

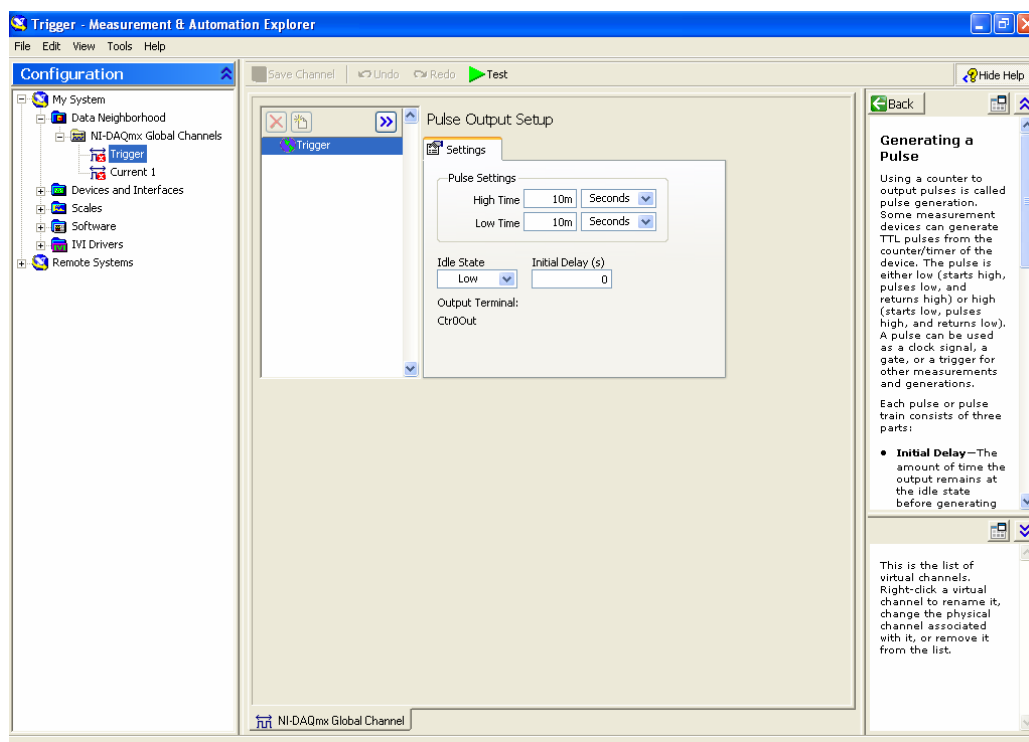


Figure 3.209: Illustration of the panel “Measurement and Automation Explorer” that configures the external trigger

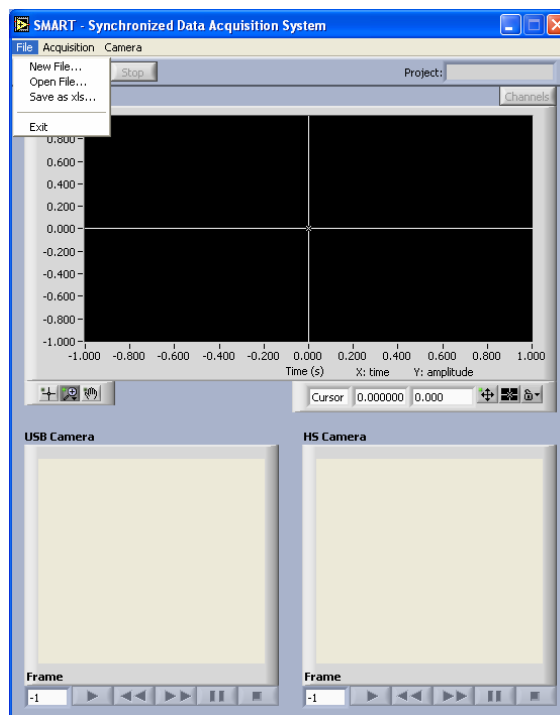


Figure 3.210: Illustration of the menu used for creating or opening a file

In order to set the image parameters, it is necessary to select the channel for the trigger of the high-speed camera among the created virtual channels and the desired

webcam. Eventually, it is necessary to set the cut-off frequency (it has to be less than half of the sampling rate) and the number of poles for the digital filter.

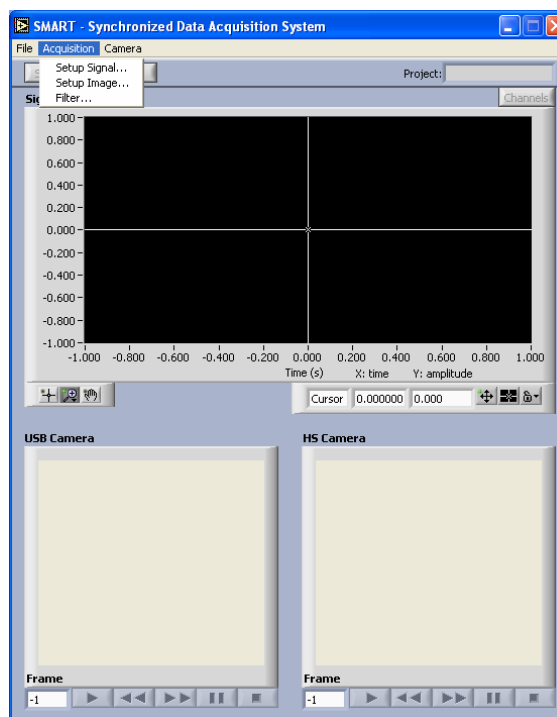


Figure 3.211: Illustration of the menu used for configuring the data acquisition

After configuring the acquisition parameters, the next step is to configure the webcam, as Figure 3.212 shows. Different webcams have different types of parameters. The webcam used for performing the final tests is Logitech brand and was configured as following:

- Brightness = 50%
- Saturation = 0%
- Sharpness = 50%
- Gamma = 0%
- Black and White mode

The resolution must be always equal to 640x480 and the diaphragm of the magnify lens must be closed.

Before starting the acquisition, it is necessary to select the channels of which signals will be shown on the signal graph. It can be done, pressing the “Channels” button and selecting the desired channels. After that, pressing the “Start” button, the data acquisition starts.

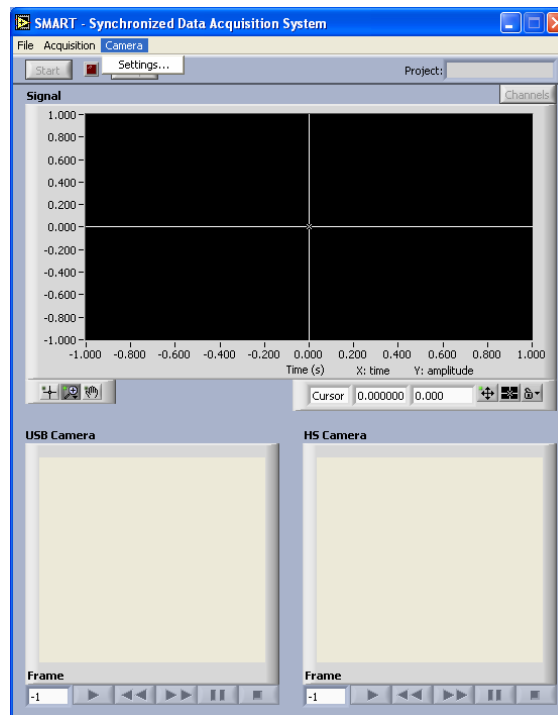


Figure 3.212: Illustration of the menu used for configuring the USB camera

CHAPTER 4

EVALUATION OF THE SYSTEM “SMART”

Two sets of experimental trials were done using the GMAW process. The first one was performed with single wire and the second one with double wire (tandem). A third set of experimental trials was performed with Resistance Spot Welding (RSW) process. In all of them, current and voltage signals were collected, as well as, video camera images.

4.1 First set of experimental trials – single wire GMAW

The objective of these trials was to verify the possibility of the arc welding visualization by using a webcam. Besides that, the efficiency of the synchronism among electrical signals (welding current and arc voltage), USB camera frames and HS camera frames had to be also verified. The HS cameras are usually used by researchers in order to obtain more detailed images of the arc welding.

Figure 4.1 and Figure 4.2 show the rig configuration used for the first set of trials. Two plain carbon steel plates were positioned (as illustrated by Figure 4.3) over the carriage, which moves at a constant speed when it is turned on, by a controller, before starting the data acquisition. The torch head was driven by a step motor, in such a way that it could be oscillated in a horizontal movement when wished. The only possible travel angle of this torch head was the right angle. Then, the first trial of this set was performed just to check any possible image distortion.

