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DEVELOPMENT AND ASSESSMENT OF MONITORING AND CONTROL SYSTEMS FOR PIPELINE WELDING

Carolina Pimenta Mota
Instituto Federal de Goiás, Itumbiara, Brazil.
cpimentamota@gmail.com

Marcus Vinícius Ribeiro Machado, Louriel Oliveira Vilarinho, Roberto Mendes Finzi Neto
Federal University of Uberlandia, Brazil
mvrmachado@pontal.ufu.br, vilarinho@mecanica.ufu.br, finzi@mecanica.ufu.br

Abstract. *Arc welding is a fundamental process in both construction and repair of pipelines and, therefore, special attention must be considered. Thus, monitoring and control systems play a fundamental role for the correct assurance of weld quality and proper documentation. Therefore, it is proposed, developed and assessed a series of independent embedded ("autonomous") systems to be used during pipe welding. The presented systems are for wireless signal monitoring, vision-based joint tracking and waveform synchronized weaving. The first one is a system for wireless arc-welding signals monitoring, which comprises an independent embedded system, capable of monitoring different welding process signals and that communicates in a robust and flexible way to different devices is crucial for the industry, with a user-friendly system, using the state-of-the-art in communication technology. Three acquisition channels are available (voltage, current and wire feed speed), and validated by instrumentation in GTAW and GMAW welding (short circuit, spray and pulsed), demonstrating wide applicability and robustness at a low hardware cost. The vision system for joint tracking is based on the use of high-power (70 W) laser diodes with low cost. Its use with man-assisted supervision can led to a dedicated system for joint tracking and process parameter control, such as arc length and weaving amplitude during pipe welding. The assessment of the whole vision system was carried out during GTA and GMA welding. The third proposed system is an embedded and dedicated system capable of monitoring the torch angles (attack and working angles) during torch movements (travel speed and weaving). By using the measurement of the torch angle, the system can control the power source and lead to different set of parameters (in the present version, three different sets are possible). The idea is to have different set of parameters when weaving, so the sidewall of the joint can have one set of parameters and the root another one. Also, the torch position during pipe welding (12 to 6 o'clock, for instance) can be monitored and the power source controlled, so different welding parameters can be set.*

Keywords: *Welding, pipeline, instrumentation, wireless, vision system, synchronous weaving.*

1. INTRODUCTION

According to ISO 3834 (2005), welding is a special manufacturing process, because quality assurance cannot be realized by final inspection only. The joining is totally dependent on personnel, equipment and facilities. Therefore, development and improvement of equipment and methods are needed for constant monitoring.

Different devices from different manufacturers could provide monitoring for several variables in welding process, with focus on specific parameters, with advantages and limitations. Programmable equipments are also available, which are adaptable to welding monitoring with addition of signal conditioners and transducers. On-going trend follows the creation of equipment for practical and simple use, with the elimination of adaptive circuits and greater flexibility. This is highlighted by the fact that the monitoring equipment must be adapted to the manufacturing environment and not otherwise. The demand for flexibility is accomplished by replacing traditional cabling system by wireless communication one, which is not readily applicable for welding monitoring.

The initial idea of building an embedded device (complete and independent system, but prepared to perform an unique and determined task - Oliveira, 2006 and Cunha, 2007) with wireless communication and flexibility is originated in the dissemination of computer networks for manufacturing environments and technological development of communication products and portable data. This scenario points toward the integration of welding monitoring with wireless communication, which is an achievable reality and promising technology. By integrating this technology related to welding, it is possible to expand its application to control systems and remote monitoring, which could assist welding in hostile environments, as well as assist specialists perform remote supervision.

Therefore, in this work it is proposed, developed and assessed a series of independent embedded ("autonomous") systems with specific features (proprietary technology, scalability, portability, autonomy, flexibility and low cost / simplicity of operation) to be used during pipe welding, namely:

- Wireless signal monitoring,
- Vision-based joint tracking and
- Waveform synchronized weaving.

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The first one is a system for wireless arc-welding signals monitoring (so-called MoSo), which comprises an independent embedded system, capable of monitoring different welding process signals and that communicates in a robust and flexible way to different devices is crucial for the industry, with a user-friendly system, using the state-of-the-art in communication technology.

