RADICLE
Real-Time Dynamic Control System for Laser Welding

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Project Title: Real-time dynamic control system for laser welding		
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EC Project Officer: Christoph Helmrath	**Email:** christoph.helmrath@ec.europa.eu	
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Contents

1. Summary

In order to ensure that the impact of the RADICLE project is as wider as possible, a dissemination plan was outlined at the proposal stage, for the implementation of several dissemination activities throughout the duration of the project as well as after the project conclusion.

In addition to these early staged planned activities, the dissemination plan is constantly being updated as the project is developing and new dissemination opportunities occur.

As projected in the Dissemination Plan around the project mid-term public dissemination events including an open day event was planned for the final stages of the project.

This deliverable report D7.7 covers public available material developed in the last 6 months of the project to showcase the results and final system:

- The RADICLE project was showcased at the week long I4.0 Exhibition Hannover Messe in April 2018 on the European Commission project stand organized by the FoF Fortissimo project.
- The open day event was planned to present the project results to leading organisations and key personnel of the manufacturing industry, showcase the final RADICLE system and receive vital feedback from experts. This event was planned to take place in the 18th of October 2018 at MTC in the United Kingdom.
- Other dissemination material in the form of video, websites, leaflets, press releases are documented in D7.15 Final plan for the dissemination and exploitation of results and can be seen on the project website www.radiclelaser.com.

This report on the dissemination of the work conducted under the RADICLE project has been prepared in accordance with the requirements of Grant Agreement 636932. The production of this document is the responsibility of the appointed Exploitation Manager.

This document shows the already carried out final dissemination activities and materials and the planned activities for the RADICLE project.

2. RADICLE project featured at Industrie 4.0

During the Industrie 4.0 Exhibition, held at Hannover Messe in 23rd April – 27th April 2018 the RADICLE project was present on the European Commission stand of H2020 projects run by the FoF project Fortissimo.

The EC stand was located in Hall 6 and presented around 15 EU funded H2020 projects, as shown in Figure 1.

