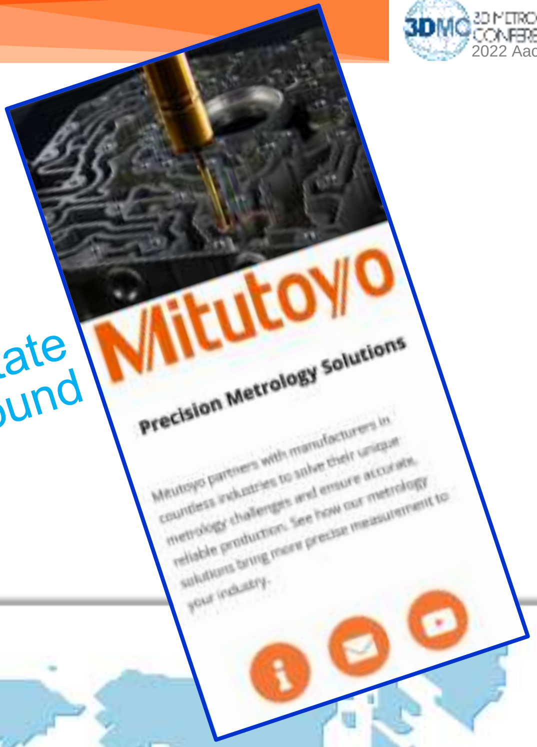
From technical consideration on performance evaluation of optical 3D CMS

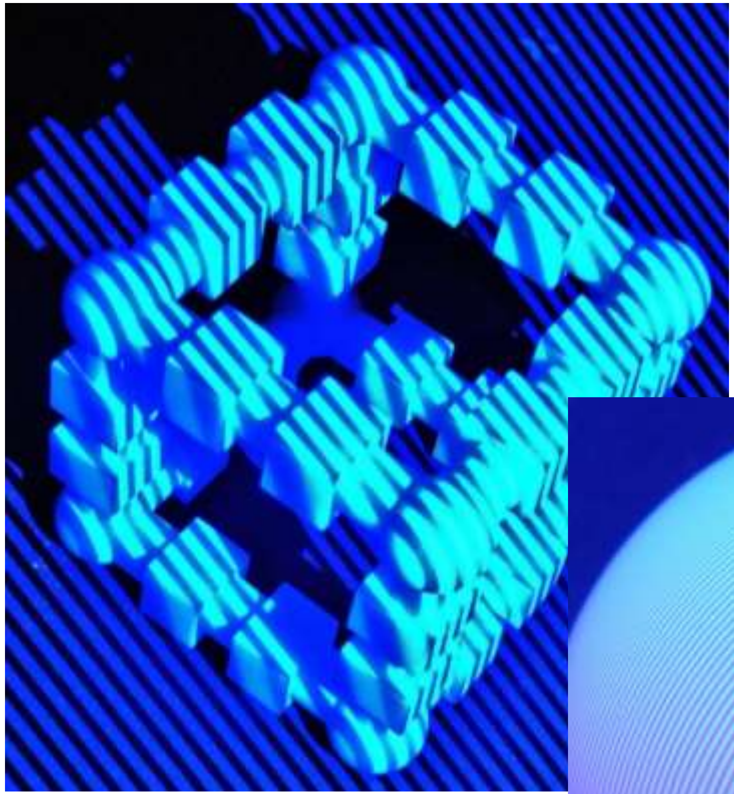
Mitutoyo Corporation
Makoto Abe

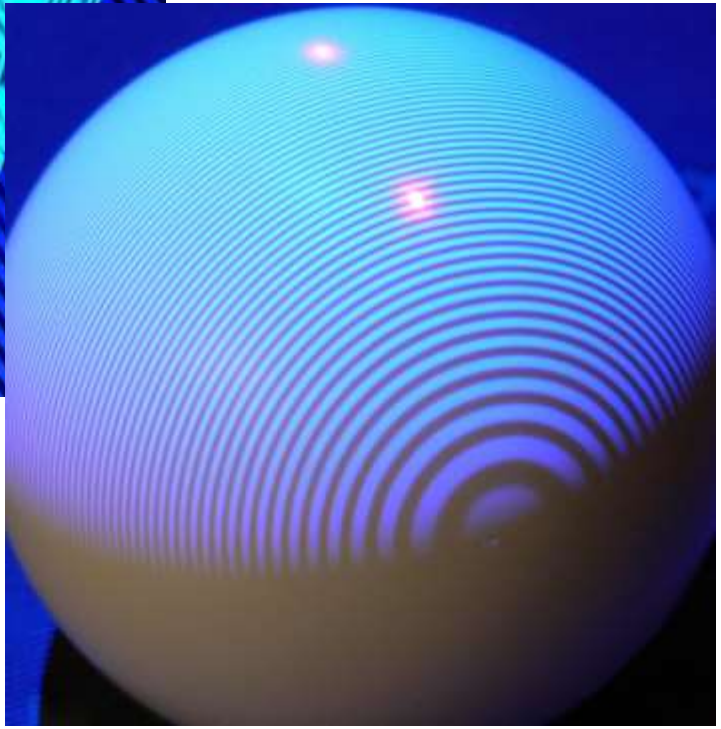
Please don't hesitate to take a look around Mitutoyo booth



Dominant portion of this study was conducted at National Metrology Institute of Japan
under financial support made by Ministry of Economy and Trade in Industry, Japan
and cooperative research pursued by Mr. S. Yokota under supervision of Prof. Dr. I. Yoshida, Hosei Univ., Japan.