The vision system for joint tracking is based on the use of high-power (70 W) laser diodes with low cost. Its use with man-assisted supervision can led to a dedicated system for joint tracking and process parameter control, such as arc length and weaving amplitude during pipe welding.

The third proposed system is an embedded and dedicated system capable of monitoring the torch angles (attack and working angles) during torch movements (travel speed and weaving). By using the measurement of the torch angle, the system can control the power source and lead to different set of parameters (in the present version, three different sets are possible).

2. EXPERIMENTAL APPROACH

2.1 Wireless signal monitoring

Initially, devices and circuits for conditioning should be selected. The Hall Effect transducer LEM HT500-SBD was defined, with a measuring range of ± 500 A, effective linearity of 0.5%, frequency response at 50 kHz and output voltage ranging from ± 5 V (LEM, 2002). The transducer for wire feed speed is an encoder, Bourns EM14, of 64 pulses per revolution per phase (it has two stages) with a lag of 90 degrees between the phases to indicate the direction and speed of rotation up to 120 RPM (Bourns, 2008). The electrical signals conditioning from the transducers is for the voltage signal made with an electrical circuit composed of a voltage divider to adjust to the range of the A/D converter, a galvanic isolator, ISO122P (Burr-Brown, 1993), to protect the microcontroller (MCU), an Butterworth low-pass second order analog filter (Malvino, 2006) with cutoff frequency at 625 Hz (as previously determined in Machado, 2011) and a buffer for impedance matching. For the current signal there is no need for galvanic isolation and the speed signal power is not required the use of any conditioning circuit.

The selection of the MCU requires prior knowledge of the requirements relating to it, as A/D converter resolution and sampling rate, the program memory and data amount in accordance with the wireless communication module (TCP/IP stack size) and processing speed. According to the resolution requirement previously defined (Machado, 2011), it is necessary an A/D converter resolution of 12-bit (Tab. 1). In this case, the Microchip ZeroG ZG2100M was chosen as the Wi-Fi communication module. This choice is due to the documentation availability on the communication protocol, examples of TCP/IP stack use (the library cell is supplied by the manufacturer), and national technical support and, finally, integrated manufacture development boards availability (Microchip, 2010).

Table 1. Comparison of resolution in the measurements for different resolutions of A/D converters

Parameter	Range	Required resolution	A/D 10 bits	A/D 12 bits	A/D 14 bits
Voltage (V)	±100	0,1	±0,196	±0,048	±0,012
Current (A)	±500	1	±0,978	±0,244	±0,061

Considering the A/D converter resolution, processing speed and program memory and data amounts in each MCU, the dsPIC33FJ256GP710 was defined as the device to be used. Its transmission efficiency is equivalent to greater processing power MCUs with lower cost, and its 16-bit architecture with wide documentation (Microchip, 2007) makes it more accessible for programming.

The human interface of the developed MoSo system (Welding Monitor in Portuguese), shown in Fig. 1, is based on web server technology and it is accessible by any equipment with a built-in web browser. The main page of the system has a configuration section, where the user can select between window times of acquisition (0.5 to 4 s), finite and continuous acquisition, and the possibility to save the last waveforms on hard drive. Once initiated, MoSo receives the point sequence from the embedded system and generates graphs of tree parameters monitored: voltage, current and wire feed speed. It also shows the rectified mean and RMS (root mean square) values of each parameter.

After the definition of these requirements for hardware and its integration, the assessment of the MoSo was carried out by monitoring conventional GMAW with short-circuit and spray transfers, GMAW-Pulsed, GTAW-AC (alternating current) and GTAW-Pulsed. Due to the excessive numbers of runs, some of them are presented and this work and the others are available in Machado (2011). The welding parameters used in these runs are shown in Tab. 2 and involves short-circuit, spray and pulsed (controlled) metal transfer for GMAW and pulsed and alternating-current pulsed GTAW. In authors view, these runs present a good representation of possible signals acquire during arc welding. The waveforms from MoSo system are compared to a USB “reference” system, with higher sampling rate (125 kS/s) and no filtering. Bead on plate weldments were deposited on mild steel (SAE 1020) plates.

