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A framework for in-process quality inspection of laser welding applications

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Abstract

A framework for integrating in-process quality inspection for laser welding applications is presented here. The proposed hardware and software architecture was developed in the context of the ZELD-e EIT-funded project and is able to deliver a fully working system for monitoring and quality assessment of laser welding applications, towards the quality improvement and rapid certification of the joints, paired with predictive/preventing control capabilities based on a long-term optimization schema through the utilization of Artificial Intelligence (AI) and Decision Support System technologies in the context of process energy optimization.

1. Introduction

Laser Welding is a joining method and, compared with conventional welding methods, presents higher productivity, flexibility, effectiveness, and numerous advantages, such as deeper penetration, lower distortions, and higher welding speeds. However, it is such a complex manufacturing process that the visually recognizable quality of the weld is affected by several process variables and other factors, such as defects in the material's microstructure, contaminations on the work-piece surface, and alteration of the beam's properties, resulting in a non-acceptable product. The potential weld defects affect the mechanical properties of the welded components, and as a result, the risks of part failure are significantly increased [1].

The quality assessment concerns the evaluation of the melt pool dimensions (penetration and bead width) and the formation of weld defects such as cracking, porosity, undercut, inclusions, and humping effect. During the process of laser welding, melt pool area, keyhole, plasma and spatters comprehend different types of welding signals, like optical and thermal signals, which can be directly associated with the welding quality. In traditional welding applications, different types of sensors have been used for monitoring the welding quality. Among them, optical and infrared (IR) monitoring has been studied and widely applied recently [2]. In optical monitoring, geometrical features of the melt pool, keyhole, spatters, and plasma plume distribution frequently change during the laser welding process. These dynamic signals are closely related to the fluctuation of the joint quality. High-speed and CMOS cameras are commonly used for capturing images like the plasma or melt pool area during laser welding. Thermal information is also vital, being indeed a thermal manufacturing process since the material is melted by the laser beam. IR cameras are able to reflect the thermal distribution of the welding area more comprehensively and can also estimate the geometrical structure (i.e., width/depth) of the melt pool and heat-affected zone by analyzing the emitted thermal radiation. Studies have shown that these characteristics of the molten pool could effectively reflect the stability of the welding process.

2. The ZELD-e Monitoring System

2.1 Vision architecture

The vision architecture for in-process laser welding monitoring is illustrated in Fig. 1. In short, there are two vision sensors for monitoring the welding process, mounted on a special bracket attached to the laser head, and connected to an edge device responsible for running all machine vision/learning algorithms for inspecting the laser welding process and performing quality assurance. Containerized updates are made via docker files through a secure VPN connection between the edge device and the accessible teams. Finally, a User Interface (UI) running on the edge device is able to demonstrate the functionalities, visualize both visual sensors and provide access to the AI-generated metadata to the system operator [3].

