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Authoring Partner: EWF	
Contact Person: Rita Bola	
Email: rgbola@ewf.be	Phone: +351 914 044 390 Fax: NA
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Name of the Scientific Representative of the Project's Co-ordinator, Title and Organisation	Name: Paola De Bono Tel: +44 (0)1223 899000 E-mail: paola.debono@twi.co.uk
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1. 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 intelligent sensor's technologies for quality assurance and semi-automated process parameter configuration. The ModuLase process head has unlocked the potential of greater flexibility of fibre-delivered laser sources and addresses a number of arising industrial challenges, including:

- The rising need for flexible manufacturing systems, to support an increasing variety of product mixes;
- 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.

Training, knowledge transfer and raising awareness are key activities to ensure the uptake of new technologies, hardware, software, discoveries and outcomes by industry. In this respect, in order to raise awareness about the outcomes and results of ModuLase, a set of training activities took place in the course of the project. D1.5 'External training, workshops and seminars report' results from activities in Task 1.5. Main aim of the present report is to provide an overview of training activities carried out throughout the duration of the project. Table 1 summarises scope of Task 1.5 and D1.5.

Table 1 – Task 1.5 and D1.5 Descriptions (according to the GA 723945)

Task 1.5 – Training
<p><i>This task targets the organization of training/dissemination workshops. For this purpose, a set of materials, like training manuals and guidelines will be developed and prepared. A database of videos and photos will also be created, with the assistance of all partners, to facilitate training.</i></p> <p><i>The training workshops will be organised for two different targets, internal training (aimed at staff of the project partners) and external training. A set of external training workshops will be organised during the last three months of the project in different countries mainly aiming at engineers and engineering students. This will allow a wider dissemination of the project results.</i></p> <p><i>EFW will also <u>introduce a training module</u> related to the project results into their <u>standard training packages for engineers</u>. This will ensure that the necessary workforce receive training on the developed technology. The RTD performers, the end-users and EFW will organise technical seminars and events during which they will present the results of ModuLase.</i></p> <p><i>A final event will be organised, to gather all the industry stakeholders from several sectors and present the main results and expected gains of its deployment for the targeted markets, providing for a faster acceptance and integration of the project results in the value chain.</i></p>
D1.5 External training, workshops and seminars report (M57)
<p><i>This deliverable results from activity in Task 1.5. This report will be submitted towards the end of the project and aims to capture the <u>external training activity</u> that has been on going in the project. A set of external training workshops will be organised during the last three months of the project in different countries mainly aiming at engineers and engineering students. This will allow a wider dissemination of the project results.</i></p>

2. Training Materials and Manuals

A set of training materials were developed to complement and aid the training activities carried out throughout the timeframe of the project. These materials will be available, in the project's common repository, for the consortium to use where they see fit even after the end of the project.

Presentations

During the timeframe of the project's presentations were created to showcase project, share information and knowledge in an effective and didactic way.

At the start of the project, a presentation providing an overview of the project scope was produced, showcasing its goals and expected outcomes (Figure 1).



Figure 1 - Slides from the first presentation

The full presentation can be seen in Annex I – Initial Project Presentation.

As the project evolved and results were achieved, a new presentation was created, focusing on the outcomes and providing a more technical overview of the work developed (Figure 2).



Figure 2 - Slides from the updated presentation

The full presentation can be seen in Annex II – Updated project presentation.

Additional presentations (to introduce the technology) are also available in the project website and covers the following topics:

- Basics of Laser technology; Laser beam cutting; Laser beam welding & Laser cladding;
- Basics of Process Monitoring and Control;
- ModuLase Key Technologies: Set-up, Capabilities and Processes.

In order to complement the ModuLase training activities, and for students to have a reference document and address any doubt they might have, the ModuLase consortium prepared a manual with the different steps needed to use the Control User-Interface (Figure 3). The full document can be seen in Annex III – ModuLase Software and Hardware Architecture Manual. The software developed ensures the adequate control of the hardware enabling the fast configuration of the machine to be adjusted to the work being done. All this is done through a user-friendly interface.