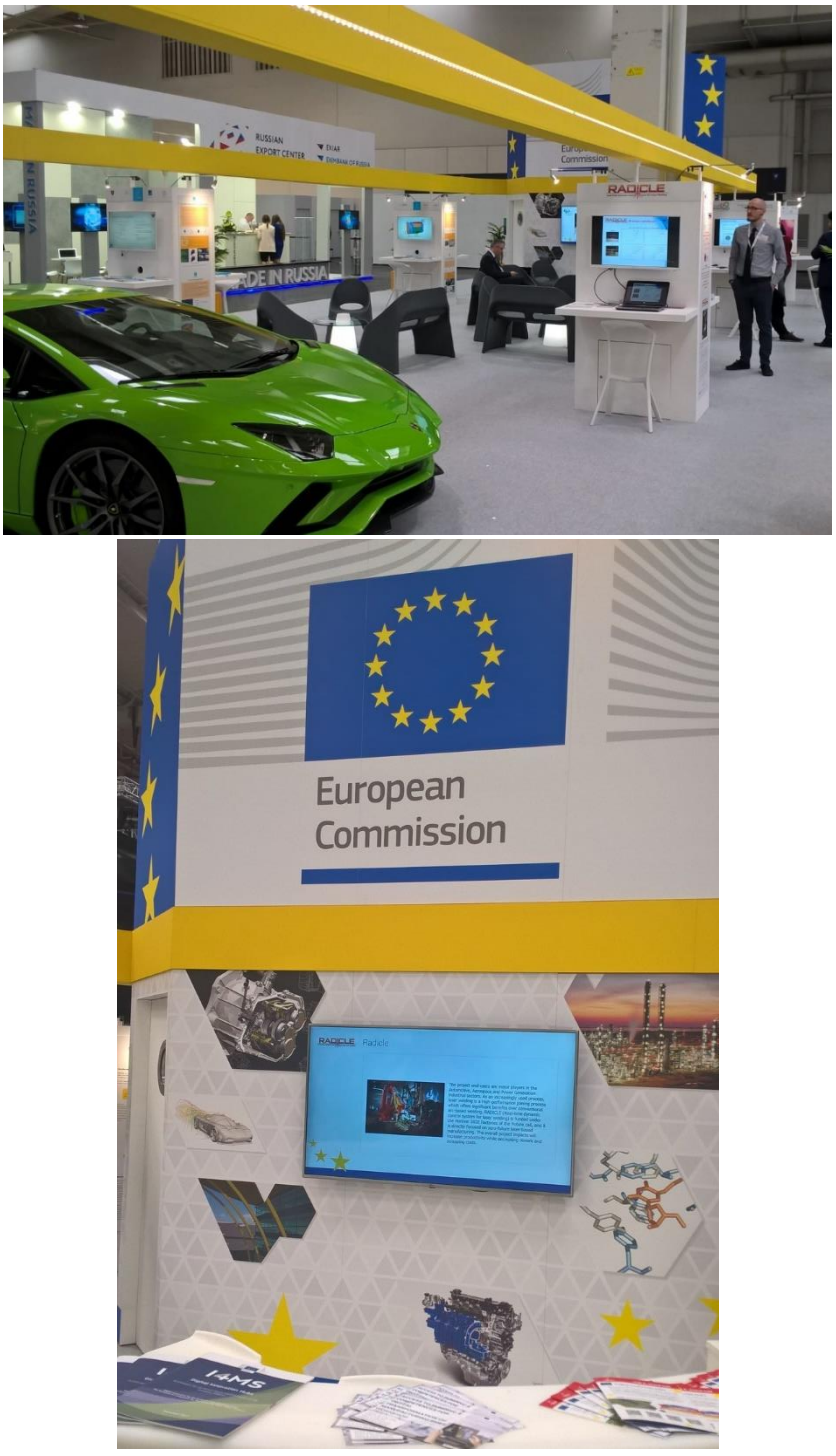

Figure 1 – RADICLE booth and EC stand

The stand was very successful and attracted 1000 to 2000 people each day and was there for 5 days of the show. The RADICLE pod was manned by the MTC and LOE.

A rolling presentation of the projects aims, scope and the final system developed as well as a video of laser welding was presented. It also included the link to the project website for more information.

3. Public Day – RADICLE Open Forum Event at MTC, UK (October 2018)

An open forum day was planned for 18th October 2018, at the MTC to promote the RADICLE project to leading organisations and persons of the manufacturing industry and showcase the final RADICLE system with a demonstration and presentations from all of the project partners.

3.1. Agenda

The following agenda was prepared to display the achievements of each partner in the RADICLE's development and bring forth the latest technological breakthroughs.

RADICLE
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Agenda

Meeting	RADICLE Open Forum Event
Date	18th October 2018
Location	Tilly Schilling, MTC

10:00 – Start.
10:00 – Welcome and RADICLE project overview – MTC
10:20 – End user requirements – RR, GKN, GE
10:35 – Weld quality process windows – TWI/MTC
10:50 – Optical metrology of laser welding of metal components – Dan Lloyd, LOE
11:05 – RADICLE welding head – Permanova/Bit Addict
11:20 – Sensor data analysis – Olli Nurmi, VTT
11:35 – RADICLE Conclusions, further work – MTC
11:50 – Laser Welding at CRF (Fiat): from research to manufacturing plant – Giuseppe D Angelo
12:05 – MODULASE project: multi-purpose/reconfigurable laser processing head - TWI
12:20 – Developing Coaxial laser and Wire Additive Manufacturing – Ryan Cotterill, MTC
12:35 – Summary

12:40 – Lunch - Other EU project/partner stands (SHARK, OpenHybrid / TWI, EWF, LOE)

1:30 – Tour MTC facilities and RADICLE laser cell demonstration

2:30 – Tea and close

The objective of the Agenda was to involve all project partners and present:

- An overview of the project objectives by MTC
- The end user requirements for laser welding by RR, GKN and GE
- Process window development by TWI and MTC
- Sensor suit selection and development by LOE
- RADICLE head design and functionality by Permanova and Bitaddict
- Data analysis and algorithm development by VTT
- Final results of trials MTC and TWI
- CRF would present on their internal prospective of laser welding for the automotive industry
- Two other welding-related presentations were also planned to widen the scope of interest.

Finally, the consortium aimed at performing a demonstration of the MTC laser cell and RADICLE system.

3.2. Event

The event was promoted directly to relevant stakeholders through the partners' contacts networks, including MTC and EWF members. A link was included to the dedicated registration page for the RADICLE Public Day, available at: https://www.eventbrite.co.uk/e/multi-sensor-control-system-for-laser-welding-tickets-50259132418. Besides the targeted efforts to present the event, social media was also used to publicly disseminate the event (Figure 2).

