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Ultrasonic imaging of antique statue combining laser vibrometry and photogrammetry

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Within the framework of the conservation of cultural heritage, non-destructive inspection methods are of interest, especially ultrasonic investigation which is the only method with a direct and physical relationship with the mechanical state of the medium. The ultrasonic measurements are usually performed with a transmitter and a receiver applied on opposite positions at the surface of the artwork to measure the time of flight from whom the ultrasonic velocity will be deduced. This traditional device presents two main limits/drawbacks:

- Working on artworks which may be fragile or damaged requires special attention. The use of a coupling agent such as grease or echographic gel is not possible due to the risk of permanent staining. The quality of the direct contact of the transducers on the carved surface is usually not sufficient to get reliable and stable measurement. Anyway, the pressure applied on the surface of the artwork may induce some unacceptable physical deteriorations, even when pieces of latex are interlayered between the sensors and the stone surface. Eventually the ideal would be to avoid any contact during the measurement to prevent any physical or esthetic deterioration.
- The results are global and it is difficult to put in evidence local heterogeneities like cracks and other flaws through the material.

The aim of this study is to experiment the potential of the ultrasonic imaging by the use of laser vibrometry combined with photogrammetry to fix these drawbacks.

Test piece



Site museum of Alba la Romaine

This method is applied on a Roman marble statue of the site museum of Alba-la-Romaine (MuséAI, Ardèche, France).

Within the frame of a multidisciplinary study, a global ultrasonic auscultation was made in order to assess the mechanical diagnosis and to design a safe, reversible and non invasive base for this artwork [1]. The results shown that the marble was very homogeneous and in good condition with an average ultrasonic velocity of 4200m/s.

Nevertheless an in-depth auscultation was needed on several worrying pluricentimetric cracks noticed in the left groin and close to the left arm.

It was decided to test a scanning laser beam as receiver to make some ultrasonic mappings and evaluate the depth and opening of the cracks as well as the homogeneity of the marble within the artwork.



The statue on its base (Trajan Emperor)



Cracks in the left groin

Methodology

3 steps

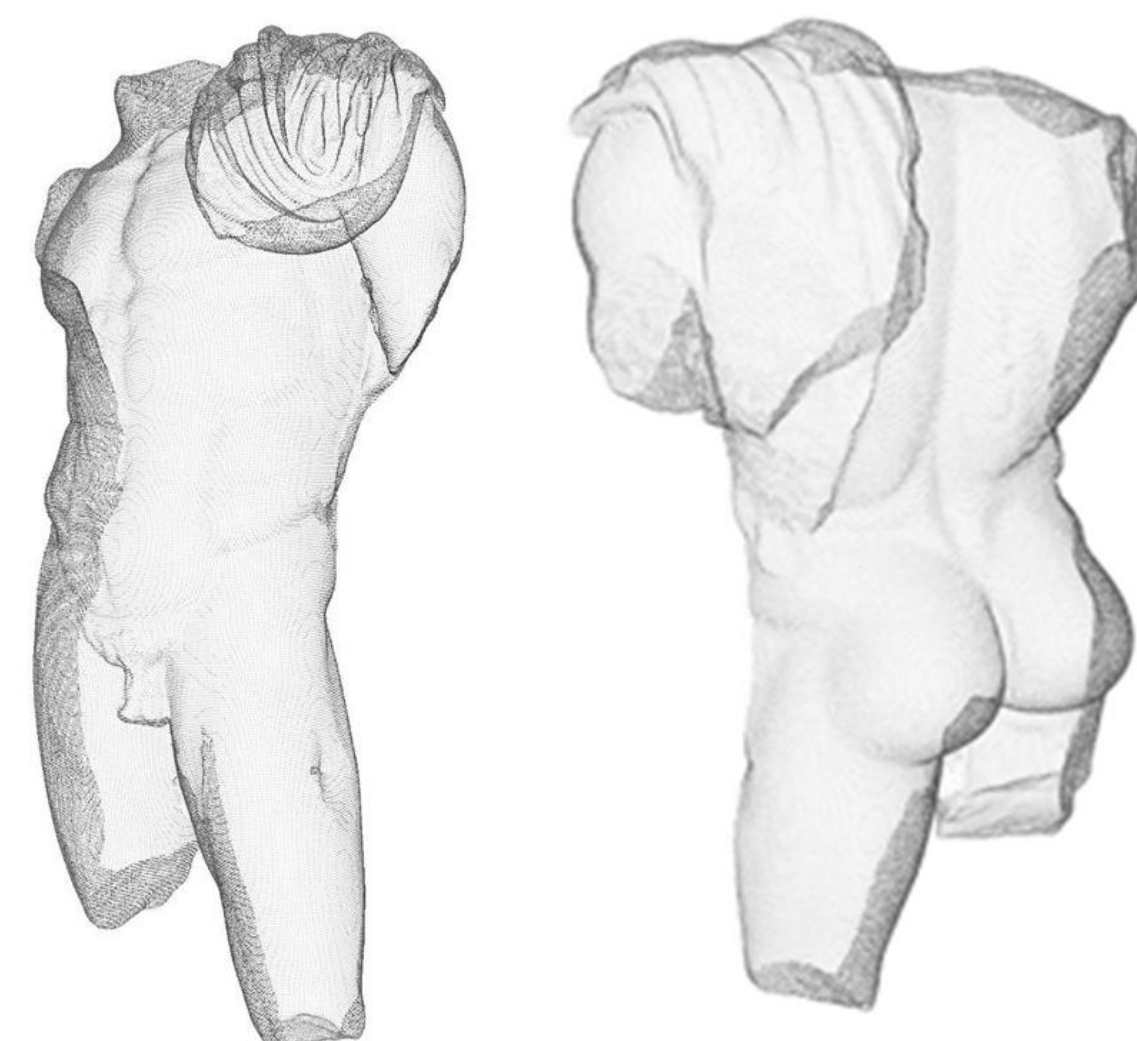
- 1) The geometrical model is built using 3D photogrammetry