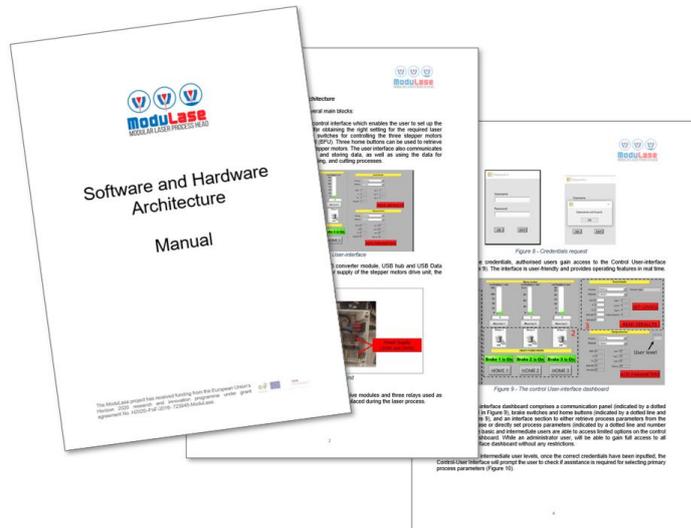


Figure 3– Software and Hardware Architecture – Manual

Database of Photos and videos

Photos, videos and associated training materials to support delivery of training sessions to external entities are available on the project website in the Documents tab (<https://www.modulase.eu/documents.html>).

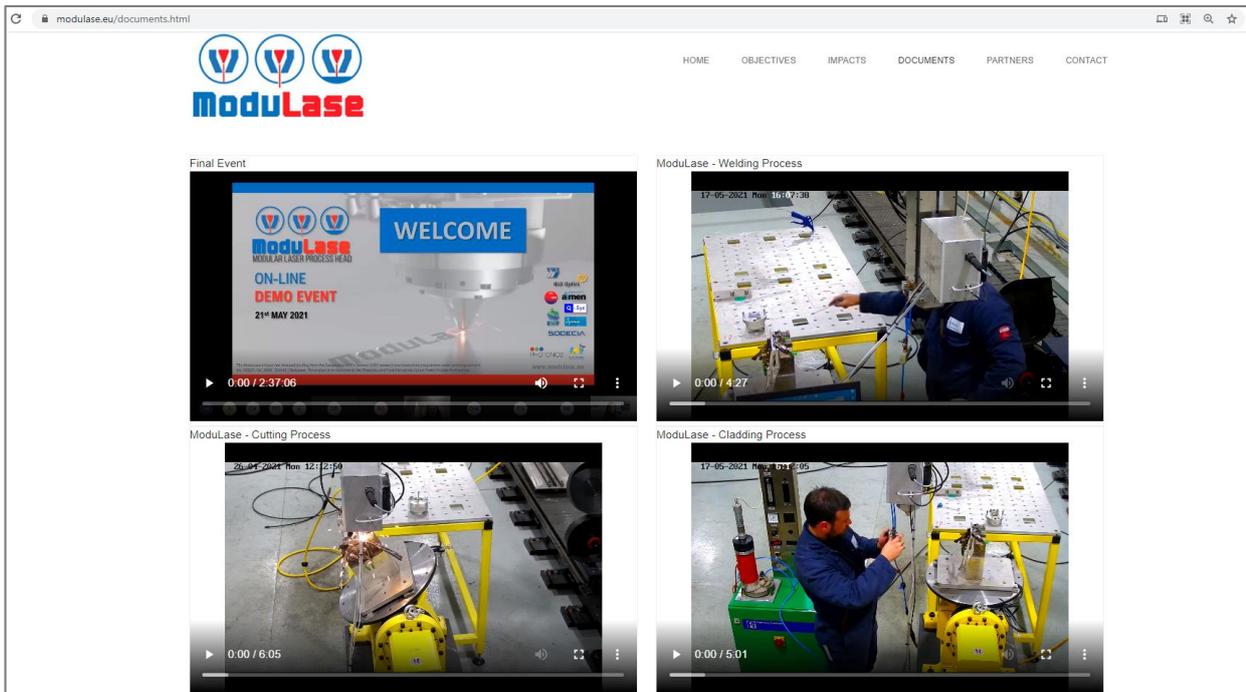


Figure 4– Evidence of database of ModuLase Training Materials

3. External Training, workshops and seminars

Within the timeframe of the project a set of activities were carried out, targeting not only engineering students but also engineers and operators. The activities targeting engineers and operators were carried out directly to industry, enabling the raise awareness regarding the ModuLase system. During delivery of the training sessions, it was ensured that personnel needing to acquire knowledge on the operational aspects of the ModuLase system was involved.