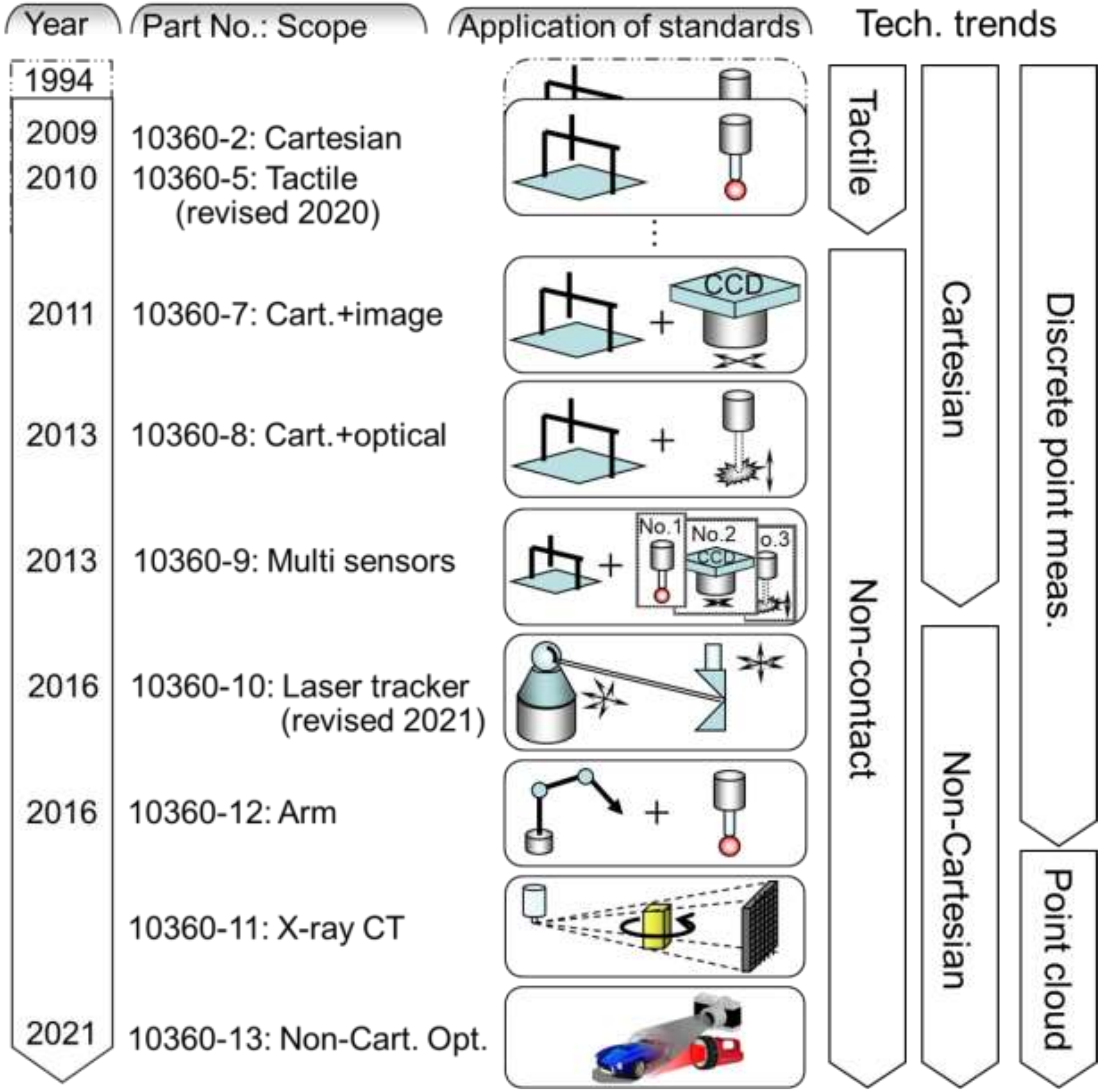
Talk content today

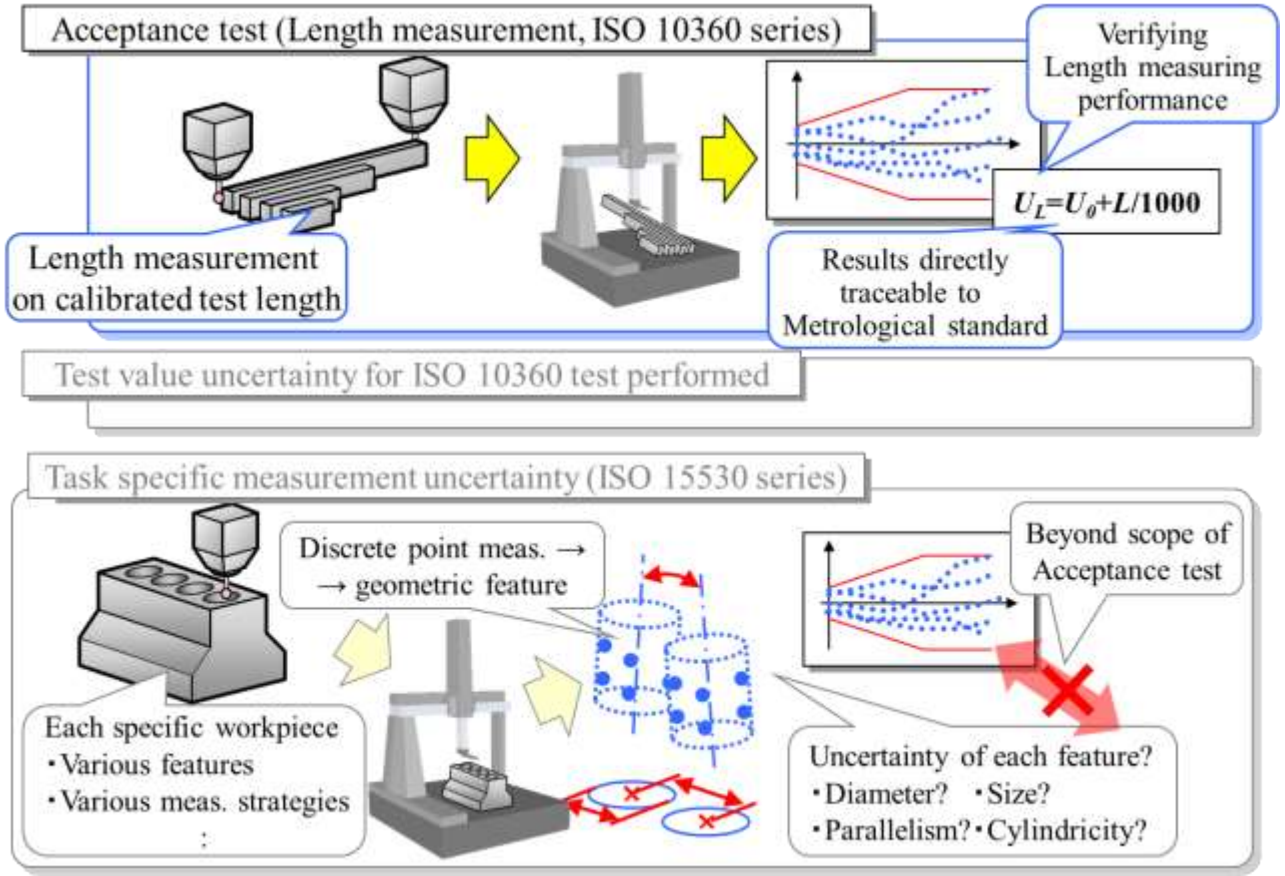




- ISO 10360-13 : 2021
  - (GPS) Acceptance and reverification tests for coordinate measuring systems, Part-13 : Optical 3D CMS
- With in technical challenges
  - Influence from:
    - Surface color of objects to be measured
    - Concatenated measurement when global coordinate system unavailable
    - Capture efficiency of CMS error when double ball bar measurement performed
    - Trade-off between spatial resolution and smoothing function
    - Partial departure from bi-directional performance evaluation in discrete point-to-point manner