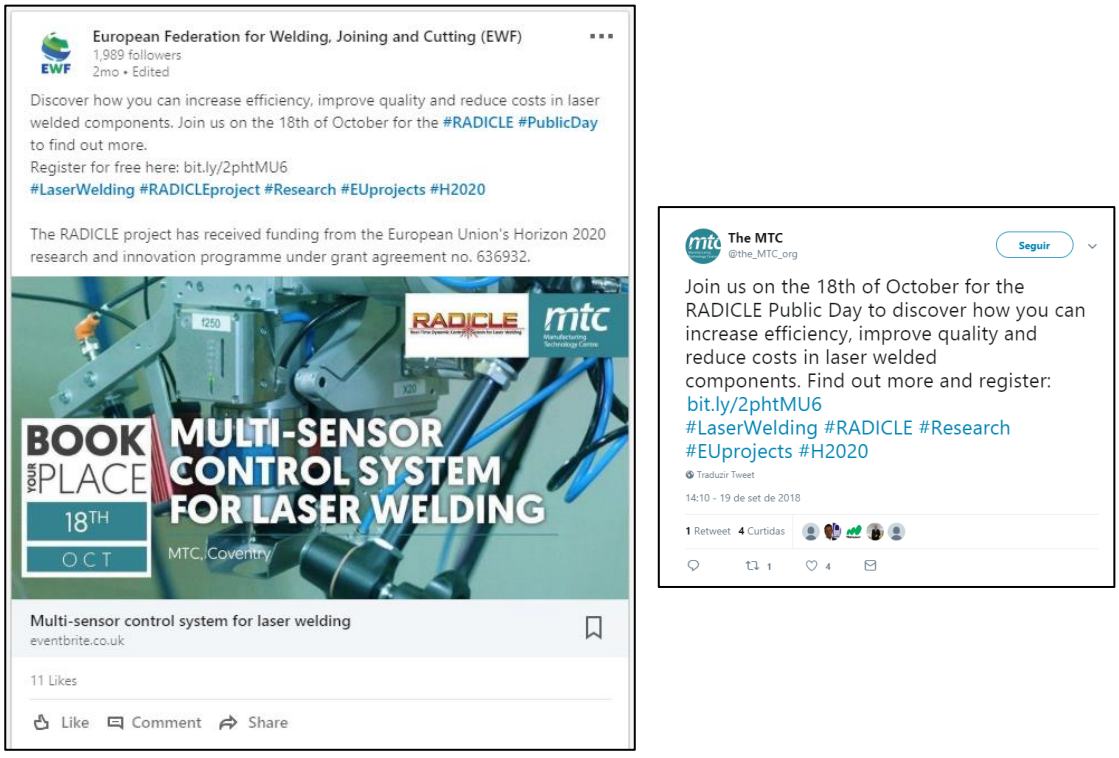


Figure 2 – Examples of social media posts communicating the RADICLE Public Day

Although a lot of effort went into publicizing the event, the consortium faced huge challenges to assure people's attendance. Ultimately, only 4 people were registered in the event with 1 week to go.

The consortium was fully aware of the need to assure the final communication of results to a wider audience, and that target did not realistically seem possible with the above situation.

Therefore, a decision was taken by all project partners to cancel the event on the 18th and continue to prepare final dissemination material and presentations to be used through the RADICLE project website, and for future events (after the end of the project) where we know we can present the results of the project to a wider audience.

3.3. Final publicly available materials for RADICLE project

In all, 8 presentations were prepared by the project partners for the Public Day, to showcase the RADICLE project achievements The next pages contain the slides from the "10:00 – Welcome and RADICLE project overview – MTC" presentation that summarised the whole project with contributions from the other partners.

The remaining presentations are also available for future opportunities to disseminate the outcomes of RADICLE.

RADICLE
Real-Time Dynamic Control System for Laser Welding

Partners

BIT ADDICT
CENTRO RICERCHE FIAT
EWF
GKN AEROSPACE
Laser Optical Engineering Ltd
pioneering laser technology
mtc Manufacturing Technology Centre
PERMANOVA Lasersystem ab
TWI
Rolls-Royce
VTT

The RADICLE project has received funding from the European Union's Horizon 2020 Programme for research, technological development and demonstration under grant agreement no. H2020-FoF-2014-636932 — RADICLE. Information is provided as is and no guarantee or warranty is given that the information is fit for any particular purpose. The user thereof uses the information at its sole risk and liability.

RADICLE
Real-Time Dynamic Control System for Laser Welding

Objectives

The RADICLE project aims to create a multi-sensor, real-time adaptive control system for laser welding that can deliver zero defects.

The overall impacts of successful implementation of the RADICLE technology through our consortium and the wider welding sectors will enable us to achieve the following impacts:

- 30% reduced energy usage;
- 30% reduced emissions;
- Reduction of the need for part scrappage or rework;
- Saving up to 20% - 30% of labour input;
- Reduction or removal of the need for final NDE testing of the parts;
- Giving a 35% floor space reduction;
- Improved working environment.

