

FLASH

Flexible Laser-Based Manufacturing

D4.1 – Process monitoring unit validated for breakthrough detection, defect detection feature specific profile testing

HORIZON-CL4-2023-TWIN-TRANSITION-01-02.



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ABBREVIATIONS

BTS	Breakthrough sensor
GUI	Graphical User Interface



General Information

Project	
Title	FLASH
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Executive Summary

This deliverable presents a multi-sensor monitoring system developed within the FLASH project to enhance quality assurance in laser-based manufacturing. Building on Synova's Breakthrough Sensor, the solution combines optical and acoustic sensing with unified data acquisition and analysis. A compact, industrial-ready prototype was implemented and validated on multiple laser processes. Results demonstrate reliable process fingerprinting and effective detection of deviations under realistic operating conditions.

1. INTRODUCTION

Within the FLASH project, an advanced monitoring system was developed to improve process control and quality assurance in laser-based manufacturing. Building upon Synova's Breakthrough Sensor concept, the proposed solution extends optical process monitoring through the integration of complementary acoustic sensing, broadband spectral analysis, and unified data acquisition and processing. The resulting prototype provides a non-intrusive, multi-sensor approach for real-time process observation, reference-based comparison, and defect detection across several laser processing applications.



2. BREAKTHROUGH SENSOR FROM SYNOVA

Prior to the FLASH project, Synova developed a **Breakthrough Sensor (BTS)** (EP3691828B1) capable of significantly reducing total processing time. In simplified terms, the BTS consists of a photodiode sensor, a dichroic mirror, and a focusing lens (Figure 1a).

During Laser MicroJet® processing, a plasma is generated at the sample surface. The light emitted by this plasma is guided back through the waterjet in the opposite direction to the processing laser, following the same optical path. A dichroic mirror within this path reflects only green-wavelength light while transmitting all other wavelengths. The transmitted plasma light is then focused into an optical fibre, which carries the signal to a photodetector.

The photodetector measures the signal intensity at a specific wavelength to determine whether plasma is present and, consequently, whether cutting is still occurring. At the start of the process, the signal intensity is high and gradually decreases as the cut deepens and less light escapes. A predefined threshold intensity indicates when cutting has effectively stopped. If the measured signal remains below this threshold for a specified duration, breakthrough is confirmed.

Once breakthrough is detected, the control program automatically advances to the next processing step. This eliminates the need for security passes and thereby improves overall processing efficiency.

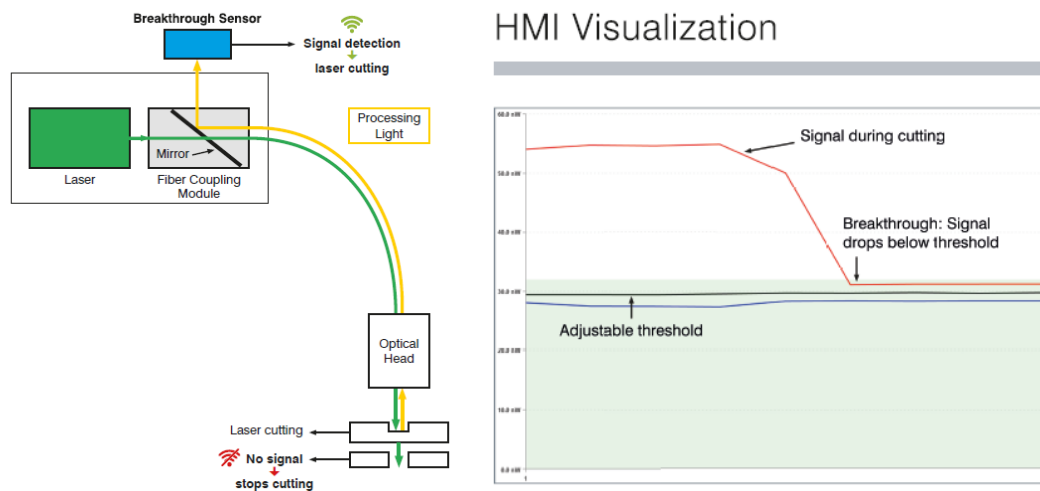


Figure 1: Breakthrough sensor implementation and results. (Left) Schematic of the Breakthrough Sensor (BTS); (Right) Synova HMI visualisation of breakthrough detection.