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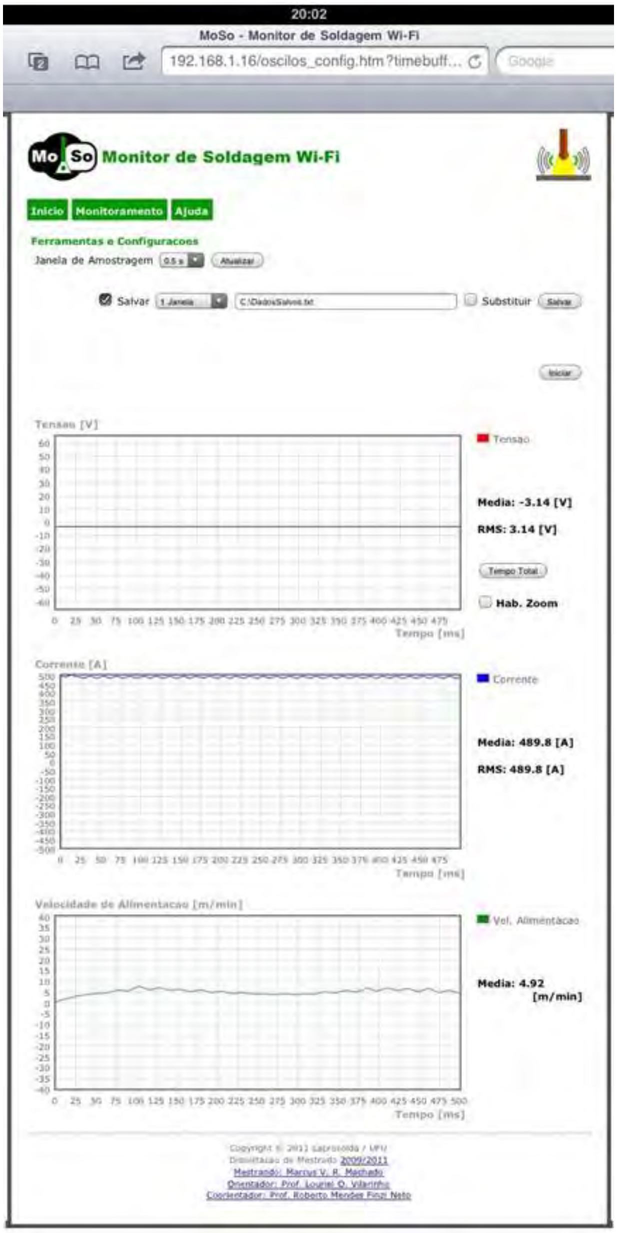

Figure 1. Human interface of MoSo (in Portuguese)

Table 2. Welding parameters using during assessment of the MoSo monitoring system

Parameters	Run				
	MAG01	MAG02	MAG03	TIG01	TIG02
Voltage (V)	19.0	38.0	—	—	—
WFS (m/min)	4.0	15.0	5.5	—	—
CTWD (mm)	15	22	22	—	—
EPD (mm)	—	—	—	3	3
Shielding gas	Ar25%CO_2	Ar8%CO_2	Ar8%CO_2	Ar	Ar
Ip (A)	—	—	210	-250	-150
tp (ms)	—	—	10,0	150	2
Ib (A)	—	—	70	-100	50
tb (ms)	—	—	10,0	400	3

Note: Travel speed: 20 cm/min (GMAW) and 15 cm/min (GTAW); Filler wire for GMAW: ER70S-6 with 1.0 diameter; Electrode for GTAW: W-2%Th with 2.4 mm diameter; EPD: Electrode-Plate Distance

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2.2 Vision-based joint tracking

The developed vision system is so-called ViaSolda and comprises an analogic low-cost camera (CCD Costar SI-M331) with very low exposure time (1.25 µs) and resolution of 768x494 pixels. Also ViaSolda system uses a developed near-infrared (905 nm) illumination set that consists of a set of 19 high-power laser diodes (Osram SPL PL90_3), as shown in Fig. 2. These diodes are used together with a lens system capable of spreading the spot lighting. ViaSolda also has a high power circuit and a programmable MCU (microcontroller) capable of generating enough power to the diodes and an electronic trigger to turn the camera on (shuttering) and the illumination system at the same time. In this case a frequency of 30 Hz (frames per second) was selected (Mota, 2011).