RADICLE Project

Real-Time Dynamic Control System for Laser Welding

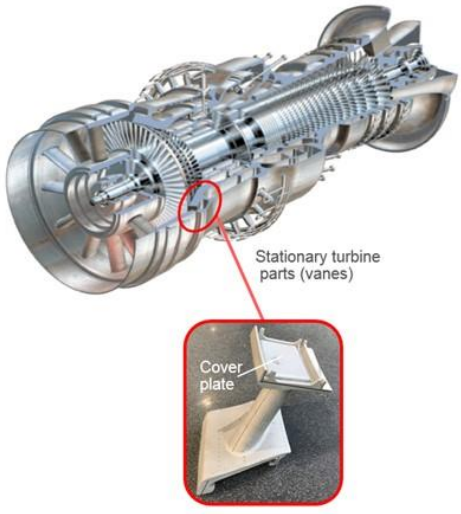
The RADICLE project aims to develop automated process control for laser welding by:

- The identification of the processing window.
- The selection and integration of a sensor array to enable state-of-the-art process monitoring.
- The development of an adaptive process control system that is able to analyse the sensor data and optimise the laser welding parameters.

RADICLE Industrial Needs

Real-Time Dynamic Control System for Laser Welding

GE focus in the RADICLE project



GE targets within Radicle

- Focus on turbine vanes
  - demonstrate feasibility for joining of inserts and cover plates
  - explore laser welding as a cost-efficient alternative to brazing
- Replace batch manufacturing with lean processes enabling single part flow and shorter cycle time
- Achieve zero defects in joining dissimilar material combinations
- Optimize the weld quality using novel multi-sensor process monitoring system

RADICLE
Real-Time Dynamic Control System for Laser Welding

Industrial Needs

Proprietary and confidential restrictions on title slide apply throughout this presentation

Fabricated structures by GKN

GP7000 TEC
Nickelbase Superalloy

RR Trent XWB ICC
Titanium Alloy

PW1000 30k TEC
Nickelbase Superalloy






A380

A350

A320 NEO

RADICLE
Real-Time Dynamic Control System for Laser Welding

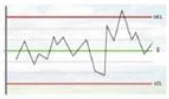
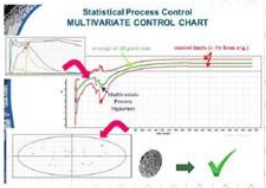
Industrial Needs

Proprietary and confidential restrictions on title slide apply throughout this presentation

Preparing for Automation and 4.0 systems

Information generated in the process development phase to be used again

- Go/No Go systems
- Key process variables
- Key features for quality
- Sensor data
- Production data

SPC

Machine learning

RADICLE
Real-Time Dynamic Control System for Laser Welding

Industrial Needs

Laser Welding at CRF: from research to manufacturing point

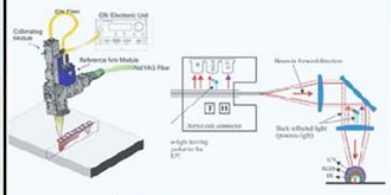
FCA FIAT CHRYSLER AUTOMOBILES | CRF

Laser Welding @ CRF

Process

- ✓ materials
- ✓ optics
- ✓ parameters
- ✓ robots
- ✓ laser

Monitoring



- ✓ Sensors
- ✓ HW for Data acq.
- ✓ SW for analysis
- ✓ melt pool dynamics
- ✓ model of keyhole

Maintenance

- ✓ CPS
- ✓ IoT
- ✓ Signal pre-process
- ✓ Features extraction
- ✓ Fault prognosis
- ✓ Key performance indicator
- ✓ Optimization
- ✓ Error corrective & compensation

Production @ Fiat Plants

Maserati Levante | Alfa Giulia | Jeep Renegade

Production @ Fiat Plants

October 2018

RADICLE
Real-Time Dynamic Control System for Laser Welding

Industrial Needs

Rolls-Royce Operates in many highly regulated industries

RADICLE Real-Time Dynamic Control System for Laser Welding

Industrial Needs

Product Integrity & Right First Time through increased process understanding

- Process Knowledge derived from broader process signal understanding offers routes to
  - More stable process window development
  - Extend range of application
  - Weld more complex materials
  - Eliminate process variation
  - Reduce post weld inspection

RADICLE Real-Time Dynamic Control System for Laser Welding

Industrial Needs

Application	Material	Thickness	Configuration	Key issues
1 	INCONEL Ti Steel S355	3mm, 6mm, 11mm	Butt	Porosity. Surface geometry.
		1mm, 3mm, 8mm	Butt	Cracking. Surface geometry.
		1.2mm – 1.2mm	Overlap	Material ejection. Cap underfill.
3 		0.6mm – 10mm	Overlap (partial penetration)	Cracking.
Generic material: No specific target application		6mm	Butt	Cracking. Porosity.