Within the FLASH project, three different laser sources and three different processing heads are used, alongside additional laser-based processes such as welding. These variations require an adaptation of the existing BTS system. To address this, Synova has collaborated with Aimen to replace the photodiode with a spectrometer. The spectrometer provides a wider measurement range, enabling reliable detection across a broader range of signal intensities and processing conditions.



3. IMPROVEMENT MADE UPON BREAKTHROUGH SENSOR

The monitoring approach developed within the FLASH project builds upon the principles of Synova's Breakthrough Sensor, which is presented in the previous section of this document. The Breakthrough Sensor established the use of optical emissions from the laser-material interaction as a means to monitor process stability and detect anomalies. Building on this proven concept, the FLASH monitoring system extends its capabilities through the integration of additional sensing modalities, enhanced optical analysis, and advanced data processing. In particular, the combination of broadband spectral measurements, multi-channel photodiode detection, and complementary acoustic monitoring enables a more comprehensive and robust characterization of the laser process. This evolution transforms the original sensor concept into a unified, multi-sensor monitoring platform suitable for a wider range of laser-based manufacturing applications and industrial deployment scenarios.

During the FLASH project, an advanced monitoring system was developed to enhance quality assurance and process reliability in laser-based manufacturing. The solution, jointly developed by Aimen and Synova, combines acoustic and optical sensing to monitor the laser-material interaction in real time. The system was implemented as a complete hardware and software prototype and validated across several representative laser processing applications.

The monitoring concept is based on the acquisition of sound and light signals generated during stable and defect-free laser operations. These signals are used to establish a reference process signature, or "fingerprint," that characterizes correct process behaviour. During operation, newly acquired signals are continuously compared against this reference, enabling the detection of deviations that may indicate defects, instabilities, or abnormal process conditions.

Acoustic monitoring is achieved through a microphone array mounted around the laser processing head. The captured acoustic emissions are strongly correlated with key physical phenomena occurring during laser processing. In the current implementation, acoustic data are analysed by comparing spectral features across repeated process cycles, allowing consistent processes to be distinguished from abnormal ones.

Optical monitoring complements the acoustic measurements by capturing a portion of the light reflected and emitted during processing. The optical system provides both broadband spectral information via the mean of a spectrometer and targeted measurements at selected wavelength ranges associated with laser radiation, thermal emission, and plasma generation, via an array of photodiodes. This dual approach ensures robust monitoring across a wide range of laser applications.

