X-ray and Neutron tomography for Cultural Heritage

Maria Pia Morigi

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Outline

- INFN-CHNet: mission, structure and activities

- Activities of Bologna unit within INFN-CHNet
  - Research
  - Education
  - Third party services

- CHNET_NICHE
INFN – CHNet: the mission

Born to coordinate the cultural heritage activities of INFN facilities. Formalized in 2017

MISSION:

- Common **R&D** lines and activities
- **Sharing funds** from the Institute and projects
- **Technology & knowledge transfer**
- **Answering** the issues of the Italian **public Institutions** devoted to the preservation of the **Cultural Heritage**
- **Expanding the network worldwide**
- Interacting with other National Institutions for the creation of an **Italian hub for Cultural Heritage**
The structure

CHNet has opened to external partners in order to fulfill its mission

1\textsuperscript{st} level nodes:
Laboratories in INFN facilities

2\textsuperscript{nd} level nodes:
Universities, Restoration Centres, Associations with complementary competencies

3\textsuperscript{rd} level nodes:
Foreign research centres/Universities outside Europe.
- Each 3\textsuperscript{rd} level node is bound to a 1\textsuperscript{st} level node
- Each 3\textsuperscript{rd} level node is encouraged to create a local network with different competencies in its own country $\rightarrow$ Global Research Infrastructure
The infrastructure

Fixed Labs
- Medium-large scale facilities (IBA, ¹⁴C, ...)

Mobile Labs
- Thermography

Digital Labs
- Web tools for data fruition

TL dating
- X-ray imaging

XRF
- XRD

Mass Spectrometry

Data Storage and fruition
The activities

INFN-CHNet

- **Research (50%)**
  - INFN
  - External Projects

- **Education (20%)**
  - **Public Engagement (40%)**
  - **Access to Laboratories and Instrumentation (30%)**

- **Third Mission (30%)**
  - **Technology Transfer (30%)**
The governance

Three Working Groups following the Network activities

CHNet working groups

- **WG1** RESEARCH
  - Fixed Labs: Task 1.1
  - Mobile Labs: Task 1.2
  - Digital Labs: Task 1.3

- **WG2** EDUCATION & TRAINING
  - Fixed Labs: Task 2.1
  - Mobile Labs: Task 2.2
  - Digital Labs: Task 2.3

- **WG3** ACCESS
  - Fixed Labs: Task 3.1
  - Mobile Labs: Task 3.2
  - Digital Labs: Task 3.3

- **WG4** - SUSTAINABILITY

A Working Group supporting the activities of the others

Research Infrastructure → Fixed, mobile and digital laboratories
CHNet node in Bologna: expertise and activities

X-ray Imaging Group

Maria Pia Morigi; Matteo Bettuzzi; Rosa Brancaccio; Fauzia Albertin

EXPERTISE: Development of acquisition systems for X-ray Computed Tomography for diagnostic investigations, both in the laboratory and on-site, on works of art and archaeological finds of different materials and sizes.

X-ray Computed Tomography (CT) is a powerful non-destructive technique, capable of displaying in a 3D way the internal structure of the investigated objects. Thanks to this feature, it is currently playing an increasingly important role in the field of Cultural Heritage diagnostics. The aim of the tomographic survey of an artefact is to obtain information on its construction technique and conservation status, both for knowledge and for setting-up a proper restoration.
Micro-CT system

Very high spatial resolution – voxel size < 10 μm

Trabecular microstructure of a child bone from the Anthropology Museum of UNIBO (voxel size: 10 μm).
CT system for medium-size objects

High spatial resolution – voxel size $\approx 50 \text{ - } 100 \mu m$

Flat panel
- VARIAN PS2520D
  - Solid State Detector + CsI:Tl scintillator
  - $19.5 \times 24.5 \text{ cm}^2$
  - $1536 \times 1920$ pixel
  - $127 \mu m$ pixel

Microfocus X-ray tube
- KEVEX PXS10
  - Tungsten anode
  - 5-130 kV
  - 0.5 mA
  - 53° beam angle
  - 7-100 $\mu m$ focal spot

Japanese theatre mask (ICR - Rome).
CT system for large-size objects

X-ray detector

HAMAMATSU C10900D
- Solid State Detector + CsI:Tl scintillator
- 12 x 12 cm²
- 1216 x 1232 pixel
- 100 µm pixel

X-ray tube

YXLON SMART EVO 200D
- 30–200 kV
- 0.5 – 6 mA
- 750 W
- 1 mm focal spot

African wooden statue
(Pigorini Museum – Rome)
Education: Training Camps

One-week Summer Schools on non-destructive in-situ Diagnostic techniques on Cultural Heritage, organisation led by INFN

Target: bachelor or master degree graduated in science or humanities applied to cultural heritage, and restorers

- Publication of a call
- Selection of about 20-30 participants
- Laboratories in small groups (5-6 p) on selected artworks, with different techniques and together with researchers of ENEA, INFN, CNR and restorers of OPD

A fee is required to cover only part of the accommodation cost; the rest is covered by the MIUR

http://chnet.infn.it/it/formazione/training-camps
Education: Training Camps

SANSEPOLCRO (AR) 2014

L’AQUILA 2015

SIRACUSA 2016

ALGHERO (SS) 2017

GIOIA DEL COLLE (BA) 2018

TROGIR 2019

http://chnet.infn.it/it/formazione/training-camps
Third Mission: Access to Laboratories and Instrumentation

