Terahertz time domain spectroscopy and imaging applied to cultural heritage

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Photo: Firenze, 4 Sep. 1966
Intervention for conservation is like medical operation.

Scientific analysis is desired to understand the history of artworks.

History of the artwork: materials and structure (techniques) of original and previous conservations.

Conservation planning: materials to clean, to support, to colour, to varnish...
Uses of THz waves in general

**Spectroscopy (Material analysis)**

- 100GHz~15THz
- FTIR
- 12THz~120THz
- 400 cm\(^{-1}\)~4000 cm\(^{-1}\)

**Non destructive testing (Internal structure observation)**

- ~300MHz
- 1~10GHz

- 100GHz~3THz
- TDS Imaging

XRF

OCT

X-ray
THz waves (0.1-10 THz) = T-rays = Sub mm waves = Far-infrared

500 cm⁻¹ = 15 THz
Advantages of THz waves

THz waves can reach preparation layers
Completely non-destructive
Sufficiently high resolution in analysing support and preparation
Varnish is transparent
Traditional mineral pigments have particular response (absorption peaks, reflection levels)

THz pulse echo:
Time of flight

Pulse in time domain---FFT---Spectra in freq domain
Commercially available THz instruments

FTIR (from 60'~)
- ABB-Bomen
- JASCO
- Bruker

Instruments used for artwork
- Tochigi Nikon

TDS, TDS based imaging (90'~)
- Z-omega
- Menlo
- Otsuka
- Advantest
- JFE Techno Research

CW, CW imaging
- Synview
- Toptica
- Emcore

THz Camera
- NEC LongWave
- Photonics (MIT)
Specimens to establish measurement protocols

Pigments in "Libro dell'Arte" by Cennino Cennini, ~1400 ca.

Tempera su tavola - Galleria degli Uffizi

Affreschi (buon) - Prof. ssa Misao Oono

Paravento giapponese - Museo Nazionale Tokyo

Pareti della casa - Mitsui Housing
Spectroscopy: material analysis, usually in transmission

XRF, XRD, FTIR, EPMA, etc can do even better, if sampling is allowed.


K. Fukunaga et al., IRMMW-THz, 2007
Example: Transmission imaging

Sumerian Cup ~3000BC

Transmission Through Base Between 0.4 and 1.0 THz

- ~34% has noise floor transmission
- ~40% has ~10% transmission
- ~18% has ~20% transmission
- ~8% has ~30% transmission

**Verderame (Mineral Pigment)**

Reflection measurement is desirable in practice.

Internal structure is observed in reflection mode in time domain.

Frequency band used by common THz-TDS imaging systems.

Imaging system: Picometrix T-Ray 4000 15 cm sq @ 1 mm resolution < 20 min
Material mapping only with reflection level

Only the point 'a' is measured for orange.

K. Fukunaga et. al., JEOS-RP, Vol. 5, No. 10024, 2010

THz imaging can suggest points for precise measurements
Tempera panel paintings
Politico di Badia, Giotto, 1300

Restauro: 2008.10-2009.02, Stefano Scarpelli
Analisi: THz & XRF (NICT), FORS (IFAC), EPMA (ICVBC),
FTIR & Gas-Mass (Univ. Torino),
Foto UV, IR, X-ray (Pan-Art)


Smoothing gesso layer
=Medieval technique

Gold leaf under paint
THz can prove what was done.

No proper preparation layer was made. (Only gesso was put.) This previous conservation caused a new problem of tension.

Two canvas sheets were sewed up. The convex part was in front side before. Conservator managed to push into opposite side, by using a suction table.
Condition examination of wood panel

Before

Below varnish

Canvas with gesso

Insect holes in the wood panel (3D map can be obtained)

After

Repainted parts are removed.

Rosso Fiorentino, Ritratto di giovinetta, Oil on wood, 1514/5, Galleria degli Uffizi
THz waves can see feet of bird mummy

**Bird Mummy from Egypt**

THz waves can see fabric layers in detail, but....


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Galleria degli Uffizi
Inner Mongolian Museum
The Metropolitan Museum of Art, NY
Tokyo National Museum

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Kyoto University

NICT has measured so far...

Giotto di Bondone, "Polittico di Badia", Tempera on wood, 1300
Kiyomizu Temple, decorative wood wall and pillars 1500~1630
Inner Mongolian wall painting (fresco a secco), 1600
Takamatzuzuka wall painting (fresco a secco), 700
Willow bridge and water mill, paper panel painting, 1600~1700
Tribuna, zoccoli, decorative wood wall, 1580
Rosso Fiorentino, "Ritratto di ragazza", tempera on wood, 1514
Mummy of Kharushere ca. 825-712 BC
Aizendo, decorative wood wall, 1597
Masaccio, "Trittico di San Giovenale", tempera on wood, 1422
Simon Vouet, "Santa Cecilia", oil on canvas, 1626
Tanzan temple, wood panel painting, 1627
Korin Ogata, "Iris with eight bridges", Panel Screen, 1710
We go anywhere on the earth...

The storage of the MET NY

Tribuna@Uffizi
The world first museum

A balcony of a shrine in the mountain covered with snow

The world first city in Turkey