500 photos (Nikon D800E – 36Mpixels, 2 focal lengths 24 and 50mm)

The MicMac photogrammetric open-source suite of tools is used to generate the point cloud.

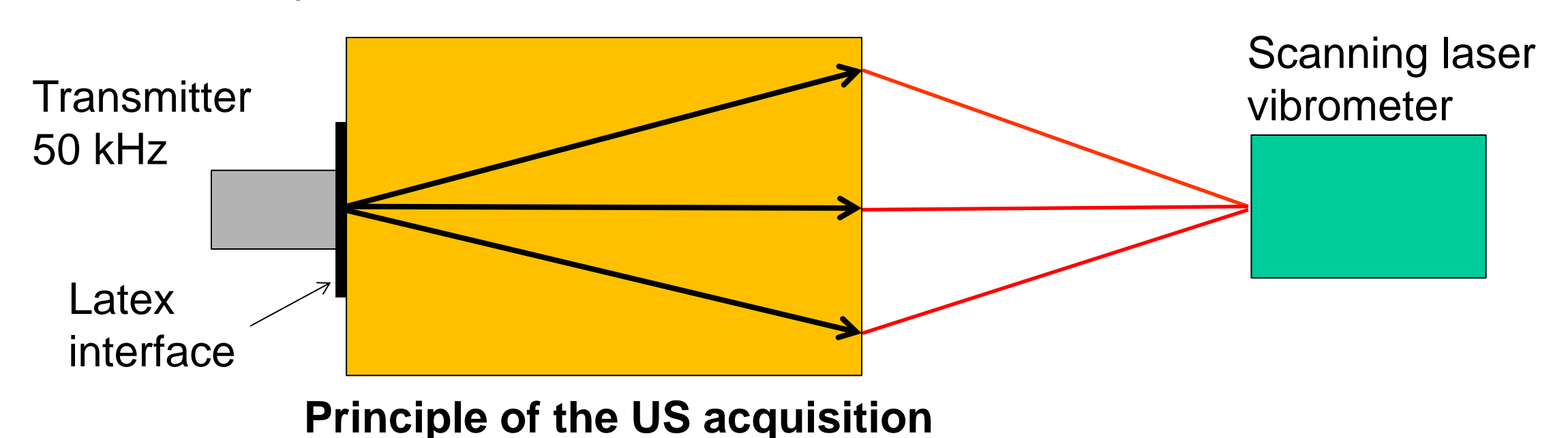


Photographic acquisition (storeroom of the museum)



Points cloud

- 2) Ultrasonic signals acquisition is performed using a red He-Ne scanning laser vibrometer (632.8nm) monitored by a camera.
- 3) The ultrasonic image is built by combining the geometrical model and ultrasonic signal processing. The distances d are deduced from the geometric model to calculate the velocity ($V=d/t$) and the attenuation ($A=A_0e^{-\alpha d}$). The absolute amplitude measure provided by the laser is employed to reconstruct both velocity and attenuation maps.



