SOLUS | SMART OPTICAL AND ULTRASOUND DIAGNOSTICS OF BREAST CANCER

The SOLUS project: Smart optical and ultrasound diagnostics of breast cancer

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Background (I)

- **Breast cancer**
  - The most common cancer in women in Europe and worldwide (more than 2 million new cases diagnosed in 2020) *[GLOBOCAN 2020]*
  - About 1 in 8 women in Europe and US will be diagnosed with breast cancer in the course of her lifetime
- **Role of early diagnosis**
  - Mammographic screening reduces breast-cancer mortality: ranging from 28% to 35% *[Nelson et al, Ann Intern Med, 2016]*

Background (II)

- **Limitations of screening mammography**
  - Detection of previously occult benign breast lesions
  - The cumulative risk of a false-positive mammogram over a 10-year period of yearly screening reaches 50-60%
- **Consequences**
  - Needless additional imaging and invasive procedures
    - Negative impact on the patient's quality of life
    - High burden for the healthcare systems

General goal of the project

To support the *in vivo* diagnosis of breast cancer **improving the discrimination of lesions that are borderline between benign and malignant lesions**

- Patients' quality of life
- Sustainability of the healthcare systems

SOLUS

"Technical" objectives towards the general goal

- **Main objective**

  Develop an innovative **multi-modal tomographic system** combining *ultrasound and optical imaging*

