Software and Hardware Architecture

Manual

The ModuLase project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. H2020–FoF-2016- 723945-ModuLase.

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Introduction

The ModuLase project developed a re-configurable highly flexible processing head system capable of covering welding, cladding, and cutting, through the use of three modular end-effectors. The ModuLase process head system also includes an intelligent sensor's technologies for quality assurance and semi-automated process parameter configuration. The project head has unlocked the potential of flexibility of fibre-delivered laser sources and address a number of arising industrial challenges, including: the rising need for flexible manufacturing systems, to support an increasing variety of product mixes and the need to maximise equipment utilisation rates, by eliminating down-time associated with changing of laser, processing heads and equipment stoppages and reducing capital investment costs.

The following document provides an overview of the Modulase Hardware and Software comprising a control user interface and knowledge database system, developed to ensure the adequate control of the hardware of the ModuLase system.

ModuLase Software and Hardware Architecture

The hardware architecture consists of several main blocks:

Control User-interface: This is the user control interface which enables the user to set up the correct positioning of the optical lenses for obtaining the right setting for the required laser process. The interface consists of three switches for controlling the three stepper motors implemented within the Beam Forming Unit (BFU). Three home buttons can be used to retrieve the home position for each of these three stepper motors. The user interface also communicates with the knowledge database for reading and storing data, as well as using the data for implementation and set up of welding, cladding, and cutting processes.

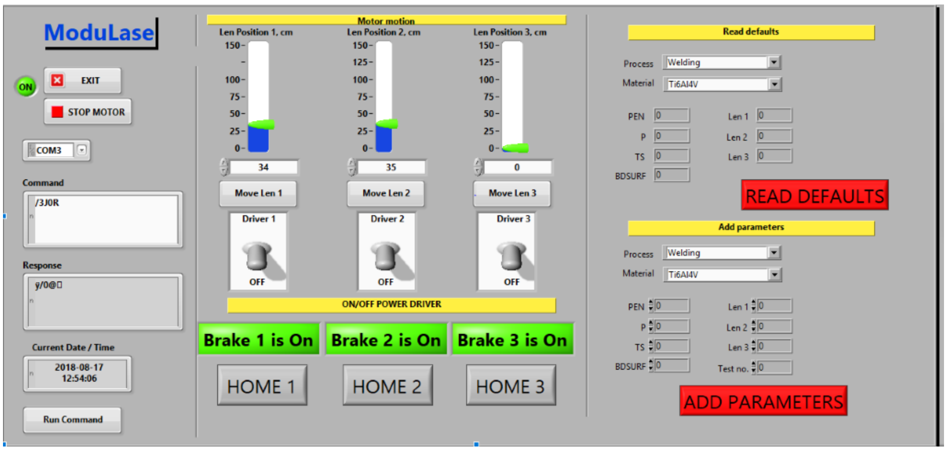

Figure 1 - Control User-interface

Control unit: Consists of a power supply, a USB converter module, USB hub and USB Data Acquisition (DAQ) units. This is used as the power supply of the stepper motors drive unit, the relays and as a central hub for moving data.

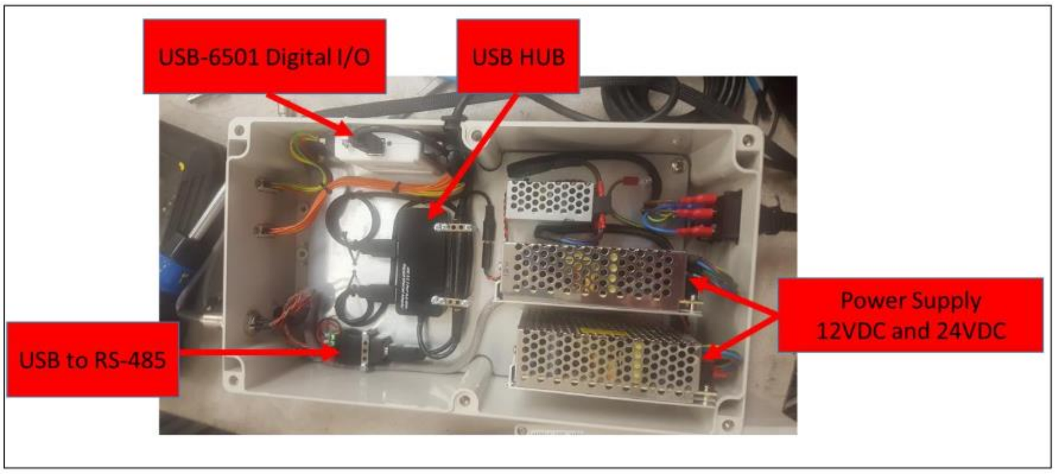

Figure 2 - Control Unit

Motor drive unit: Consists of the three stepper motor drive modules and three relays used as the brake system to ensure the optical lenses are not displaced during the laser process.