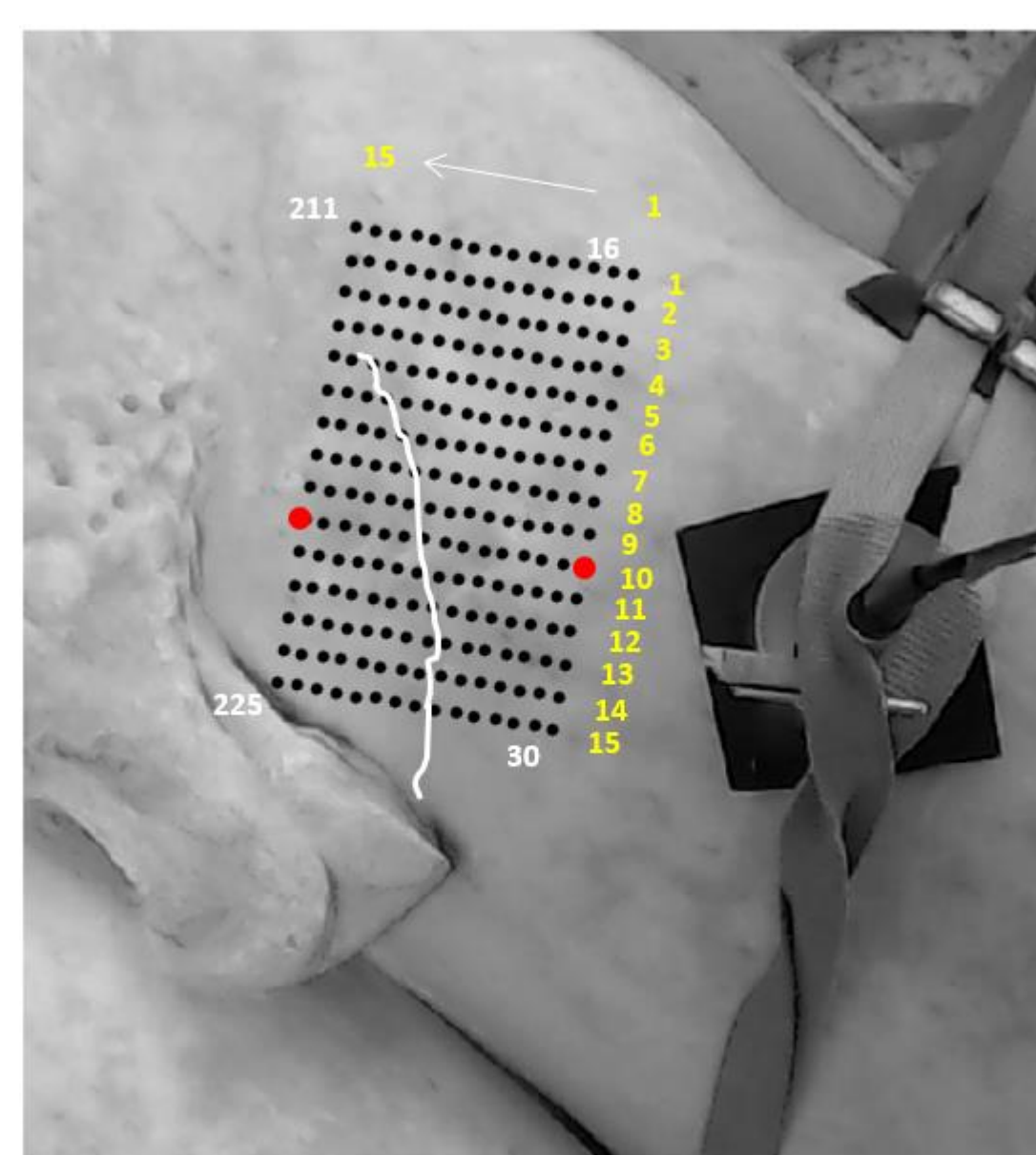
Principle of the US acquisition

Application test on the statue

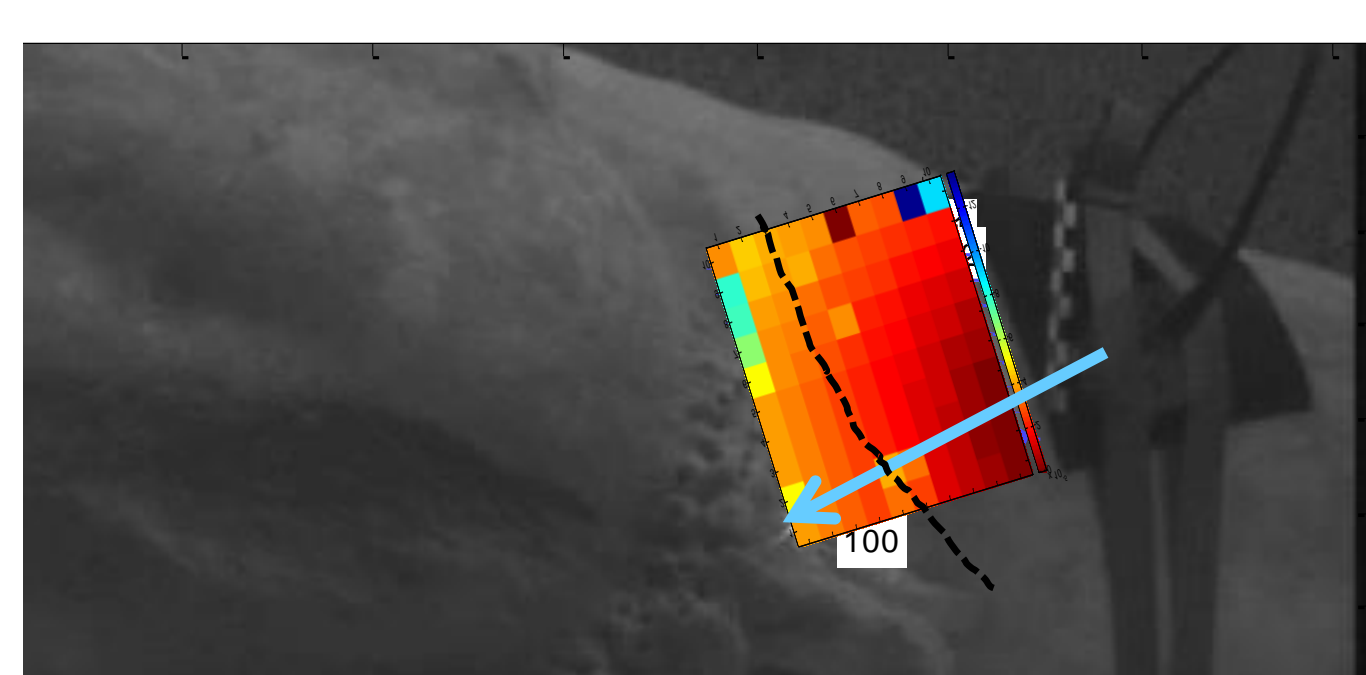
a) Auscultation of crack