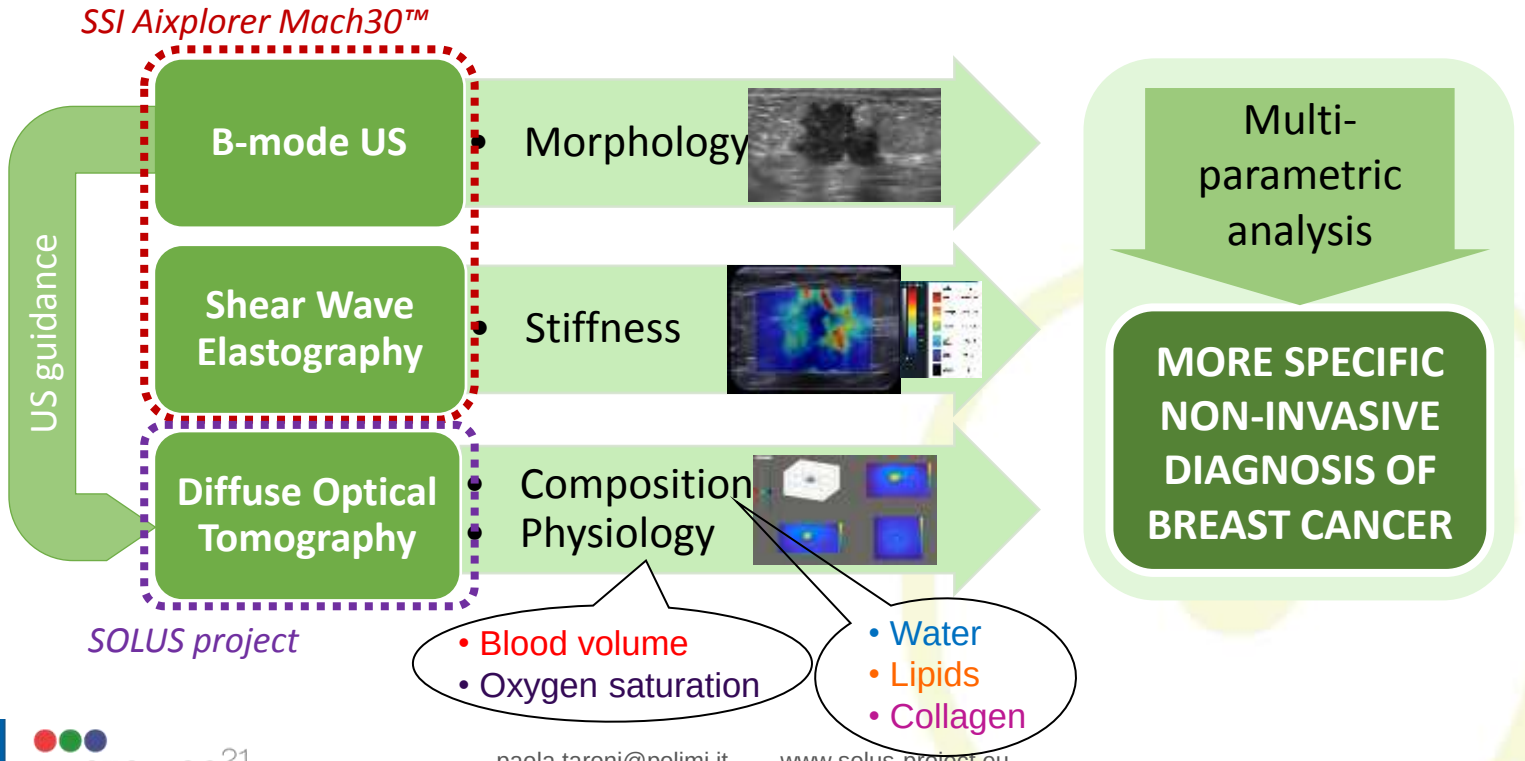
  ⇨ Breast imaging ⇨ Medical imaging

- **Specific/intermediate objective**

  Develop an innovative, ground-breaking, low-cost, small size photonic module – the **Smart Optode** - to perform in depth diffuse optical measurements

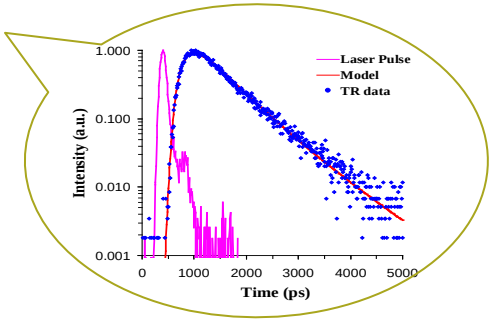
  ⇨ Non diagnostic medical applications
  Other fields