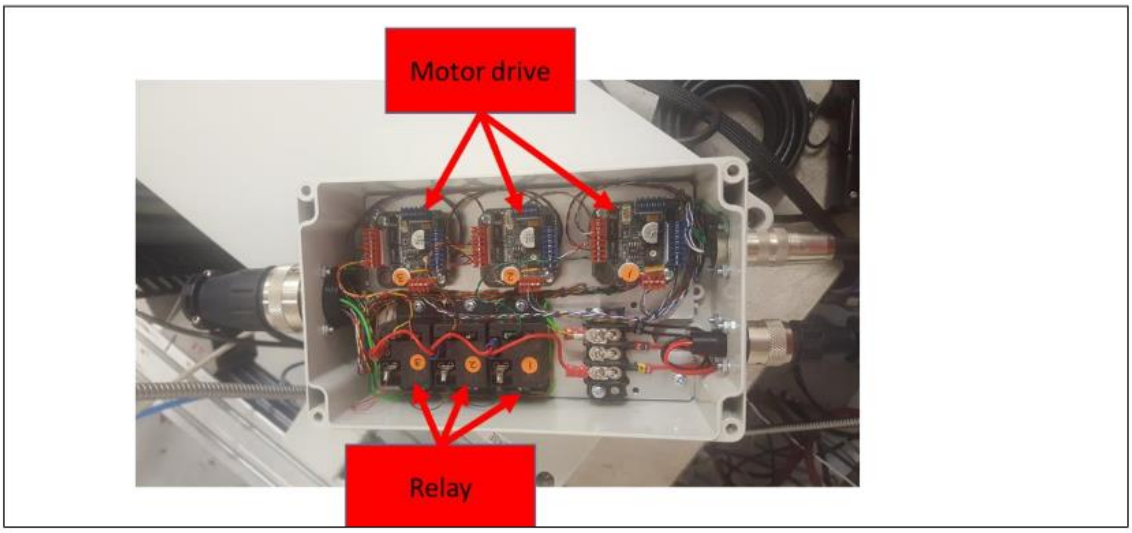

Figure 3 - Motor drive Unit

Beam Forming Unit (BFU): Consists of the optical lenses and the stepper motors. This is used to command the stepper motor for the optical lenses' displacement.

