RADICLE

Real-Time Dynamic Control System for Laser Welding

Initial development of an online control system for laser welding

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. 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.

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Partners

BIT ADDICT
PASSION FÖR UTVECKLING

CRF CENTRO RICERCHE FIAT

EWF FEDERATION FOR WELDING, JOINING AND CUTTING EUROPEAN

GE

GKN AEROSPACE

Laser Optical Engineering Ltd
pioneering laser technology

mtc Manufacturing Technology Centre

PERMANOVA Lasersystem ab

TWI

ROLLS ROYCE Rolls-Royce®

VTT

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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.

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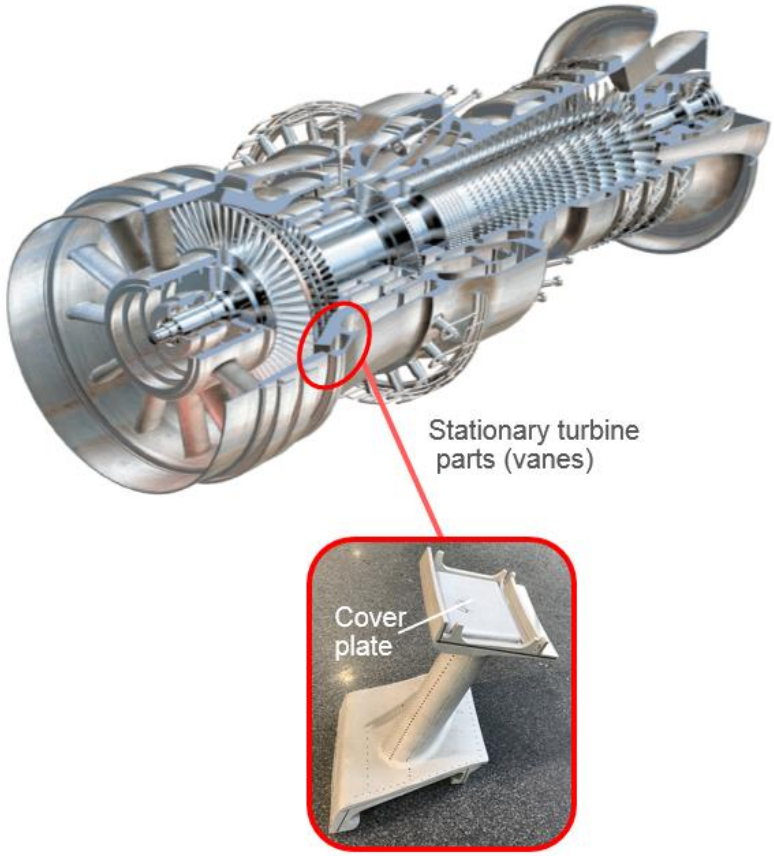
Project

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.