Experimental device

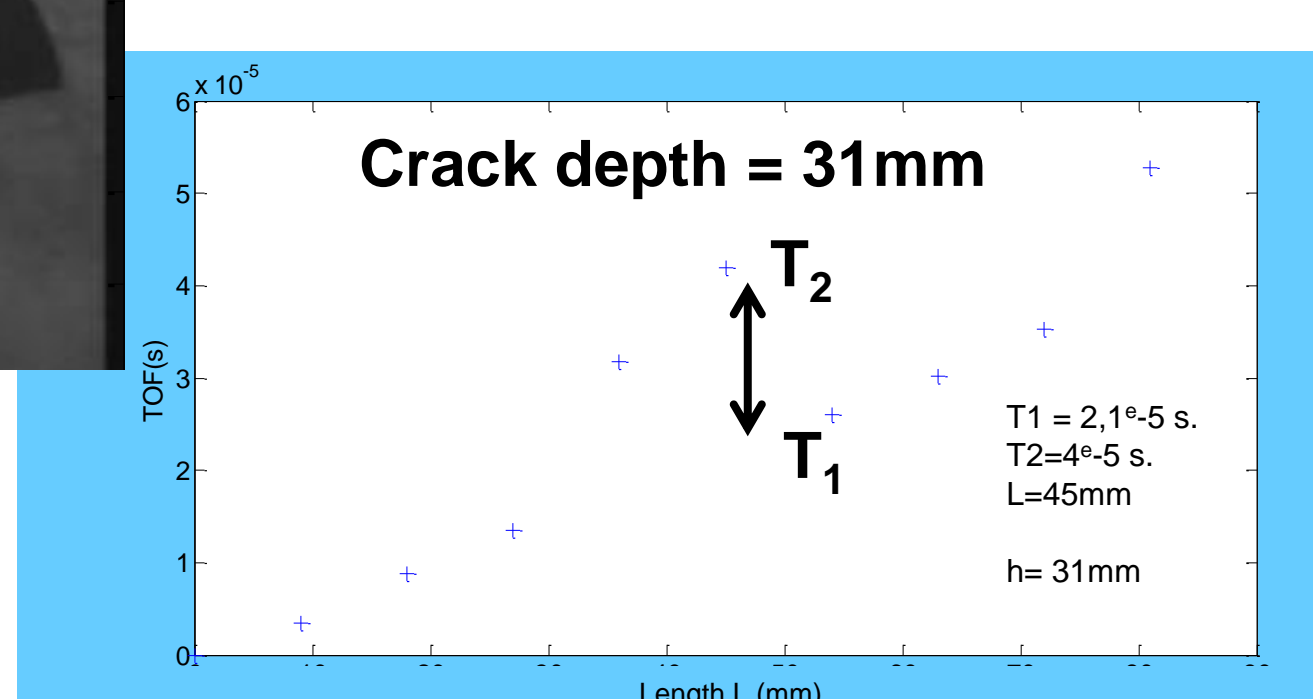


Auscultation of the crack area



Time Of Flight map

The distance L is computed using the 3D geometrical model