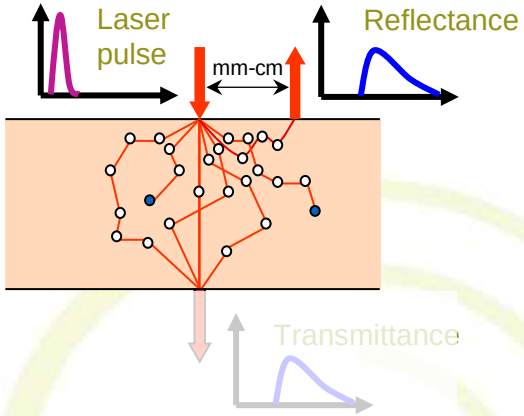
SOLUS concept



Time domain diffuse optical spectroscopy

- Effects of light propagation
  - Attenuation
  - Delay
  - Broadening



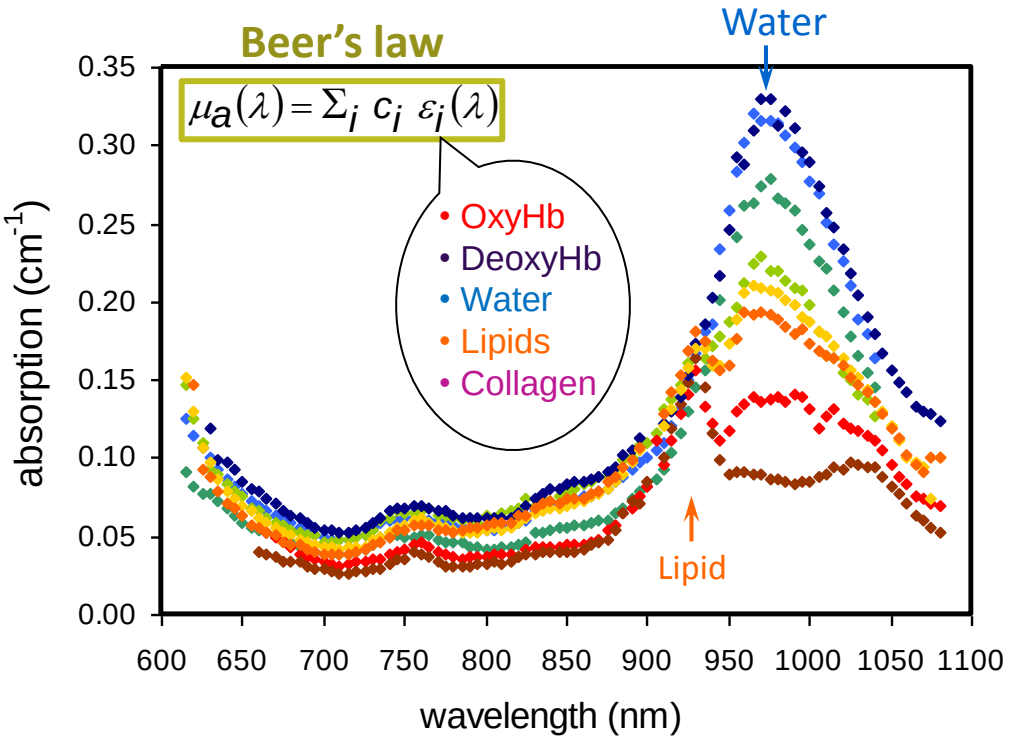


- Theoretical model:
  Diffusion approximation to Radiative Transport

  → Absorption coefficient → Tissue **composition**

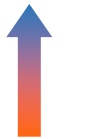
  → Scattering coefficient → Tissue **structure**

