INSIDDE project: Unveiling the secrets of art through graphene-based terahertz technologies

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***Abstract*—In this paper we describe how terahertz technology can be applied in different areas of cultural heritage to analyze paintings and ceramics, producing digital surrogates that, together with the developed applications and functionalities, will bring closer art to citizens.**

***Keywords*—Terahertz technologies, graphene, image processing, 3D modelling, augmented reality, art, INSIDDE.**

I. Introduction

The project INSIDDE ("Integration of technological solutions for imaging, detection and digitisation of hidden elements in artworks") [1] is intended to cover the whole value chain, from the design and implementation of a graphene-based terahertz scanner to the reutilization of the resulting digital models to facilitate the access of citizens to these surrogates. In order to do so, an overall approach bringing together different technologies and techniques has been put into practice following the scheme shown in Fig. 1.

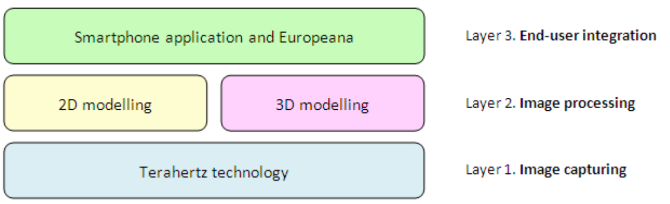

Fig. 1. The overall approach of INSIDDE lies in the use of terahertz technology to bring art closer to researchers and citizens.

In this paper, each of the blocks will be described together with the latest outcomes obtained, some of them already commented in [2].

II. Graphene-Based Terahertz Technology

The incorporation of graphene films into terahertz multipliers and mixers [3] is one of the keys to design cost-efficient and reliable transmitters and receivers in the frequency bands ranging from 140 GHz to 325 GHz. Although higher frequencies were considered at the beginning, it was deemed (and contrasted) that to penetrate clay walls a lower band was needed.

The terahertz scanner [4] has been built integrating the aforementioned devices into an XYZ table that allows the heads to be moved in the three dimensions and, consequently, with the capability to be used for both 2D and 3D artworks, paintings and archaeological pieces respectively. This is complemented by (i) a focusing system consisting of different lenses to achieve a beamwidth appropriate for the envisioned applications and (ii) a laser sensor that contributes to the improvement of the spatial resolution and the automatic positioning of the transmitters and receivers.

The continuous-wave imaging system works in reflection mode so that paintings do not need to be disassembled, paving the way for a portable version.

Fig. 2. Image of the still life painting used to validate the THz scanner.

Fig. 3. Photograph of the samples and reproductions prepared to calibrate the THz scanner and some original pieces of ceramics (a pot and a balsamarium) situated on 3D printed moulds.

During the initial phases, the consortium concentrated on the development of the transmitters and receivers, and the preparation of samples was (and is still being) required. These are based on a still life painting (Fig. 2). For the 3D models, we are also using original pieces (two pots and two balsamaria from the third century A.D.). Some of the pieces and samples can be seen in Fig. 3.

III. 2D Image Processing

As mentioned before, one of the fields that are being investigated is the use of terahertz imaging for the analysis of paintings. Led by the restorers and art experts involved in the project, attempts in different areas were made to help them to analyse and discover hidden features in artworks with the purpose of better understanding art and facilitate the restoration process. For example, although we have discarded the detection of underdrawings with charcoal, we are advancing towards the identification of pigments.

In order to achieve the latter goal, we have developed machine learning algorithms that can learn the terahertz response patterns of paint materials, as well as implementing image processing techniques to pre-process the resulting terahertz images. To evaluate our algorithms, artificial samples were prepared with early 20th-century paint materials (see Fig. 4) – the still life employed in the validation phase was painted during this period – and scanned using the developed terahertz imaging system.

Fig. 4. Sampling paintings with different paint colors (such as titanium white and ivory black).

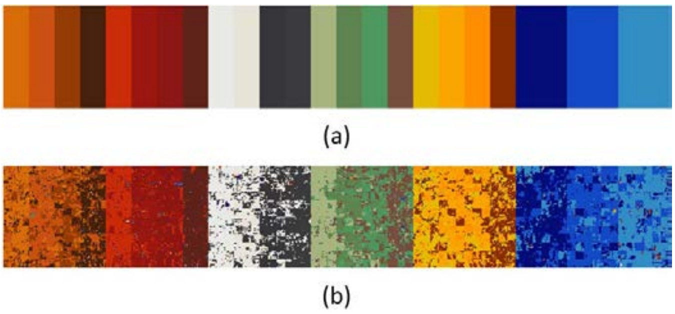

Fig. 5. Prediction of paint colors based on terahertz spectrum. The figure shows (a) ground truth annotation of paint colors of a sample painting created by combining the canvases shown in Fig. 4, (b) estimated paint colors by applying our classifier on the terahertz images.