Industrial Needs

GE focus in the RADICLE project



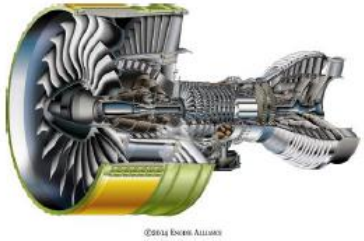
GE targets within Radicle

- 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

Industrial Needs

Fabricated structures by GKN

GP7000 TEC
Nickelbase Superalloy



A380

RR Trent XWB ICC
Titanium Alloy

A350

PW1000 30k TEC
Nickelbase Superalloy

A320 NEO

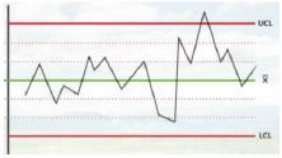
10110 Rev. 23

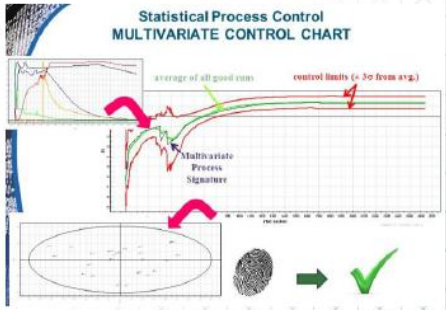
Industrial Needs

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

10110 Rev. 23

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Industrial Needs

Laser Welding at CRF: from research to manufacturing point

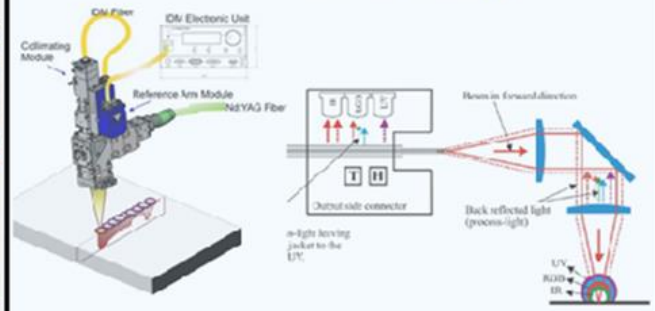
FCA FIAT CHRYSLER AUTOMOBILES | CRF

Laser Welding @ CRF

Process

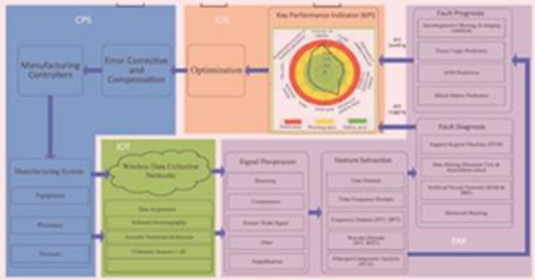
- ✓ materials
- ✓ optics
- ✓ parameters
- ✓ robots
- ✓ laser

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

Industrial Needs

Rolls-Royce Operates in many highly regulated industries

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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

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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.

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Analyses of sensor options

Plasma detection

Reflected Laser Power

Camera (Illuminated)

Photodiode

Inline-coherent imaging

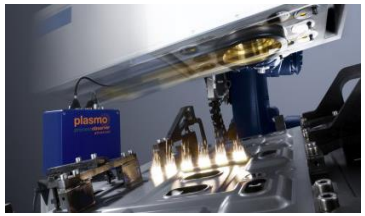
Laser Power

Plasmo

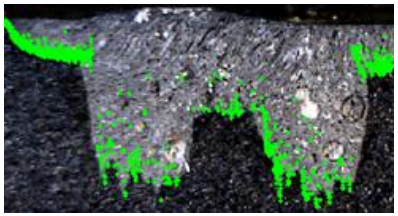
LLD

LWM (Precitec)

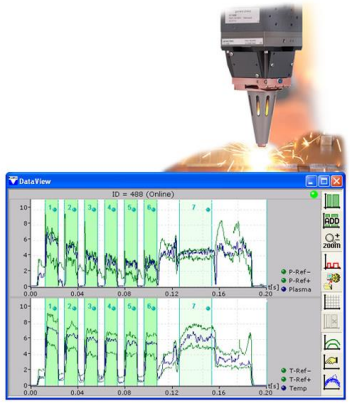
Promotec



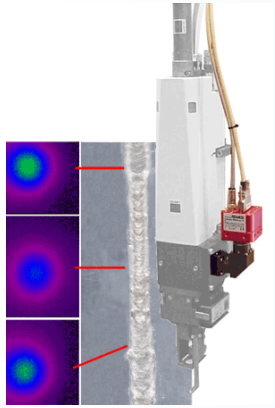
(www.plasmo.eu/site/en/)



(www.laserdepth.com/)



(www.precitec.de/)



(www.prometec.com/)

