1.2.1 Distance

The shortest distance between two points on a sphere lies on a "great circle", which is a circle on the sphere's surface that is concentric with the sphere. The great circle section that connects the points (the line of shortest distance) is called a geodesic. There are several equations that approximate the distance between two points on the back of the eye along the great circle through those points (the arc length of the geodesic), with varying degrees of accuracy. The simplest method uses the "spherical law of cosines". Let λ_s,ϕ_s; λ_f,ϕ_f be the longitude and latitude of two points s and f, and $\Delta\lambda \equiv |\lambda_f - \lambda_s|$ the absolute difference of the longitudes, then the central angle is defined as

$$\Delta\widehat{\sigma} = \cos^{-1}\left(\sin\phi_s \sin\phi_f + \cos\phi_s \cos\phi_f \cos\Delta\lambda\right)$$

where the central angle is the angle between the two points via the center of the sphere, e.g. angle a in Figure UUU.1.2-6. If the central angle is given in radians, then the distance d, known as *arc length*, is defined as $R\Delta\widehat{\sigma}$ where R is the radius of the sphere.

This equation leads to inaccuracies both for small distances and if the two points are opposite each other on the sphere. A more accurate method that works for all distances is the use of the Vincenty formulae. Now the central angle is defined as

$$\Delta\widehat{\sigma} = \tan^{-1}\left(\frac{\sqrt{\left(\cos\phi_f \sin\Delta\lambda\right)^2 + \left(\cos\phi_s \sin\phi_f - \sin\phi_s \cos\phi_f \cos\Delta\lambda\right)^2}}{\sin\phi_s \sin\phi_f + \cos\phi_s \cos\phi_f \cos\Delta\lambda}\right)$$

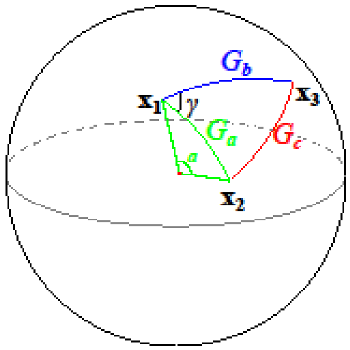

Figure UUU.1.2-6: Example of a polygon on the service of a sphere

Figure UUU.1.2-6 is an example of a polygon made up of three geodesic G_a, G_b, G_c, describing the shortest distances on the sphere between the polygon vertices x_1,x_2 ,x_3 Angle γ is the angle on the surface between geodesics G_a and G_b. Angle a is the central angle (angle via the sphere's center) of geodesic G_a.

If the length of a path on the image (e.g. tracing of a blood vessel) is needed, this can be easily implemented using the geodesic distance defined above, by dividing the traced path into sections with lengths of the order of 1-5 pixels, and then calculating and summing the geodesic distance of each section separately. This works because for short enough distances, the geodesic distance is equal to the on-image distance. Note that sub-pixel accuracy is required.

UUU.1.2.2 Area

To measure an area A defined by a polygon on the surface of the sphere where surface angle (such as γ in Figure UUU.1.2-6) α_i for $i=1,\dots,n$ for n angles internal to the polygon and R the radius of the sphere, we use the following formula, which makes use of the "angle excess".

$$A = R^2 \left(\sum_i^n \alpha_i - (n-2)\pi\right)$$

This yields a result in physical units (e.g. mm^2 if R was given in mm), but if R^2 is omitted in the above formula, a result is obtained in units relative to the sphere, in steradians (sr), the unit of solid angle.

UUU.1.2.3 Angle

In practice, if the length of the straight arms of the calipers used to measure surface angle (such as γ in Figure UUU.1.2-6) are short then the angle measured on the image is equivalent to its representation on the sphere, which is a direct result of using the stereographic projection as it is conformal.

UUU.1.3 Introduction to 2D to 3D Map for Wide Field Ophthalmic Photography

A 2D to 3D map includes 3D coordinates of all or a subset of pixels (namely coordinate points) to the 2D image. Implementations choose the interpolation type used, but it is recommended to use a spline based interpolation. See Figure UUU.1.3-1

Pixels' 3D coordinates could be used for different analyses and computations e.g. measuring the length of a path, and calculating the area of region of interest, 3D computer graphics, registration, shortest distance computation, etc. Some examples of methods using 3D coordinates are listed in the following subsections.