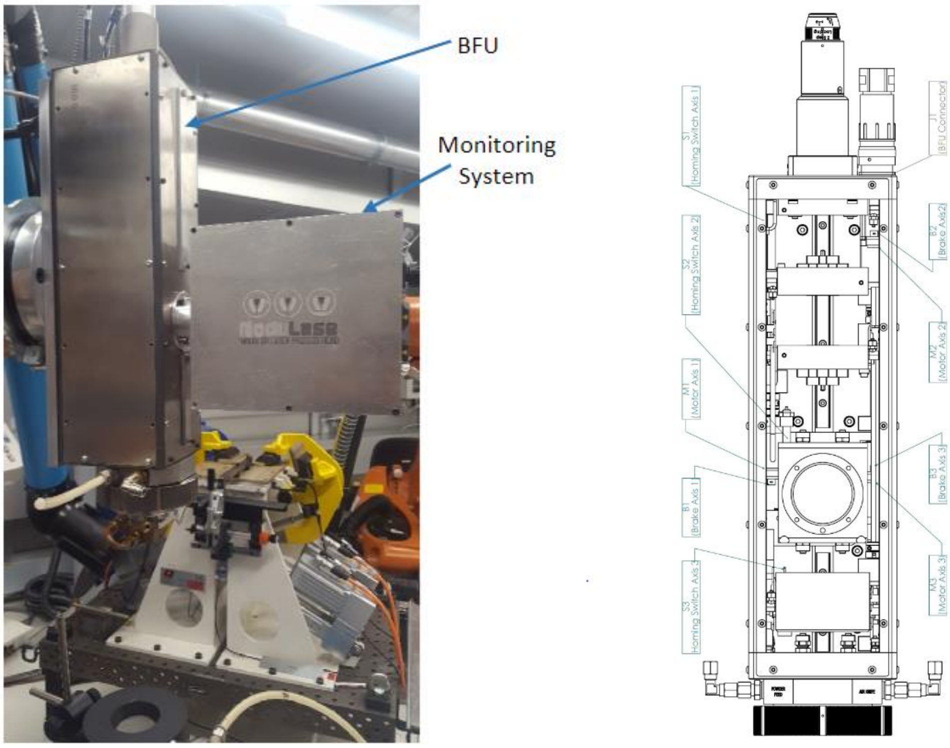

Figure 4 - BFU + Monitoring system (left); BFU components layout (right)

Monitoring User-interface: Easy and friendly user-interface, which consists of different configurations for defect detection during the laser process. In-depth, the interface includes applications for on-line monitoring, and off-line monitoring. The capabilities of this quality assurance system are: real-time processing up to 1000 images per second; on-line diagnosis and defect counting; real-time information visualisation; process data recording; off-line monitoring; labelling and training.

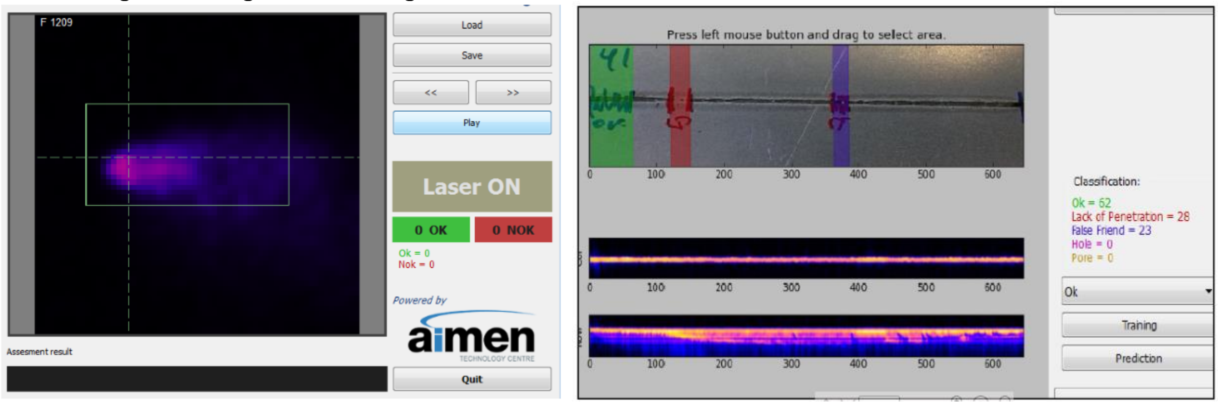

Figure 5 - Real-time image ofe melt pool for automatic detection of defects (left); Training of the detection system (right).

Embedded system: Consists of two sensors (Medium Wavelength Infrared (MWIR) and visible spectral range), hardware for image acquisition (electronics and optical setup) and a software package. The software package includes image processing, a defect detection software, based on a machine learning solution for welding and cutting and the control loop used for cladding processes.