Taking advantage of the terahertz responses of sample paintings as features, we have trained logistic regression classifiers to identify colors. The mean accuracy of our color classification system reaches to 65%. We can say that most of the confusions are caused by similar color types. In Fig. 5, we can visualize the quality of the classifications produced by the classifier implemented. We have applied the classifier on the painting samples of Fig. 4 asking it to predict the paint color based on the terahertz images. The resulting visualisations show that our trained classifier can predict paint colors quite reliably (in Fig. 6 the names of the colors used to prepare the samples are listed).

Light Ocher	
Dark Ocher	Green Earth
Raw Siena	Chrome Oxide
Raw Umber	Cobalt Green
Cadmium Orange	Burnt Umber
Cadmium Red	Cadmium Yellow
Cadmium Red Med	Med Cadmium Yellow
Indian Red	Dark Cadmium Yellow
Titanium White	Indian Yellow
Zinc White	Ultramarine Blue
Lamp Black	Cobalt Blue
Ivory Black	Cerulean Blue

Fig. 6. Description of the colors corresponding to Fig. 4.

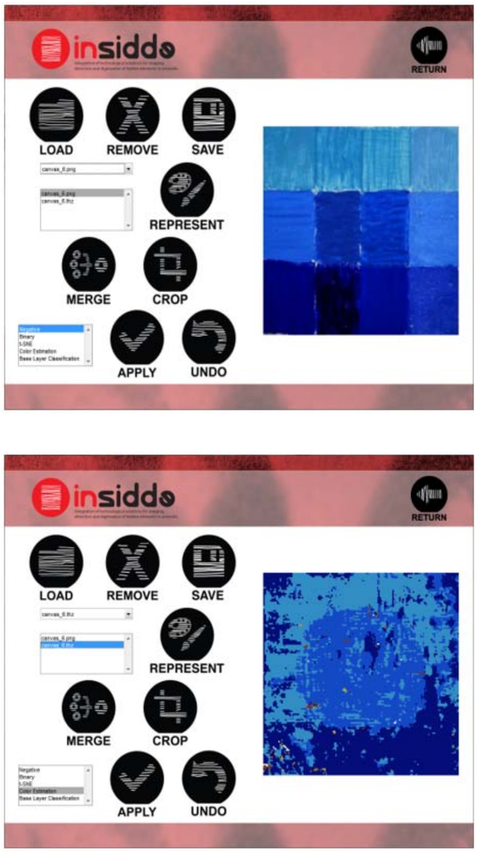

Fig. 7. Analysis window showing the image of the original painting (top), and color estimation based on its THz scan (bottom).

Additionally, a graphical user interface (GUI) has been designed to facilitate easy user interaction with the implemented image processing and machine learning approaches. This will make it easy for users to perform future analyses, even when they do not have programming skills. For example, color estimation of a sample painting (based on its terahertz scan) using the designed GUI is shown in Fig. 7. The software has been developed using Matlab language and can be downloaded for free from Matlab Central [5].

More information can be found in the public deliverables available on the website [6]. Besides the consortium is currently working on the differentiation of brushstrokes with the purpose of recreating the creative process followed by the author.

IV. 3D Data Acquistion and Processing

In parallel to the work tackling 2D image processing, we have also focused on 3D data acquisition and processing. This involves the combination of terahertz images of the interior of sealed pieces – such as balsamaria – with an accurate representation of the outer surface by means of a structured light (SL) scanner to generate realistic 3D models.

We have built a semi-automated pipeline for reconstructing the geometry and illumination-neutral color information of historical objects. The scanning is performed with a SL system in a controlled environment, recording several sequences of scans made with the object rotating at predefined angles on a turntable. The object is repositioned several times during capture, in order to achieve maximal coverage of the object's surface.

Earlier in the project we have integrated the terahertz scanning system with our visible SL scanner. We have developed a calibration method making use of custom-built 3D printed target that has features recognizable by both systems in order to correctly link them. This allows for guiding the THz arm based on the 3D data as well as for integrating the THz and colored 3D mesh data into an augmented 3D model.