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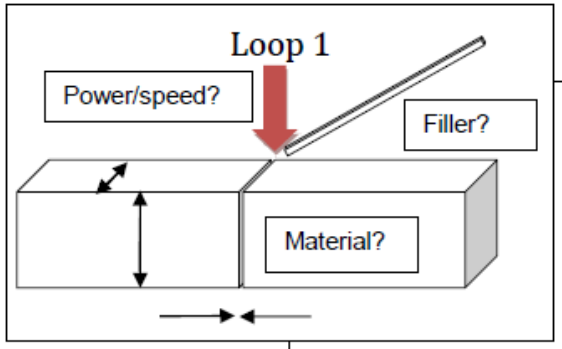
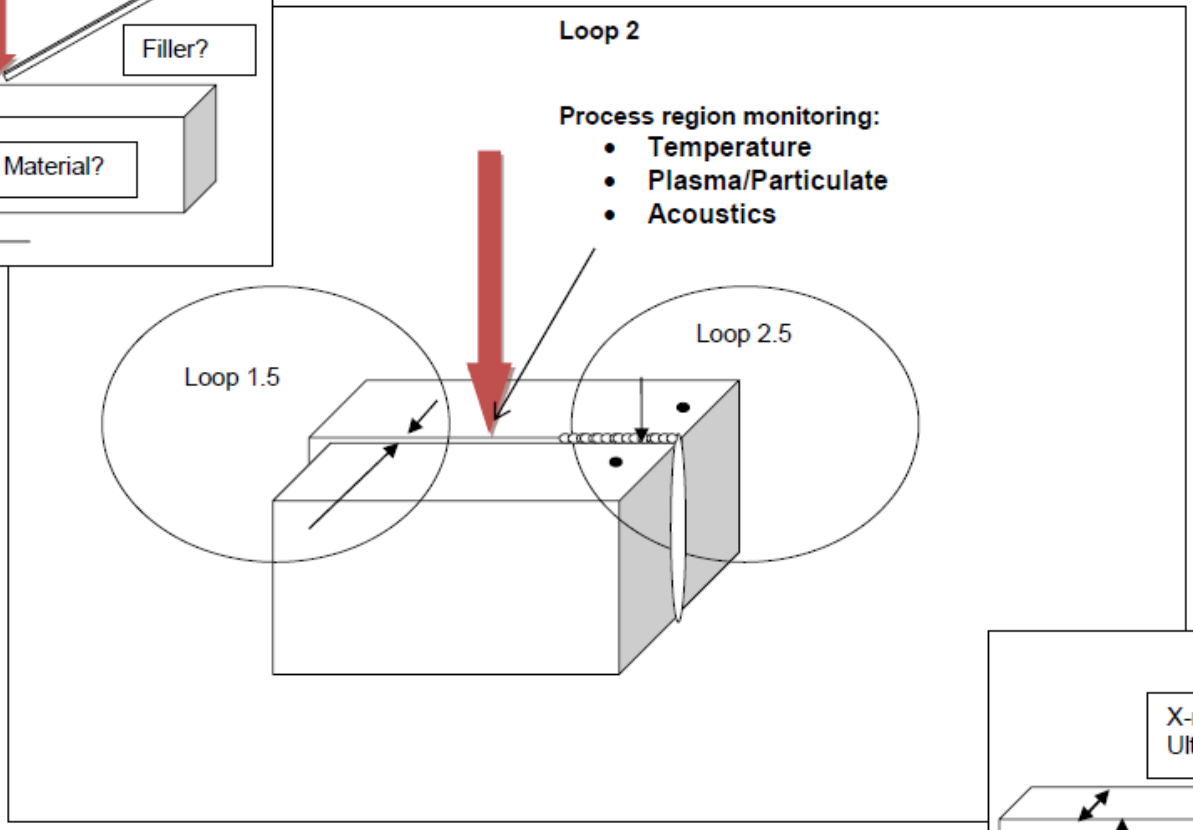
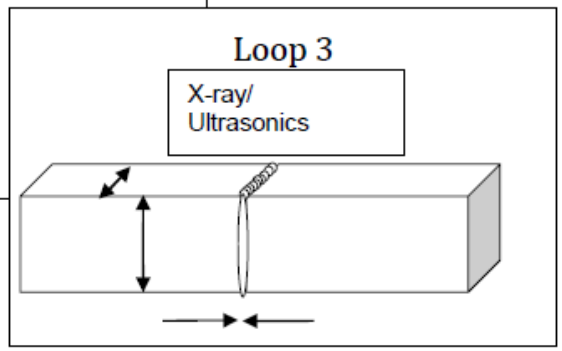
Control Loops