Moreover, the workshops organized toward engineering students were a great opportunity to showcase a new industrial approach for laser processing to the future work force. Delivered training activities are summarised in Table 2.

Table 2 – Summary of External Training Activities deployed

Activity	Place	Date	Audience Type	Attendees	Notes
Training at VET Centre	Oeiras PT	28 September 2018	EWE Course Engineers & Engineering students	24	Evidences In the subsections here-after
Seminar at University	Lisbon PT	03 December 2018	Mechanical and Materials Engineering Students	34	
Training at Industry	Ovar PT	19 December 2018	Automotive Sector Company	16	
Training at Industry	Ovar PT	04 – 08 February 2019	Automotive Sector Company	9	
Training at Industry	Ovar PT	27 – 29 February 2019	Automotive Sector Company	5	
Training at VET Centre	Grijó PT	28 September 2019	EWE Course Engineers & Engineering students	18	
Training at VET Centre	On-line	11 July 2020	EWE Course Engineers & Engineering students	15	
Seminar at University	On-line	23 March 2021	Mechanical and Materials Engineering Students	20	

Figures 5 to 13 report evidence of all external training activities delivered in the course of the ModuLase project.

VET Centre – EWE Course – ISQ Oeiras – 28th September 2018

The figure shows four ISQ presence sheets for the EWE course. Each sheet includes the course title 'SISTEMAS LÁSER, TÉCNICA DE ELABORAÇÃO E PLUMA', the date '28-09-2018', and a list of attendees with their signatures. The sheets are arranged in a 2x2 grid.

Figure 5 – EWE Course presence list

Seminar at University – IST – 3rd December 2018

The figure consists of two parts. On the left is a presentation slide titled 'Development and Pilot Line Validation of a Modular Re-Configurable Laser Process Head' for 'Task 1.5 – Training' on '3rd December 2018'. It features the ModuLase logo and mentions funding from the European Union's Horizon 2020 program. On the right is a photograph of a seminar room where several students are seated at desks, looking towards a screen displaying a presentation.

Figure 6 – Evidence of Training at IST Engineering Students

Training at Industry – Automotive Sector – Kirchoff 1st Edition – 19th December 2018

The figure shows an ISQ presence sheet for the Kirchoff 1st Edition course. It includes the course title 'GARANTIA DA QUALIDADE (SIGNIFICA, IMPERFECÇÕES, APRESENTAÇÃO RESULTADOS ANOMIAIS E RADICIS)', the date '19/12/2018', and a list of attendees with their signatures. The sheet also includes a section for 'Materiais e/ou equipamentos utilizados na sessão:' and a signature line for the instructor.

Figure 7 – Kirchoff 1st Edition Course presence list

Training at Industry – Automotive Sector – Kirchhoff 2nd Edition – 4th to 8th February 2019

Figure 8 – Kirchhoff 2nd Edition course presence list

Training at Industry – Automotive Sector – Kirchhoff 3rd Edition – 27th to 29th February 2019

Figure 9 – Kirchhoff 3rd Edition course presence list



Figure 10 – Eurico Assunção presenting the Modulase System at Kirchhoff

VET Centre – EWE Course – ISQ Norte – 28th September 2019



Figure 11 – ISQ Norte – Training workshop presence list and classroom

VET Centre – EWE Course – ISQ Norte – 11th July 2020



Figure 12 – On-line presentation of ModuLase to ISQ students

Seminar at University – IST – 23rd March 2021



Figure 13 – Evidence of Training at IST Engineering Students

4. Conclusions

This report compiles all training materials and external training activities that took place during the duration of the project. Target groups initially identified at proposal stage, both internal and external, were reached (although this deliverable reports only the external activities, there have been also internal ones – reported under D1.13 – Training, workshops and seminar reports). The training activities carried out, targeted not only industry experts but also undergraduate engineering students as well as the industry in which the ModuLase concept was showcased, increasing more the coverage of the project, including to potential end-users.

A database is available on the project website, containing training materials, from presentations, manuals, photos and videos and will be maintained available and accessible after the end of the project, so that partners will be able to use in post-project activities, as appropriate.

It is planned to have further training and knowledge sharing activities also beyond project completion, proving that the results and outcomes of the project are of added value to possible end-users.