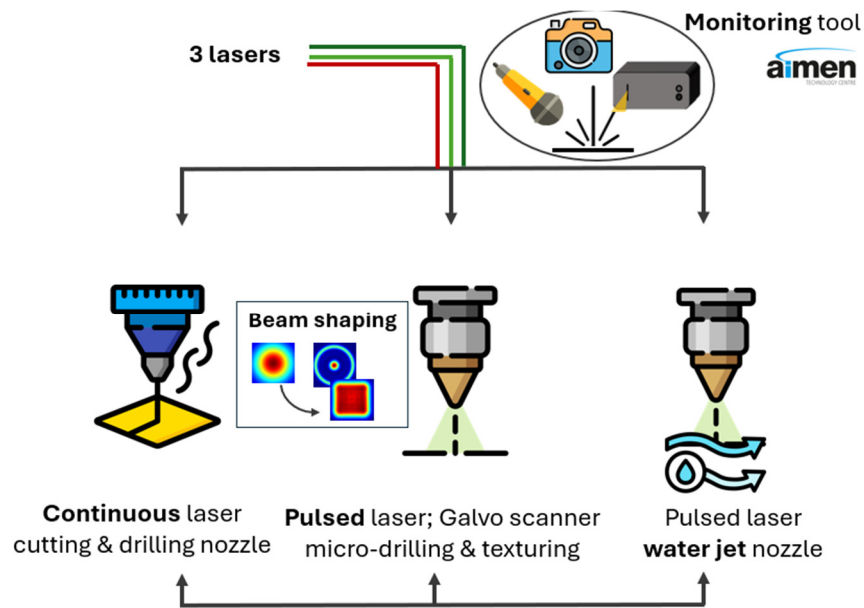


Figure 2: Concept of the new monitoring tool on the multi-head FLASH prototype, where the acoustic, spectral, and optical data are collected together.

All sensor data are acquired and processed using a unified data acquisition and software framework. The developed software includes automated signal analysis, comparison with reference signatures, and visualization tools integrated into a graphical user interface. This enables intuitive monitoring of process stability and rapid identification of deviations.

The results obtained during testing demonstrate the effectiveness of the combined acoustic and optical monitoring approach for defect detection and process validation. The developed prototype represents a significant step toward reliable, non-intrusive, and scalable monitoring solutions for industrial laser manufacturing. Future work will focus on extending defect localization capabilities and further validating the system in additional industrial scenarios.



4. EXPLOITABLE RESULTS

The FLASH monitoring system was implemented as a compact, mobile prototype housed in a ventilated half 19" rack to facilitate industrial integration. The unit consolidates the optical monitoring components, acoustic signal conditioning, data acquisition, active and passive electronics, processing hardware, and user interface into a single enclosure. Optical signals are transferred from the processing head via a standardized fibre connection, while acoustic sensors from multiple processing heads can be connected and managed through the front panel. Process synchronization is achieved using the laser trigger, either provided directly by the laser system or through an external control module. Embedded computing units handle data acquisition, analysis, and real-time visualization through a Windows-based user interface. All electrical components are safely enclosed in an air-cooled compartment, and the prototype was successfully installed and validated on various industrial laser station, demonstrating its readiness for practical deployment.