Absorption spectra and tissue composition



Scattering spectra and tissue structure

Fibrous



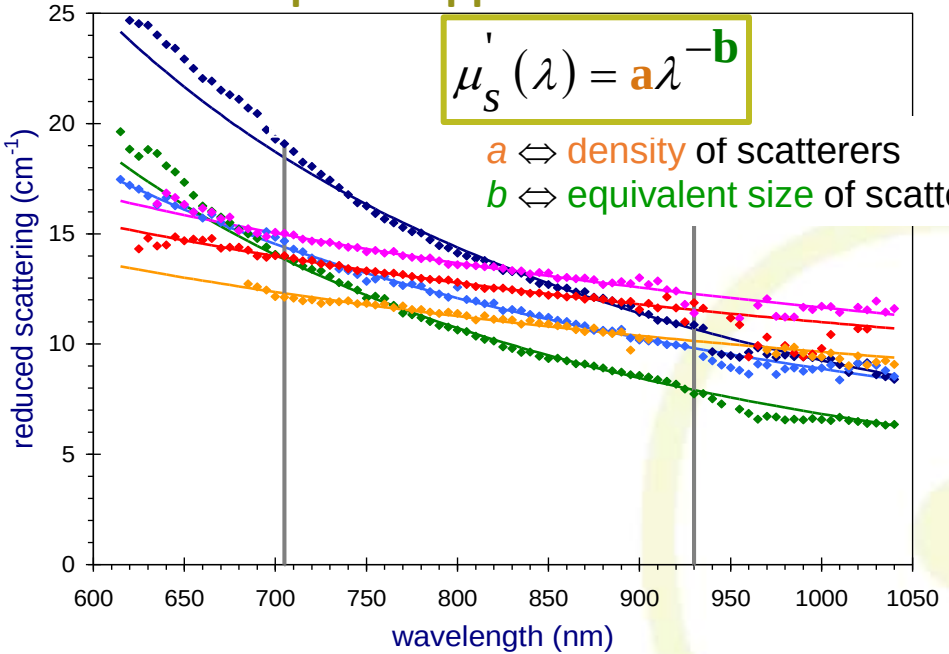
Adipose

Empirical approximation to Mie theory

$$\mu_s'(\lambda) = a\lambda^{-b}$$

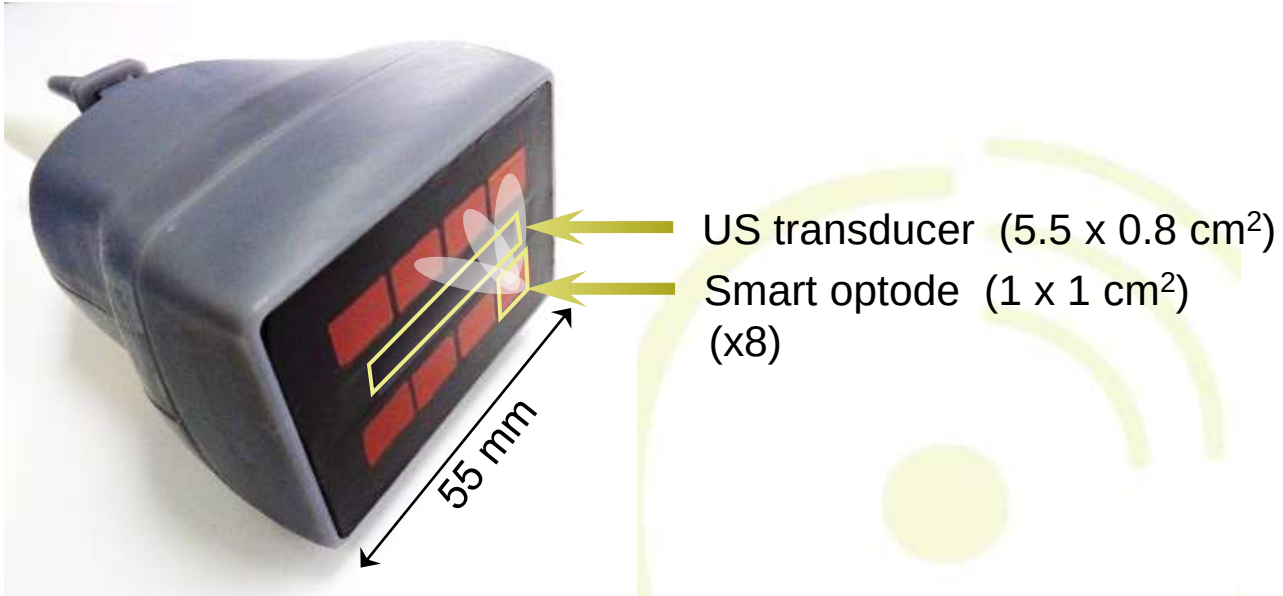
a ⇔ density of scatterers

b ⇔ equivalent size of scatterers



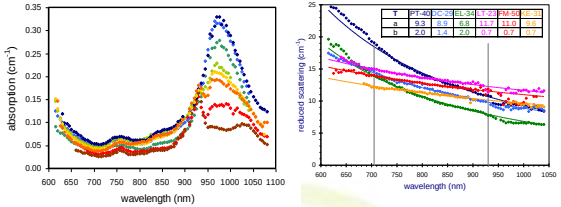
PHOTONICS21

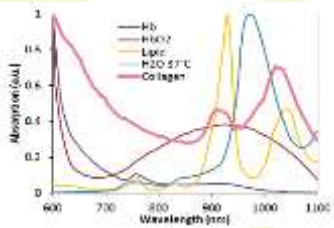
Multi-modal tomographic probe

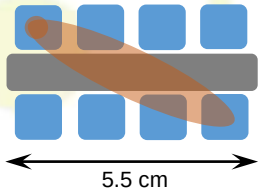


Diffuse Optics in SOLUS

- **Time domain**
  - ❖ To uncouple absorption from scattering
  - ➢ Time domain detector
- **Multiple wavelengths**
  - ❖ To estimate Hb, HbO_2, water, lipids, collagen
  - ➢ Broad spectral range (635-1064 nm)
- **Tomographic approach**
  - ❖ To identify to region of interest and improve quantification
  - ➢ Time-gated wide-area detector