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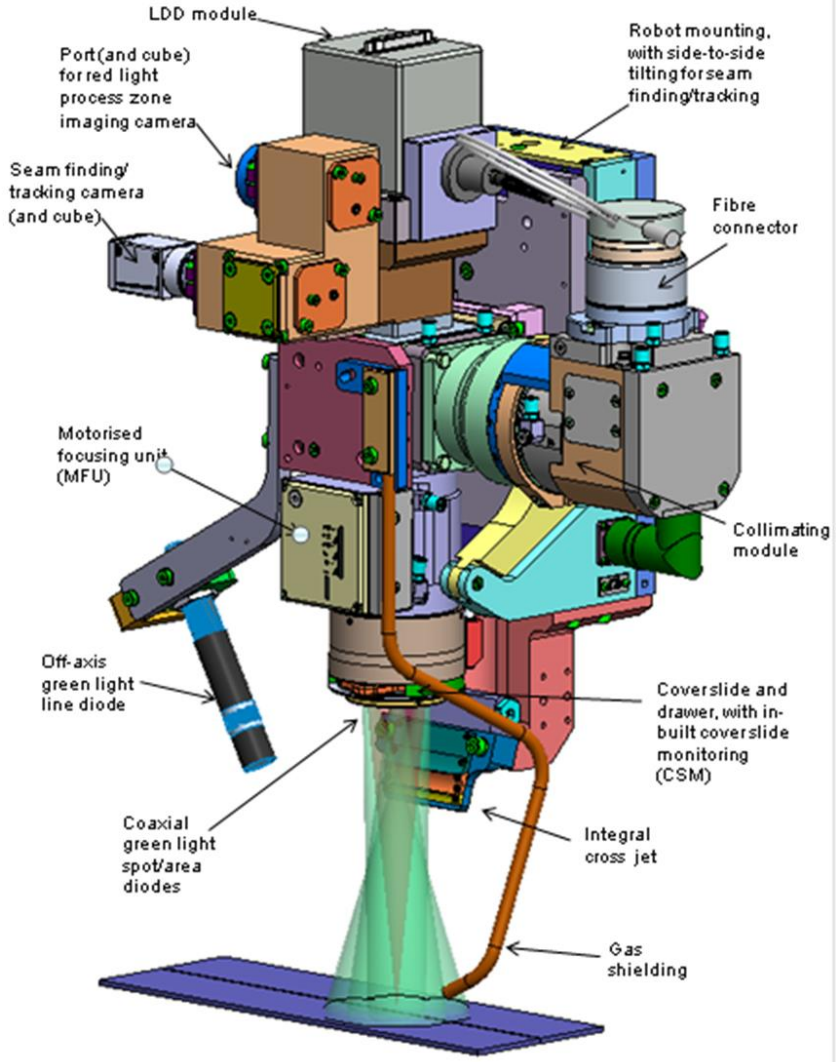
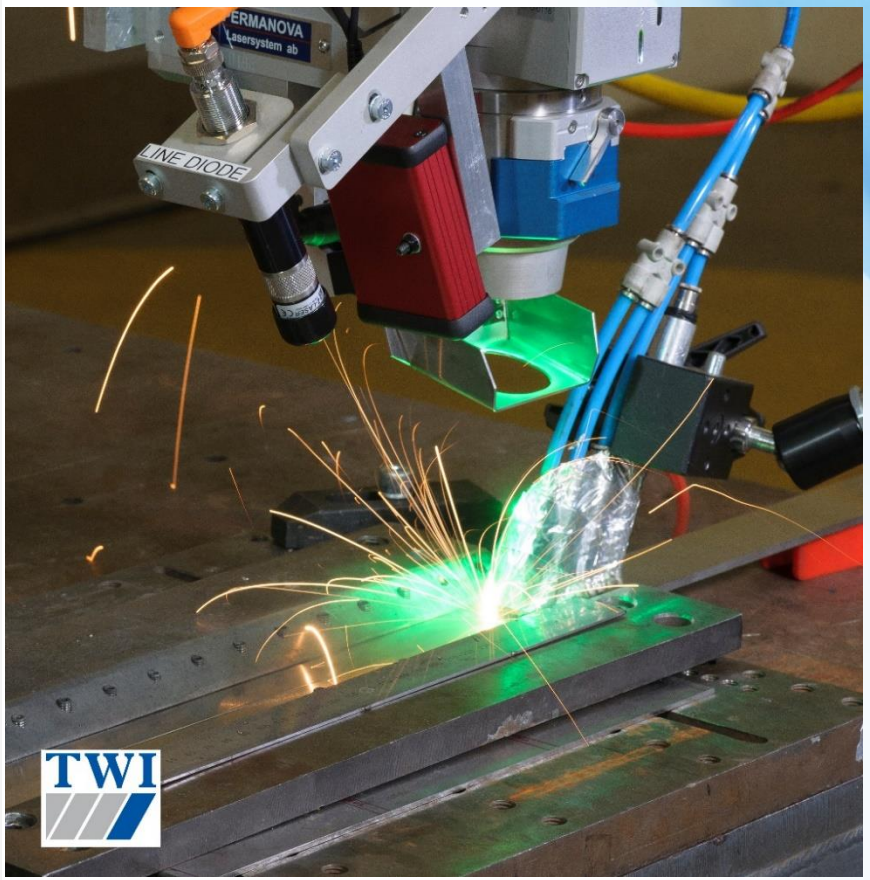
System development





