DELIVERABLE REPORT

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Name, title and organization of partner: Udo Weigel (HEMO), Lorenzo Cortese (ICFO) Partners: IMV, VERMON, UOB, POLIMI

Project website address: www.luca-project.eu

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1. Introduction

In this deliverable report D3.7, **LUCA device design upgrades** for the first fully functional LUCA demonstrator are described at the final stage of the LUCA project. Technological upgrades have been an integral part of the development road map of the LUCA demonstrator mainly for two main reasons;

First, the first fully functional LUCA demonstrator has now already undergone intense evaluation in functionality, usability, and reliability aspects by clinical partners at the hospital study. We want to use not only these valuable practical clinical experiences but also any input provided by technical partners and LUCA project reviewers to make an important step ahead towards a greatly improved LUCA device.

Second, we are well aware of the importance of cost and regulatory aspects for the final goal to commercialize the LUCA technology as well as new technical options that became available during the lifetime of the project. The LUCA demonstrator has been designed and built to allow a high degree of flexibility and aims at taking in the given scenario the most complete data sets e.g. by implementing a high number of DCS detection channels and TRS laser wavelengths. Nevertheless, evaluating the LUCA study results and weighing up cost aspects against added information value, channel/wavelength numbers may open the opportunity to provide equivalent diagnostic information with reduced component sets or latest opto-electronics and component technologies with cost or performance advantages for technological improvements.

In our road map, we have considered to develop a design upgrade plan based on input from the clinical evaluation and subsequently start implementing step by step the planned upgrades into a new LUCA device during a dedicated prototype optimization (PO) phase (see D7.11) in continuation of the LUCA project. In the initial project time line, we contemplated to implement basic first upgrades already right after the clinical study ends. However, due to the unexpected Covid-19 pandemic the clinical study was suspended and resulted in a

significantly extended study duration but also shifted the first LUCA device upgrade implementations entirely to the PO phase after the project.

The planned tasks to develop a compact, medical grade, fully movable LUCA device design upgrade within this deliverable were completed and all goals were achieved as planned.

2. LUCA device design stages

I. LUCA demonstrator prototype

The LUCA demonstrator has been reported in Deliverable 3.5 (see Figure 1, reproduced here for completeness), and it is routinely used for the LUCA clinical research campaign since July 2019.

Figure 1: The fully functional LUCA demonstrator prototype (left, as reported in D3.5) at an initial practical testing session (right).

During the measurement campaign, practical experience with the LUCA system revealed minor aspects for immediate improvements on usability and bugs which have been

documented. These improvements were related to the software suites (see WP2) and described in detail in Deliverable 2.9. A detailed report the LUCA demonstrator and tests performed has been recently published on Biomedical Optics Express:

L. Cortese, G. L. Presti, M. Zanoletti, G. Aranda, M. Buttafava, D. Contini, A. D. Mora, H. Dehghani, L. D. Sieno, S. de Fraguier, F. Hanzu, M. M. Porta, A. Nguyen-Dihn, M. Renna, B. Rosinski, M. Squarcia, A. Tosi, U. M. Weigel, S. Wojtkiewicz, and T. Durduran, *"The LUCA device: a multi-modal platform combining diffuse optics and ultrasound imaging for thyroid cancer screening,"* Biomedical Optics Express (2021).

II. Compact table-top device

In the first stage, as an initially planned upgrade and supported by user feedback received on overall dimensions and mobility requirements for comparable hospital examination equipment, we re-configured / re-designed the LUCA device in a compact table top version compatible with use in combination with a standard medical cart.

The following design considerations guided this intermediate step

- use of existing optical modules, i.e. Diffuse Correlation Spectroscopy Module (DCSM), Time Resolved Spectroscopy Module (TRSM) and Ultra Sound Module (USM) ,
- reduce Main Module (MM) to few core components for compact module dimensions and eliminate redundant I/O channels,
- transfer real-time post-processing of the NIRFAST Evaluation Module (NEM) from a dedicated hardware module to offline post-processing software application suitable to run on standard computer hardware,
- simplify inter-modular connection concept

Ideas for this intermediate step were elaborated during M37-M48 in particular with the intention to avoid any compromise on data quality and channel flexibility and major redesign of optical core modules. The schematic view of the design concept is illustrated in Figure 2.