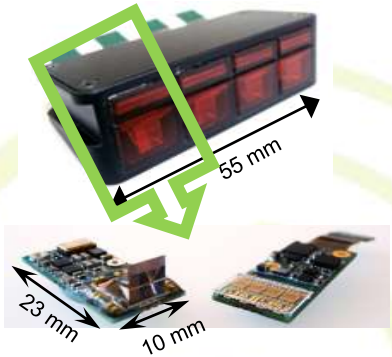


State of the art of time domain diffuse optics

2015: 600-1350 nm
single point

2017: 8 wavelengths
2 channels

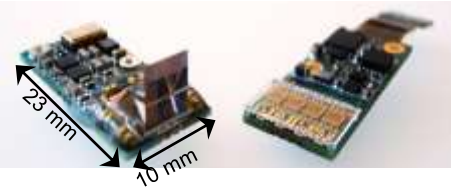
2020: 8 wavelengths
tomographic

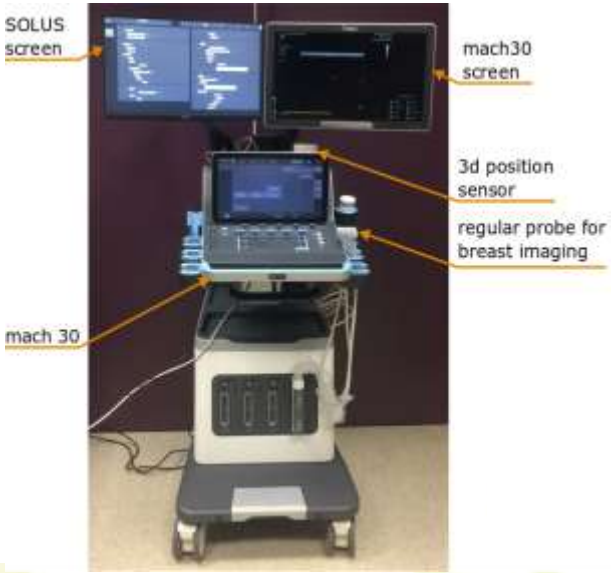


m^3 dm^3 cm^3

DEVICE SIZE

Timeline

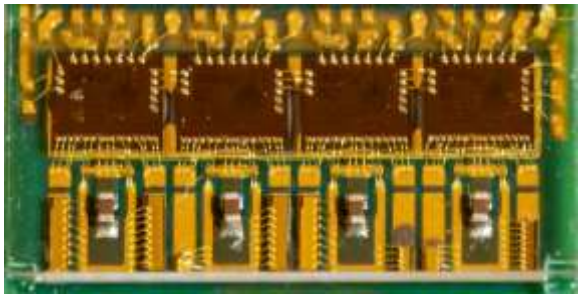


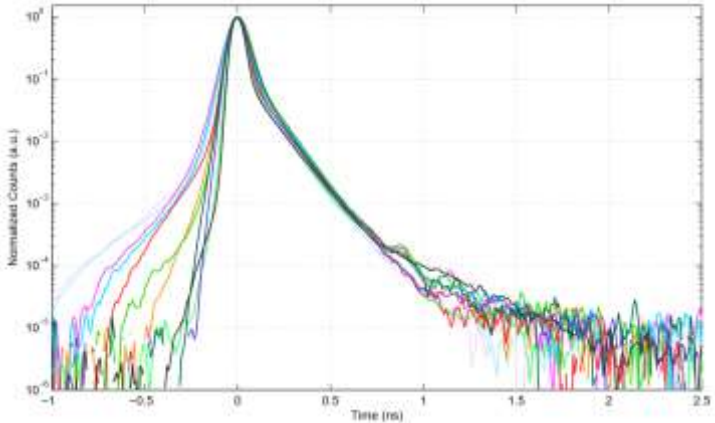


- Picosecond pulsed laser driver
- Wide area gated SiPM detector
- Dedicated acquisition electronics

Optode components	Single optode	Multimodal probe & system	Clinical validation
Developed and validated in laboratory settings		Integrated and under characterization	Start in Summer 2021

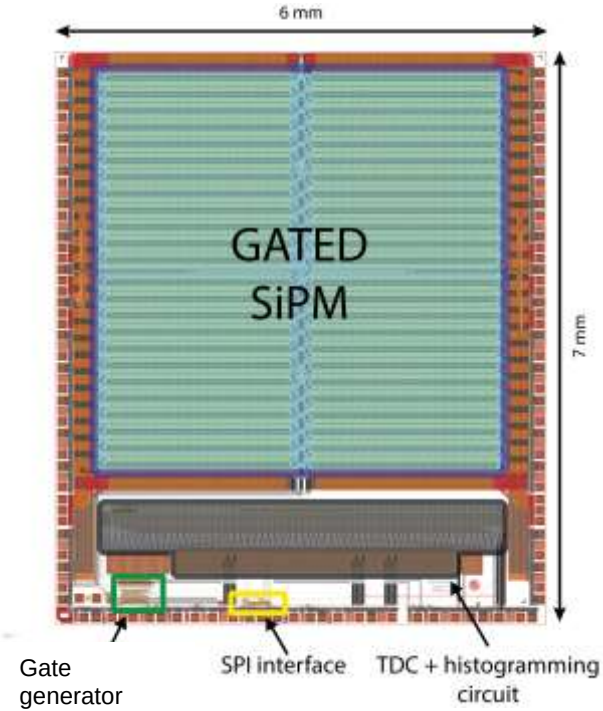
Multiple wavelength picosecond pulsed lasers