Development of ISO 10360 series

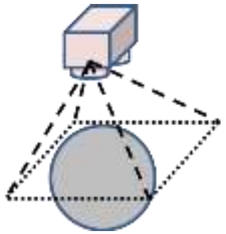




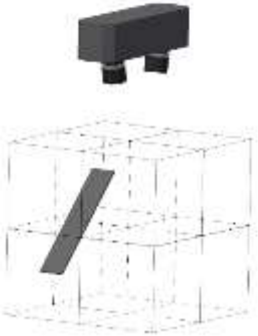
- Dedicated :
  - Historically for Cartesian CMMs
  - Extended to state-of-the-art CMSs
- Widely accepted :
  - To verify conformance to the specification of CMS
  - Acceptance and re-verification
    - Measuring performance when complex geometry is measured supposed to be covered by another frameworks

Framework of ISO 10360-13 for testing Optical 3D cms

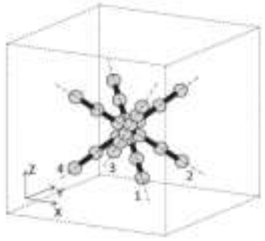
- Performance verification on:
  - Probing error, interpreted as spatially local error
    - Calibrated test sphere referred
    - Sphere measurement for verifying error in size and form

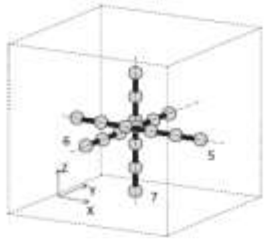


  - Distortion error, for meas. volume corresponding to FOV of CMS
    - Calibrated double-ball-bar and calibrated flat-surface referred
    - Double-ball-bar : 12-orientaions on 2x2x2-boxels and 3-repeated
    - Flat-surface : 6-orientations / positions

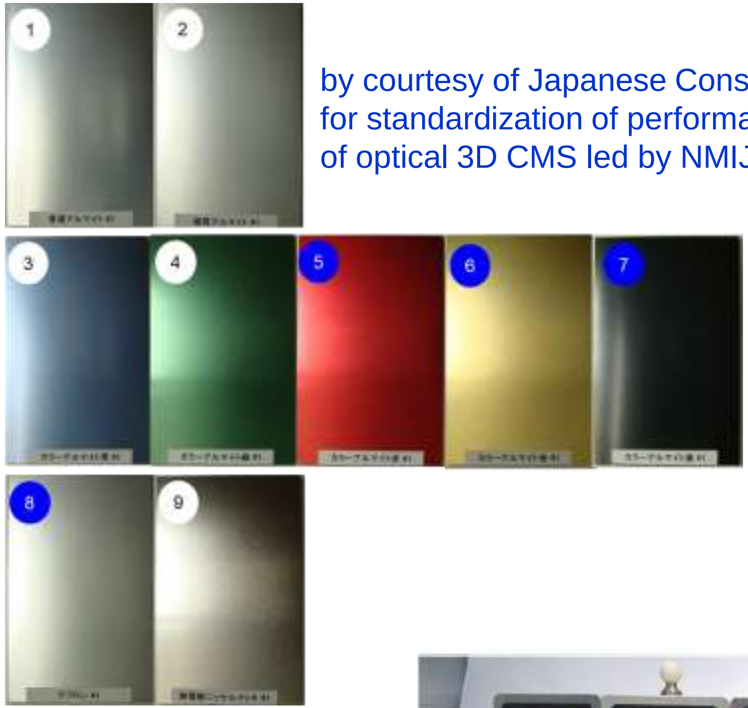


  - Concatenated length measurement error, for larger meas. volume
    - Meas. range often extended, beyond size of FOV of CMS
    - 7-orientations, 5-lengths, and 3-repeated