The travel angle refers to the angle in which welding takes place. It may be a right angle, a push angle or a drag angle, depending on the position of the torch. When the torch is pointing back to the weld direction, it is known as pulling (or dragging) the weld. When the torch is pointing forward to the weld direction, it is referred to as pushing the metal. At the right angle, the torch is perpendicular to the weld direction. Once Figure 4.3 (a) does not illustrate any of these cases, the denomination “plate angle” will be used for referring to the angle on that illustration.

The high-speed camera was set with a sampling rate of 5kHz, at a resolution of 256X128 pixels and a playback rate of 5Hz. As explained in section 3.2, the USB camera

frames are acquired at 10fps, with a resolution of 640x480, by a Trust webcam. The image parameters were set as following:

- Brightness = 50%
- Saturation = 0%
- Sharpness = 50%
- Gamma = 0%
- Black and White mode

The diaphragm of the magnify lens was closed and filters were used, as explained in section 3.1. Concerning the electrical signals, different values of sampling rates were adopted in order to verify if it would affect the synchronism between signal samples and HS camera frames. Table 4.1 summarizes the signal sampling rate, plate angle and torch oscillation values, used for doing the six experimental trials of this set.

The distance between the torch and the webcam was about 700mm, while the high-speed camera was positioned about 2000mm away from the torch, both at the same alignment in relation the longitudinal centreline of the weld bead. No digital filter, as mentioned in section 3.2, was employed at first.



Figure 4.1: Illustration of the ring configuration used for doing the first set of trials (single wire GMAW)

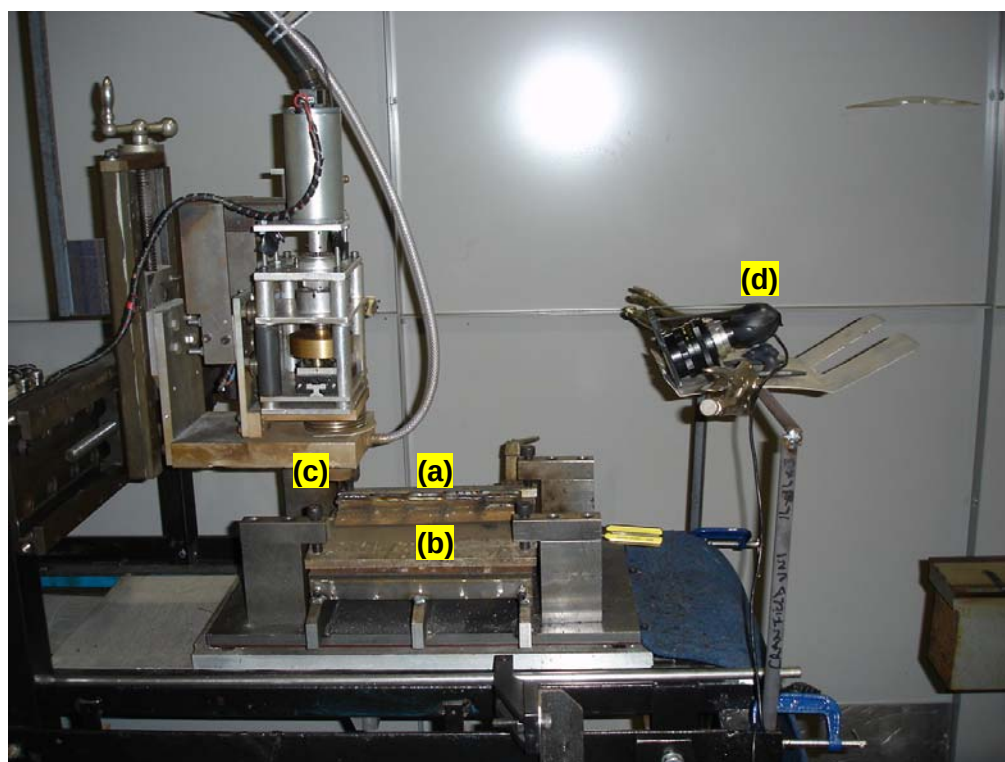


Figure 4.2: (a) side view of the test plate, (b) test plate carriage, (c) torch head and the (d) webcam, in details

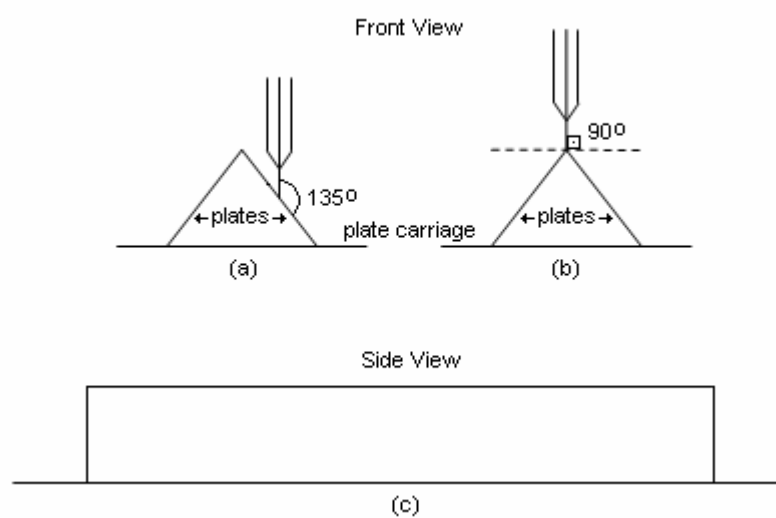


Figure 4.3: Schematic arrangement of the plates (3mm - thick) for welding in relation to the torch position: (a) at a plate angle of 135°; (b) at a plate angle of 90°; (c) and a side view of the test plate

Table 4.1: Parameter setting for the first set of trials

Trial	Signal Sampling Rate (kHz)	Plate Angle (°)	Torch Oscillation (Hz)
test1	5	135	0
test2	5	90	0
test3	5	90	5
test4	13	90	0
test5	4	90	4
test6	5	90	5

Results:

After setting the system, bead-on-plate welds were carried out. In order to evaluate the level of similarity between the waveforms provided by this device and the system, the signal samples were also acquired by a digital oscilloscope at 5kHz. All of these waveforms seemed to be very similar.

Good results related to the arc image, acquired by the webcam, were presented. Since there was only one wire, the arc length could be detected, even if the torch oscillated. However, by comparing Figure 4.4 and Figure 4.5, it is possible to see that the detection of the arc length would be more difficult for a “plate angle” of 135°.

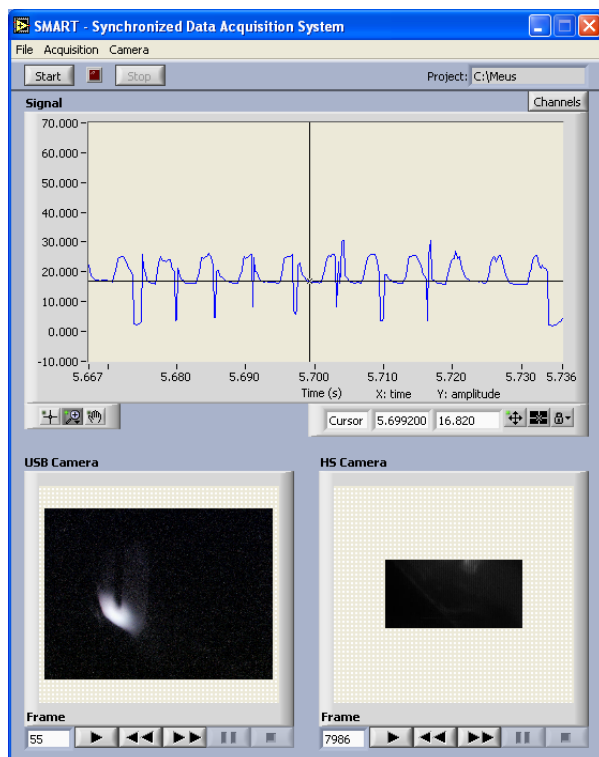


Figure 4.4: Illustration of a shot of the first set of trials - Test1 (“plate angle” equal to 135°) - voltage traces (top), USB frames (left bottom) and HS frames (right bottom)