Figure 2. Vision system: set of 19 driven laser diodes

The laser diodes and the camera were set in a as shown in Fig. 3, during the filming of GTAW and GMAW processes. The visualization of the welding processes was carried out by varying the welding parameter accordingly to Tab. 3. The weldments were carried out by using a power source Miller PipePro 450RFC and filler wire ER70S6 with 1.2 mm diameter for GMAW. For GTAW, power source IMC MTE Digitec 300 and EWTh-2 electrode with 2.4 mm diameter was used. In both processes bead-on-plate weldments were carried out over ½"-thickness mild-steel plates.

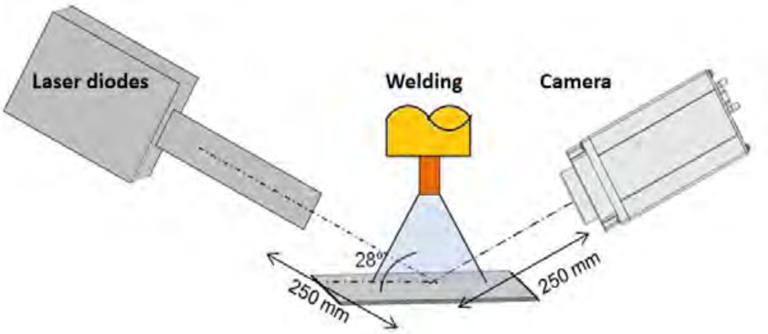

Figure 3. Setup for filming GTAW and GMAW processes

Table 3. Welding parameters for process filming

Parameter	GTAW	GMAW
Shielding Gas	Pure Ar	Ar+25%CO_2
Current (A) / Voltage (V)	100-250 A (12-14V)	18-30 V (150 A)
WFS (m/min)	—	2.5
Travel Speed (cm/min)	10	20
Electrode to plate distance (mm)	3	15

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2.3 Waveform synchronized weaving

The constant need for expansion in pipeline routes demands continuous advances in metal fabrication, especially welding. This is underlined by the requirements of field joining of pipes, which involve variability in geometry, consumables, equipment, personnel skills, land site and weather. Among those, the tolerance of pipe geometry and the groove itself is a major concerned when mechanized welding is performed. Therefore, it is important to develop strategies that can cope with poor geometric tolerances, which are estimated from 1.6 to 3.0 mm for both root opening and alignment of the groove. In this work, the proposed strategy for overcoming this limitation is the use of synchronous waveforms with torch positioning during its weaving, when GMAW welding. One possible idea is to vary welding parameters, such as positive to negative polarities or high to low currents, dependently to the waving setup, as shown in Fig. 4. Also different waveforms can use, since they are synchronized with weaving.

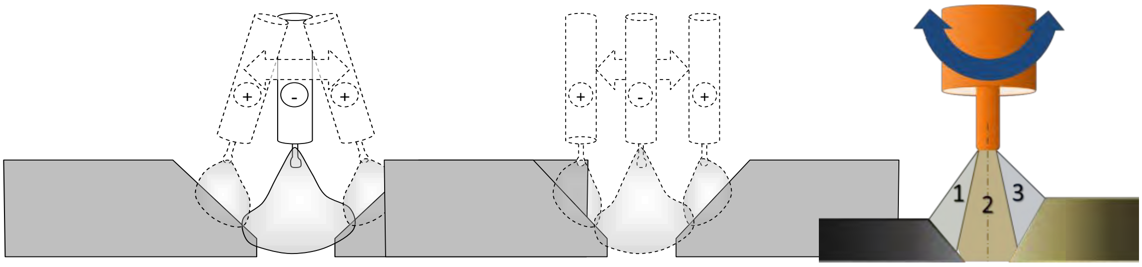

Figure 4. Different conceptions of synchronous weaving

Therefore, it was developed and assessed a system capable of monitoring the torch angles (attack and working angles) during torch movement (travel speed and weaving). This system (Fig. 5) is so-called Conparte (Parameter Control System by Weaving, in Portuguese). During the weaving three regions are considered (as shown in Fig. 4) and numbered 1, 2 and 3. Once each of these regions is identified, the Conparte system commands a welding power source (IMC DIGIPlus A7) to select a specific welding program. The identification of each spatial region can be done by different sensors. In this case, a three-axis accelerometer (MMA7361L), a magnetic-contact sensor (9028PA) and an optic infrared receiver (TCST1103) were used (Fig. 6). Conparte system was assessed during weaving parameters shown in Tab. 4. As mentioned, it identifies three mentioned regions and set three different programs in the power source, accordingly to Tab. 5 for GMAW with ER70S-6 1.2-mm wire and Ar+25%CO_2, as shielding gas.

