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Pyroelectric sensor signals processing for early-warning generation in CO_2 laser welding

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ABSTRACT

Three different techniques were chosen for processing pyroelectric sensor signals that would provide early warnings of malfunctioning in the CO_2 laser welding. The corresponding algorithms were implemented using the mean, the root mean square and variance of a suitable number of digitized signal samples. Each pair of these algorithms was found complementary in reaching 100% success in the early individuation of the defects. The one based on the variance was more efficient than the other two in identifying the causes of malfunctioning. The processing times ranged from 20 μs to 200 ms, and the spatial resolutions varied from 18 μm to 0.5 mm.

1. Introduction

One of the most diffuse applications of laser material processing [1] in the automobile and aerospace industries is the welding of metallic sheets using a continuous wave (CW) laser. In these fields, the CO_2 laser is commonly used because of the high-energy requirement. Infrared sensors are often used for welding monitoring [2–4] off-axis with respect to the direction of the laser beam. Recently, new technologies such as high-speed CMOS cameras [5] have gained some interest especially when associated with on-axis applications for Nd-YAG lasers at shorter wavelengths. Important applications of spectrometers in fiber have also been found for plasma monitoring [6,7]. However, these applications have time responses conditioned by full spectra acquisition and quite elaborated processing of the data. Online quality control for CO_2 laser welding is still usually based on photodiodes that monitor the electromagnetic emissions coming from the welding process [8]. For point applications, in an equivalent-to-photodiodes extension in the near infrared (NIR) we used a home-made pyroelectric sensor, which showed itself to be capable of delivering alerts, which we evaluated in terms of the percentage of defects avoided after the first warning. These types of sensors are often used for IR laser beam alignment [9] and human recognition [10]. Several industries produce single-element pyroelectric sensors and arrays. Some of these are optimized in a single spectral range of their responsivity, which extends from the ultraviolet (UV) to the NIR wavelengths. With regard to online welding monitoring applications, we wanted to explore the speed possibilities of this home-made high-gain pyroelectric sensor, which was designed to detect the small irradiance changes connected with the lack of full penetration. In particular, we studied the early warning capability in practical situations in which we simulated a change in the optimized laser power and focusing distance (i.e. the distance from the laser beam focussing lens to the specimen) that determined the appearance of defects. For the monitoring, we considered a procedure for correlating defects to the mean, to the root mean square (rms) and to the maximum variance of a convenient number of signal samples, and implemented three different algorithms. Two of these algorithms can be utilized together in order to provide both the earliest alert time and the identification of the causes of malfunctioning in the laser welding.

2. A pyroelectric sensor for laser welding

There are several characteristic signals associated with the laser beam welding process. When the focused laser beam melts the metal, a key-hole is formed and is sustained by the evaporation of metal from the weld pool. Plasma is formed within and above the keyhole by means of ionization of the shielding gas and of the metallic vapor. The infrared emission from the weld pool, which is considered to be one of the most important emitted radiation, is typically in the range 900–2300 nm [2]. The emission

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from the weld includes the contributions from both the hot molten metal and from the key-hole plasma. According to studies performed by other researchers, in the case of an N_2 shielding gas in CO_2 laser welding, large gas plasma periodically obscures the metallic plasma and the keyhole [11].

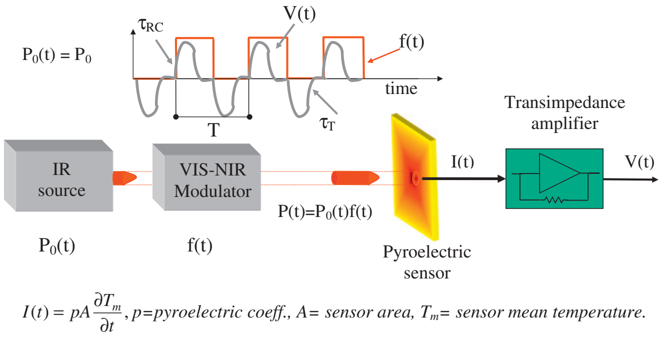

Fig. 1. Typical response of the pyroelectric sensor to a square-wave modulated radiation. The response of the pyroelectric signal to a transient is characterized by two times: τ_{RC}, due to the equivalent electrical impedence of the sensor and τ_T, due to the thermal constant of the sensor. The definition of the pyroelectric current $I(t)$ is also reported.