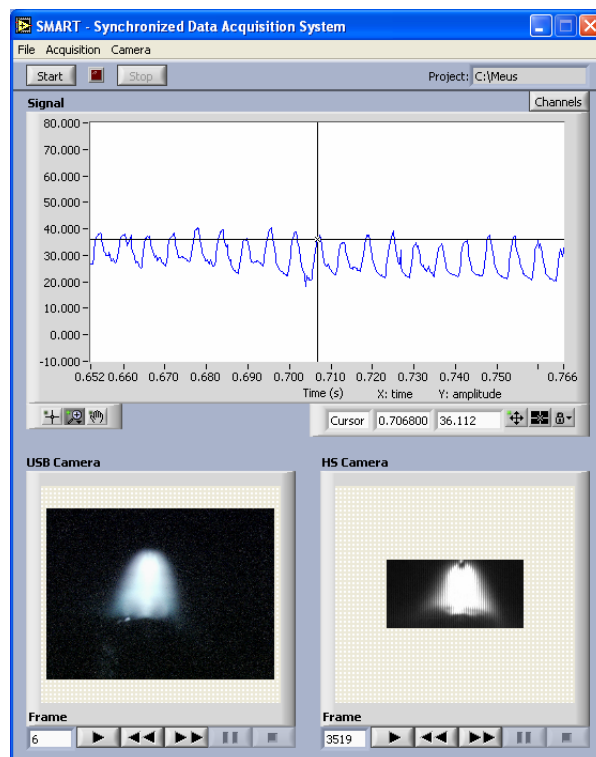


Figure 4.5: Illustration of a shot of the first set of trials - Test2 (“plate angle” equal to 90°) - voltage traces (top), USB frames (left bottom) and HS frames (right bottom)

A synchronism between signals and webcam frames was observed. When the arc welding is turned on, the webcam frame that shows this moment and the buffer of signal samples, which represents its arc voltage value, are plotted, as shown by Figure 4.6 and Figure 4.7. In a similar behaviour, when the arc welding is turned off, the webcam frame that shows this moment and the its buffer of signal samples, which are equal to zero, are plotted, as shown by Figure 4.8 and Figure 4.9.

Nevertheless, no synchronism between signals and high-speed camera frames was observed. It is due to a delay existent between the moments that the acquisition board starts the signal acquisition and triggers the high-speed camera. This delay was not even constant, making impossible to synchronize those signals. Then, it was necessary to modify the program in order to guarantee a more deterministic delay, according to section 3.2.

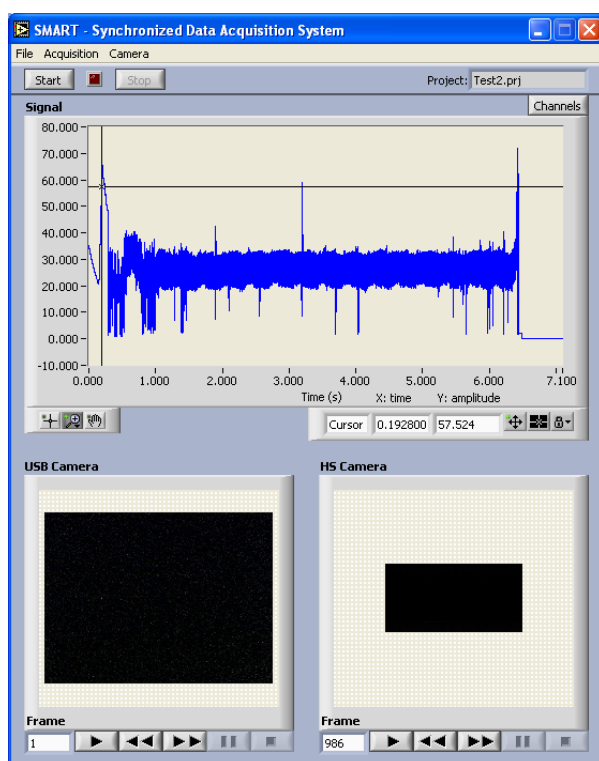


Figure 4.6: Illustration of a shot of the second set of trials - Test2 (there is still no arc welding) - voltage traces (top), USB frames (left bottom) and HS frames (right bottom)

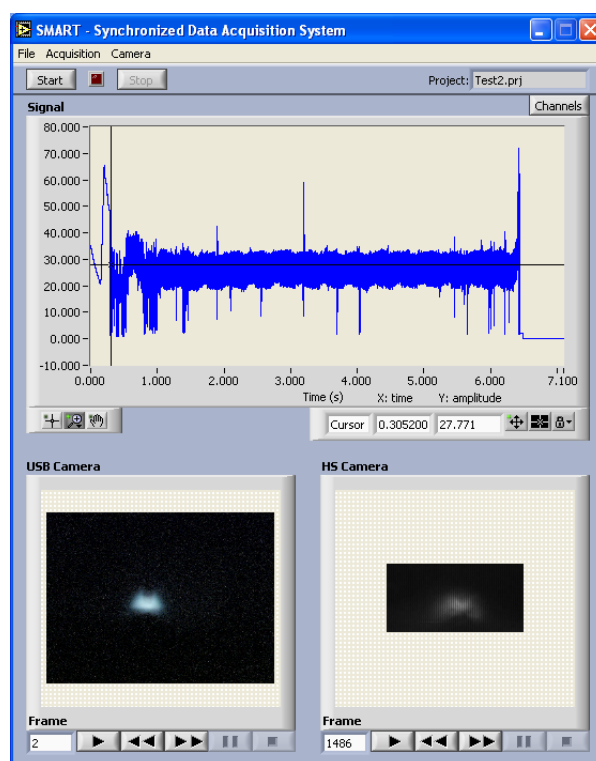


Figure 4.7: Illustration of a shot of the second set of trials - Test2 (there is already an arc welding) - voltage traces (top), USB frames (left bottom) and HS frames (right bottom)

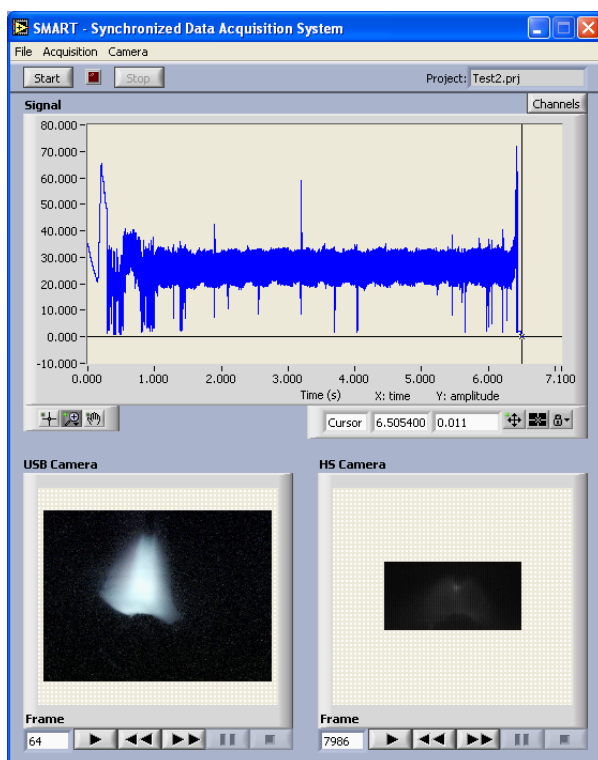


Figure 4.8: Illustration of a shot of the second set of trials - Test2 (the arc welding is being extinguished) - voltage traces (top), USB frames (left bottom) and HS frames (right bottom)

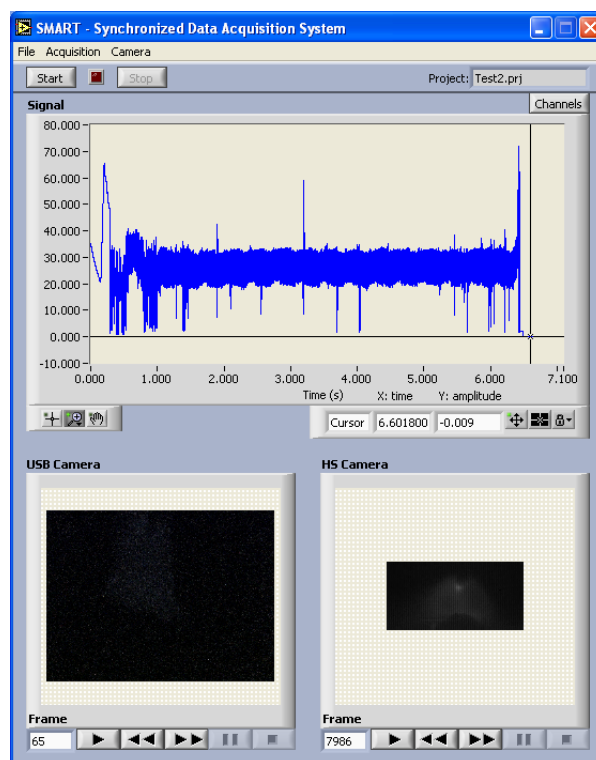


Figure 4.9: Illustration of a shot of the second set of trials - Test2 (the arc welding is already extinguished) - voltage traces (top), USB frames (left bottom) and HS frames (right bottom)

In order to analyse the effect of using different sampling rates for acquisition of signal samples and high-speed camera frames, it was forced the synchronization of these data by considering the delay occurred in each trial. When the sampling rate used for acquiring the signals is not a multiple value of the sampling rate used for acquiring the high-speed camera frames, the accurate of the frame-by-frame analysis decreases. It is because the system calculates the quantity of signal measurements that should be considered at each frame, by dividing the sampling rate used for acquiring signals by the sampling rates used for acquiring frames of USB and HS cameras. If the results are not integer values, there will be an error that propagates frame-by-frame.