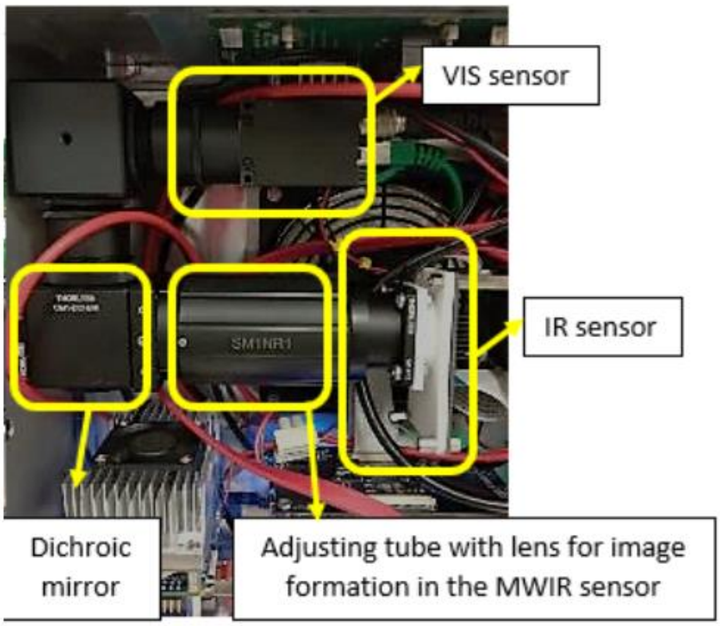

Figure 6 - Embedded System

Coupling optical system: The coupling piece and the case for the embedded quality assurance system are designed and ready to plug in the BFU.

The adequate control of the optical lens configuration is done via the ‘Control User-interface’ while the monitoring system is assessed through the ‘Monitoring user-interface’. A high-level operational flow chart is provided in Figure 7.

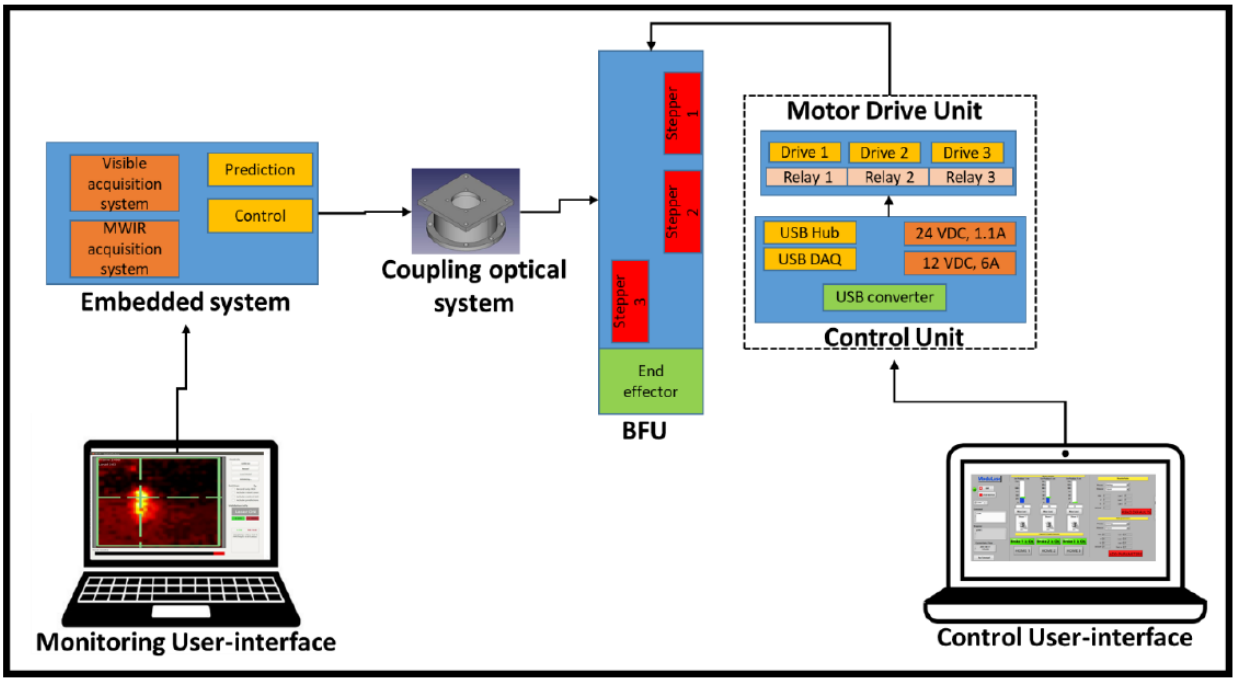

Figure 7 - High level flow chart of the optical lens control system and the monitoring system

Control User-Interface

Algorithms are incorporated within the Control User-interface to process data and provide ease of use for the laser source (i.e. simplify the laser process parameter settings) and flexibility (for automated optical configuration settings), without the need for expert knowledge in laser processing. Three different user's levels (basic, intermediate and administrator) are implemented. Features of the three different user levels are:

- Basic user (Level 1): Enables the user to gain access to the knowledge database in order to retrieve the process parameters needed for the laser process operation choice.
- Intermediate user (Level 2): Enabling the user to set process parameters independently (without the need to rely on data in the knowledge database).
- Administrator user (Level 3): Provides full control of the interface. This user can perform modification to the current interface and add process parameters.