The bipolar signals delivered by the pyroelectric sensor that we used for the welding monitoring are proportional to the variations in the radiation emissions (mostly in the NIR region) that take place during the welding process. Fig. 1 shows the typical voltage response $V(t)$ of the pyroelectric sensor to a square-wave-modulated continuous radiation source, together with the definition of the pyroelectric current $I(t)$. The voltage response to an impulsive excitation is characterized by two time constants: τ_{RC}, due to the equivalent electrical impedence of the sensor, and τ_T, due to the thermal constant of the sensor. These two constants determine the rise and decay times of the voltage signal as indicated in the same figure.

Since the pyroelectric sensor response is a time derivative, it is expected to be rather sensitive to all the induced transients, also to those linked to "darkening" events, due to the plasma opaque phase, which can complicate the on-axis imaging and monitoring of both the plasma and the weld pool. Recently, signals from different spectral regions, which were collected independently using different photodiodes [8], were found strongly correlated. With our sensor, of broad and filtered spectral response, we found a close correlation between the interruption of the regular

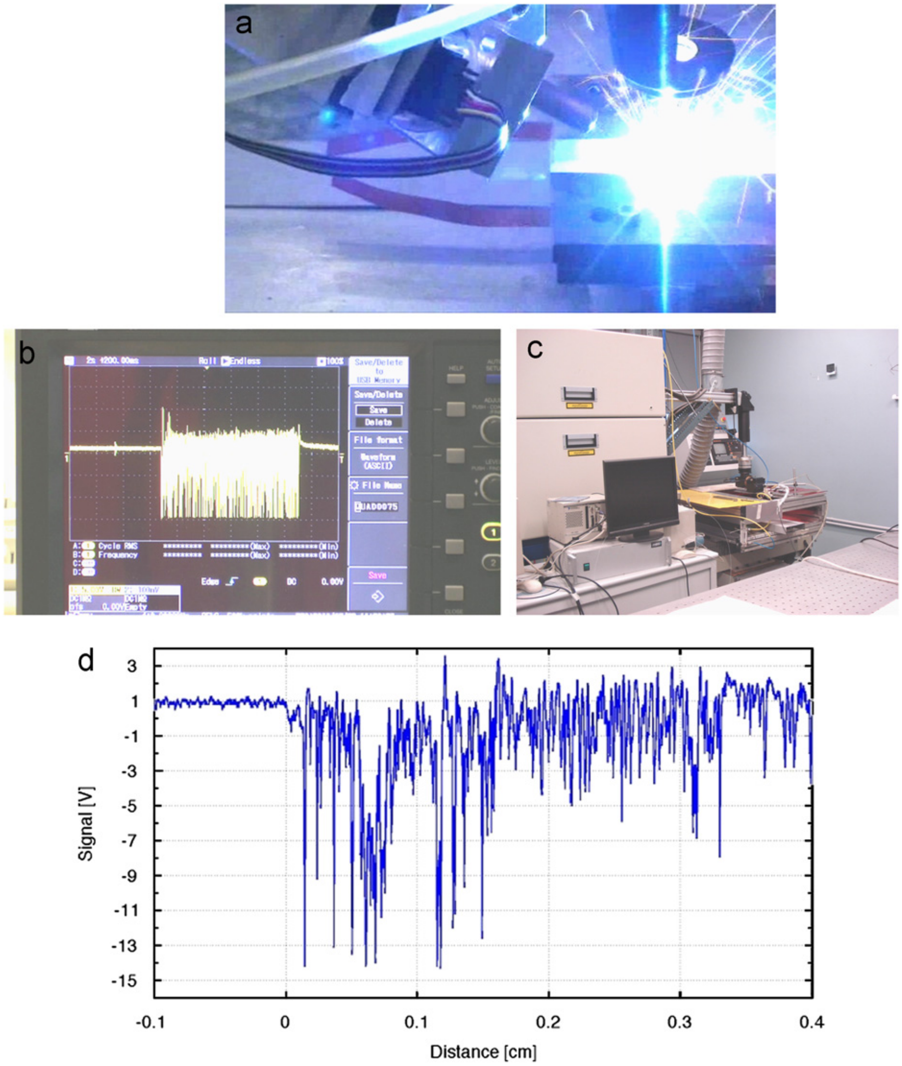

Fig. 2. (a) Sensor and welding laser. (b) Pyroelectric signal sampled by the oscilloscope for the best focus lens position and a power $P=1940$ W. (c) The CO_2 laser and optics for beam transportation and focusing. (d) A zoom of the signal in correspondence of the key-hole formation.