Sub-surface Terahertz Imaging through Uneven Surfaces: Visualizing Neolithic Wall Paintings in Çatalhöyük

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Abstract: Portions of Neolithic paintings at Çatalhöyük, Turkey, are hidden under uneven covering layers of plaster. Traditional terahertz data analysis has proven unsuccessful at sub-surface imaging of these paintings. An imaging technique is presented, based around Gaussian beam-mode coupling, to visualize the obscured painting.

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1. Introduction

Summer 2011 saw the first deployment of a portable terahertz (THz) imaging system in an archaeological setting: Çatalhöyük in rural Turkey (to become a UNESCO World heritage site in 2012). It is a site of Neolithic domestic dwellings, the walls of which were repeatedly re-painted and re-plastered over their lifetime. Exposing the underlying paintings, often without indication of their presence, is time consuming, arduous and sometimes fruitless. Exposed this season was a line composition above a burial site – a painting of such significance that from exposed sections it was evident that the pattern was repeated throughout the layers of the wall; this made it a reliable test base for the use of THz imaging in the imaging of sub-surface paintings.

Work began on a section of the wall where an exposed line was seen to continue under a plastered section before being exposed further along the wall. This section of the painting is shown in Figure 1a, while Figure 1b shows the "pitch-catch" configuration which was used to collect the data. This particular section of the wall, in principle, proved an ideal test bed for the technique. However, the covering plaster was uneven, and this resulted in traditional THz imaging techniques being inadequate for the task of successfully reconstructing the sub-surface image. The data collection method had no facility to correct for defocusing of the beam as it was scanned over the uneven wall surface. Furthermore, the uneven covering surface deflected the THz signal away from the detector, rendering any comparative spectroscopic analysis across the image impossible. A signal processing technique correcting for the uneven wall surface, and hence the defocusing and deflection effects, is presented in this paper, together with the resulting reconstructed sub-surface image of the Neolithic wall painting.

(a)

(b)

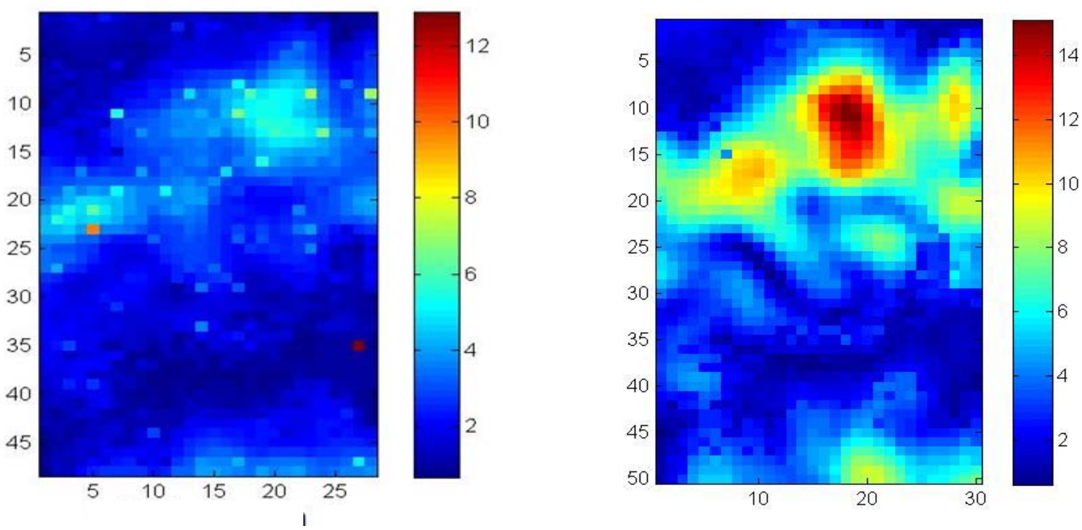
Figure 1 (a) shows a section of Neolithic wall with a line section covered with uneven plaster, imaged section highlighted. Figure 1 (b) shows the "pitch-catch" experimental configuration.

2. Methodology

A three-dimensional surface profile for the wall was created from the THz time domain data. A zero *z* (depth profile) plane was defined from the time shift of the signal reflected from the wall which gave the largest amplitude. This was assumed to be the focal plane of the experimental configuration. Deviation from this plane in the *z* direction was defined by the differential time delay between each pixel and the pixel defining the zero plane. Differential gradients were determined in the *x* and *y* directions of the image through the time delay differential between adjacent pixels in each direction. This three dimensional surface profile was converted into the spherical coordinate system to better match the geometry of the experimental configuration.

The incident THz beam was assumed to be a fundamental Gaussian beam-mode. Deviation of the wall surface profile from the focal plane was calculated in the zenith, azimuthal and orthogonal projection dimensions. The resulting propagation of the beam to the wall surface, either in advance of or beyond the theoretical focal plane, and its deflection from the optimum line of reflection were calculated. These misalignments were used to evaluate the overlap integral describing the coupling between this displaced reflected beam and the detector, based on the work of Kogelnik [1] and Joyce and DeLoach [2], and this used to correct for the percentage of radiation deviated from the detector due to the uneven surface of the wall.

This correction was applied, pixel by pixel across the image and then a frequency integration image created using standard THz imaging techniques. This image is shown in Figure 2 (a) and compared to a standard frequency integration image in Figure 2 (b). Further, the line exposed in Figure 2 (a) can be compared to the highlighted section in Figure 1 (a); the expected line can be followed across the THz image.



(a) (b)

Figure 2 (a) shows a THz image of a section of Neolithic wall following a coupling integral correction, corresponding to the image section highlighted in Figure 1 (a). Figure 2 (b) shows a traditional THz image of the same section.

3. Conclusion

A novel image processing technique is presented to correct for uneven surfaces above sub-surface features, to aid the imaging of those features. A methodology for calculating a beam coupling integral has been demonstrated and this correction applied to an image data set to reveal more clearly an embedded paint layer from a Neolithic wall at the archaeological site of Çatalhöyük.

4. References

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