Each user level requires access credentials to gain access to the Control User-interface, as shown in Figure 8.

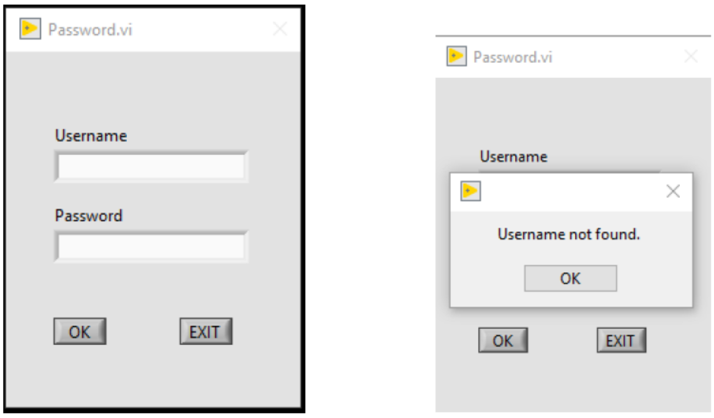

Figure 8 - Credentials request

After inserting the credentials, authorised users gain access to the Control User-interface dashboard (Figure 9). The interface is user-friendly and provides operating features in real time.

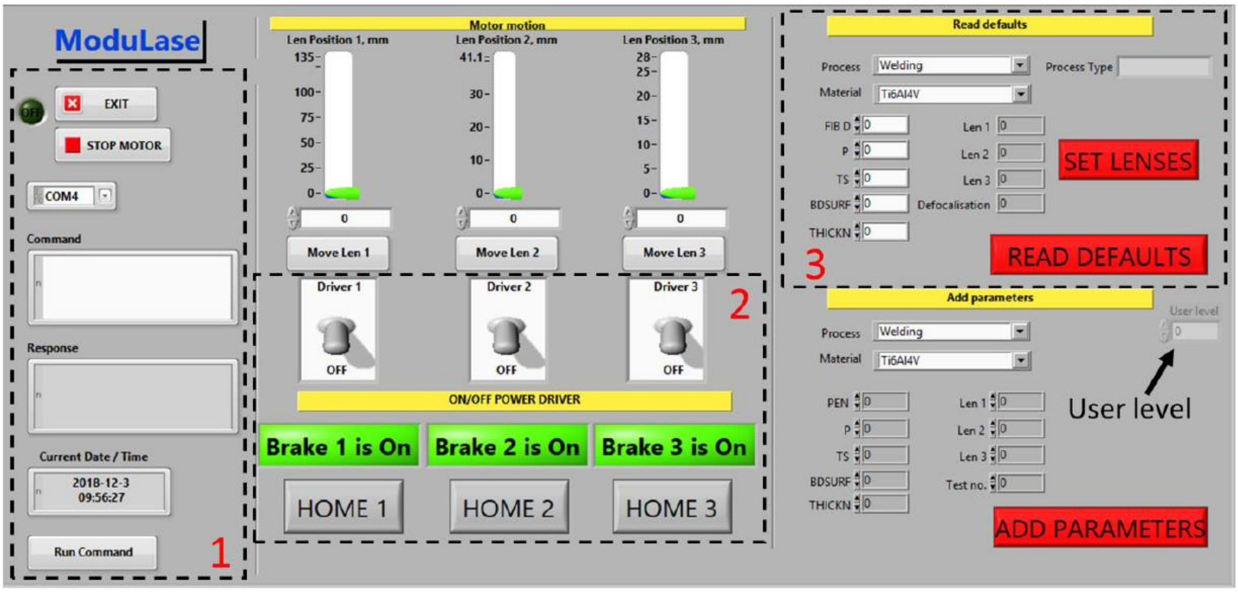

Figure 9 - The control User-interface dashboard

The Control User-interface dashboard comprises a communication panel (indicated by a dotted line and number 1 in Figure 9), brake switches and home buttons (indicated by a dotted line and number 2 in Figure 9), and an interface section to either retrieve process parameters from the knowledge database or directly set process parameters (indicated by a dotted line and number 3 in Figure 9). The basic and intermediate users are able to access limited options on the control user interface dashboard. While an administrator user, will be able to gain full access to all Control User-interface dashboard without any restrictions.