E-RIHS.it
EUROPEAN RESEARCH INFRASTRUCTURE FOR HERITAGE SCIENCE

Annual calls for access to Laboratories and Instrumentation

ECCEHOMO PROJECT

STA.VE. PROJECT
Third Mission: third party services

A common price list available online

~ 15 different techniques

~ 10 involved nodes

A quotation request form available online

The requests are received by the Access WG and sent to the proper CHNet node

INFN CNTT writes down the contract

After the activity is performed, funds are shared between the CHNet network and the involved INFN structures
Third Mission: third party services

In situ CT analysis of a celestial globe by Vincenzo Coronelli (Marciana Library – Venice)
Third Mission: third party services

Transfer of equipment on-site
Third Mission: third party services

Details of the inner structure

3D rendering
RESEARCH: CHNet_NICHE

CHNet – NICHE

Cultural Heritage Network – Neutron Imaging for Cultural HEritage

N.Gelli, F. Grazzi - National Coordinators

Partners: Fi, Pv, Bo, MiB, To

Duration of experiment: 2 years
Neutron Imaging: non-destructive technique for morphological information, complementary to other more usual techniques (IBA, XRF, X-Ray Tomography, ...)

- **Goal**: development and optimisation of a system for imaging and tomography with thermal neutrons at the TRIGA Mark II reactor of the LENA Lab in Pavia.

- Take advantage of the TRIGA beamline used for PGNAA in the framework of the CHNet_TANDEM experiment, in order to realise the first Italian facility of neutron radiography and tomography devoted to cultural heritage applications, to be used also by external users.

- Integrating the new facility with the other instrumentation of the CHNet network
**The radiographic method**

**Narrow Beam Attenuation**

\[ I = I_0 e^{-\Sigma d} \]

Scattered neutron \( \Sigma_s \)

Transmitted beam \( I \)

Absorbed neutron \( \Sigma_a \)

Incident beam \( I_0 \)

\( \sigma_{\text{tot}} = \sigma_{\text{sc}} + \sigma_{\text{ass}} \)

**Exponential Attenuation Law**

\[ I = I_0 e^{-\Sigma d} \]

\[ \Sigma = \Sigma_a + \Sigma_s \]

**Macroscopic Cross Section \( \Sigma \)**

\[ \Sigma = N \sigma \quad [cm^{-1}] \]

\[ N = \frac{\rho}{A} N_A \quad [cm^{-3}] \]

\( N := \text{number density} \quad [cm^{-3}] \)

\( \rho := \text{material density} \quad [g \text{ cm}^{-3}] \)

\( A := \text{atomic weight} \quad [g \text{ mol}^{-1}] \)

\( N_A := \text{Avogadro number} \quad 6.022 \times 10^{23} [\text{mol}^{-1}] \)
X-Rays and neutrons: different interactions with matter

First table: X-ray attenuation coefficient (energy 150 KeV) in gray scale for all the elements.

Second table: macroscopic cross section for thermal neutrons.
Neutronigraphy is not equivalent to conventional radiography; in fact, for X-rays, fixed their energy, the absorption coefficient is a regular function of the **atomic number** $Z$ of the investigated medium. The absorption coefficient for neutrons, on the other hand, is not simply linked to the atomic number, nor to the mass number of the different nuclides, but it also varies with the energy of neutrons in an irregular way.

Mass attenuation coefficients for thermal neutrons and X-rays (100 keV) as a function of the atomic number.
Why neutrons:

- Higher penetration and contrast between nearby elements in metals.
- High sensitivity to hydrogen (organic materials).

Neutron imaging

Radiography

Tomographic slice

Volume rendering
Model of the facility

- **Pin hole**
  - diametro: 1 cm
  - L/D: ~250

- **Rivelatore** LiF/ZnS(Ag) 2/1
  - spessore: 250 μm

- **Campo di vista**
  - 80x80 mm

- **Specchio**

- **Stage lineare**

- **Sistema ottico**
  - CCD + Obiettivo 20 mm

- **Tavola rotante**
  - Passo angolare ~0.96

**Note:**
- **Pin hole diametro:** 1 cm
- **L/D:** ~250
Variable geometry in order to obtain the best illumination and the best resolution.
**CHNet_NICHE**

**Milestone 1 (month 6):** simulations and development of a preliminary measurement system at LENA (FI and PV)

**Milestone 2 (month 12):** experimental tests (FI, TO, PV, BO) and optimization of the measurement system; preliminary characterization of the new facility (spatial resolution, dynamic range, etc.). First application on test objects.

**Milestone 3 (month 18):** realization of the beam limiter and completion of the measurement point with shields and motorization (FI, MIB, PV). Definition of empirical laws for attenuation in the new geometry (FI, TO, BO).

**Milestone 4 (month 24):** application to case studies of interest, digital data processing and comparison with X-ray tomography (FI, TO, BO).
Activity 2020: development of detector
Test object

Line pair gauge
Thank you!

Maria Pia Morigi
morigi@bo.infn.it
mariapia.morigi@unibo.it

https://chnet.infn.it