RADICLE
Real-Time Dynamic Control System for Laser Welding

Analyses of sensor options

Plasma detection

Reflected Laser Power

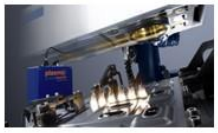
Camera (Illuminated)

Photodiode

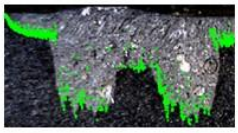
Inline-coherent imaging

Laser Power

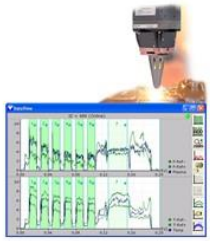
Plasmo | LLD | LWM (Precitec) | Promotec



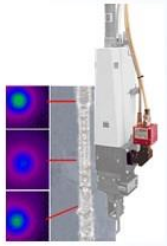
(www.plasmo.eu/site/en/)



(www.laserdepth.com/)



(www.precitec.de/)



(www.prometec.com/)

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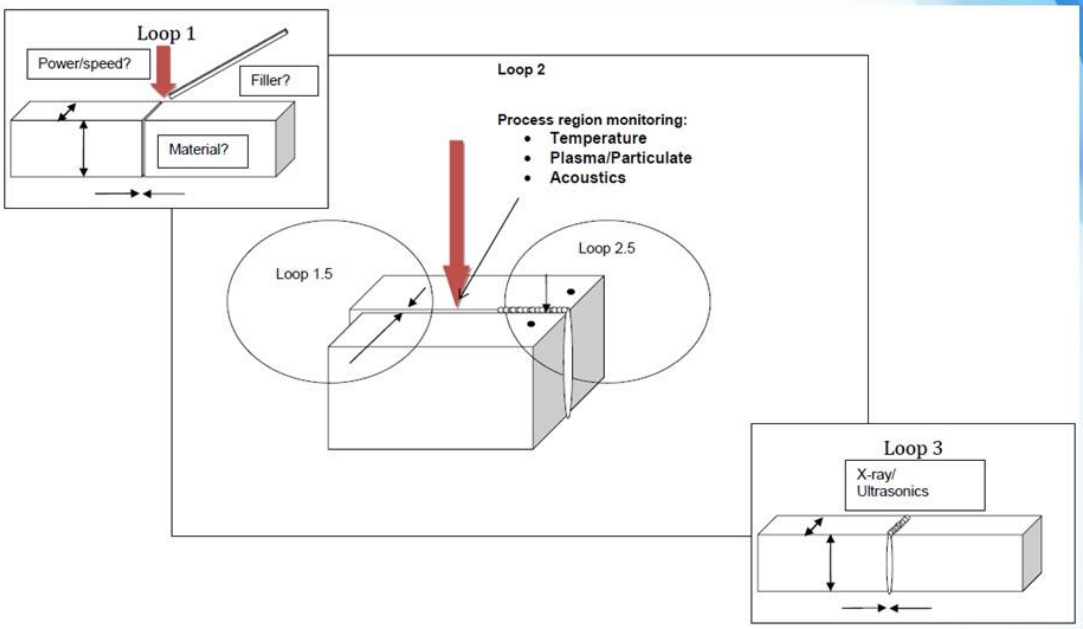
Control Loops



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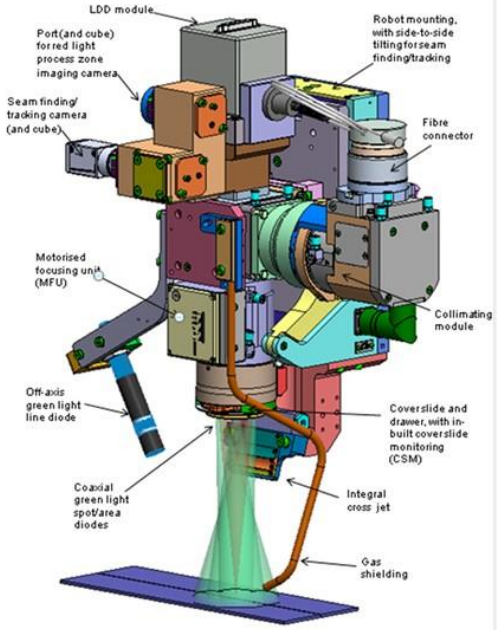
System development