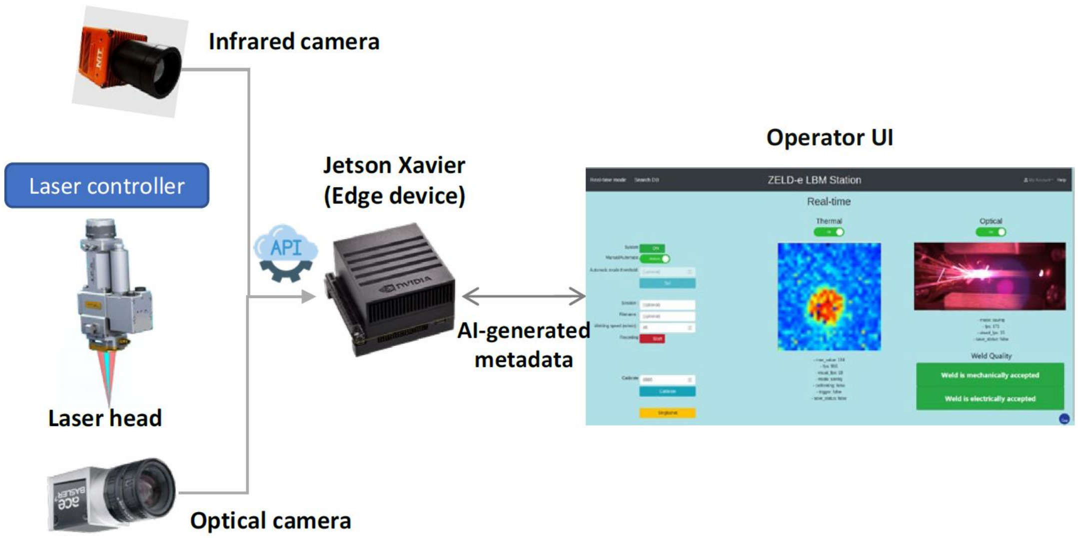

Figure 1: Vision system architecture of the Zeld-e approach.

2.2 Edge processing device

The utilized edge processing device is a Jetson AGX Xavier unit, an NVIDIA Jetson platform that delivers power efficiency and flexible form factors to build software-defined intelligent machines. Jetson AGX Xavier provides unique functionality for compute density, energy efficiency, and AI inferencing capabilities on edge devices, being the next evolution in next-generation intelligent machines with end-to-end autonomous capabilities. It includes a 512-Core Volta GPU with Tensor Cores, an 8-Core ARM v8.2 64-Bit CPU, 32 GB 256-Bit LPDDR4x memory, and 32 GB eMMC 5.1 storage.

2.3 Optical components

Two types of vision sensors are utilized on the ZELD-e system architecture, an Infrared (IR) and an Optical Camera, both attached to the laser head using a specialized bracket as seen in Fig. 2. The IR camera operates at a wavelength range of 1μm – 5uμ and has been utilized, tested and verified in other similar welding applications. It is a Tachyon 1024 microCAMERA from NIT which uses an uncooled MWIR PbSe detector, IP67-rated with an industrial USB connection and 1 kHz frame rate, ensuring perfect integration in the production process. The Optical camera is a Basler acA1920-155uc USB3.0 global shutter module, a color high-speed camera with a Sony IMX174 CMOS sensor that can deliver 164 frames per second at 2.3 MP resolution.

(a) (b)

Figure 2: (a) ZELD-e camera modules attached to the laser head and (b) User Interface illustrating the data acquisition of both camera modules along with the vision analytics produced in real-time.

To avoid damaging the cameras from the IR laser reflections (laser wavelength range is 920nm – 1070nm), appropriate filters have been selected. Regarding the IR module, a premium high-pass blocking filter has been installed with a cut-off wavelength of 1100 nm. For the Optical camera, two filters are utilized. The first one is a Ø25.0 mm premium short-pass filter with a cut-off wavelength at 900 nm, utilized to filter out the frequency of the laser profile. The second is a Neutral Density (ND) filter that can provide the necessary drop in throughput and uniformly lower the light that is transmitted through the lens and onto the sensor. The filter is a Ø25 mm square unmounted filter that can uniformly attenuate over the 350 to 1100 nm wavelength range at a specific Optical Density (range of different ND filters from 0.1 to 4.0 optical density values).

2.4 Data acquisition pipeline

The data acquisition (DAQ) pipeline incorporates the NVIDIA Jetson edge device at the core of the system's operations. Inputs of the DAQ pipeline are the sensor data, the remote access, and the Quality Assurance model updates. Outputs of the DAQ pipeline are the compressed video stream, the sensor's status data, the edge module status data, the welding machine status data, and the weld quality label.

2.5 User Interface

The ZELD-e UI has been developed as a web application. Essentially, it is an application program that is stored on a remote server and delivered to the client over the network through a browser interface. The web server hosting the UI is deployed on the Jetson machine and communicates with the sensors using the MQTT protocol. Three are the main screens of the user interface:

- The “real-time” screen, which provides the functionalitiesfor real-time displaying and recording of the two cameras(Fig. 1).
- The “Search DB” screen, provides the functionalities ofsearching through the recording sessions.
- The “Analytics screen”, which displays the video playbackand some IR data statistics (Fig. 2b).

Acknowledgements

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