5. Annexes

Annex I – Initial Project Presentation

The below presentation is accessible at: www.modulase.eu/documents.html

ModuLase Introduction to the Project

Background of the Proposal

- Despite the unrivalled versatility of fibre-delivered laser sources to perform a wide range of processes, the potential flexibility is currently limited by the need to change the processing head for the different processes to be performed (e.g.: welding, cutting and cladding)
- The majority of industrial laser systems are employed to perform low-variety and high-volume manufacturing operations
- Current manufacturing trends (such as increased automation, individualisation and next-shoring) are driving the need to develop manufacturing systems which are capable of performing a higher variety of manufacturing operations and product mixes
- Need to maximise equipment utilisation rates, by eliminating down-time associated with changing of laser processing heads and equipment stoppages
- Increasing need by industry to reduce capital investment costs

ModuLase Call

- H2020-IND-CE-2016-17, FOF-13-2016 call
- Factories of the Future: Photonics Laser-based production
- Start date: 1st September 2016
- Duration: 36 months
- Received EC funding: €2,458,465 (€2,184,565 Grant)
- Programme directly focused on "Rapid individualised laser-based production"

Consortium

- 8 participants from 4 countries
- 50% RTO, 25% SMEs and 25% LEs
- End users within the power, aerospace and automotive sectors

Activities	Consortium
Beam Forming Unit	ULO Optics
End Effectors	TWI, ULO Optics
Process monitoring and quality control	ammen
Laser processing development and validation	TWI
User friendly Operating/User interface	-Sys
Representing needs of European Industry	EWF
Automotive, power and Aerospace applications	SODECIA

ModuLase Overall Objectives

The ModuLase project is developing a re-configurable highly flexible processing head system, capable of covering welding, cladding and cutting

The ModuLase process head system will:

- Be capable of welding, cladding and cutting, through the use of three modular end-effectors
- Include intelligent sensor technologies for in-process monitoring
- Be linked to an intelligent system, in order to achieve adaptive process control, quality assurance, and semi-automated process parameter configuration

ModuLase Key Features

- Reduced capital investment costs:**
 - End-users will save as much as 59% when installing the ModuLase head (with three end-effectors considered in this project)
 - Higher savings possible for organisations adopting more end-effectors
 - Further savings may be realised when replacing end-effectors due to wear or damage
- Maximise laser equipment utilisation rates by reducing down-time:**
 - Anticipated changeover time of <1 minute for the proposed ModuLase process head
 - Improved utilisation rates
 - The ModuLase system will allow manufacturers to adopt parallel process cell layouts, rather than sequential process cell layouts; reducing the risk of production-line stoppages

ModuLase Key Features

- Reduced running costs:**
 - Modular end-effectors easily and cheaply replaceable
 - Reconfiguring the BFU to match the required beam configuration will save time and cost.
 - The integrated process control and monitoring system also helps minimise, if not eliminate, defects and therefore save on re-work or scrappage.

ModuLase Technologies & Industry Focus

ModuLase Technologies

Beam Forming Unit (BFU):

- The adaptable optical elements of the BFU will be capable of delivering a wide range of laser beam energy distributions, suitable for welding, cutting and cladding applications.
- A range of high-value goods, e.g. those made from advanced materials (advanced alloy steel, titanium, aluminium, etc.) will be covered.

End-effectors:

- Three rapidly interchangeable end-effectors will be developed to cover welding, cutting and cladding applications.
- The end-effectors will have a plug and play system to allow them to be changed on the end of the process head within a time of 1 minute.

ModuLase Technologies

Process monitoring and quality control:

- A process monitoring system suitable for welding, cladding and cutting processes will be developed.
- It will be embedded into the ModuLase system, in order to assure process stability and also enabling to reduce additional time and costs involved in the process.

User friendly Operating/User interface:

- The ModuLase system will comprise a user friendly HMI interface, enabling to input the material grade, its thickness and the laser process required.
- Both the Quality Assurance System and BFU shall adjust vision and optical configurations and deliver the beam accordingly with minimal user contact.