4.2 Second set of experimental trials – double wire GMAW

Figure 4.10 shows the rig configuration for the second set of trials, which had the same objective of the first one, although it was performed with double wire GMAW. As it is

possible to see, only one plain carbon steel plate (20mm - thick) was positioned over the carriage (what provides a “plate angle” always equal to 90°), which also moves at a constant speed when it is turned on, by a controller, before starting the data acquisition. The torch head could not oscillate.

The high-speed camera setting did not change, that is, a sampling rate of 5kHz, at a resolution of 256X128 pixels, and a playback rate of 5Hz. A Logitech webcam was used for performing these trials and it was set as the webcam used for performing the first set of trials. Its frames were also acquired at 10fps, with a resolution of 640x480. The diaphragm of the magnify lens was also closed and the same filters were used, as explained in section 3.1.

Concerning the electrical signals, a sampling rate of 25kHz for all trials was used. The low-pass digital filter had already been implemented (as item 3.2 explains) and the configuration of its parameters was cut-off frequency equal to 1000kHz and number of poles equal to one.

The cameras were in the same position but not at the same alignment, being the distance between the torch and the cameras about 700mm.

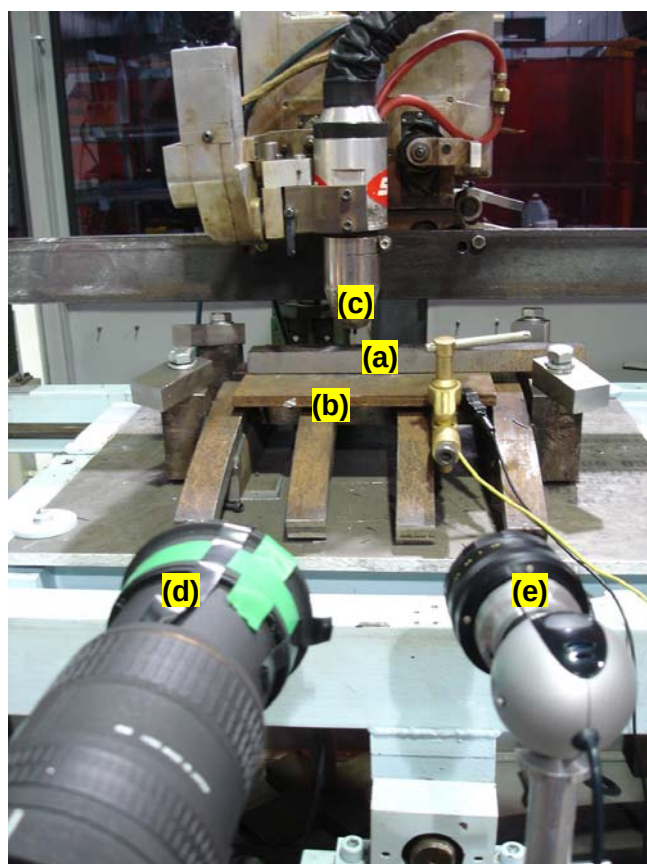


Figure 4.10: (a) test plate, (b) test plate carriage, (c) torch head, (d) high-speed camera and (e) the webcam, in details, illustrating the rig configuration used for doing the second set of trials (tandem GMAW)

Results:

Four trials for this set were performed. In the first one, the arc image acquired by the webcam was not satisfactory. Due to the presence of two wires under a out-of-phase pulsed current, when one arc is turned brighter (pulse current) the other one is turned dimmed (base current) and vice-versa, so the arc image is not very defined, as Figure 4.11 shows. Thus, this first trial was disposed and the webcam was not used for performing the next ones.

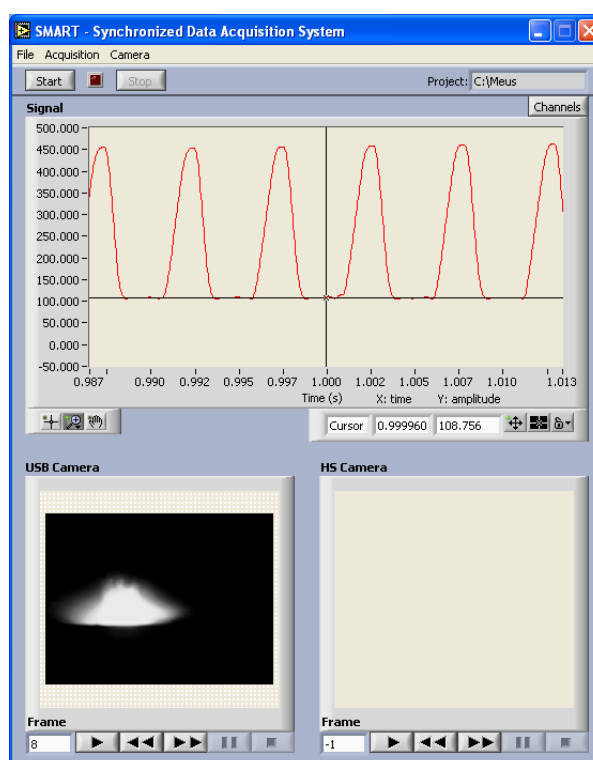


Figure 4.11: Illustration of a shot of the second set of trials - Test 1 (disposed trial) - voltage traces (top), USB frames (left bottom) and disabled HS frames (right bottom)

The modifications implemented in order to make constant the delay explained in section 3.2 were positive. Table 4.2 shows the results obtained by connecting the output that triggers the high-speed camera to one of the input channels of the acquisition board. Then, by acquiring this signal, it would be possible to determine the delay, before going to a real trial, as shown by Figure 4.12. It characterized a simulation of trials, which found a delay value around 0.002650 seconds. After that, bead-on-plate welds were carried out. Table 4.3 shows the results obtained. It is possible to verify the determinism in the delay values. Once the sampling rate normally used for acquiring frames of high-speed cameras in the welding area is around 5kHz, a variation of 0.0002 seconds is acceptable. With this sampling rate, 0.0002 seconds represents 1 frame. Thus, 1 frame can be in advance or delayed, during a frame-by-frame analysis.

Table 4.2: Trigger delay - Simulation of trials

Trial	Continuous Samples Delay (s)	Finite Samples Delay (s)
1	0.002499	0.002650
2	0.002550	0.002650
3	0.002552	0.002649
4	0.002599	0.002652
5	0.002650	0.002798
6	0.002450	0.002599

Table 4.3: Trigger delay - Final tests

Trial	Delay (s)
Test2	0.002509
Test3	0.002600
Test4	0.002597

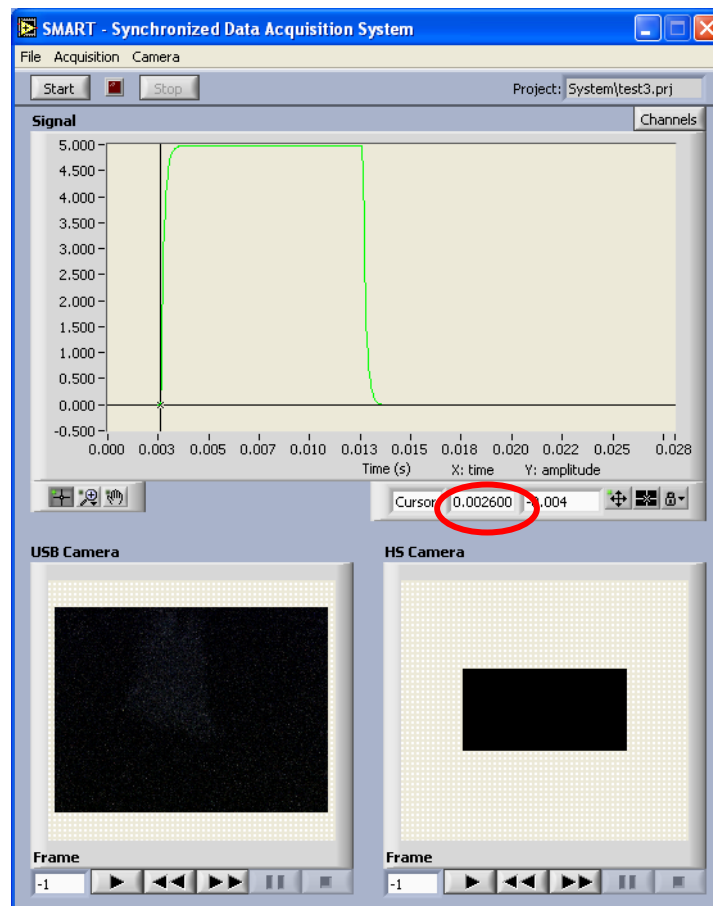


Figure 4.12: Illustration of a shot of the second set of trials - Test 3 (determination of the trigger delay, by simulation) - trigger pulse (top), disabled USB frames (left bottom) and disabled HS frames (right bottom)