Figure 5. Conparte system

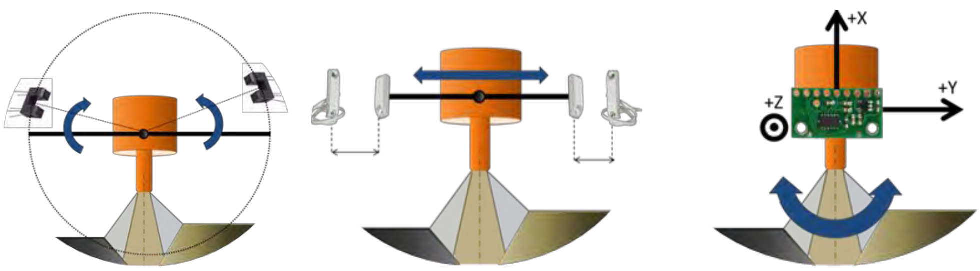

Figure 6. Sensors used in Conparte system: magnetic 9028PA (left), optic infrared receiver TCST1103 (center) and accelerometer MMA7361L (right)

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Table 4. Parameters used for assessing Conparte system

Parameter	Range
Weaving frequency	0.25 to 1 Hz
Weaving amplitude	3 to 6 grades and 10 mm
Lateral stop	0,25 s
Travel speed	5 mm/s

Table 5. Programs used for validating Conparte system

Sensor	Program	Current (A)	Wire feed speed (m/min)
Optic infrared receiver	P2	150	3.0
	P4	200	3.5
Magnetic-contact sensor	P2	300	6.0
	P4	260	8.0
Three-axis accelerometer	P1	220	6.0
	P2	260	8.0

Note: In all cases, the pulse period was set as 18 ms for each program

3. RESULTS AND DISCUSSION

3.1 Wireless signal monitoring

The whole system was tested with GMAW short-circuit and spray, GMAW-Pulsed, GTAW-AC (alternating current) and GTAW-Pulsed. Using the statistical parameter knows as Pearson coefficient (r), the waveforms saved by MoSo where compared to a reference system (from a worldwide manufacturer of DAQ systems), and shows results above 0.7, indicating a strong correlation between the waveforms. The rectified mean and RMS values obtained show acceptable relative errors, almost all below 2.5% (required by the standard BS7570:2000 for welding equipment). Some of these results are presented in Figss 7 to 11, as a comparison between the results (waveforms) from MoSo system and reference one. The resemblance between the obtained signals from both developed and reference systems is evident for most of the runs, with the exception of GTAW-AC process. In this case, the steep slope in the electrical signals during the polarity change demands a higher sampling rate for a perfect determination of the waveform profile. However, it must be pointed out that the peak and base values are correctly determined by MoSo system. Moreover, the mean and rms values are properly calculated. Therefore, the developed system met its objective and is capable of performing the required tasks.

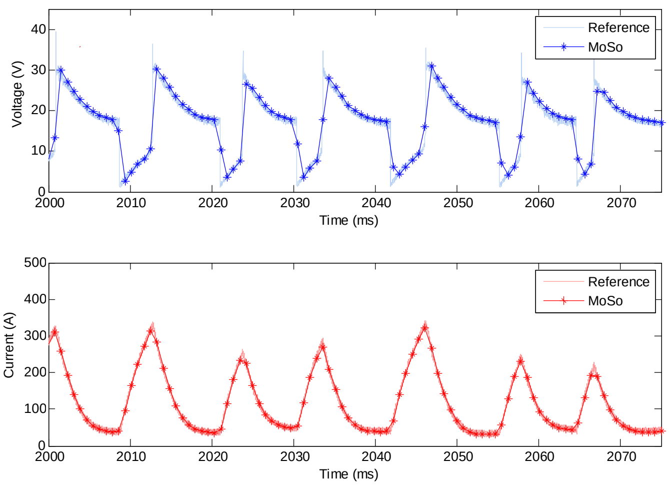

Figure 7. Current and voltage signal obtained for Run MAG01 by using MoSo and reference systems