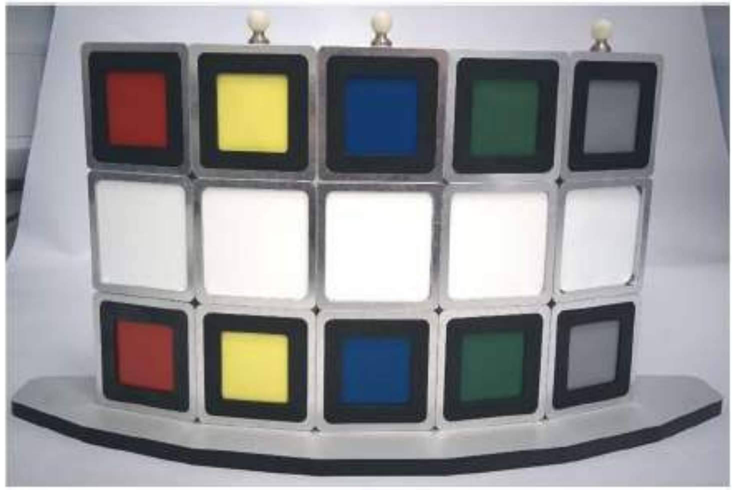




Dependency on surface color of an object to be scanned



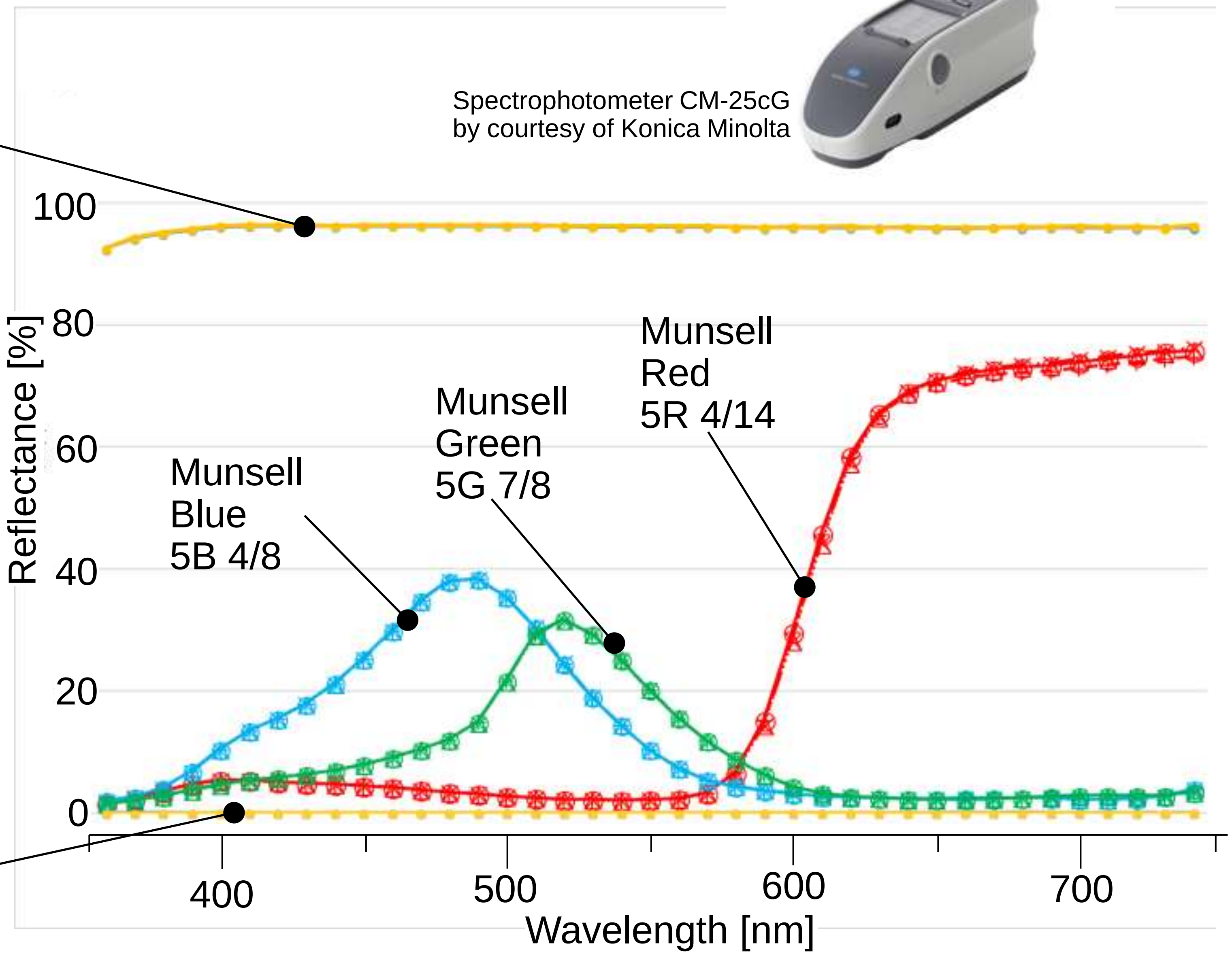
by courtesy of Japanese Consortium
for standardization of performance evaluation
of optical 3D CMS led by NMIJ, presented in 2009



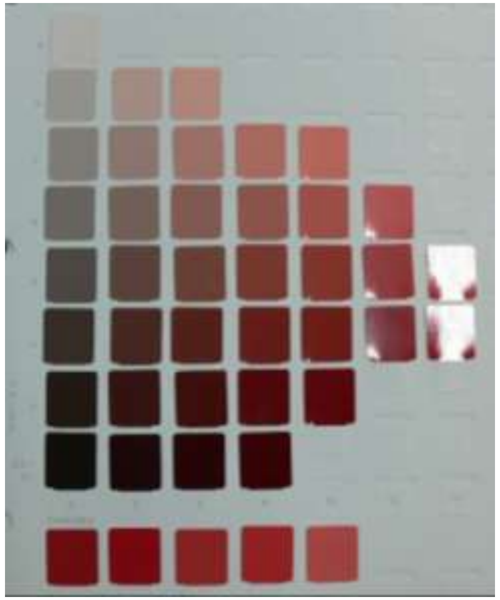
Source : ISO/TC213/WG10/N1137
submitted by NPL, UK.

- A couple of trials performed in the past in terms of performance evaluation of optical 3D CMS
  - Typically using painted samples
- Many different color systems have been standardized independently in history
  - Munsell color system
  - Natural color system (NCS)
  - PCSS color system
  - Federal standard color system
  - ISCC-NBS system
  - BS 4800 colour system
  - RAL colour system
  - Pantone matching system (PMS)
  - XYZ color system
  - CIE *L*a*b** color space (CIELAB)
  - probably more…

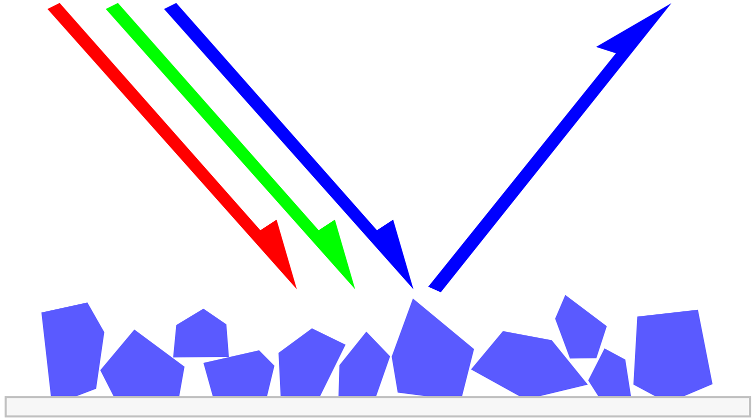
Spectral reflectance theoretically encompasses all the color systems



Spectrophotometer CM-25cG
by courtesy of Konica Minolta



Surface color?



Schematic of surface color

Ukiyo-e famous as usage of Hiroshige-blue

- Optical reflection on theoretically opaque solid surface
  - Number of more complex phenomena known, but
    - excluded in terms of development of acceptance testing,
    - potentially subject of process capability analysis or equivalent
      - Reflecting phenomena in transparent sublayer
      - Fluorescence
      - Fragmented reflective boundary of materials
- Quantitative measure
  - Spectral reflectance across visible wavelength traceable to corresponding national metrology standard