ModuLase Technologies

Adaptability for Industrial Applications:

The ModuLase system will be able to cover cutting, welding and cladding applications

Summary of Key Deliverables

- Three end effectors manufactured for cutting, welding and cladding
- BFU manufactured
- Embedded Process Monitoring assembled
- Laser process parameters for assembly and testing of process head (BFU + end effectors + process monitoring)
- System and software integrated with new knowledge gained from TWI trials
- Final system developed from its initial specification, testing of requested settings with actual beam settings and embedded monitoring system included
- Final Demonstration of the ModuLase system in industrial environment and to an industrial audience

Thank you

Rita Bola
Project Manager

EWF/INM-IMB Secretariat
Av. Real Colégio, 53 - TagusPark
2748-239 Póvoa do Varzim - Portugal
Email: info@ewf.eu

Annex II – Updated Project’s Presentation

The below presentation is accessible at: www.modulase.eu/documents.html

Development and Pilot Line Validation of a Modular Re-Configurable Laser Process Head

Task 1.5 – Training

Introduction

- The Modulase project was created to develop a re-configurable laser processing head capable of performing three different processes: **welding, cutting and cladding**.
- The system is able to perform the three different processes through the use of three modular end-effectors.
- Modulase also includes in-process monitoring through the use of intelligent sensor technologies.
- The monitoring system allows for adaptive process control, quality assurance, and semi-automated process parameter configuration.

Concept Scheme

Concept Scheme

Equipment development – from concept to prototype

- Beam Formin Unit – BFU
- Gas delivery unit – GDU
- Modular end effectors
- Camera-based quality assurance unit
- Integrated software interface

The system includes dedicated software with a knowledge database and board algorithms which allow for the correct settings and process parameters to be calculated for each application. The camera-based monitoring unit is integrated into the processing head and is compatible with all three of the processes performed by the system.

Equipment development – from concept to prototype

Equipment development – BFU

Equipment development – BFU

Equipment development – GDU and End-effectors Design

Equipment development – End-effectors

Quality assurance

- Effective and compatible with the three different laser processes
- The arrangement includes camera-based sensors which cover different spectral bands from visible (VIS) to infrared (IR) embedded electronics and optical components
- The molten bath is monitored in real time
- Deviations from stable reference conditions are captured, localized and identified as anomalies of the process

Quality assurance – System design and optical design constraints

Quality assurance – Process Validation Trials – Cutting Case

Process parameters:
Material: Titanium
Thickness: 1.5mm
Power: 650W
Gas flow: 1.2bar

Quality assurance – Process Validation Trials – Welding Case

Detected defects:

- Undercuts
- Pores
- Holes
- Lack of penetration
- False friend

Quality assurance – Process Validation Trials – Welding Case

Quality assurance – Process Validation Trials – Cladding Case

Quality assurance – Process Validation Trials – Cladding Case

Quality assurance – Summary

- Defects are detected with a success rate higher than 95%. Future improvements will also allow defects to be classified
- The monitoring system developed is able to detect "non cut" cases in laser cutting process with an accuracy higher than 90%

Intelligent software

For each parameter, the algorithms within the software architecture allow to:

- Type the value in
- Upload the value from the knowledge database

The software has the capability to select the optimal arrangement and process parameters as a function of specific workpiece.

- The software interfaces with the BTU, the motion system, the CA-system and the laser machine.
- The PMI is capable to provide a real-time update on the process status.

Intelligent software – Top Level Software Architecture

Intelligent software – Knowledge Database

- Quick process configuration
- Reducing the expertise required to optimise the laser processes

Intelligent software – Knowledge Database

- Laser Material Interaction Conditions
- TIMINT**: Time of Interaction
- AVPD**: Average Power Density
- ENESPT**: Specific Point Energy

$$TIMINT = \frac{BDSURF}{TS}$$

$$AVPD = \frac{4 \cdot P}{\pi \cdot \delta \cdot SURF}$$

$$ENESPT = P \times TIMINT$$

P = Laser power
TS = Tool speed

Intelligent software – Control User-Interface

- User-friendly
- User-levels:
 - basic
 - intermediate
 - administrator

Intelligent software – Control User-Interface

Modular cells for laser processing

ModuLase vs. Conventional Technologies

Industrial Scenario 1	Industrial Scenario 2	Industrial Scenario 3	ModuLase System
1 power source 1 manipulation system 3 heads 3 fibre Changing of the head	2 power sources 3 manipulation systems 3 heads 3 fibres 2 process workpieces at the same time	2 power sources 1 manipulation systems 3 heads 3 fibres	2 power sources 1 manipulation system 2 head with 3 end-effectors 1 fibre