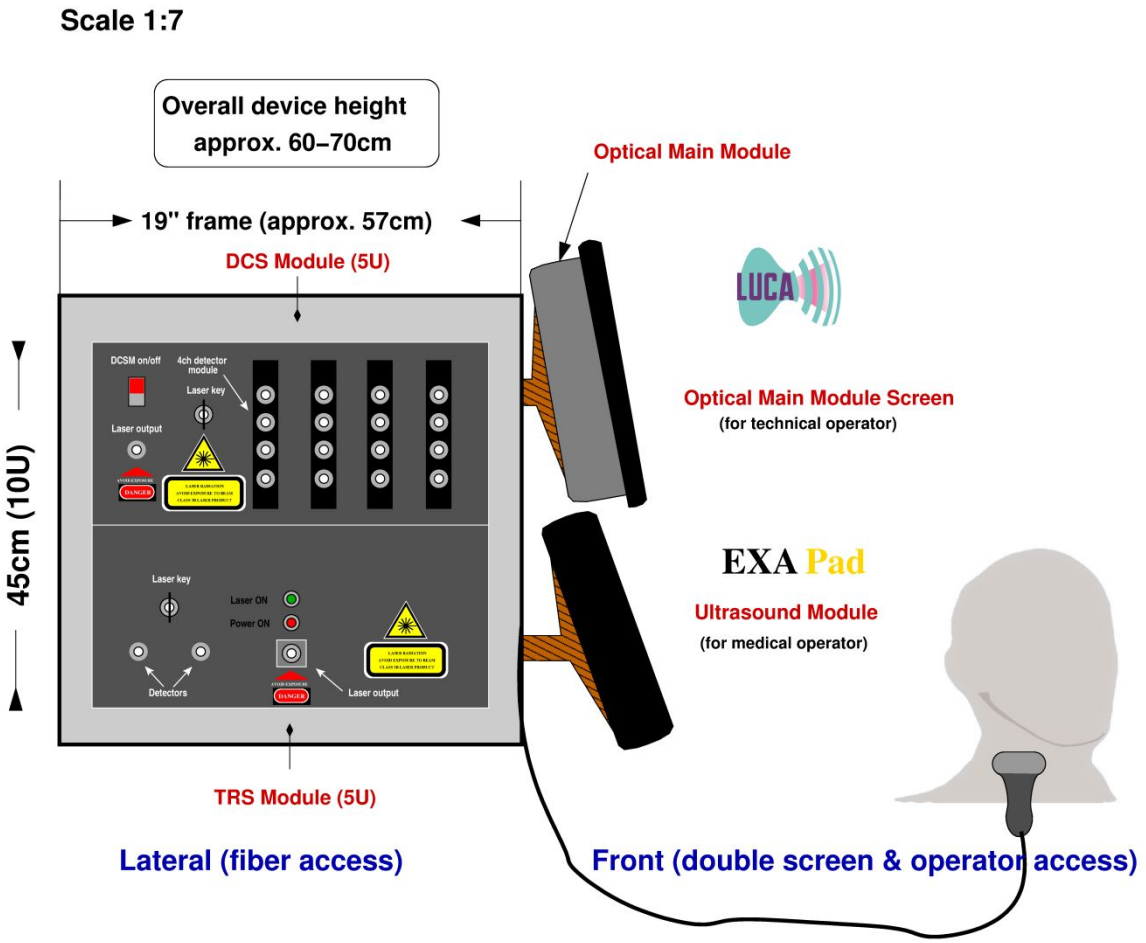

Figure 2: The compact table-top LUCA device (2020) based on a compact 10U/19” frame, redesigned MM and separate NEM.