For the basic and intermediate user levels, once the correct credentials have been inputted, the Control-User Interface will prompt the user to check if assistance is required for selecting primary process parameters (Figure 10).

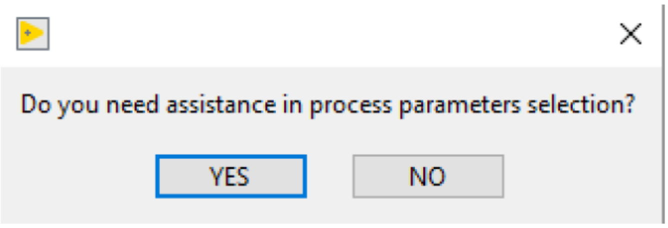

Figure 10 - Process parameters assistance request

If the user selects yes, the user interface will follow the basic user mode and the section of the knowledge database to retrieve primary process parameters (section indicated by the dotted black line and number 3 in Figure 9). These will appear as shown in Figure 11.

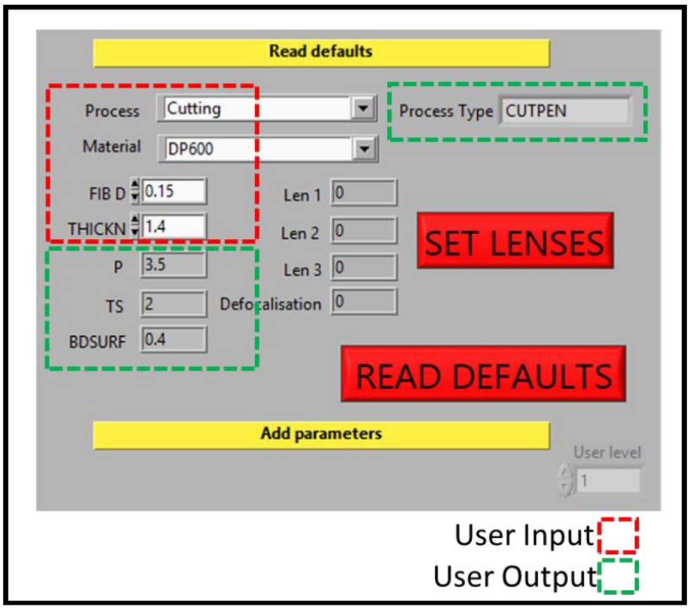

Figure 11 - Knowledge database access for basic user

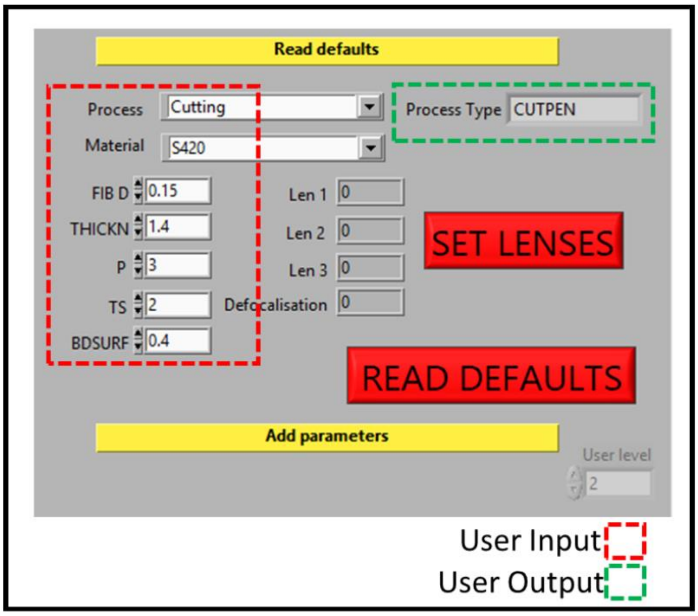

Figure 12 - Knowledge database access for expert user

The main difference between the basic and intermediate user levels is related to the number of primary process parameters that the user will have to input into block number 3 in Figure 9, also as shown within the red dotted line in Figure 11 and Figure 12 respectively. Specifically, in the case of the basic level, the user is allowed to insert only 4 primary input parameters which are:

- Process;
- Material;
- Fibre Diameter (FIB D);
- Thickness (THICKN).