PERMANOVA Lasersystem ab

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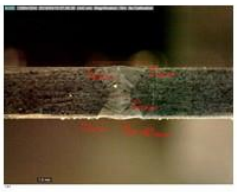
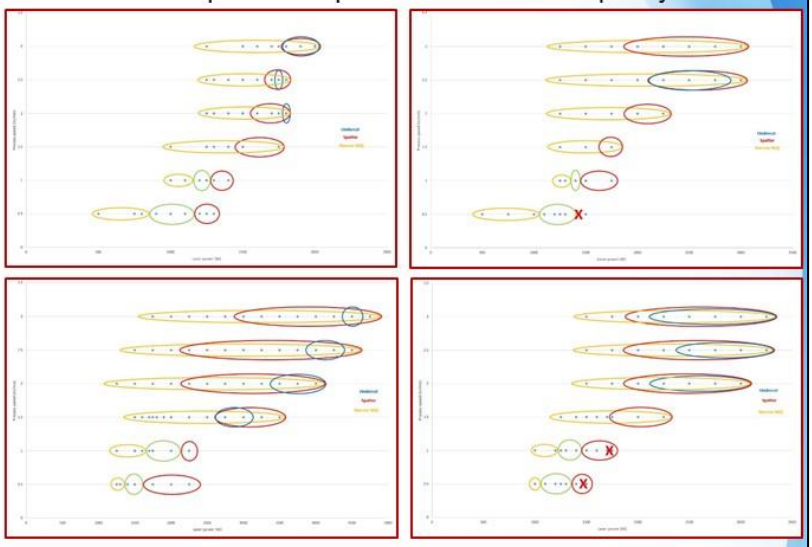
Process windows

Example: Weld parameters vs weld quality

Pass

Fail





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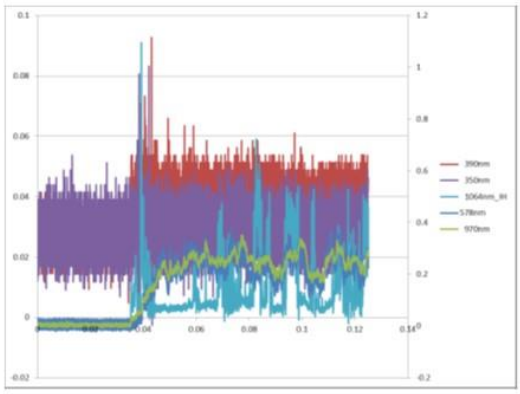
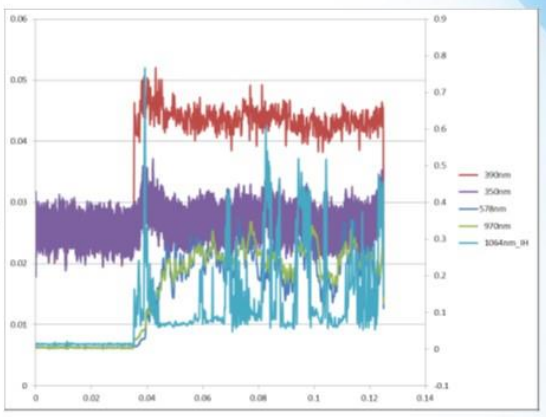
Data filtering and Sensor selection



Raw

MSSA filter



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System Learning

1 st - Define the stable parameters for the process:

- Based on customer specification for integrity and geometry;
- There may be multiple parameter regimes for stable processing.

2 nd – Map how defects manifest with changes in parameters.

Allowing the system to be:

- Independent of the application;
- Able to work with different materials.

Algorithm: Development and integration

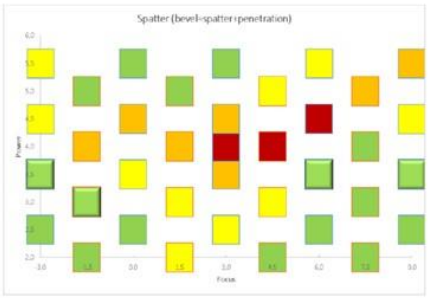
a) Set of **features** that describe the welding process reliable and with proper resolution;

b) **Machine learning techniques** to teach the system state of the welding process and possible actions;

c) **Action selection mechanism** that uses the information available according to the process parameters that can be changed.

Off line Analysis

Spatter quality classes vs. diode KLD heatmap



Power \ Focus	-3	-1,5	0	1,5	3	4,5	6	7,5	9
5,5	0,85	0,71	0,56	0,5	0,62	0,59	0,79	0,78	0,62
5	0,87	0,6	0,4	0,059	0,21	0,18	0,68	0,8	0,85
4,5	0,91	0,68	0,38	0,19	0	0,5	0,96	0,89	0,9
4	0,96	0,85	0,61	0,33	0,52	0,88	0,93	0,91	0,97
3,5	*0,96*	*0,88*	*0,87*	*0,66*	*0,77*	*0,84*	*0,97*	*0,95*	*0,98*
3	*0,96*	***0,82***	*0,8*	*0,67*	*0,75*	*0,75*	*0,88*	*0,93*	*1*
2,5	0,95	0,87	0,86	0,78	0,82	0,81	0,89	0,93	0,98
2	0,93	0,83	0,76	0,78	0,75	0,79	0,85	0,93	0,91