A frame-by-frame analysis of the high-speed camera frames show that these frames are adequately synchronized with the electrical signals. When the arc welding of the torch on the right is turned on (Figure 4.13), the cursor on the graph shows a pulse peak of the voltage signal. When it is turned off (Figure 4.14), it is shown a pulse base of that signal. Figure 4.15 and Figure 4.16 show that the same happens for the next peak.

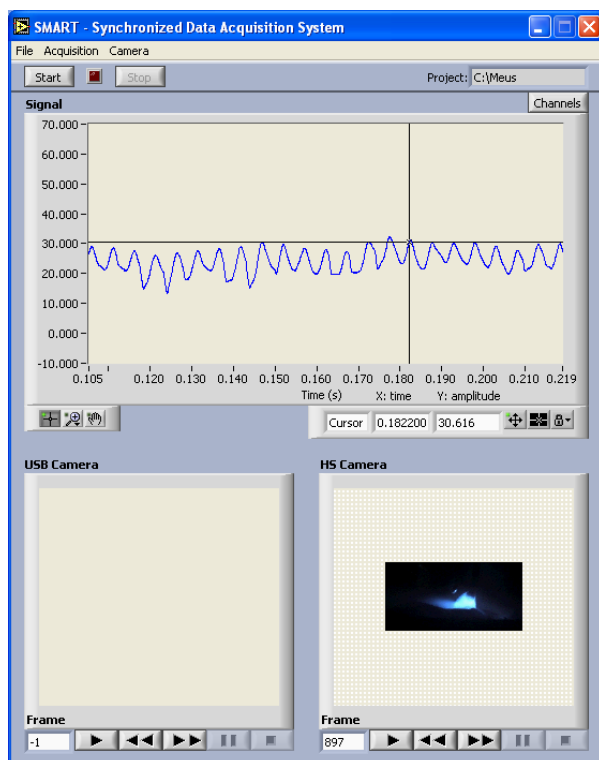


Figure 4.13: Illustration of a shot of the second set of trials - Test 1 (the arc welding is turned on) - voltage traces (top), disabled USB frames (left bottom) and HS frames (right bottom)

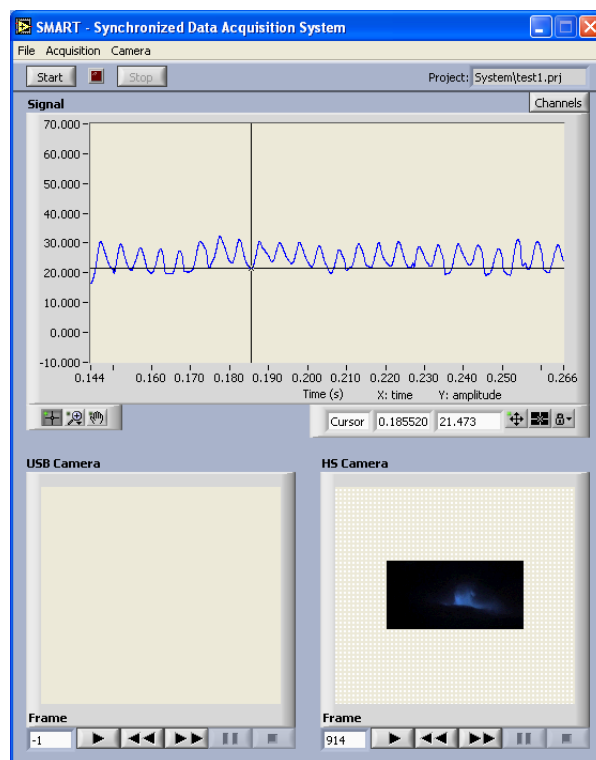


Figure 4.14: Illustration of a shot of the second set of trials - Test 1 (the arc welding is turned off) - voltage traces (top), disabled USB frames (left bottom) and HS frames (right bottom)

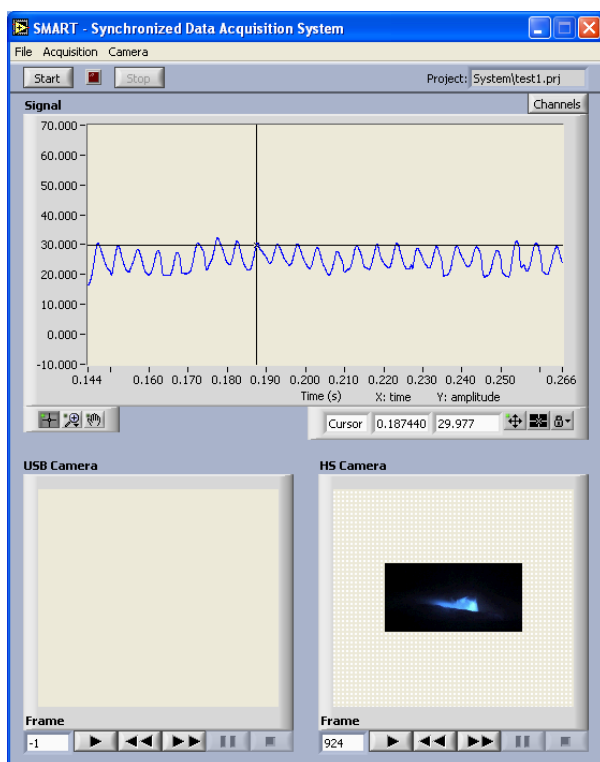


Figure 4.15: Illustration of a shot of the second set of trials - Test 1 (the arc welding is turned on again) - voltage traces (top), USB frames (left bottom) and HS frames (right bottom)

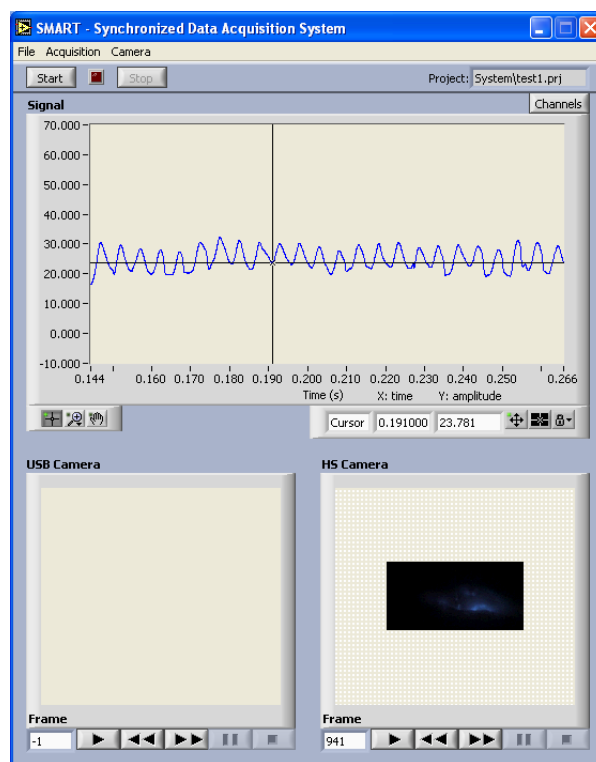


Figure 4.16: Illustration of a shot of the second set of trials - Test 1 (the arc welding is turned off again) - voltage traces (top), USB frames (left bottom) and HS frames (right bottom)

4.3 Third set of experimental trials – RSW

The objective of these trials was to verify the applicability of the system for a different type of welding process. In the RSW process, two metal sheets are clamped together and the spot welding is carried out. There is no presence of arc welding. Thus, besides the synchronization between electrical signals (arc voltage and welding current) and USB camera frames, these trials aimed at to grab the movement of the welding clamp and a circumstantial presence of spatters.

