# Cyclododecane as a Reversible Contrast Enhancer for the Terahertz Imaging of Frescos

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*Abstract*— **Cyclododecane (CDD) is a wax-like hexane used as a totally reversible, volatile binding medium for many cultural heritage applications. We investigate CDD using THz-TDS and DFTS, and consider its potential as a contrast enhancing agent for multilayer fresco paintings.**

## I. INTRODUCTION

CYCLODODECANE (CDD) is a wax-like cyclic hexane ($C_{12}H_{24}$) commonly used by art conservators as a volatile binding medium to consolidate and protect works of art with delicate, porous or friable surfaces during their transportation or cleaning [1]. It is particularly useful for this purpose because—in addition to being easily applicable, durable and water resistant—it is completely reversible and sublimates away at room temperature over the course of some weeks or months, leaving no residues or need for mechanical or chemical removal.

THz time-domain spectroscopic imaging has demonstrated an advantage over some other reflectometric techniques, such as IR reflectography, in that the terahertz pulses have a "time-of-flight" with partial transmission and partial reflection at material interfaces. As a result, it is possible to image a painting hidden beneath several millimetres of plaster. Nonetheless, there are challenges to using THz-TDSI in cultural heritage, as artefacts are often complex, heterogeneous structures—imprecise and unique [2]. Sometimes, the ability to image a layer of paint using THz-TDSI can have less to do with the presence or properties of a material than it does with the quantity of the material and the relative properties of other adjacent materials. Qualitatively-speaking, this is called contrast. The stronger the signal reflected from the area of interest is, compared to the surrounding areas, the better the contrast, hence the better the image quality.

Not long ago, the fresco *Les Trios Hommes Armés de Lances* (Collection Campana, P44, Musée du Louvre) was part of a project which included several multispectral imaging techniques and a cleaning. It is a "true false antique painting", composed of fragments of 1st C. CE mortar bound in 19th C. CE plaster, revealed via x-ray radiography. UV fluorescence measurements detected pigment elements not present on the surface; however the volumetric measurement has no depth precision [3]. The THz-TDSI technique had the potential to determine if there was a painting hidden beneath the more modern, visible one. A region of the fresco was scanned twice; the first time, fine, human, facial features were subtly revealed; the second, 3 months later, only coarse, nebulous features could be detected. The experimental question changed from 'Is there a painting?' to 'What changed between measurements to cause such different results?'

We postulate that the visible presence of cyclododecane (CDD, a consolidant used as a part of the cleaning process to protect the pigment from the white spirit) during the first experiment improved the transmission of terahertz radiation through the plaster top layer and enhanced the contrast between the plaster and the pigment. Follow-up work includes an extensive study of traditional plasters and pigments treated with different CDD preparations), using terahertz dispersive Fourier-transform spectroscopy (THz-DFTS). It is believed that the CDD serves as an index-matching medium, replacing air in the porous plaster-matrix, thus reducing scattering and improving signal to noise. As a well-characterised, non-destructive, volatile medium, this application of CDD could significantly progress the THz imaging of covered wall paintings.

## II. RESULTS

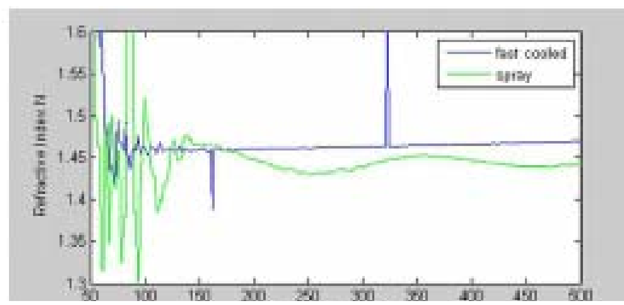


**Figure 1: Refractive indices of CCD melt and CCD spray.**

The addition of cyclododecane to plaster samples was found to increase the front surface reflection when melted onto the top of samples to form a smooth coating. This may be due to a reduction in surface scattering effects. The optical constants of CDD are the key to understanding why it can be expected to improve contrast in the terahertz imaging of concealed wall paintings. When applied in the form of a melt, it penetrates into porous materials. Consequently, it cools rapidly, and so the optical constants of the CDD applied in this manner can be expected to be close to those for the fast cooled sample presented above. Similarly, when applied as a solution or via aerosol spray, large crystals do not form, and again the optical constants of the fast cooled sample can be considered representative. For either case, the absorption is low and the refractive index is around 1.45. In comparison, the refractive index of typical wall plaster is around 2.0 throughout the terahertz range.

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