KLD > 0,95 and P 3-3.5 kW

Combinig diode and video heatmaps it is possible to identify the process sweet spots

- Using part of the data for algorithm training it is possible to improve the accuracy

Tests at MTC with Inconel718 3.2 mm

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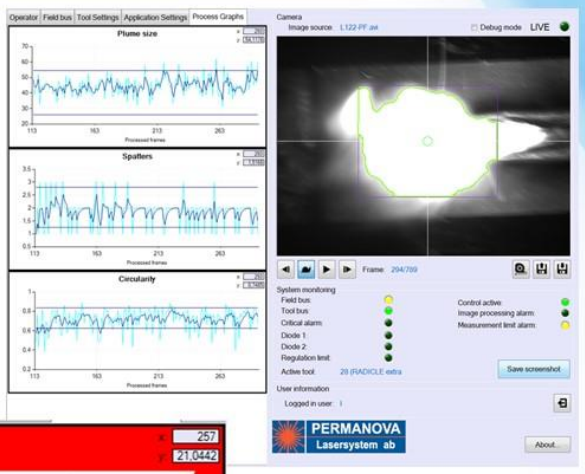
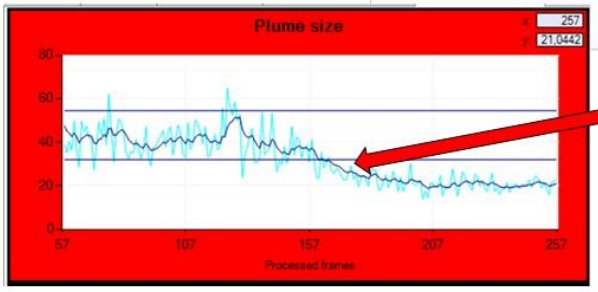
Permanova Software

Real time feed back of weld quality obtained

- Allows limits for acceptable weld quality to be set
- Capable of detecting deviations from acceptable limits to warn operator





Change in weld quality detected by sensor

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Real-Time Dynamic Control System for Laser Welding

Conclusions

THE RADICLE PROJECT HAS CREATED:

A modular system allowing users to configure the system to their specific applications:

- Photodiodes (off-axis and co-axial)
- Co-axial process zone imaging camera
- Microphone for acoustic emission analysis
- Seam tracking camera
- Keyhole depth monitoring sensor

Welding process windows for a number of ferrous and non-ferrous materials and joint configurations, supported by welding data from industrial case studies;

Welding data handling and analysis routines to extract valuable information from the welding process monitoring sensors;

The development of the architecture for a multi-sensor adaptive control system for laser welding including a machine learning algorithm able to:

- interpret raw sensor data and associated welding quality parameters
- generate the process window heatmap from the sensor data

RADICLE
Real-Time Dynamic Control System for Laser Welding

Benefits

THE RADICLE PROJECT WILL HELP COMPANIES ACROSS DIFFERENT INDUSTRY SECTORS PRODUCE LASER WELDED COMPONENTS SMARTER, FASTER AND TO HIGHER QUALITY, REDUCING INSPECTION COST:

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To help protect your privacy, PowerPoint has blocked automatic downlo...

CRF CENTRO RICERCHE FIAT

EWF

GE

GKN AEROSPACE

Laser Optical Engineering Ltd
pioneering laser technology

mtc Manufacturing Technology Centre

PERMANOVA Lasersystem ab

TWI

Rolls-Royce

VTT

http://radiclelaser.eu/

The RADICLE project has received funding from the European Union's Horizon 2020 Programme for research, technological development and demonstration under grant agreement no. H2020-FoF-2014-636932 — RADICLE.

Figure 3 - Overview of RADICLE outcome

4. Other final dissemination material

As reported in Deliverable 7.15 - Final Plan for the Dissemination and Exploitation of Results, during the final year of the project several video talks were created with the project partners discussing their involvement and benefits they had achieved through partnering with the consortium in a collaborative way.

Video presentations from Nick Blundell of MTC, Clive Grafton Reed of RR, Daniel Lloyd of LOE, Tony Pramanik of TWI and Anna Wallner of Permanova can be found on the project website (Figure 4).