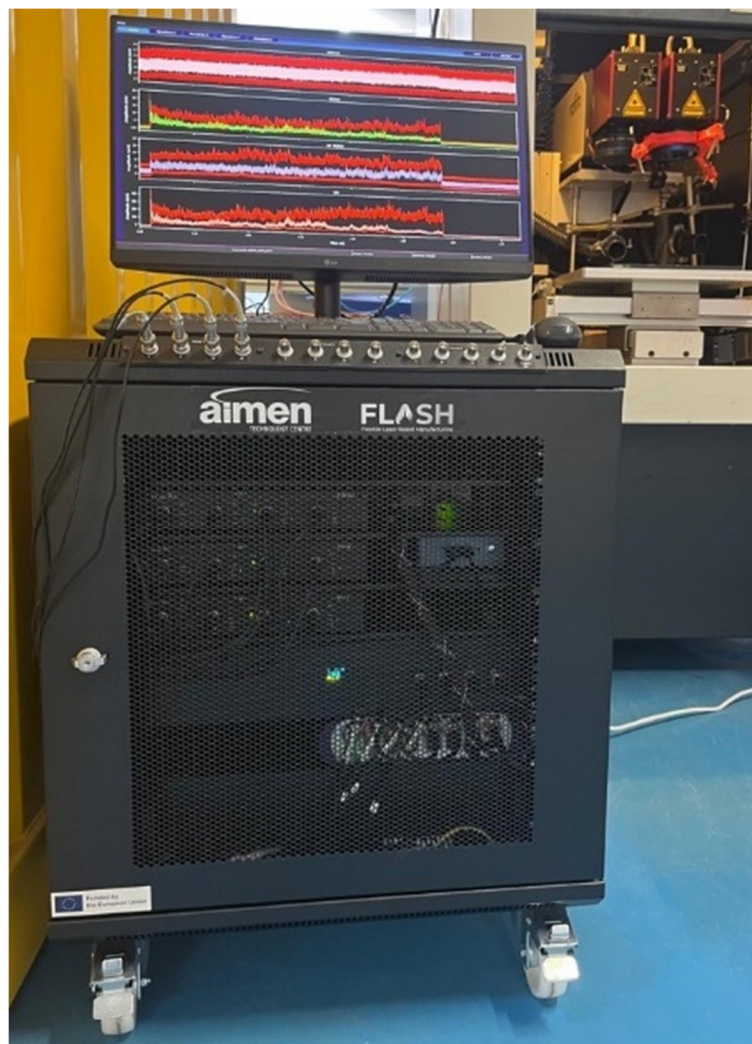


Figure 3: Flash monitoring prototype finalized.



A graphical user interface was developed to control data acquisition and support real-time monitoring of the laser process. The GUI enables live visualization of acoustic and optical signals and their comparison with reference process models, allowing verification of correct process execution and identification of deviations in time. It also provides access to the full optical spectrum acquired by the spectrometer for detailed analysis, and allows users to adjust acquisition and display parameters while coordinating and synchronizing data capture across the connected devices.

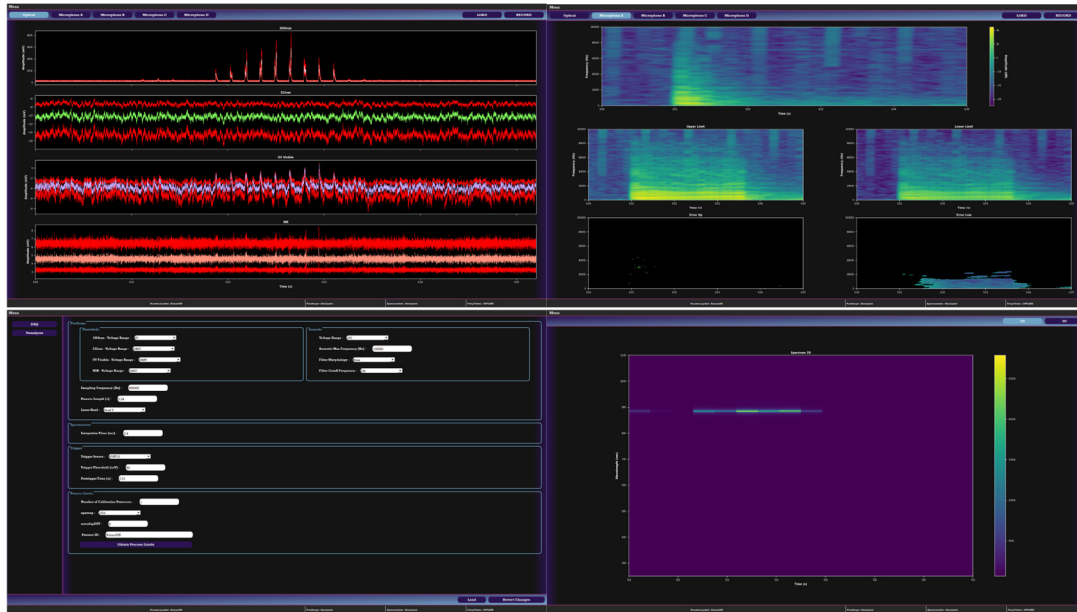


Figure 4: User interface with the parameter tab, the acoustic analysis tab, and the optical analysis tab.



5. CONCLUSION

The developed monitoring prototype demonstrates the effectiveness of combining optical and acoustic sensing to characterize laser–material interactions and detect process deviations. Through its modular hardware design, integrated software environment, and intuitive user interface, the system enables reliable process fingerprinting and real-time monitoring in industrial conditions. As an evolution of the Breakthrough Sensor, the FLASH monitoring tool represents a significant step toward robust, scalable, and application-agnostic monitoring solutions for advanced laser manufacturing, with clear potential for further extension and industrial adoption.