PERMANOVA Lasersystem ab

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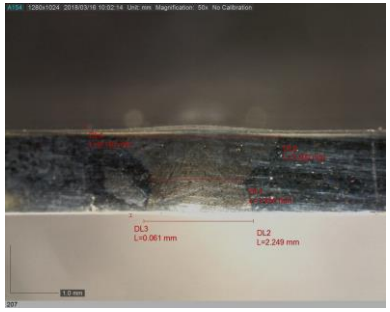
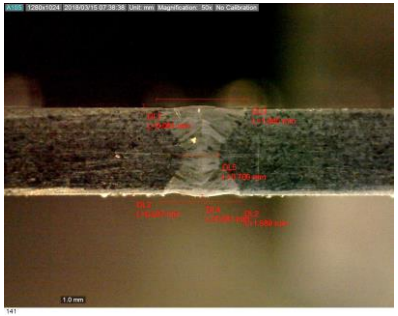
Process windows

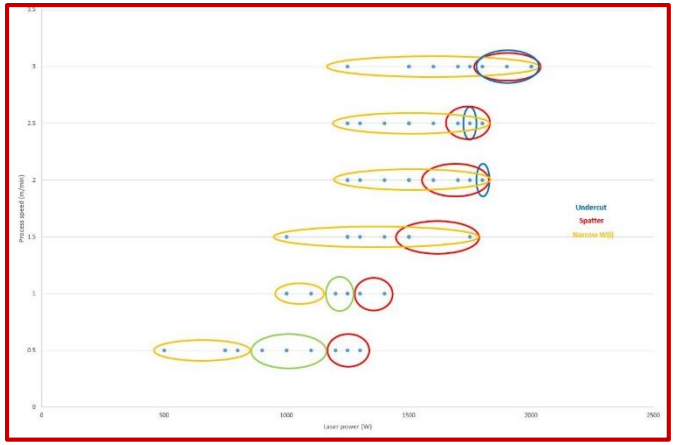
Example: Weld parameters vs weld quality