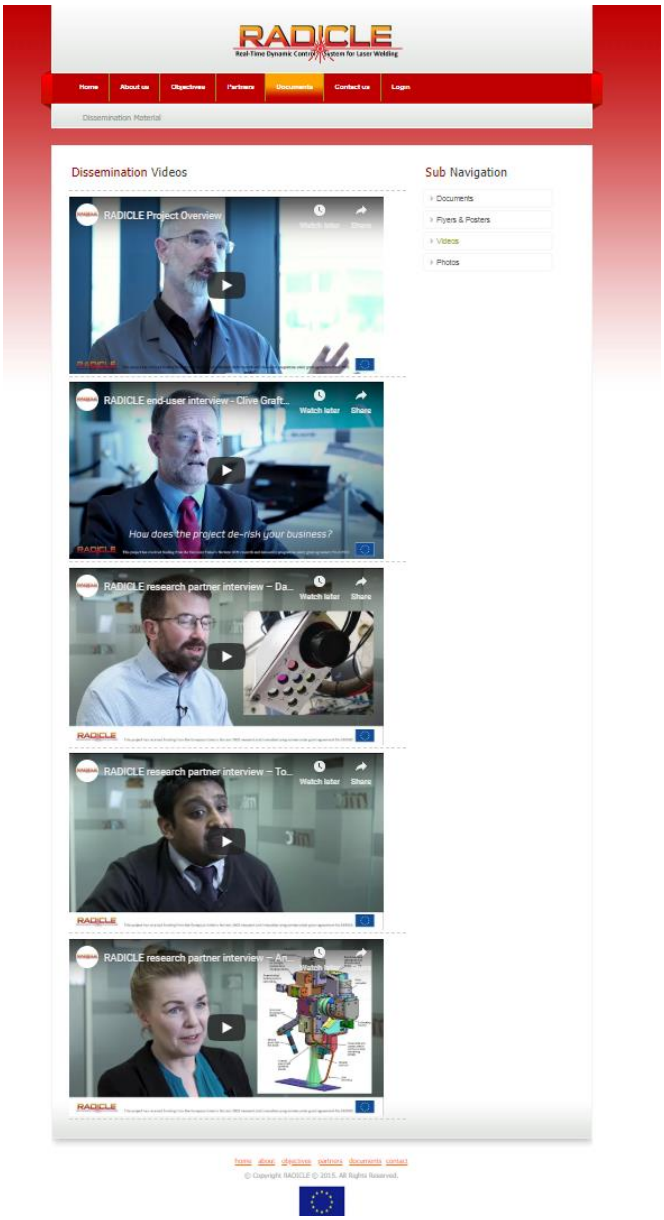

Figure 4 – RADICLE project videos

In addition, a final leaflet and roll-up banner were created for the open forum event that summarises the main conclusions and results of the RADICLE system developed for laser welding.

Figure 5 – RADICLE final leaflet and rollup banner

It is also important to mention that the project website contains the most up to date information about the project, including the final project public presentation.

5. Other public dissemination events

In order to address the fact that the RADICLE Open Forum Event did not materialise, the consortium partners made an effort to carry out further communication and dissemination activities, even after the project is finished.

Such an example was a public project presentation made to University students, from the University of Lisbon, on the 3rd of December 2018. In total, more than 30 students had the opportunity to learn about the novel developments of the RADICLE project.

Next are some pictures of the event, as well as the presence list, signed by the students.

Figure 24 RADICLE presentation to engineering students

No.	Name	Surname	Signature
1	João	Figueiredo	
2	Francisca	Velasco	
3	Matilde	Silva	
4	Duarte	Franco	
5	Guilherme	Caldeira	
6	Ana Luísa	Carvalho	
7	Carlota	Cunha	
8	Joana	Assunção	
9	Tiago	Alves	
10	Filipe	Brito	
11		Ribeiro	
12	Diogo	Mendes	
13	Bernardo	Silva	
14	João	Arrobas	
15	Henrique	Pereira	
16	David	Ribeiro	
17	Joana		
18	Lourenço	Dias	
19	João	Lobo	
20	João	Costa	
21	Ricardo	Batista	
22	Vitor	Martins	
23	Sebastião	Pedrogão	
24	Diogo	Ferreira	
25	Margarida	Carvalho	
26	Rafaela	Matos	
27	Rahel	Sampaio	
28	Miguel	Sousa	
29	Bernardo	Pinto	
30	Adolfo	Ribeiro	
31	Raquel	Henriques	
32	Ricardo	Martins	
33	André	Coelho	
34	Dinis	Machado	
35			
36			
37			
38			
39			
40			

Figure 25 Presence List

6. Conclusion

This deliverable aims at providing information regarding the efforts made by the RADICLE consortium partners to organize a Public day during the last period of the project. The document explains the efforts place into this activity, and the results.

The document also refers to other activities performed by the consortium, including dissemination materials and other dissemination events.