The high-speed camera was not used for performing this set of trials, although, a Labtec webcam was used for acquiring frames at 10fps, with a resolution of 640x480. Since there is no interest on arc length at this time, the default image setting of the webcam was kept and no magnify lens was attached to it.

Concerning the electrical signals, it was used a sampling rate of 1kHz for all trials. The parameters set for the low-pass digital filter were cut-off frequency equal to 500Hz and number of poles equal to one.

The webcam was about 500mm from the welding rig, in such a way that was possible to enclose the welding clamp and the metal sheets.

Eight trials were performed for this trial. It was applied a pressure of 86kgf (2.3kN) for all of them. Table 4.4 shows the duration in cycles of each welding function and the current used for each one. Higher values of current were used for performing the two last trials in order to provoke the presence of spatters.

Table 4.4: Setting welding parameters for the third set of trials

Trial	I_{rms} (A)	Pre-Pressure (cycles)	Pressure (cycles)	Weld 1 (cycles)	Pulse (cycles)	Weld 2 (cycles)
test1	3500	30	30	20	0	0
test2	3500	30	30	40	0	0
test3	3500	15	15	40	0	0
test4	3500	15	15	40	10	40
test5	3500	15	30	40	20	40
test6	3500	15	30	40	20	40
test7	6500	10	5	40	0	0
test8	7500	10	5	30	0	0

Results:

A frame-by-frame analysis of the USB camera frames shows that is possible to observe that these frames are quite synchronized with the current (in red) and voltage (in blue) signals. In the beginning, before executing the pre-programmed functions, the welding clamp was still opened (Figure 4.17). After that, the clamp gets closed (Figure 4.18). Then, when the metal sheets are clamped, the weld cycles start and it is possible to notice the presence of spatters (Figure 4.19). The clamp is kept closed during this time (Figure 4.20). After finishing these cycles the clamp starts to open again (Figure 4.21) and returns to the initial state (Figure 4.22). By running the software, these shots are more defined and that sequence can be better realized.

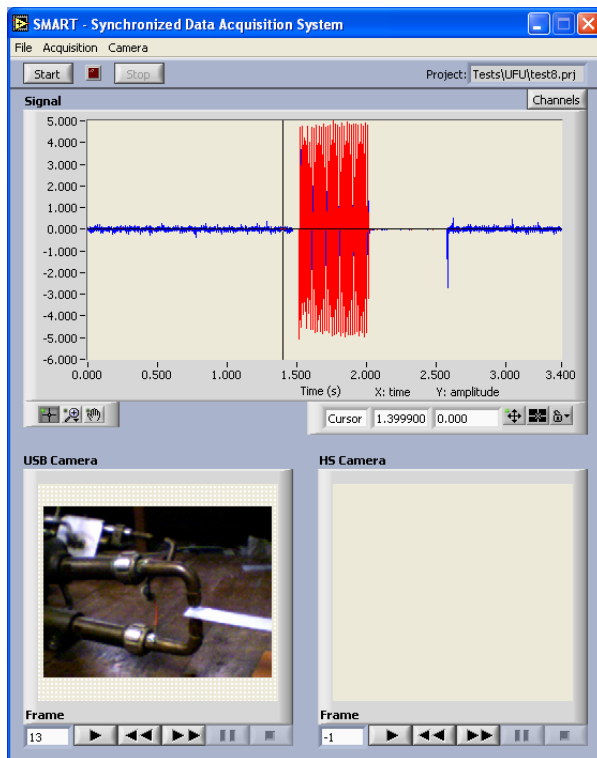


Figure 4.17: Test 8 - shot that shows the clamp still opened - voltage traces (top), USB frames (left bottom) and disabled HS frames (right bottom)

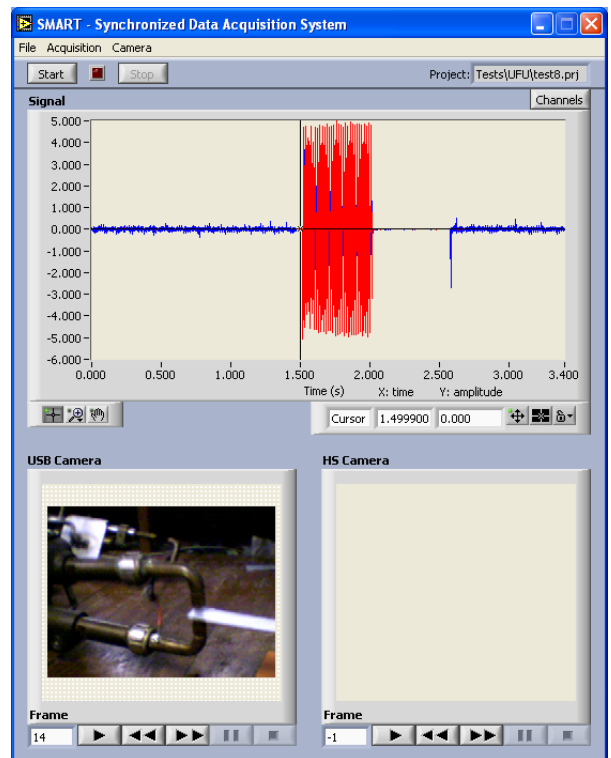


Figure 4.18: Test 8 - shot that shows the clamp getting closed - voltage traces (top), USB frames (left bottom) and disabled HS frames (right bottom)

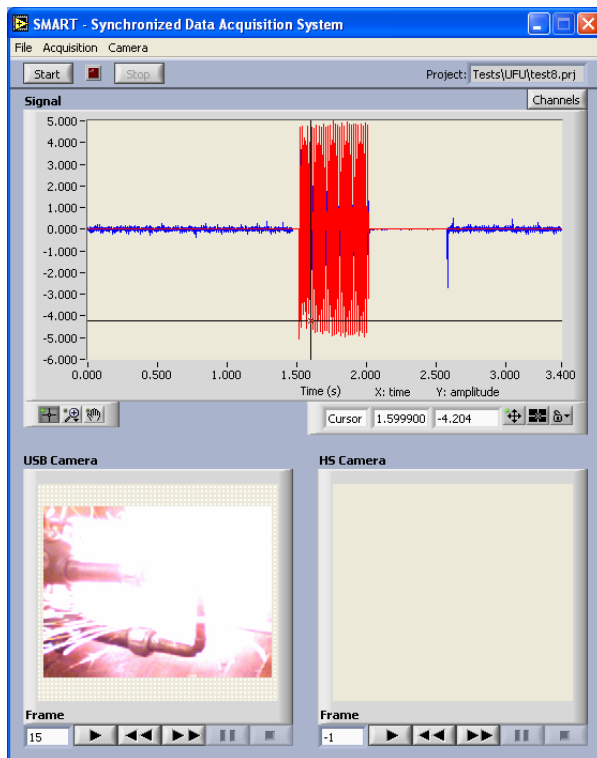


Figure 4.19: Test 8 - shot that shows the metal sheets getting clamped and the presence of spatter - voltage traces (top), USB frames (left bottom) and disabled HS frames (right bottom)

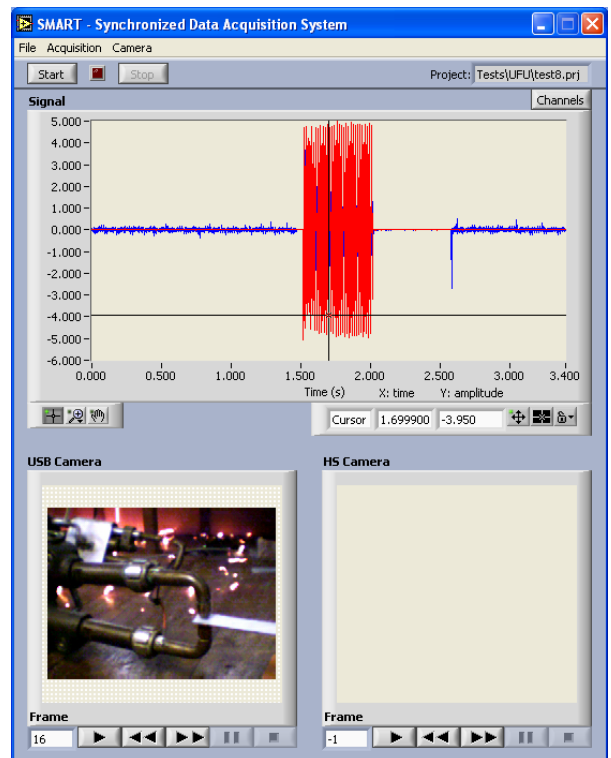


Figure 4.20: Test 8 - shot that shows the metal sheets clamped during the weld cycles and the presence of spatter - voltage traces (top), USB frames (left bottom) and disabled HS frames (right bottom)