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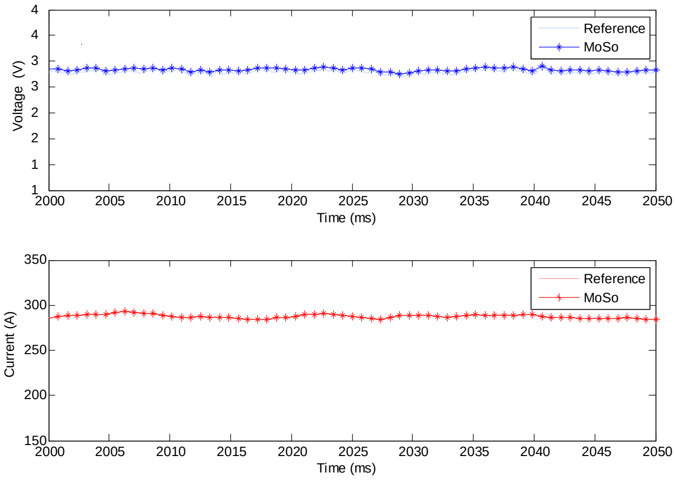

Figure 8. Current and voltage signal obtained for Run MAG02 by using MoSo and reference systems

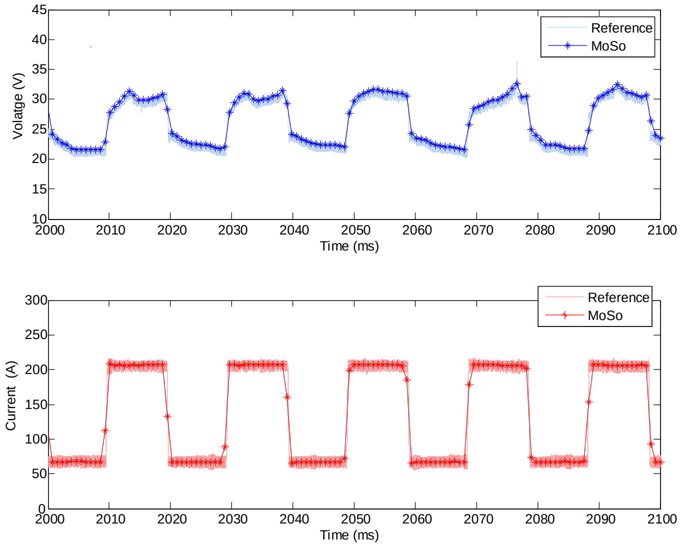

Figure 9. Current and voltage signal obtained for Run MAG03 by using MoSo and reference systems

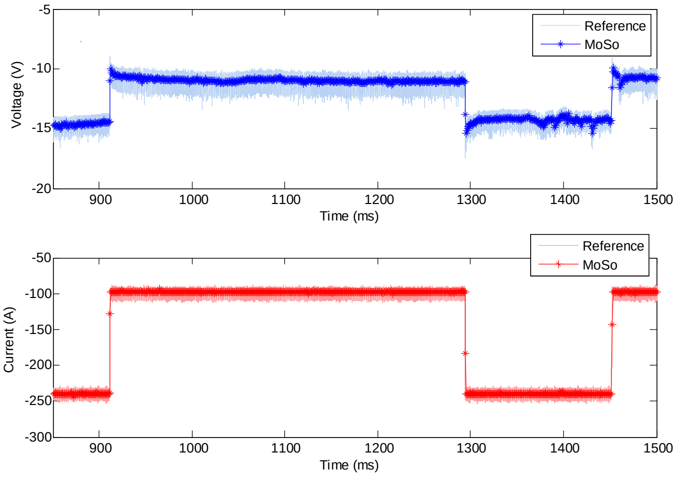

Figure 10. Current and voltage signal obtained for Run TIG01 by using MoSo and reference systems