Modular cells for laser processing

End-use Cases to validate the Technology

End-user	Component	Applications	Demonstrative Images	Outcomes
Siemens	Guard for a compressor turbine engine blade	Welding Cutting		Time: 5.76s Initial Investment: 48.12k€ Shop floor usage: 72.41% Repetitive Rate: 49%
SODECIA	Gear box forks of a car	Welding Cladding		Time: 4s Initial Investment: 40.22k€ Shop floor usage: 54.14% Repetitive Rate: 9%
EVF	Component of the body in white of a car	Welding Cutting		Time: 16s Initial Investment: 4k€ Shop floor usage: 46% Repetitive Rate: 9%
EVF	General Application	Cladding		Time: 16s Initial Investment: 4k€ Shop floor usage: 46% Repetitive Rate: 9%

Summary

- ModuLase project was able to develop a re-configurable system that allows to perform three different laser processes within a unique facility.
- The ModuLase system has great potential to boost the 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.
 - 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.

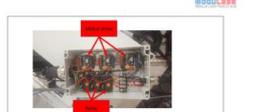
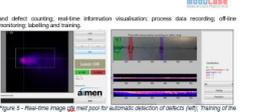
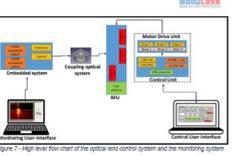
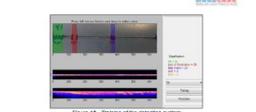
Thank you