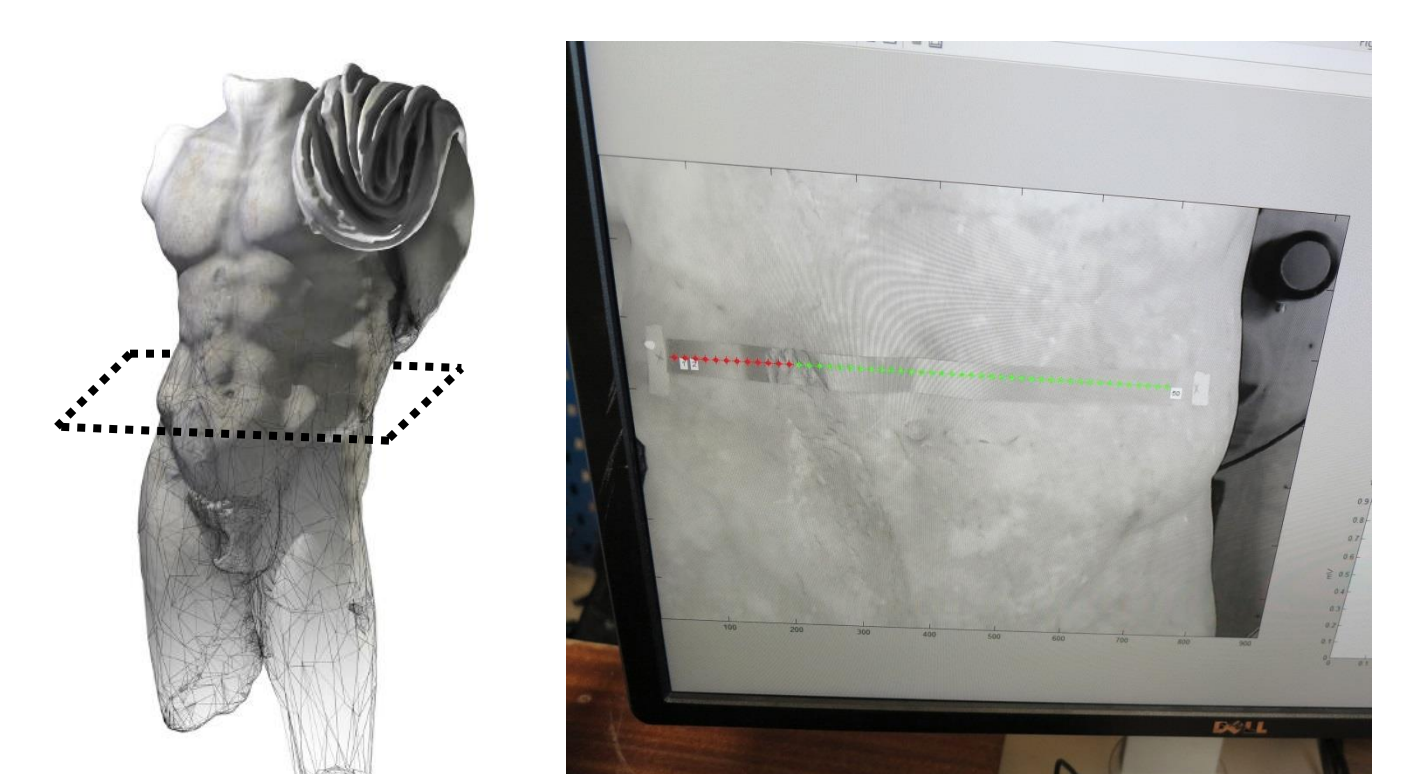


Time of flight map: Even if visible at the surface, the crack is opened only at few locations. Most