Fig. 8. Example corresponding to a digital surrogate of a piece of pottery from the third century A.D.

Recently we have extended our pipeline with an albedo reconstruction algorithm to remove the baked-in illumination present in the scene while scanning. By combining multiple overlapping recordings of the artefact, the inherent color, or so-called albedo, is recovered. In order to achieve highly detailed texture information, we have added an automatic alignment refinement step in addition to the available initial calibration step. Virtually illuminated and rendered images of a scanned ancient vessel, based on the recovered geometry and albedo, is shown in Fig. 8.

During the third trimester of 2015, the 3D models will be available. In addition to this, we are exploring the identification of materials and substances inside vessels. Some encouraging results have been obtained in this field using the frequency response of some known materials as reference. Moreover, the curators involved in the project also believe that terahertz technology may be suitable for removing deposits from the surface of pottery, since it will be able to visualize the inscriptions and engravings beneath.

V. Europeana and Augmented Reality

One of the objectives of INSIDDE is bringing closer research in cultural heritage to citizens. As a consequence we have envisioned two initiatives: (i) facilitating and promoting the integration of digitised artworks into Europeana [6] and (ii) developing an augmented reality based smartphone application which shows paintings to museum visitors in a more winsome way, improving their experience in these scenarios.

On the one hand, we prepare the resources needed to share the digital models via Europeana [7], so that any citizen can have access to this material through the internet. In this context, different media files can be found in this online platform: images, 3D models, texts, sounds and videos. We concentrate on the first two types, enriching the formats with the data obtained by means of both the terahertz and the structured light scanners.

Fig. 9. Different screenshots of the augmented reality application. From left to right: splash screen; visualisation options; X-ray image overlapping the original paintings with red dotsfor further details; unfolded hamburger menu displaying the different categories and example of information abouth the author, including audio tracks..

On the other hand, the efforts are concentrated on the design, development and subsequent testing of an augmented reality application for smartphones and tablets. The application has been implemented using Unity3D [8] and Vuforia [9] and is intended for Android in this initial phase, although other operating systems may be considered in the future. Its core implements both pattern recognition and tracking of paintings in an automatic and robust way, avoiding tags, numbers or codes - identification is successful even when the artwork is partially occluded by people walking around. Digital images obtained by means of different technologies – not restricted to terahertz but also open to infrared, ultraviolet, X-rays, etc. – are possible in order to unveil details hidden beneath the outer layers and not visible for the naked eye.

This is complemented by a friendly and intuitive graphical interface, leading the visitor to an immersive experience which also includes audio tracks and can be supported by videos, images or digital models (see Fig. 9). Besides, the application does not require a Wi-Fi connection once installed.

Fig. 10. Image of the augmented reality application.

As observed in Fig. 10, the overlapping fits perfectly on top of the original painting thanks to the registration process and it helps to go deeper into the knowledge of the artwork allowing the user to change the level of transparency. Once the painting is recognised, the user can access to information related to the author, chronology and history as well as additional insights provided by art experts and not commonly included in the guides, contributing to making art more appealing. Furthermore, the developed application includes also audio guides in order to facilitate the access to art for users with visual impairments, concentrating a great amount of different functionalities in one single device.

VI. Conclusions

The project INSIDDE started in January 2013 and will finish in December 2015. From the first moment, the consortium was aware of the importance of being in close touch with experts in cultural heritage to ensure that the technical developments are being useful to fulfil specific needs in their day-to-day activities. Furthermore, this has ensured the perfect match between dissemination and research results and the interests of visitors and general public. With the inclusion of elements that are usually relegated to scientific publications or books, a broader perspective is reached. A good example of how the INSIDDE project can achieve this is the cooperation of our colleagues from the Delft University of Technology with the Frans Hals Museum of Haarlem (The Netherlands) in the organization of the exhibition “Emotions: pain and pleasure in Dutch painting of the Golden Age”.

In the coming months the consortium expects to complete some of the tasks already running as well as making public the results.

With the purpose of better illustrating the work described in this paper, we recommend the reader to watch the video that EuroNews produced in the first trimester of 2015, featuring interviews with the partners and demonstration of the latest achievements. Although broadcasted in the week from 18 to 24 May on EuroNews Futuris, the link is still available in our website [1] and Euronews-Futuris [10].

Acknowledgment

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