Next Generation Optical Coherence Tomography for Art

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In the last 10 years, Optical Coherence Tomography has been successfully applied to art conservation, art history and archaeology.[1] OCT has the potential to become a routine non-invasive tool in museums allowing cross-section imaging anywhere on an intact object where there are no other methods of obtaining subsurface information. While current OCTs have shown potential in this field, they are optimised for biomedical applications. Some major limitations are: (i) lower depth resolution compared to conventional microscopic examination of paint cross-sections; (ii) limited probing depth through highly scattering paint.

Increasing the depth resolution involves broad band sources and increasing the probing depth needs sources at longer wavelength than conventionally used in biomedical imaging. To achieve this, two new OCT systems have been built in our current project so that when used in conjunction, they would aim to match the information from conventional invasive microscopic examination of sample cross-sections (tiny samples removed from objects):

1. A 2000nm OCT optimised for deeper penetration suitable for imaging cultural heritage objects consisting of highly scattering materials. This would allow improved imaging of highly scattering or absorbing paint layers and underdrawings beneath them (at higher transverse resolution than conventional infrared imaging), as well as pigmented objects such as coloured enamels and glass with opacifiers. A recent survey of the transparency of historical artists' pigments over the spectral range of 400nm – 2400nm has shown that the optimum spectral window for OCT imaging of paint layers is around 2200nm.[2] Excluding the lake pigments (which are all highly transparent at wavelength >600nm) in the sample of 45 historic artists' pigments studied, over 30% of the paint samples are >5 times more transparent at 2200nm than at 800nm, and ~25% of the paint samples are >2 times more transparent at 2200nm than at 1500nm. Off-the-shelf OCT sources are commonly found around 800nm, 1000nm, 1300nm and 1500nm and few OCT systems have been built beyond 1300nm. The development of long wavelength OCT requires the development of novel broadband sources at such wavelength. Two types of novel sources, a superfluorescent fibre source[3] and a swept (tuneable) laser source were developed.[4] An OCT at 1950nm has been developed and shown to reveal layer structures of both highly scattering paint such as Titanium white and highly absorbing paint such as Prussian blue.[5] These were not possible with shorter wavelength OCTs.

2. An 800nm OCT optimised for imaging at high depth resolution: targeted towards applications where the highest resolution is required but the material is relatively transparent, such as imaging of multiple thin varnish layers on painting surfaces, gel layers on degraded glass or glazes on the surface of ceramics and enamels. Since OCT depth resolution is determined by the source spectrum (specifically it is proportional to wavelength squared and inversely proportional to the bandwidth), to achieve the same depth resolution a source at 2000nm would need to have a bandwidth ~6 times

broader than the one at 800nm which is technically very challenging. The opposing demands of resolution and penetration mean that we need to build two OCTs to cover the different requirements of the various questions being investigated when imaging cultural heritage objects. An ultra-high resolution OCT at 810nm with depth resolution of 1.2 micron in varnish or glass has been developed and shown to be able to resolve thin varnish layers at similar resolution to invasive microscopic examinations currently employed in museums.[6]

A number of examples of OCT imaging of different materials using the two new OCTs will be shown to illustrate the new approach.

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