In the case of an intermediate level, the user is able to define almost all primary process parameters, which are:

- Process;
- Material;
- Fibre Diameter (FIB D);
- Power (P); Travel Speed (TS);
- Beam Diameter at the top surface of the work-piece (BDSURF).

Once primary process parameters are inserted, two more additional parameters need to be specified:

- The Defocalisation parameter, which is the distance (along the vertical axis) between the focal plane position and the plane in which the beam diameter is equal to the suppose diameter.
- The PENLAS parameter, which is the distance (along the vertical axis) between the top surface of the work-piece and the focal plane.

In the case of the basic user, both the Defocalisation and PENLAS parameters are retrieved from the knowledge database; while, in the case of the intermediate user level, they are both set by the user. After these two parameters are defined, the Control User-Interface system will automatically configure a specific optical configuration within the BFU (for the required process of interest) and visualise the lenses position information (values of L1, L2 and L3) as shown in Figure 13.

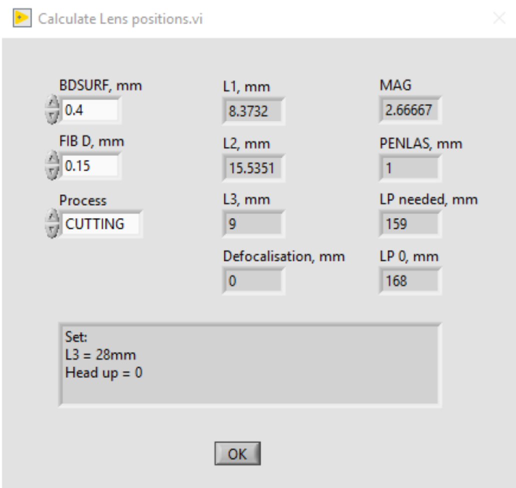

Figure 13 - Lenses position information

Parameters shown in Figure 13 can be defined as follows:

- The Magnification (MAG) coefficient, which is the relation between the Beam Diameter (BDSURF) at the focal plane and the delivery Fibre Diameter (FIB D);
- the Length Point (LP) 0, which is the distance between the lowermost location of the BFU and the focal point with the lens L3 in the home position;
- the Length Point (LP) needed, which is the distance between the lowermost location of the BFU and the focal point with the new position of the lens L3;
- L1, L2, and L3, which are the lenses positions inside the BFU;
- PENLAS and Defocalisation, as defined above;

BDSURF, FIB D, and Process defined in Figure 11 and Figure 12.

Robustness of the control system

One key feature of the control system is ensuring accurate control of the lenses position.
After the integration of the control software to the BFU, the robustness of the control system was put to the test regarding the lens position, corresponding to a specific set of process parameters, covering welding, cutting and cladding laser processes.

For each lens, a maximum travel length has been defined. The repeatability position test consisted of the following:

- For the lens number 1 (L1) the maximum travel is 135 mm, the test consisted of moving the lens by 10 mm until reaching the position of 130 mm and then move further 5 mm as final movement.
- For the lens number 2 (L2) the maximum travel is 41.1 mm, the test consisted of moving the lens by 5 mm until reaching the position of 40 mm; and then move further 1.1 mm as final movement.
- For the lens number 3 (L3) the maximum travel is 28 mm, the test consisted of moving the lens by 5 mm until reaching the position of 20 mm and then move further 8 mm as final movement.

Monitoring User-Interface

The ModuLase quality assurance system consists of an embedded field-programmable gate array (FPGA) and two camera sensors (in the visible and mid-wavelength infrared wavelengths) that are installed on the ModuLase laser head. A Robot Operating System (ROS) framework is used as the main architecture integrating the software modules. The software package is able to record the datasets and includes control interfaces to validate results. Images taken from the sensors during laser trials are representative of any variations in the process. The monitoring system was connected to the BFU through the coupling optical system as shown in Figure 14.