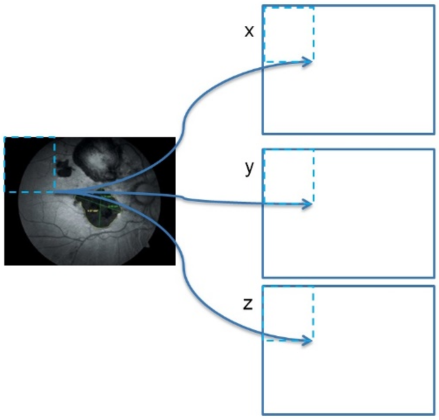

Figure UUU.1.3-1: Map pixel to 3D coordinate

UUU.1.3.1 Measuring the length of a path

Let the path between points A, and B be represented by set of N following pixels $P = \{p_i\}$ and $p_0 = A$ and $p_N = B$. The length of this path can be computed from the partial lengths between path points by:

$$l = \sum_{i=0}^{i=N-1} l_i$$

$$l_i = \sqrt{(x_i - x_{i+1})^2 + \left(y_i - y_{i+1}\right)^2 + (z_i - z_{i+1})^2}$$

Where x_i, y_i, z_i are the 3D coordinates of the point p_i which is either available in the 2D to 3D map if p_i is a coordinate point or it is computed by interpolation. Here it is assumed that the sequence of path points is known and the path is 4- or 8-connected (i.e., the path points are neighbors with no more than one pixel distance in horizontal, vertical, or diagonal direction). It is recommendable to support sub-pixel processing by using interpolation.

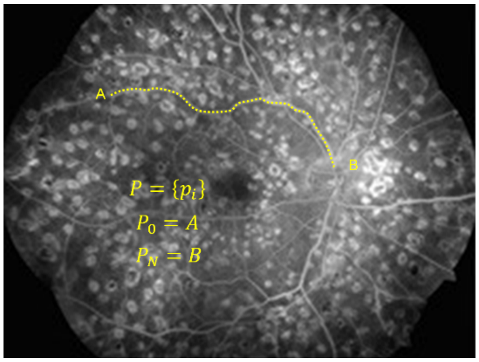

Figure UUU.1.3-2: Measure the Length of a Path

UUU.1.3.2 Shortest distance between two points

Shortest distance between two points along the surface of a sphere, known as the great circle or orthodromic distance, can be computed from:

$$d = r\Delta\sigma$$

$$\Delta\sigma = arctan\left(\frac{|\boldsymbol{n}_1 \times \boldsymbol{n}_2|}{\boldsymbol{n}_1 . \boldsymbol{n}_2}\right)$$

Where r is the radius of the sphere and the central angle ($\Delta\sigma$) is computed from the Cartesian coordinate of the two points in radians. Here ($\boldsymbol{n}_1$) and ($\boldsymbol{n}_2$) are the normals to the ellipsoid at the two positions. The above equations can also be computed based on longitudes and latitudes of the points.

However, the shortest distance in general can be computed by algorithms such as Dijkstra, which computes the shortest distance on graphs. In this case the image is represented as a graph in which the nodes refer to the pixels and the weight of edges is defined based on the connectivity of the points and their distance.

UUU.1.3.3 Computing the area of a region of interest

Let R be the region of interest on the 2D image and it is tessellated by set of unit triangles $T = \{T_i\}$. By unit triangle we refer to isosceles right triangle that the two equal sides have one pixel distance (4-connected neighbors). The area of the region of interest can be computed as the sum of partial areas of the unit triangles in 3D. Let $\{\boldsymbol{a}_i, \boldsymbol{b}_i, \boldsymbol{c}_i\}$ be the 3D coordinates of the three points of unit triangle T_i. The 3D area of this triangle is

$$A_i = \frac{1}{2}(\|(\boldsymbol{b}_i - \boldsymbol{a}_i)\times(\boldsymbol{c}_i - \boldsymbol{a}_i)\|)$$

and the total area of R is:

$$A = \sum A_i$$

Where ($\| \quad \|$) and (×) refer to the magnitude and cross product, respectively. Consider that $\boldsymbol{a}_i$, $\boldsymbol{b}_i$, and $\boldsymbol{c}_i$ are the 3D coordinates not the 2D indices of the unit triangle points on the image.

UUU.1.3.4 Transformation Method Code Sequence

If Transformation Method Code Sequence (0022,1512) is (DCM, 111791, “Spherical projection”) is used then all coordinates in the Two Dimensional to Three Dimensional Map Sequence (0022,1518) are expected to lie on a sphere with a diameter that is equal to Ophthalmic Axial Length (0022,1019).

The use of this model for representing the 3D retina enables the calculation of the shortest distance between two points using great circles as per section UUU.1.3.2.