of the crack profile is closed, may be due to self healing over time.

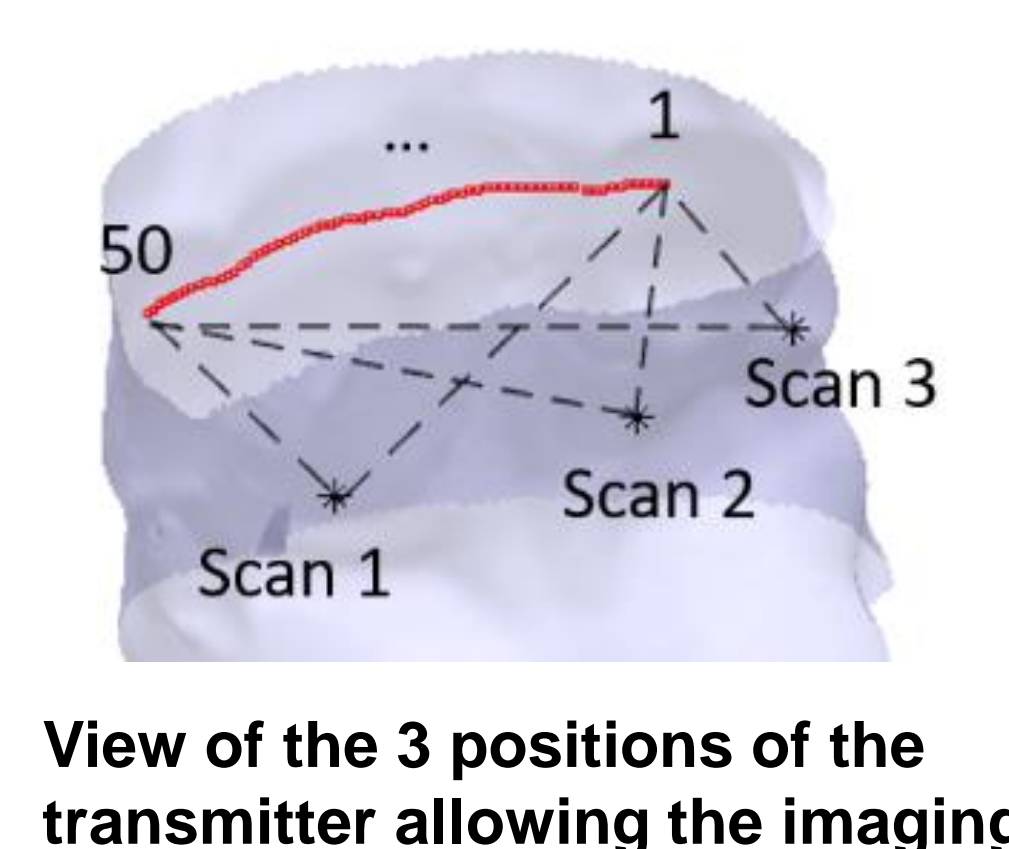
b) Auscultation of the homogeneity of the material