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

www.modulase.eu

Annex III – ModuLase Software and Hardware Architecture Manual

The below document is accessible at: www.modulase.eu/documents.html

<p style="text-align: center;">Software and Hardware Architecture Manual</p> <p>The ModuLase project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101019720 (H2020-ModuLase).</p>	<p style="text-align: center;">Contents</p> <ul style="list-style-type: none"> Introduction 1 ModuLase Software and Hardware Architecture 2 Control User Interface 6 Real-time image processing 6 Real-time image processing 6 Monitoring User Interface 6 	<p style="text-align: center;">Figure Index</p> <ul style="list-style-type: none"> Figure 1 - Control User Interface 2 Figure 2 - Control Unit 2 Figure 3 - Mirror ModuLase 2 Figure 4 - Real-time image processing (GPU) 2 Figure 5 - Real-time image processing (GPU) for automatic detection of defects (AD) 2 Figure 6 - Real-time image processing (GPU) for automatic detection of defects (AD) 2 Figure 7 - High level flow chart of the optical lens control system and the monitoring system 4 Figure 8 - Knowledge database 6 Figure 9 - The control User Interface dashboard 6 Figure 10 - Process parameter assistance request 7 Figure 11 - Knowledge database access for user level 7 Figure 12 - Knowledge database access for expert user 7 Figure 13 - Monitoring system request entry to the plant head 10 Figure 14 - Monitoring system integrator with the detection head 10 Figure 15 - Real-time image of melt pool area and automatic detection of defects 11 	<p style="text-align: center;">Introduction</p> <p>The ModuLase project developed a reconfigurable highly flexible processing head system capable of covering welding, cladding, and cutting, through the use of three modular end-effectors. The ModuLase processing head system includes an intelligent research technology for quality assurance and semi-automatic process parameter configuration. The project head has reduced the potential of flexibility of three-dimensional 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 sizes and for need to maximise equipment utilisation rates, by introducing laser-line assistance with changing laser processing heads and equipment stoppages and reducing capital investment costs.</p> <p>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.</p>
<p>ModuLase Software and Hardware Architecture</p> <p>The software architecture consists of several main blocks:</p> <p>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 cutting for the required laser process. The detection head is set up to ensure quality by controlling the laser source lenses position. The detection head is set up to ensure quality by controlling the laser source lenses position for each of these three laser sources. The user interface also communicates with the knowledge database for reading and writing data, as well as using the data for implementation and set up of welding, cladding, and cutting processes.</p>  <p>Figure 1 - Mirror ModuLase</p> <p>Beam Focusing Unit (BFU) Consists of the optical lenses and the stepper motor. This is used to compensate the stepper motor for the optical lenses displacement.</p>  <p>Figure 3 - Mirror ModuLase</p> <p>Control Unit Consists of a power supply, a USB converter module, USB to RS485 Data Acquisition (DAQ) unit. This is used as the power supply of the stepper motor drive unit, the robot and as a control hub for the robot cells.</p>  <p>Figure 2 - Control Unit</p> <p>Mirror drive unit Consists of three stepper motor also available and three trays used on the track system to ensure the optical lenses are not displaced during the laser process.</p>	 <p>Figure 3 - Mirror ModuLase</p> <p>Beam Focusing Unit (BFU) Consists of the optical lenses and the stepper motor. This is used to compensate the stepper motor for the optical lenses displacement.</p>  <p>Figure 4 - BFU</p> <p>Monitoring User Interface Easy and friendly user interface, which consists of different configurations for robot motion during the laser process. Firstly, the interface includes applications for on-line monitoring, and off-line monitoring. The capabilities of the quality assurance system are real-time processing up to 1000 images per second, displaying</p>	<p>and defect monitoring, machine information visualisation, process data recording, off-line monitoring, user interface.</p>  <p>Figure 5 - Real-time image of melt pool area and automatic detection of defects (AD)</p> <p>Embeded system Consists of two cameras (Monochrome Infrared (MIR) and visible specter range), Invariance for image acquisition (prevention) and optical sensor, and a software interface for image processing (prevention) and defect detection software, based on the machine learning solution for welding and cutting on the control loop used for cladding process.</p>  <p>Figure 6 - Embeded system</p> <p>Coupling optical sensor The coupling optical sensor is used for the embeded quality assurance monitoring (MIR) and mostly to track the BFU.</p> <p>The adequate control of the optical lens configuration is done via the 'Control User Interface' via the monitoring system is supported through the Monitoring user-interface. A high-level overview flow chart is provided in Figure 7.</p>	 <p>Figure 7 - High level flow chart of the optical lens control system and the monitoring system</p> <p>Control User Interface</p> <p>Algorithms are incorporated within the Control User Interface to process data and provide ease of use for the user. The user can set process parameters, adjust the flexibility for advanced optical configuration (welding), without the need for expert knowledge (D, laser processing). Three different user levels (Basic, Intermediate and Administrative) are implemented. Features of the three different user levels are:</p> <ul style="list-style-type: none"> Basic user level (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. Intermediate user level (Level 2): Enabling the user to set process parameters. Independently without the need to rely on data in the knowledge database. Administrative user level (Level 3): Provides full control of the interface. The user can perform modifications to the current interface and add process parameters. <p>Each user level requires access credentials to gain access to the Control User Interface, as shown in Figure 8.</p>