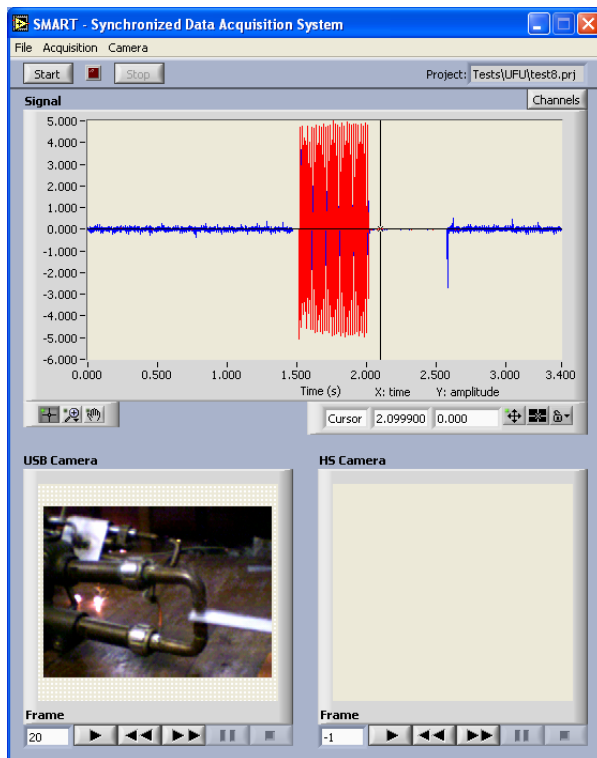


Figure 4.21: Test 8 - shot that shows the clamp getting opened after the weld cycles - voltage traces (top), USB frames (left bottom) and disabled HS frames (right bottom)

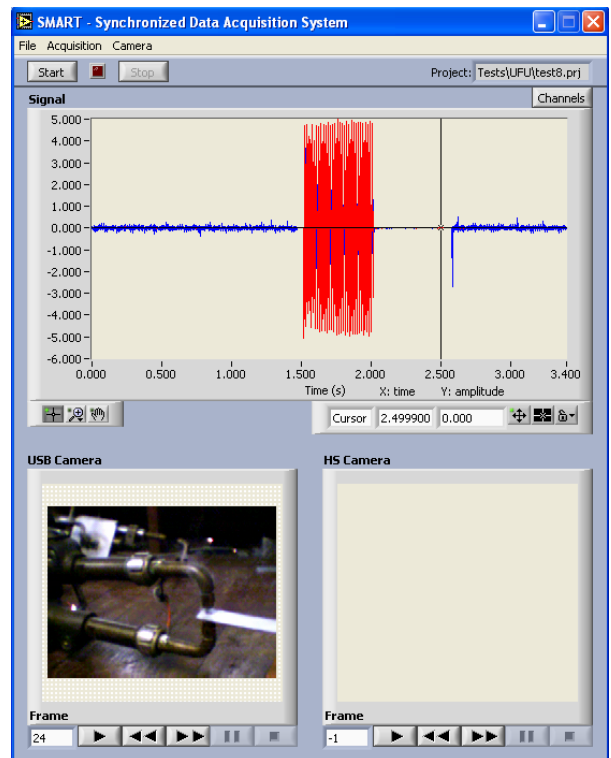


Figure 4.22: Test 8 - shot that shows the clamp back to the initial position - voltage traces (top), USB frames (left bottom) and disabled HS frames (right bottom)

CHAPTER 5

DISCUSSION

The focus of this work was on the synchronism between electrical signals and images, which is not a trivial task. These signals are acquired by different devices which work by different principles. Thus, to find a solution able to integrate all of them it was not that simple. It is believed to be a first step for future developments.

In this work, the synchronism consists on acquiring a buffer of electrical signals, an USB camera frame and a buffer of high-speed camera frames, at regular intervals of time. Thus, it was projected a system responsible for acquiring signals and USB camera frames, besides triggering the high-speed camera, which acquires frames independently.

A visual analysis of the signals and the USB camera frames can be done while the data acquisition takes place, that is, an online analysis. After it finishes, the high-speed camera frames can be downloaded into the computer. Then, these frames, the acquired signal samples and the acquired USB camera frames can be used for performing an offline analysis that relates all these data.

An ideal behaviour of the system is illustrated by Figure 5.1. The acquisition of frames and signal samples had to start at the same time (0ms), which means no delay among the acquired data. Besides, each buffer of signal samples and USB camera frame had to be immediately read after this frame became available. Webcam is the type of USB camera used for performing this work. It usually provides a sampling rate of up to 30fps. It means that at every 33.33ms (1/30), a different frame would be, in theory, available for reading, but this rate is not very accurate. According to the image resolution of the frames, for instance, 640x480, this rate decreases to 15fps.

For each frame read and plotted, a buffer of signal samples must also be read and plotted. Plotting usually takes a considerable time and the more frequent it has to be done, the slower the system becomes. Thus, in order to avoid bad performance of the system and considering a desirable image resolution of 640x480, a sampling rate of 10fps was adopted. It means that at every 100ms (1/10), a different webcam frame is read, performing the real behaviour of the system, which is also illustrated by Figure 5.1.

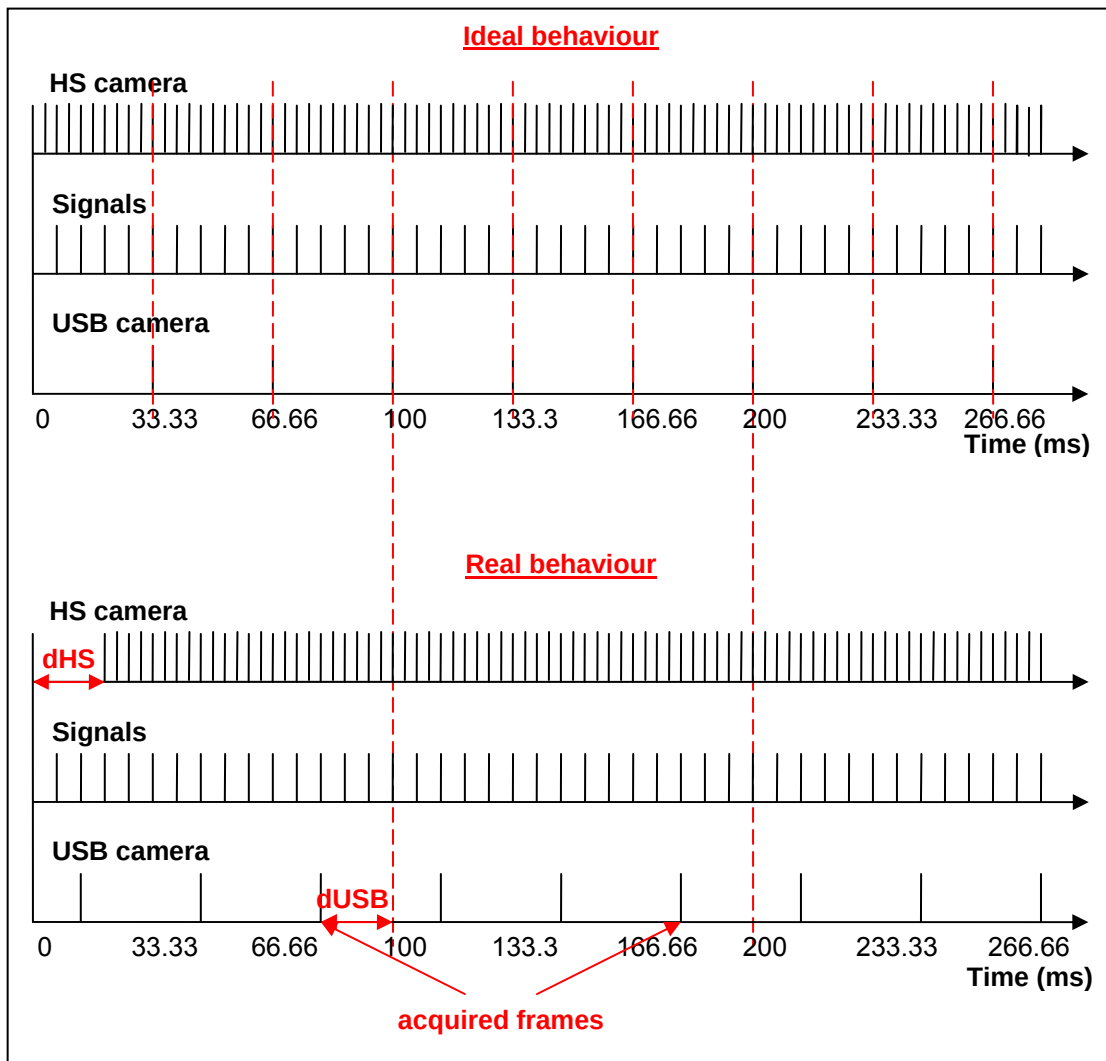


Figure 5.1: Illustration of the behaviour of the system along the time

According to the real behaviour of the system, after starting the signal acquisition, the high-speed camera is triggered. However, there is a delay (d_{HS}) between these two moments. Moreover, when an USB camera frame becomes available, it cannot be immediately read, and another delay is presented (d_{USB}), as mentioned before.