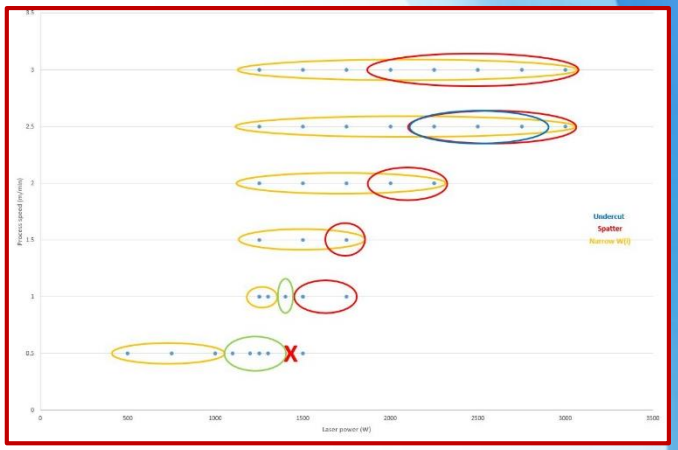
Pass

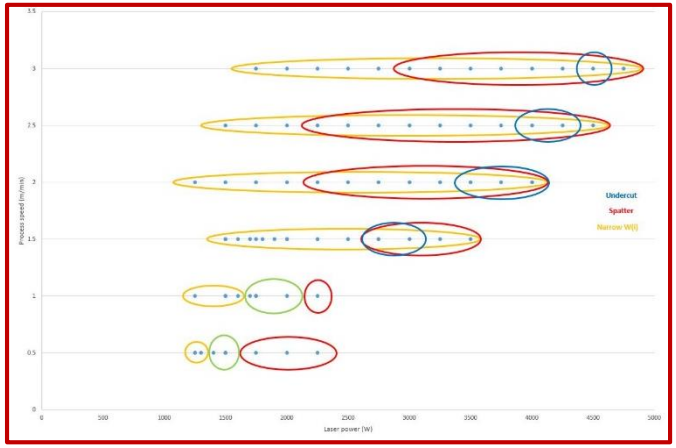


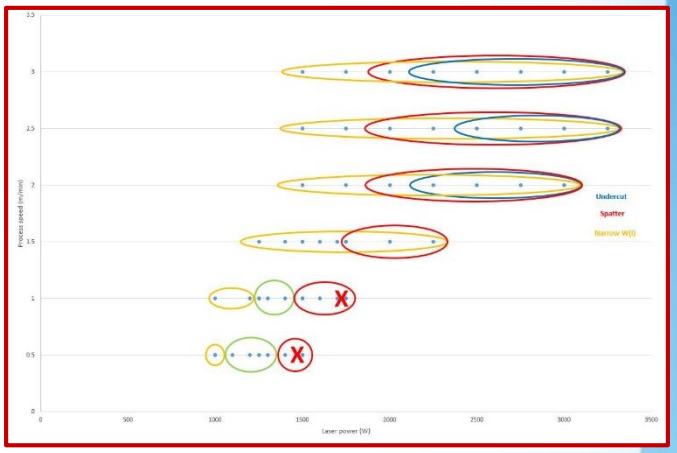
Fail



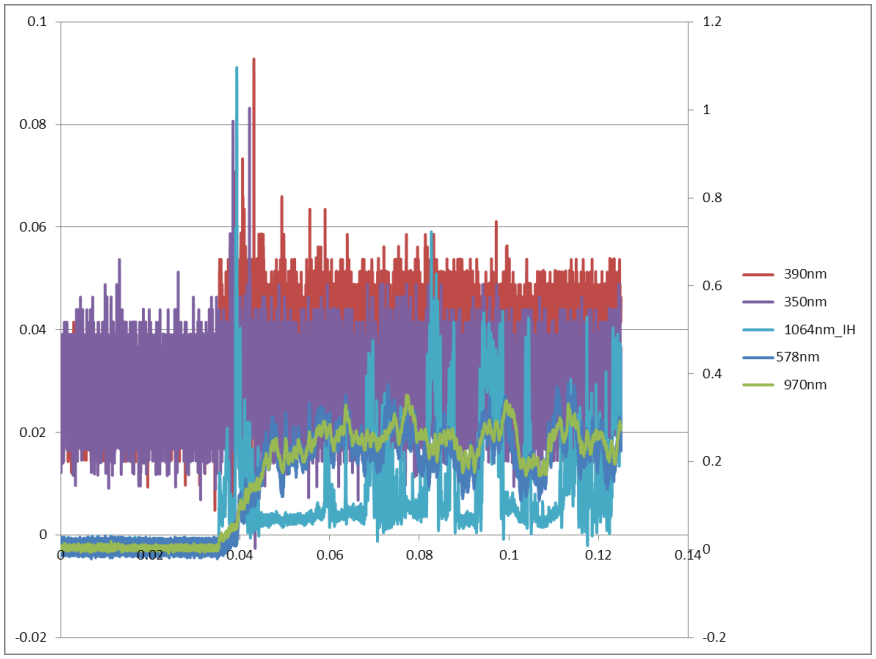






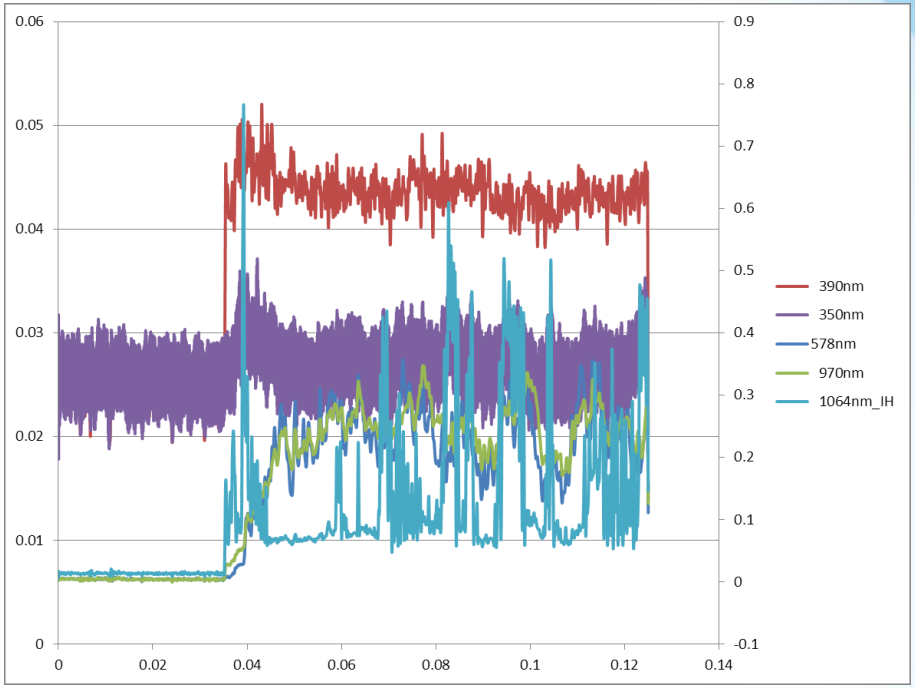


Data filtering and Sensor selection