 <p>Figure 8 - Credentials request</p> <p>After inserting the credentials, authorized users gain access to the Control User Interface dashboard (Figure 9). The interface is divided into several sections based on the user level (Figure 10). The interface is divided into several sections based on the user level (Figure 10). The interface is divided into several sections based on the user level (Figure 10).</p>  <p>Figure 9 - Control User Interface dashboard</p> <p>The Control User Interface dashboard comprises a communication panel (indicated by a dotted line and number 1 in Figure 10), a main interface section to define process parameters from the knowledge database (indicated by a dotted line and number 2 in Figure 10), and an interface section to define process parameters from the knowledge database (indicated by a dotted line and number 3 in Figure 10). The basic and intermediate users are able to access limited options on the control user interface dashboard. Only an administrative user will be able to gain full access to all Control User Interface dashboard options and functions.</p> <p>For the basic and intermediate user levels, once the correct credentials have been inserted, the Control User Interface will prompt the user to check if the credentials are required for selecting primary process parameters (Figure 11).</p>	 <p>Figure 10 - Process parameter assistance request</p> <p>If the user selects yes, the user interface will follow the basic user mode and the section of the interface to retrieve primary process parameters (section indicated by the dotted line and number 1 in Figure 10). There will also be shown in Figure 11.</p>  <p>Figure 11 - Knowledge database access for user level</p>  <p>Figure 12 - Knowledge database access for expert user</p>	<p>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 the BFU (Figure 5). 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 input only 4 primary process parameters which are:</p> <ul style="list-style-type: none"> Process Material Flame Diameter (FB D) Thickness (ET/DEN) <p>In the case of the intermediate level, the user is able to define almost all primary process parameters, which are:</p> <ul style="list-style-type: none"> Process Material Flame Diameter (FB D) Power (P) Travel Speed (TS) Down Diameter (or the top surface of the work piece (GDD/P)) <p>Over primary process parameters are required, two more additional parameters need to be specified:</p> <ul style="list-style-type: none"> The Deformation 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 exposure diameter. The FOV-D parameter, which is the distance (along the vertical axis) between the top surface of the work piece and the focal plane. <p>In the case of the basic user, both the Deformation and FOV-D parameters are implemented 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 establish the lens position information (values of L1, L2 and L3) as shown in Figure 13.</p>  <p>Figure 13 - Lens position information</p>	<p>Parameters shown in Figure 13 can be defined as follows:</p> <ul style="list-style-type: none"> The Magnification (MAG) coefficient, which is the relation between the Beam Diameter (GDD/P) at the focal plane and the delivery Flare Diameter (FB D) at the top surface of the work piece. The length (L1) of the lens, which is the distance between the entrance location of the BFU and the focal point with the lens L3 in the home position. The length (L2) of the lens, which is the distance between the entrance location of the BFU and the focal point with the lens L3 in the home position. L1, L2 and L3, which are the lens position inside the BFU. <p>FOV-D, FB-D, and Flare Diameter, as defined above.</p> <p>Robustness of the control system</p> <p>One key feature of the control system is ensuring accurate control of the lens position. After the integration of the control software to the BFU, the adjustment of the control system was done in the real world regarding the lens position, corresponding to specific set of process parameters, covering welding, cutting and cladding laser processes.</p> <p>For each lens, a maximum travel length has been defined. The repeatability position test consisted of the following:</p> <ul style="list-style-type: none"> For the lens number 1 (L1) the maximum travel is 105 mm, the test consisted of moving the lens by 5 mm and reaching the position of 100 mm and then move further 5 mm as final movement. For the lens number 2 (L2) the maximum travel is 41 mm, the test consisted of moving the lens by 5 mm and reaching the position of 40 mm, and then move further 1 mm as final movement. For the lens number 3 (L3) the maximum travel is 20 mm, the test consisted of moving the lens by 5 mm and reaching the position of 20 mm and then move further 5 mm as final movement. <p>Monitoring User Interface</p> <p>The ModuLase quality assurance system consists of an embeded field programmable gate array (FPGA) and two camera sensors (the visible and near-infrared (MIR) wavelength) 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 platform is able to record the images and includes control interface to validate results. Images taken from the sensors during laser are representative of any workpiece in the process. The monitoring system was connected to the BFU through the coupling optical system as shown in Figure 14.</p>
 <p>Figure 14 - Monitoring system integrator with the detection head</p> <p>The quality assurance system was developed to integrate with the detection head and protect the lenses and mirror from fumes and particles produced during laser processing. The interface between the monitoring system and the user computer is implemented by different real-time digital images (0.1 to 10 Hz) to detect the defects and the user interface through an analog input, enabling the control of the laser power. The visible sensor has higher resolution (540x360) than the near-infrared sensor (640x480) sensor (20x10), which means that the visible sensor requires a longer bandwidth to process the images and the FPGA cannot read data to manage the information. The system relies on a specific camera to read the visible sensor, which is used as a supplementary algorithm. The database for defect detection is based on using an OpenCVML solution. Processing algorithms make use of a principal component analysis approach, identifying the user amount of data acquired by the sensors. The main validated information required for the automatic defect detection. The software developed the advanced module configuration for defect detection during user processing. Specifically, the advanced module configuration for defect detection during user processing (Figure 15), which includes necessary parameters (Figure 15).</p>  <p>Figure 15 - Real-time image of melt pool area and automatic detection of defects</p>	 <p>Figure 10 - Training of the detection system</p> <p>Main capabilities of the quality assurance system are:</p> <ul style="list-style-type: none"> Real-time processing up to 1000 images per second On-line diagnosis and defect classification Process data acquisition Off-line optimization Labeling and training 	<p style="text-align: center;">ModuLase MODULASE PROJECT</p> <p>The ModuLase project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101019720 (H2020-ModuLase).</p> <p>The project is an initiative of the Photonics and Factories of the Future Public Private Partnerships.</p> <p style="text-align: center;">www.modulase.eu</p> <p style="text-align: center;">                </p>	<p style="text-align: center;">ModuLase MODULASE PROJECT</p> <p>The ModuLase project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101019720 (H2020-ModuLase).</p> <p>The project is an initiative of the Photonics and Factories of the Future Public Private Partnerships.</p> <p style="text-align: center;">www.modulase.eu</p> <p style="text-align: center;">                </p>