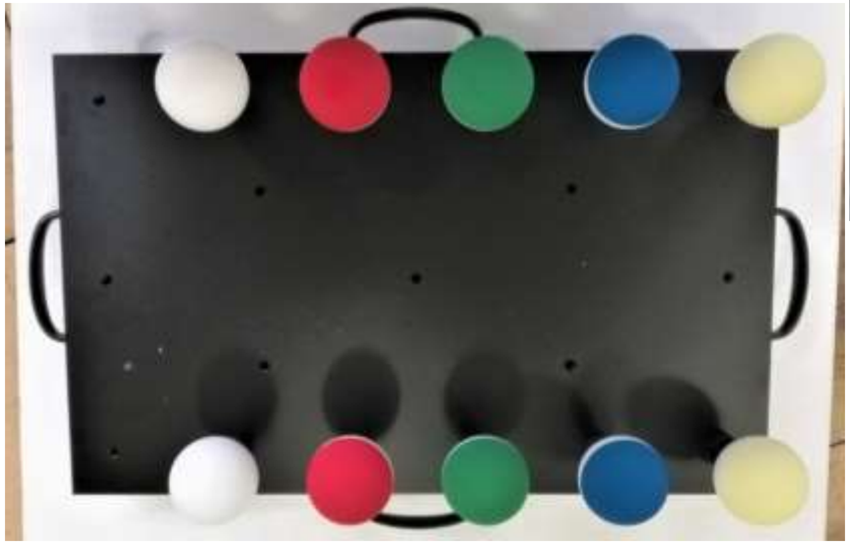
Opaque colored test sphere prototyped in practice

Pigments for Ukiyo-e painting each having similar spectral reflectance with:

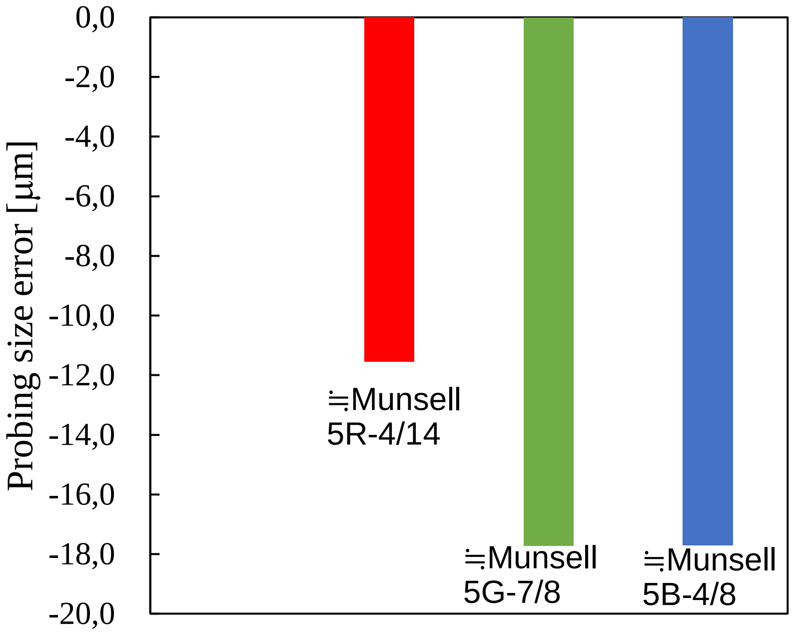
- Red : ≒Munsell 5R 4/14
- Green : ≒Munsell 5G 7/8
- Blue : ≒Munsell 5B 4/8

http://www.kissho-nihonga.co.jp/

Billiard ball, easy to imagine, but hard to use…

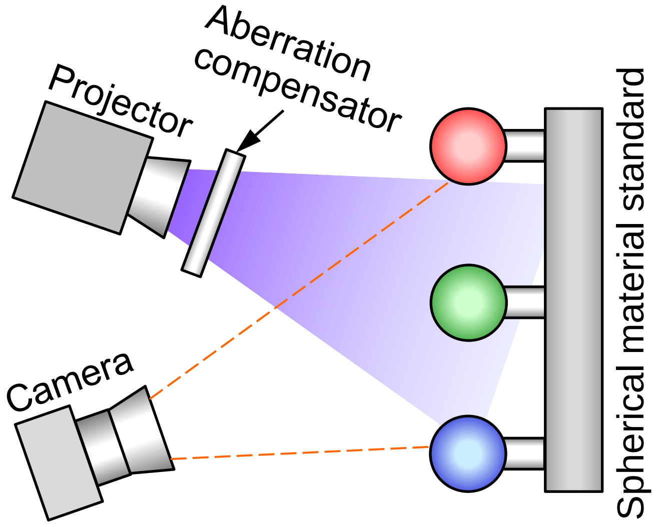


Prototyped test spheres, Metrology grade base sphere (45 mm) made of LovTEC, low volume scattering ceramics
https://krosaki-fc.com/en/ceramics/lovtec.html

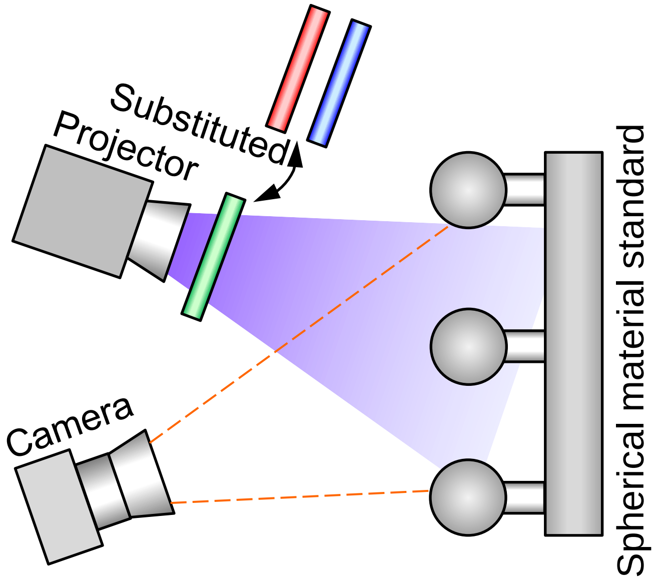


Size error evaluated on prototyped test spheres, Reference size value obtained by high spec tactile CMM, Size error measured by an optical 3D CMS plotted

Consideration on color for ISO 10360-13 development



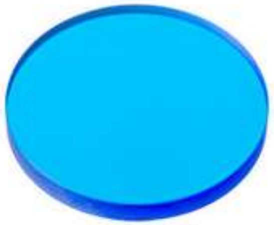
~To be newly designed~
Material standard having
intended
spectral reflectance