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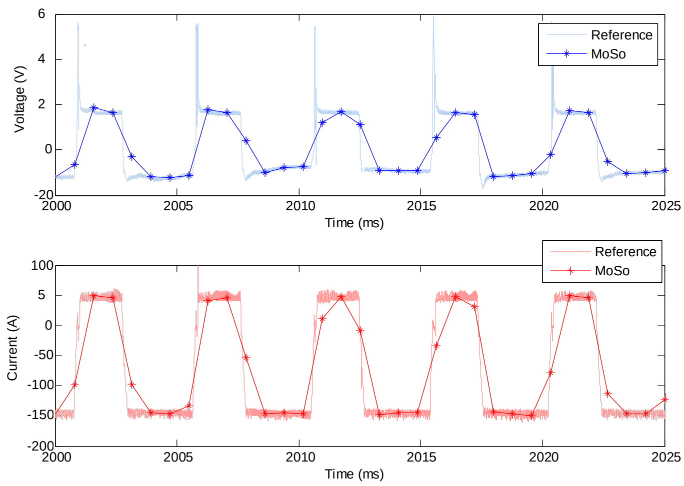
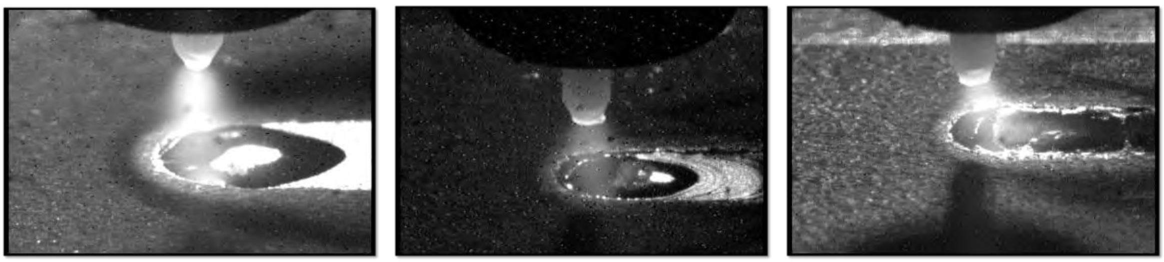


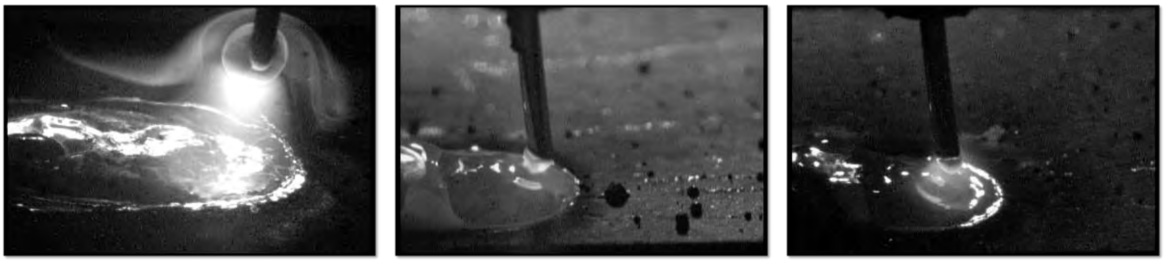
Figure 11. Current and voltage signal obtained for Run TIG02 by using MoSo and reference systems

3.2 Vision-based joint tracking

The images obtained by ViaSolda are shown in Fig. 12. It is possible to assert that the developed low-cost vision system is fully capable of viewing the weld pool and its surrounds and, therefore can be used as a vision-based joint tracking system.



(a)



(b)

Figure 12. ViaSolda system images from left to right: (a) GTAW at 250 A, 150 A (shorter exposure) and 150 A (longer exposure) and (b) GMAW at 150 A for globular transfer (30 V), short-circuit transfer during short-circuit (18 V) and short-circuit transfer during open arc (18 V)

3.3 Waveform synchronized weaving

The final acquired signals for the three sensors are shown in Figss 13a, 13b and 13c, respectively for optic infrared receiver, magnetic-contact sensor and three-axis accelerometer sensors. These images show the synchronization between the program selection (P2 or P4) according to Table 5, with immediate response shown in current curves. Therefore, it is possible to state that Conparte system was capable for performing waveform synchronized weaving.