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.

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Algorithm: Development and integration

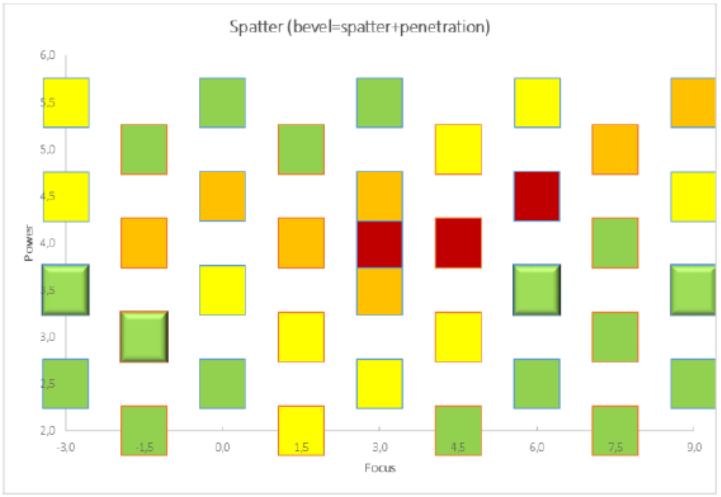
a) Set of **features** that describe the welding process reliable and with proper resolution;