Figure 14 - Monitoring system integrated within the Modulase head

The quality assurance system is enclosed into a metal casing to avoid interferences from ambient light and protect the sensors and lenses from fumes and particles produced during laser processing. The interface between the monitoring system and the user computer is performed by Ethernet. An analog signal between 0 to 10 V is used to connect the system with the laser source through an analog input, enabling the control of the laser power. The visible sensor has higher resolution (544x544) than the mid-wavelength infrared (MWIR) sensor (32x32), which means that the visible sensor requires a bigger bandwidth to process the images and the FPGA processor is not able to manage this bandwidth. The system relies on a specific software for defect detection, which is based on supervised-learning strategies. The software for defects detection, is based on using an OpenLMD1 solution. Processing algorithms make use of a principal component analysis approach, decomposing the vast amount of data acquired by the sensors to the real valuable information required for the automatic defect detection. The software package includes different configurations for defect detection during laser processing. Specifically, the software includes applications for on-line monitoring (Figure 15), off-line monitoring and training (Figure 16).

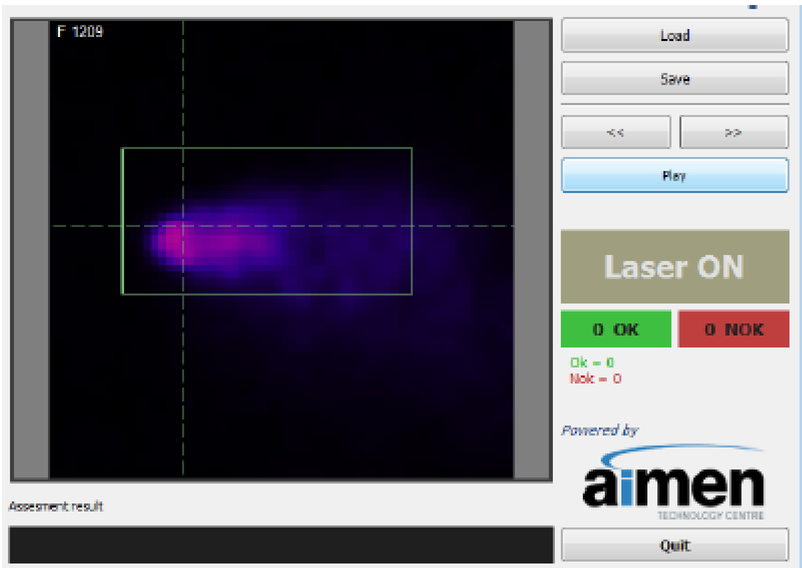

Figure 15 - Real-time image of melt pool area and automatic detection of defects

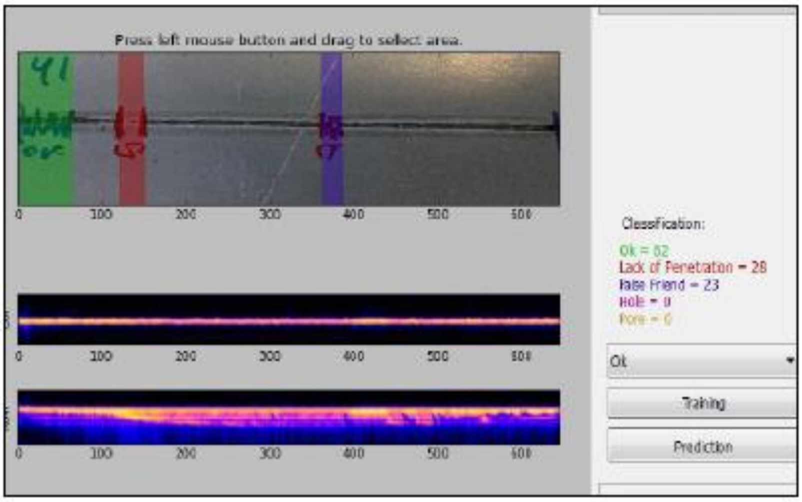

Figure 16 - Training of the detection system

Main capabilities of the quality assurance system are:

- Real time processing up to 1000 images per second;
- On-line diagnosis and defect counting;
- Real time information visualization;
- Process data recording;
- Off-line monitoring;
- Labelling and training.

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The project is an initiative of the Photonics and Factories of the Future Public Private Partnerships.

www.modulase.eu

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