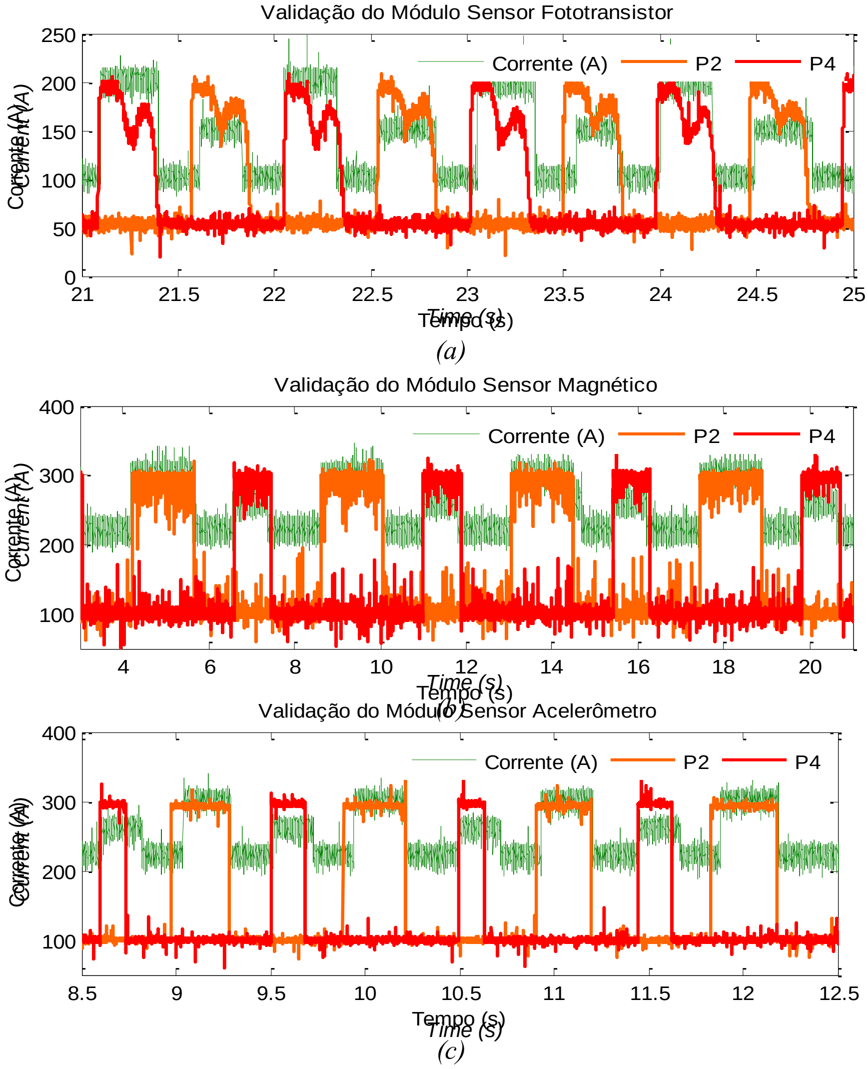


Figure 13. Signals obtained during the assessment of Conparte system for different sensors: (a) optic infrared receiver, (b) magnetic-contact sensor and (c) three-axis accelerometer

4. CONCLUSIONS

Concerning each developed system, it is possible conclude that:

- A wireless monitoring system for arc welding process (so-called MoSo) was proposed and assessed in this work. The signals to be monitored, voltage, current and wire feed speed, have been defined and characterized in their frequency characteristics. A Hall effect transducer for current and an encoder for wire feed speed was chosen, as the dsPIC33FJ256GP710 processor board and the Wi-Fi module for data transmission. A Web Server has been shown the most appropriate, dynamic and flexible user interface. It is possible to conclude that the resulting system can be developed with own technology, scalability, portability, autonomy, low cost and flexibility/simplicity operation;
- The developed ViaSolda system was capable of overlaying the welding-arc radiation in both GTAW and GMAW, and proved as a potential tool for remote-supervisory automation, in a similar way that a welder controls the weld pool, i.e., it is possible to conclude that the developed low-cost vision system is fully capable of viewing the weld pool and its surrounds and, therefore can be used as a vision-based joint tracking system.;
- During its assessment, Conparte system proved capable of synchronizing different waveforms against the weaving movement up to 2.5 Hz of weaving frequency, for different sensors: three-axis accelerometer, magnetic-contact sensor and optic infrared receiver. It is possible to conclude that Conparte system is a new technical insight for performing waveform synchronized weaving;
- Finally it is possible to conclude that these proposed, developed and assessed independent embedded (“autonomous”) systems are powerful tools be used during pipe welding for monitoring and control.

5. ACKNOWLEDGEMENTS

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