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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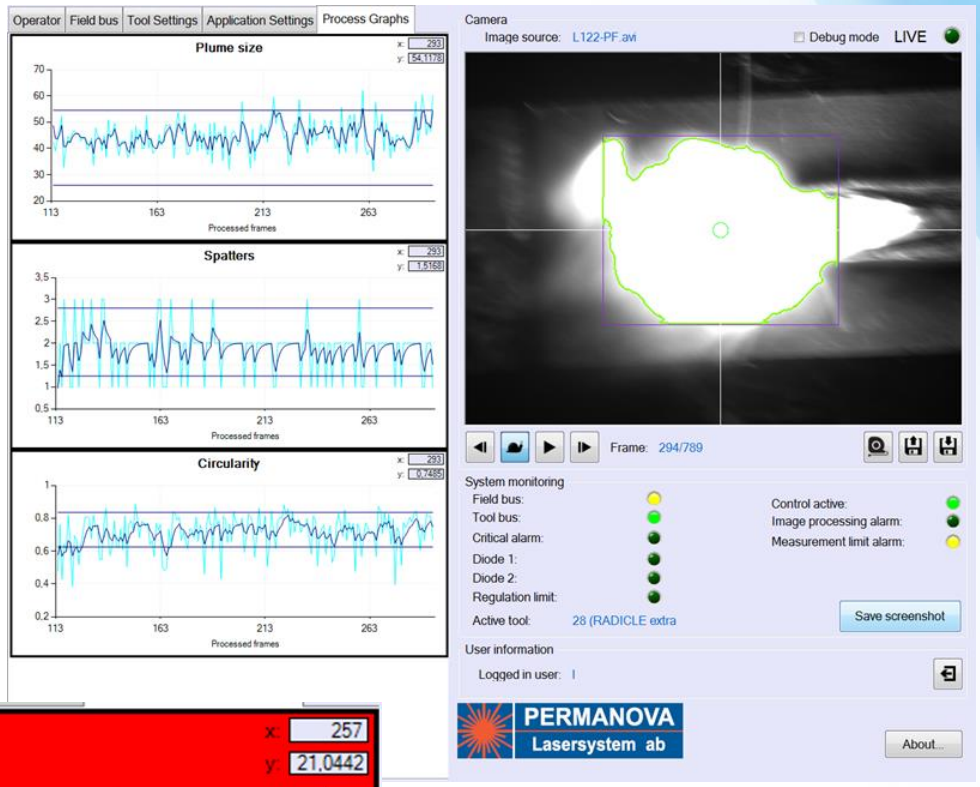
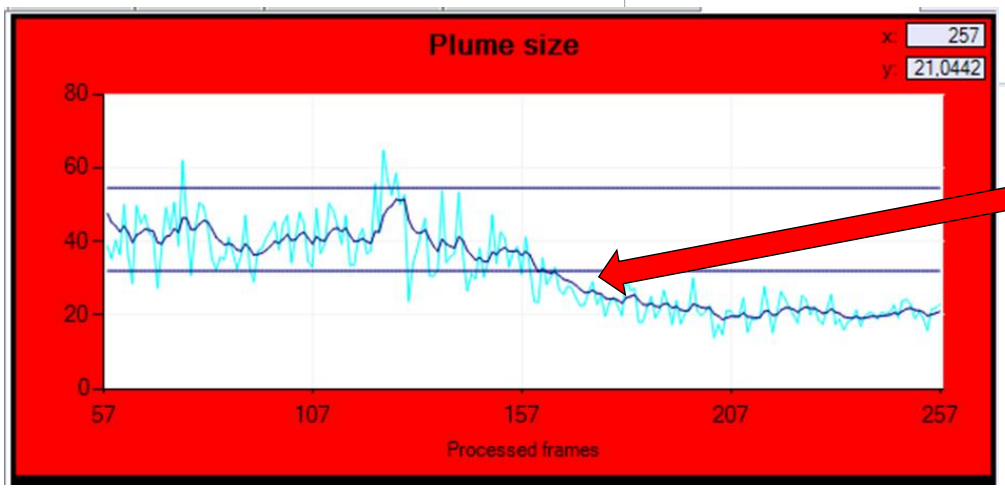
Permanova Software

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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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

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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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