- **Integrated dual-channel Laser Driver**
  Tunable pulse-width and delay with 1 ps steps
  Tested up to 80 MHz repetition frequency
- **8 wavelength lasers**
  Specifically selected (635-1064 nm)
- **Resulting performances**
  FWHM < 240 ps
  Output power: between 1.5 and 6 mW
  Negligible exponential tail or secondary peaks

Fast-gated dSiPM with integrated TDC



- **Digital SiPM**
  - Photon collection area: 4.9 × 4.7 mm^2
  - Controllable active area: up to 8.6 mm^2
    hot-pixel shutdown → lower noise
    signal equalization
  - Gate-on transition: <500 ps, up ≈3 mm^2
  - Temporal response
    235 ps (FWHM) for a single active pixel
    ≈500 ps for an active area of ≈4 mm^2
- **Time to Digital Converter**
  78 ps resolution, 128-channel histogram builder

*Conca et al, IEEE J. Solid-State Circuits **55:3097 (**2020)*

SOLUS

The smart optode

Ultra-compact system for time domain multi-wavelength DOT

- **Responsivity**: >10^6 m^2sr @600 nm for an active area of 2 mm^2
  - ✓ 10x larger than for state-of-the-art systems
- Retrieval of **optical properties** (homogeneous medium)
  (μ_a = 0.06-0.4 cm^{-1} and reduced scattering μ_s' = 4-17 cm^{-1})
  - ✓ Relative error on Absorption: 10% (median)
  - − Relative error on Scattering: up to 40%
- Sensitivity to **deep absorption perturbations**
  $\Delta\mu_a$ = 0.16 cm^{-1}, 1 cm^3, embedded in bkg medium (μ_a = 0.1 cm^{-1} and μ_s' = 10 cm^{-1})
  - ✓ Sensitivity: down to 3.5 cm with 2% contrast

The multi-modal SOLUS system

Calibration and performance assessment on-going

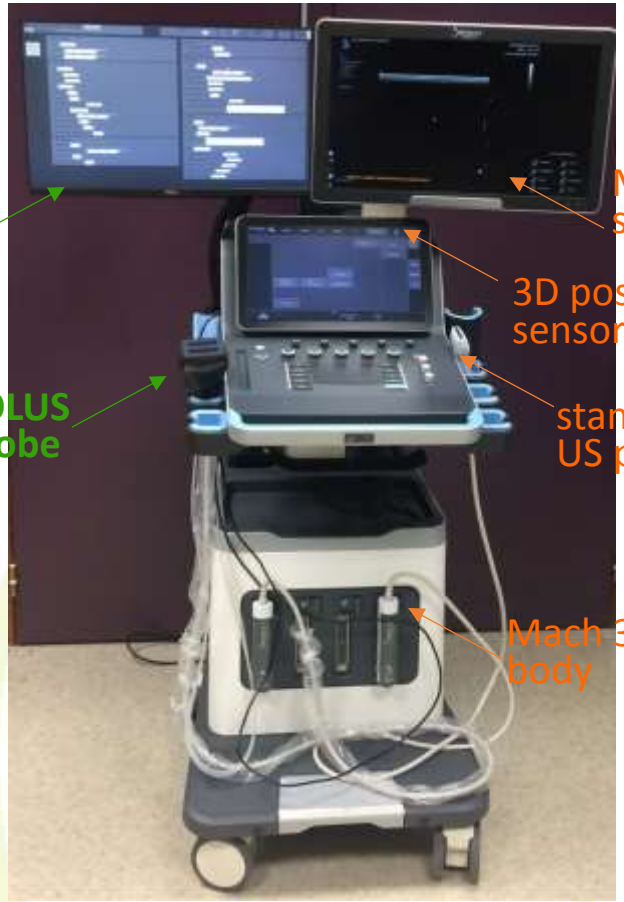
SOLUS screen

SOLUS probe

cooling system

3D position bay

medical grade power supply



Mach 30 screen

3D position sensor

standard US probe

Mach 30 body

Next steps

Clinical validation of the SOLUS system

- 3 radiologists
- “Mock sessions”
  - Train medical doctors
  - Test the system usability and ergonomics
- Pilot clinical feasibility study
  - 20 benign (BIRADS 2-3) and 20 malignant (BIRADS 4-5) lesions

Smart optode

- Investigate the optode potential
  - Development of wearable devices (medical, sport, rehabilitation fields)
  - Use in other fields (e.g., fruit quality assessment)

Thank you for your attention

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www.solus-project.eu
www.photonics21.org

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