Major changes are:

- change device overall cabinet from a 25U/19” frame (total device height approx. 165cm. cp WP3 presentation, LUCA interim review meeting) to a 10U/19” frame (total device height approx. 65cm),
- new MM with compact UTX motherboard, lower footprint I/O electronics, single compact 12V PSU, and reduced electrical I/O channels in a new case located in one combined unit with the optical main module screen,
- largely HW independent NEM software application (can be offered with licensing option),
- redesign of internal cable connections

III. LUCA fully movable, medical grade device

Several practical aspects contributed to the decision for an independent new design of the LUCA device based on the intermediate step of a compact table-top device.

Due to the adaptation of the clinical research campaign to the Covid-19 pandemic situation a separation into an initial intermediate design upgrade - to be implemented during the LUCA project - and a completely new design approach to be developed and implemented during PO phase after the LUCA project required as well a revision. A meaningful continuation of the development based on the compact design concept and in preparation of the PO phase will allow us to enter the PO phase with concept at a higher level of elaboration. The implementation of an intermediate design would have been incompatible with the ongoing clinical campaign.

With the foundation of a spin-off company PioNIRS from POLIMI as a TRS module manufacturer, and the continued expansion of HemoPhotonics as a DCS module manufacturer, a certain degree of new development on the optical module core modules of the LUCA device became feasible early on. Modern clinical equipment providers offer medical grade cart systems with an increasing number of customization options including computer hardware, monitor and battery solutions suitable to accommodate LUCA technology.

A fully movable, medical grade LUCA device concept is outlined in Figure 3. The core opto-electronic components of the DCSM and TRSM are combined in an 8U/19” high frame.

Based on modern near-infrared enhanced single SPAD detectors, the number of DCSM detection channels can be reduced from presently 16 to 12 without signal quality loss due to higher quantum efficiency of this detector technology in comparison to 4 channel modules. This reduces also correlation timing units by one fourth and simplifies the detector control electronics. Dedicated active heat sink units per detector pair can contribute to further enhance stability and detector lifetime.

The DCSM can be operated primarily with a single 12V PSU or battery power line. In combination, a compact size reduction to a 4U/19” module size can be used.