Auscultation of the marble homogeneity at the level of the hip



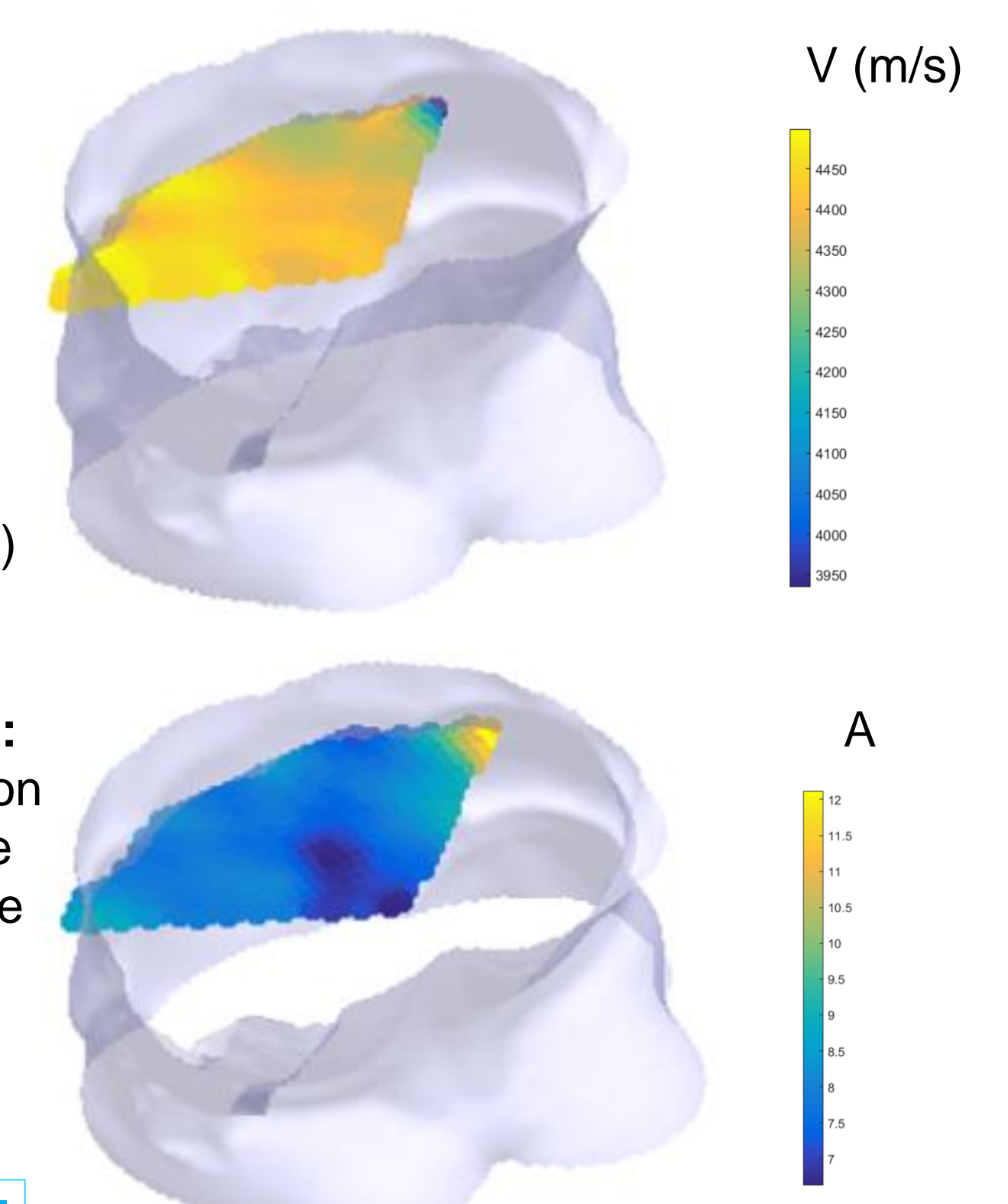
Use of the geometric model



View of the 3 positions of the transmitter allowing the imaging

Velocity map: homogeneous marble of high cohesion (average velocity ~ 4250m/s)

Attenuation map: Regular attenuation without any visible interface within the marble



The test results show that using laser vibrometry and photogrammetry offer the possibility to image both the marble homogeneity in the bulk of the statue as well as crack profiles at its surface (perspective: to use a second laser as transmitter to have a full no contact configuration).