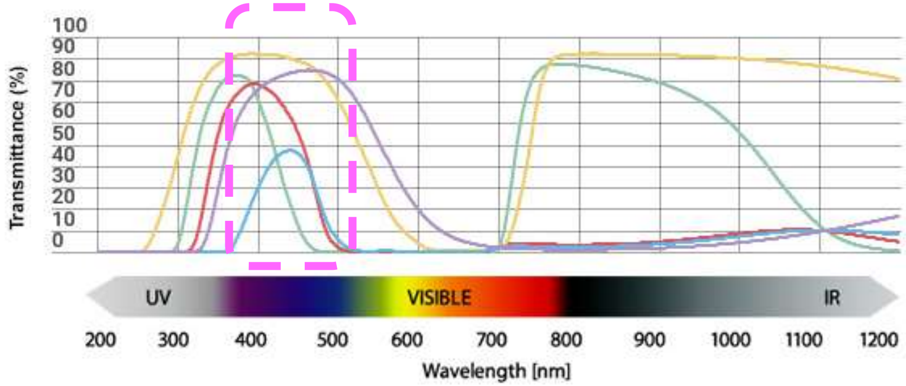


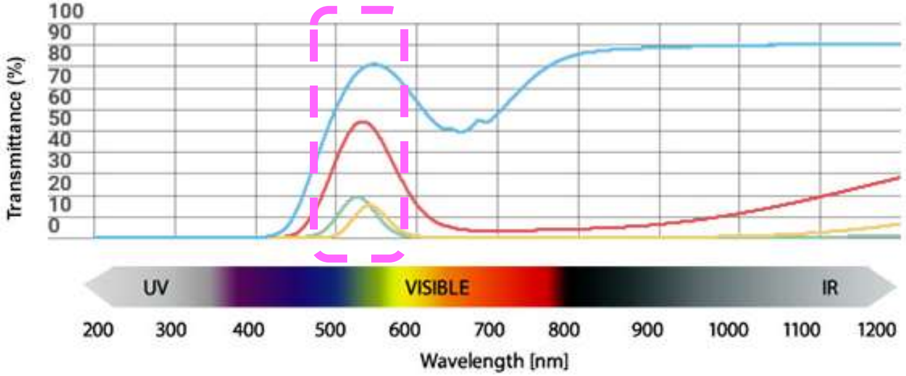
~Conventional~
Material standard having
white or gray reflectance
x
Optical filter having
intended
spectral transmittance

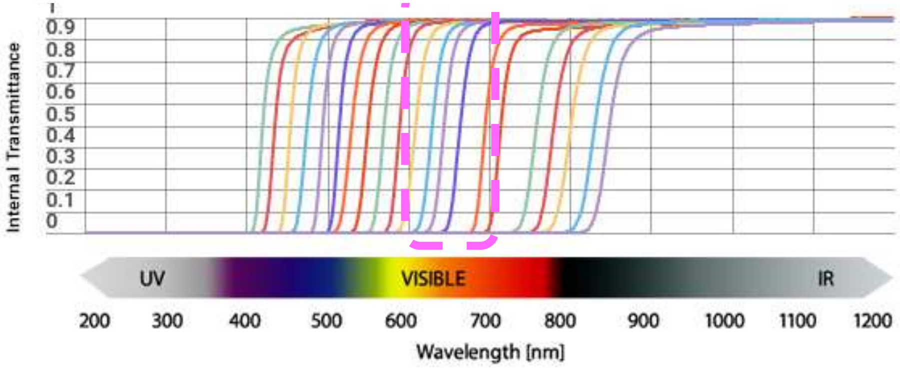
- Spectral reflectance
  - Primary quantitative description of surface color.
  - Several instruments commercially available.
- However, one more step forward needed
  - For realizing practically useful material standard
    - Not-requiring tedious pigment painting or similar
    - Not-increasing variation of expensive material standard needed for performance evaluation
  - Surface color for optical 3D CMS can be modelized by convolution built by :
    - [Light source]
      x **[spectral reflectance]**
      x [detector sensitivity]
  - Can be approximated by decomposition:
    - [Light source]
      x **{ [white/gray reflectance]**
      x[spectral transmittance] }
      x [detector sensitivity]