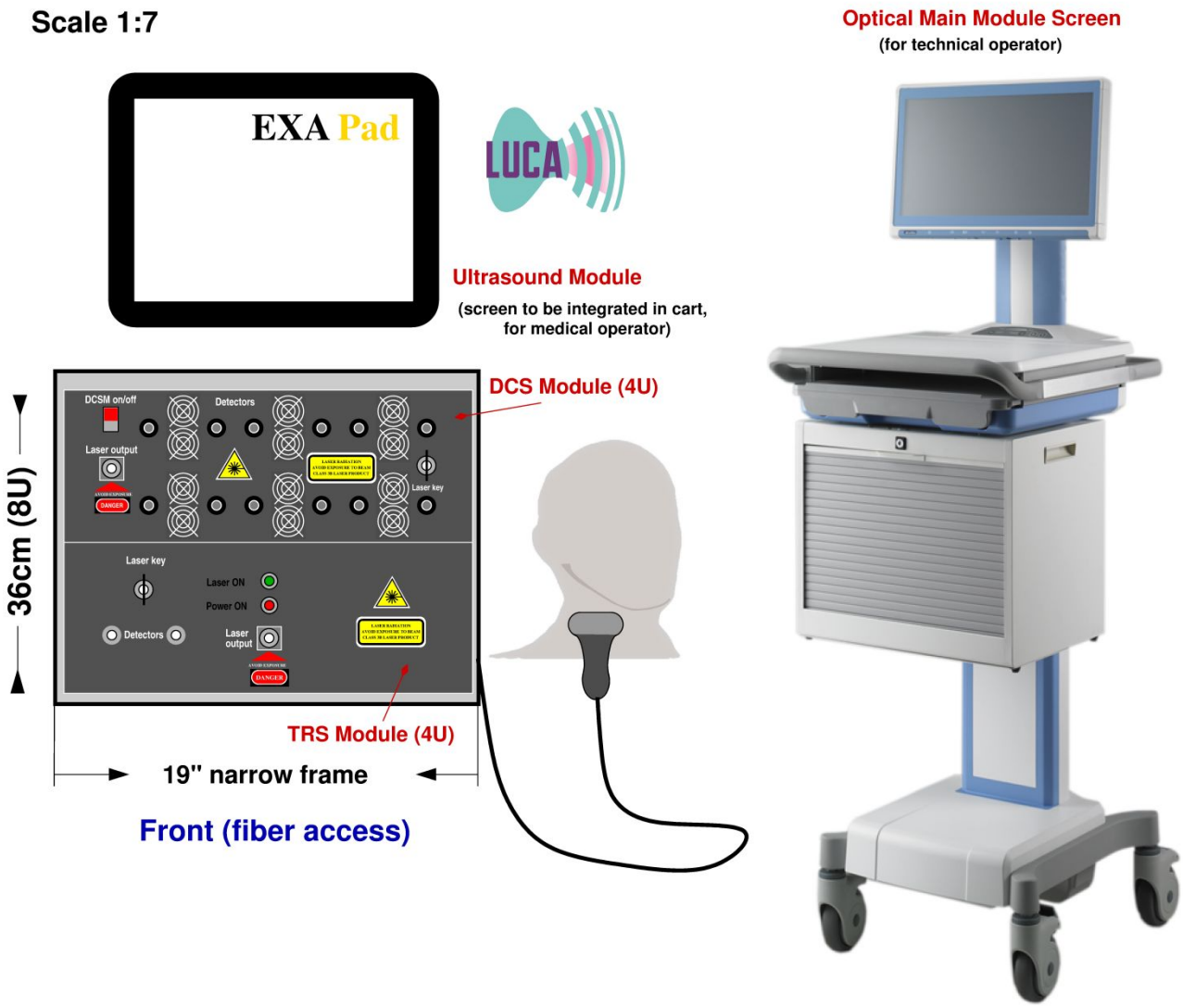

Figure 3: The medical grade LUCA device concept (left, the LUCA USM and combined DCSM/TRSM). The medical grade cart is equipped with a screen for the optical module control with integrated computer, a box container (below tray) for accommodating the combined DCSM/TRSM and a medical grade smart battery solution (in the base). The LUCA EXA Pad requires an additional lateral fixation.

For the TRSM, based on data quality evaluation, a reduction of TRS wavelengths from 8 to 4 can be considered. Accordingly the number of individual laser diode modules, individual fiber coupling units, fiber attenuation units and a more compact fiber

switch unit would allow to reduce the TRSM size to a ≤4U/19” module size. Voltage supply configuration to a single supply voltage (within the range 14,4V-19V) can be also implemented.

The clinical grade cart system provides a height adjustable tray with box container fixation mechanism with a load capacity of up to 30kg for accommodation of the combined DCSM/TRSM. The system screen is equipped with an integrated computer for LUCA optical main module control. The fully movable base contains also the medical grade battery solution.

The LUCA USM (EXA Pad) requires as a second screen an independent fixation at the cart.

3. Conclusions

The fully functional LUCA demonstrator was presented and tested *in vivo* with the aim of demonstrating its usability in terms of US and optical performances. The functionality tests that were performed demonstrated that LUCA system is suitable to acquire US images of the thyroid together with simultaneous optical acquisitions. Minor upgrades to the LUCA demonstrator version presented in D3.5, have been implemented following the indication arising from the LUCA clinical campaign.

An intermediate table-top design upgrade for the LUCA prototype has been elaborated and further developed for a fully movable medical grade LUCA device. This design concept is planned to be finalized and implemented during the Prototype optimization (PO) phase after the LUCA project according to the planned development road map (see D7.11). In ensures a smooth transition to the expansion of the clinical trials of the LUCA concept.

Finally, as mentioned in other relevant deliverables, several LUCA partners (ICFO, HemoPhotonics , POLIMI) and the new SME (PioNIRS) are partners in a new project titled VASCOVID (101016087). The benefits of this partnership is detailed in WP7 (exploitation activities). Briefly, in terms of the LUCA demonstrator’s future, it implies that HemoPhotonics is

evolving into a medical device manufacturer through a close relationship with medical regulatory professionals. The designs mentioned here will benefit from that experience.

The planned design update tasks within this deliverable were completed and all goals were achieved as planned.