Towards realization of intended spectral transmittance





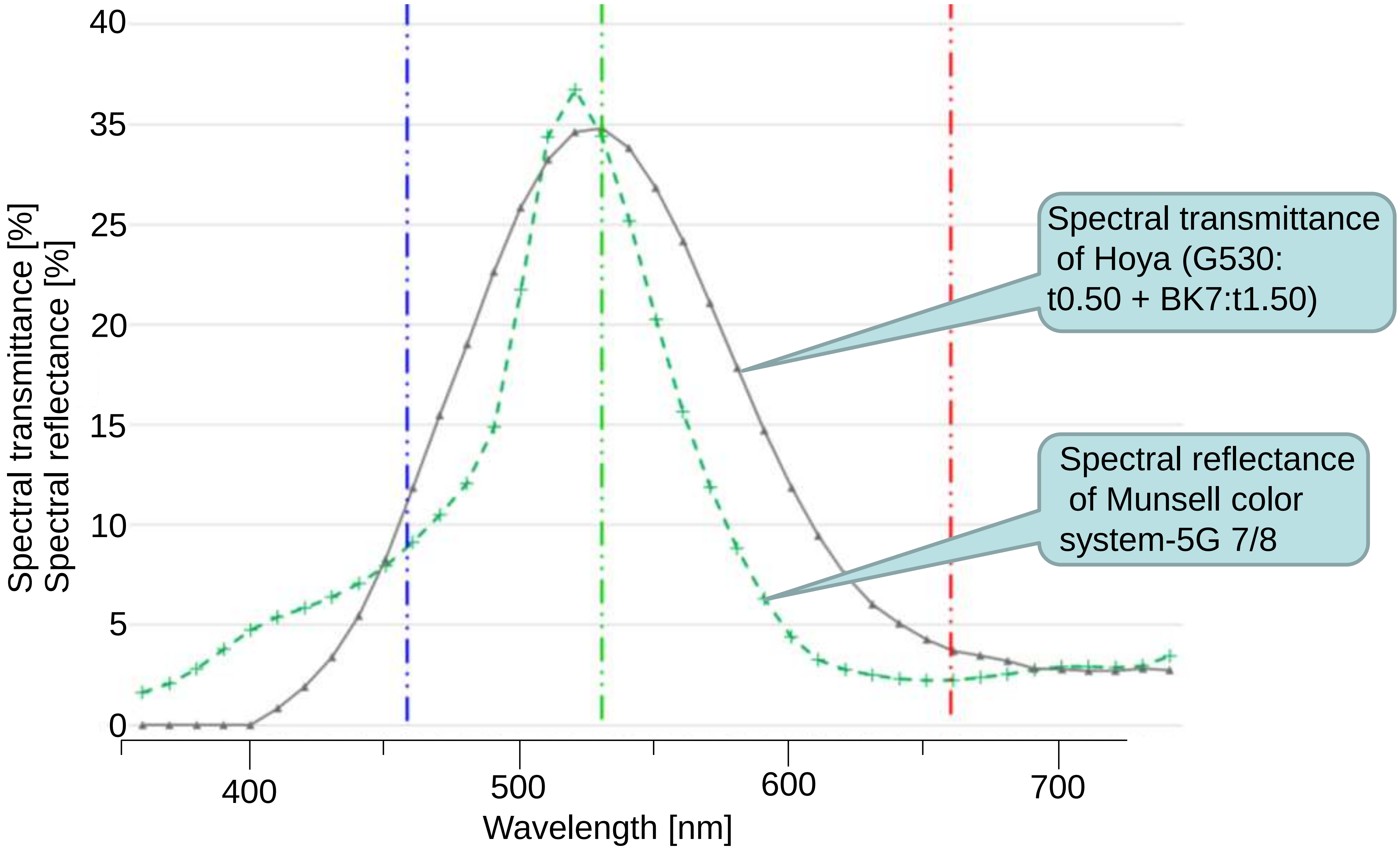




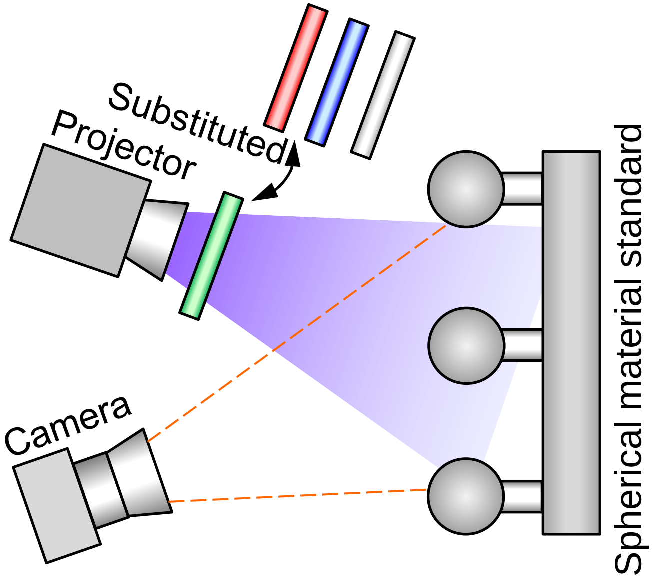
https://www.hoyacandeo.co.jp/english/products/eo/color/index.html

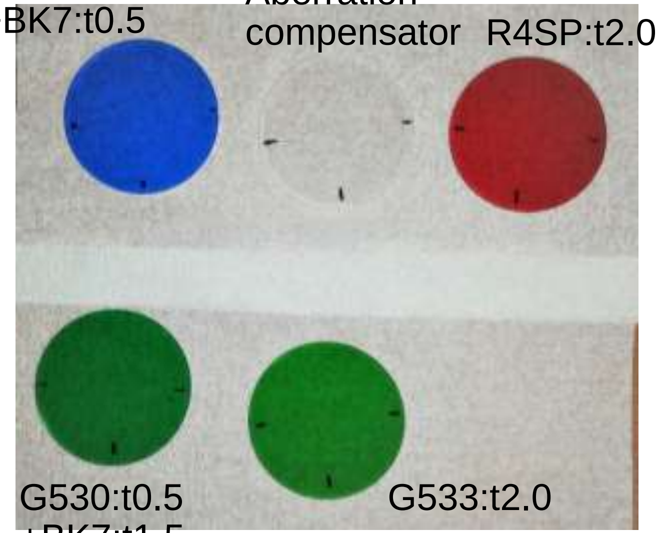
- Overall transmittance
  - Tunable by adjusting thickness of filter substrate
- Spectral curve
  - Depending on choice from available filter materials
- Aberration influence to optical 3D CMS due to thickness of filter
  - Total thickness adjusted to be the same by coupling filter substrate with transparent substrate
    - Blue B410:t1.5 + BK7:t0.5 adjusted to Munsell 5B-4/8
    - Green G530:t0.5 + BK7:t1.5 adjusted to Munsell 5G-7/8
    - Red R640:t2.0 adjusted to Munsell 5R-4/14

Spectral characteristics color filter prototyped, an example

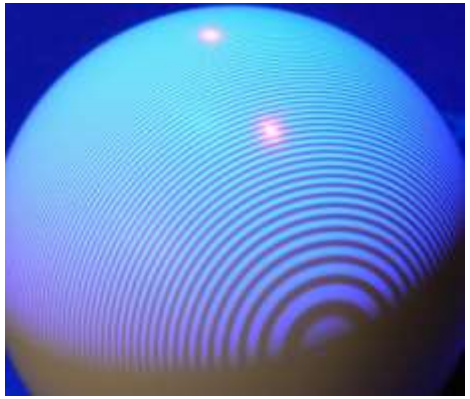


Experimental outline

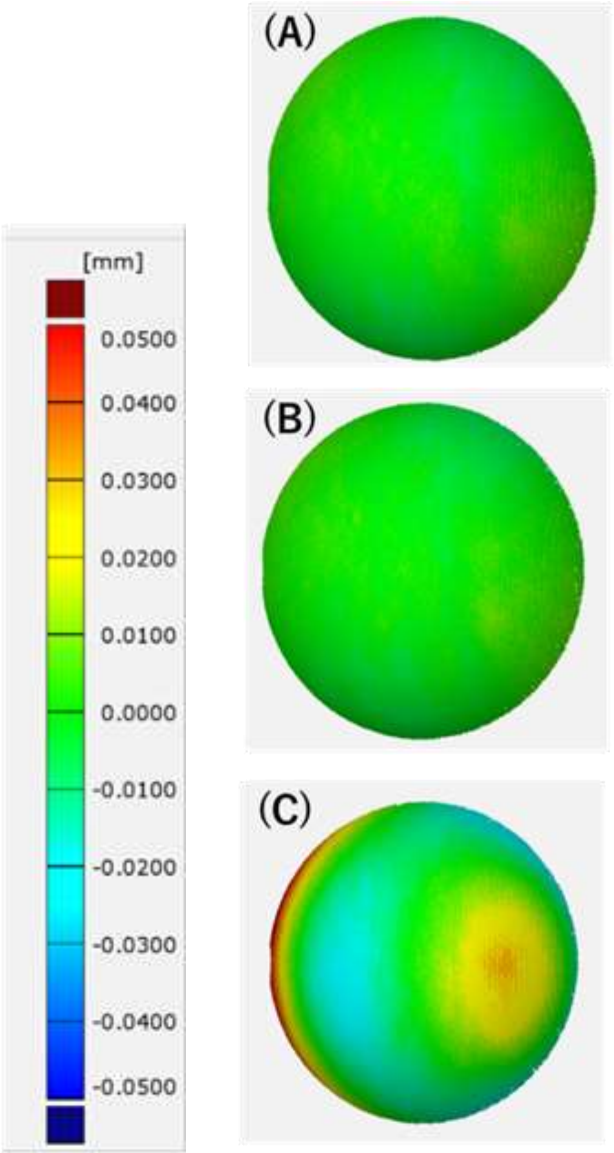




- Preparation of color filter with:
  - Intended spectral transmittance
  - Same total thickness for same aberration
- Insertion of aberration compensator
  - Qualification of optical 3D CMS performed
    - according to the manufacturer’s procedure
  - Measurement on conventional white material standard performed
    - Aberration compensator and respective filters are substituted
    - Metrology grade sphere size measure

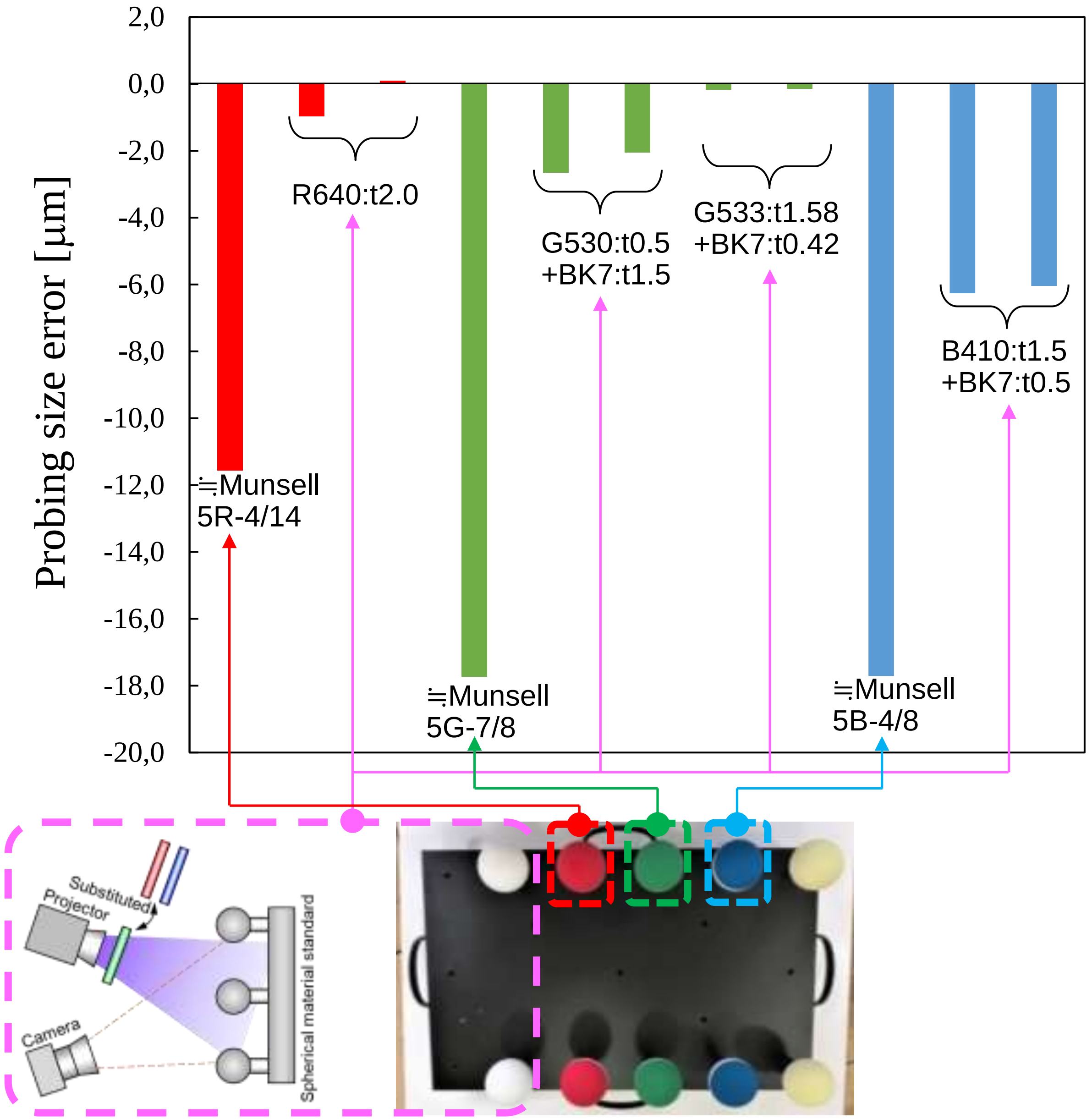


System qualification including aberration influence?



- (A) Normal operation procedure (as reference)
  - No-substrate installed
  - Qualified as the manufacturer's procedure
  - Then sphere measurement performed
    - Comparable to best practice known
- (B) Aberration compensator installed and qualified
  - Aberration compensator (t2.0 mm) installed
  - Qualified as the manufacturer's procedure
  - Then sphere measurement performed,
    - Influence by aberration fairly well compensated through qualification
- (C) Qualified and aberration compensator installed
  - Qualified as the manufacturer's procedure (no-substrate)
  - Aberration compensator (t2.0 mm) installed
  - Then sphere measurement performed
    - Significantly influenced by aberration

Probing size error tested experimentally



- Influence of surface color on measuring performance of optical 3D CMS tested
  - Usage of color filter emulating surface color
  - seems to show reasonably acceptable characteristics
- Potentially applicable for verifying influence of surface color to performance of optical 3D CMS
  - Poly-chromatic optical 3D CMS
  - Mono-chromatic optical 3D CMS

Summary

- Influence of surface color of object to be scanned studied
  - Proposal to utilize “spectral reflectance / transmittance”
  - Proposal to utilize :
    - Conventional material standard used for optical 3D CMS to verify the measuring performance
    - And, installation of color filter for emulating spectral characteristics to mimic surface color
  - Feasibility experimentally demonstrated applicability for
    - Poly-chromatic optical 3D CMS
    - Mono-chromatic optical 3D CMS
  - It turns out :
    - Spectral sensitivity of mono-chromatic optical 3D CMS doesn’t make much sense
    - Brightness information for mono-chromatic optical 3D CMS within wavelength range in interest only may make sense