If d_{HS} is deterministic, it is possible to shift the HS camera frames and provide synchronism when doing the offline analysis. In this case, determinism means that d_{HS} has the same value every time the acquisition runs, under any circumstance. It is not very simple to do, since a multitasking operating system does not offer determinism. However, establishing an acceptable limit for the variation of the delay and triggering the high-speed camera immediately after starting the signal acquisition, it does not make a serious matter.

In the other hand, the effect of the delay d_{USB} cannot be treated. Since the webcam tries to equilibrate the quantity of brightness when it starts to acquire the first frames, the sampling rate is very irregular during this time and these first frames are very bright and not

good for analysis. In order to avoid this situation, the system starts the webcam, waits for a while, starts the signal acquisition and triggers the high-speed camera. After that, at every 100ms, the last available webcam frame and a buffer of signal samples are read and plotted. Thus, dUSB does not present the same value every time the signal acquisition starts. A smaller irregularity is also presented along the acquisition of the subsequent frames. Thus, the acquired webcam frame cannot be related to only one signal sample, but to the entire buffer of signal samples. A solution to increase the accurate of the webcam's sampling rate would be to transfer the responsibility of grabbing each frame, from the webcam to the computer.

Then, the way as the system is currently working, makes possible to do an offline analysis of signals and images. It can be done by visualization of buffers of signal samples, USB camera frames and HS camera frames, all of them related one-by-one. However, more improvements can be done in order to increase the possibilities of applications for this work.

CHAPTER 6

FUTURE DEVELOPMENTS

The arc length is directly related to the arc voltage. Then, an arc length control is usually done by correcting variations in the arc voltage value. For this purpose, an arc voltage reference that provides the desirable arc length must be set. It is done by visualizing the arc length. An algorithm could be developed in order to detect the arc length by processing the USB camera frames. Having the correspondent arc voltage at each frame, it would be possible to set its reference value automatically.

If a data transmission was implemented, the adjustment of these welding parameters could also be done by distance. In this case, even if the arc length could not be detected by an algorithm, the user could remotely see the arc welding and adjust its length by changing the arc voltage, also by distance.

Another improvement of the system would be to increase the sampling rate of the webcam frames. As explained in Chapter 5, increasing this rate, the system becomes slower, since the data plotting becomes more frequent. However, a compromise could be established. During the acquisition, the data could be plotted using the current rate of 10fps, but it could be stored at a higher frequency, of 30fps, for example. Thus, it would be possible to do an online analysis in order to monitor a weld and immediately act on the system by distance (moving the camera, for example), as well as, more details could be seen during an offline analysis.

Different types of USB cameras could be performed. An infra-red camera, for example, could be used for detecting spatters during a weld. Besides that, more than one USB camera could be integrated to the system, offering a better visual analysis of the welding phenomena.

The sound emitted by the arc would be another interesting aspect for remote monitoring. Listening to this sound, the feeling of the professional working away is increased. Besides that, the metal transfer mode could be identified by audio signal analysis. The acquisition of this signal would be possible if an amplifier was correctly built for it and connected to the acquisition board of the system. The audio board of the computer could not be used for acquiring that signal. Since this device is controlled by the operating system, its synchronization with the other devices (acquisition board, USB camera, HS camera) would

not be possible and would decrease the performance of the system. Moreover, the sampling rates provided by this device could not be suitable for audio signal analysis, since they are fixed at few possible values.

The sampling rate of the signals also affects the performance of the system. Higher rates means more points being plotted at each interval of time and more computer memory has to be allocated for this purpose. Then, even if the acquisition board manages to provide a high sampling rate, if the computer does not manage to read the data and plot it on the graph more quickly, the performance of the system decreases. Thus, it is necessary to use powerful computers for higher sampling rates.

In order to provide a more consistent synchronism among the signals, a master clock could be used for all devices. Since every acquisition board of National Instruments is very accurate, its clock could be used for the high-speed camera and the webcam as well. However, it would be necessary to use a clock divider for the webcam and find a way to take its control. Thus, the three devices would acquire under the same clock source.

A last concern is about LabVIEW, the programming language used for performing the system. In spite of being quite easy to program with this language, the documentation about its functions is still poor. National Instruments has headquarters around the world to help the developers, but most of time, it is not enough for not ordinary developments. These circumstances make longer the development of the system. In order to save time when developing LabVIEW applications, it is advisable to attend appropriate courses for training offered by National Instruments. In some cases (basic), it can be done on internet for free. In other cases it has to be paid and it is expensive.

CHAPTER 7

CONCLUSIONS

This work shows that it is possible to acquire electrical signals and images synchronously in an integrated system. The introduction of low-cost cameras was feasible, by providing images suitable for image analysis. Using the existent resources in the laboratory, it was possible to build a prototype for the hardware with enough flexibility and suitable for different types of welding processes. Eventually, a portable format for the system was developed, which is more appropriate to the different types of work environment.

The system was tried in single wire GMA welding with reasonable success. However, the system is still incomplete and limited. Concerning the incompleteness, the arc length still needs to be determined by an algorithm to be developed for this purpose. When tried with double wire GMA welding the results were not so good, showing some limitations. Due to arc energy alternation, the acquisition rate of the USB camera is not high enough to focus on only one wire.

When tried in resistance spot welding, the system was quite successful, too. It was possible to visualize the movement of the welding clamp and the presence of spatters during the weld. Data transmission still needs to be integrated to the system in order to provide a remote monitoring of such events. Thus, the monitoring could be centralized and the presence of a specialist in the plant would not be necessary.

However, a list of possible improvements were carried out, pointing out the design of a more comprehensive system, which can be used to enlarge the field of applications. In order to integrate this work to an automated welding system for pipeline repair, for example, it is still necessary to develop the control of the welding parameters that would take the data provided by this work.

Therefore, the system developed in this work is believed to be a first step for future developments. From this point, it is possible to integrate other resources and implement different applications in the welding area.

CHAPTER 8

REFERENCES

1. ALFARO, S. C. A.; VARGAS, J. H.; VILARINHO, L. O.; WOLFF, M. A. High Speed Images of Resistance Spot Welding Synchronized with Electrical Signals. **18th International Congress of Mechanical Engineering**. Brazil, p. 8, 2005.
2. ARCON WELDING INC. **Welding Process**. Available on <www.key-to-steel.com>. Access date: 15/01/2005.
3. BÁLSAMO, P. S. S.; VILARINHO, L. O.; VILELA, M.; SCOTTI, A. Development of an Experimental Technique for Studying Metal Transfer in Welding: Synchronized Shadowgraphy, In: INT. J. FOR THE JOINING OF MATERIALS, 2000, The European Institute for Joining of Materials (JOM), Denmark, v. 12, n. 1, pp. 1-12 (ISSN 0905-6866).
4. CARY, H.B. **Arc Welding Automation**. New York: Marcel Dekker Inc, 1995. p. 527.
5. DROUET, M.G; NADEAU, F. Acoustic Measurement of the Arc Voltage Applicable to Arc Welding and Arc Furnaces. **Journal of Physics E: Scientific Instruments**. Canada, v. 15, n. 3, p. 2, 1982.
6. FERRARESI, V. A.; FIGUEIREDO, K. M.; ONG, T. H. Metal Transfer in the Aluminium Gas Metal Arc Welding. **Journal of the Brazilian Society of Mechanical Science & Engineering**. Brazil, v. 25, n. 3, p. 6, 2003.
7. GILSINN, J., et al. A Welding Cell That Supports Remote Collaboration. In: NINTH INTERNATIONAL CONFERENCE ON COMPUTER TECHNOLOGY IN WELDING, 1999, Detroit. p. 7.
8. LI, P.; ZHANG, Y. Robust Sensing of Arc Length. **IEEE Transactions on Instrumentation and Measurement**. v. 50, n. 3, p. 8, 2001.

9. MAEDA, T.; ICHIYAMA, Y. Development of Adaptive Control of Arc Welding by Image Processing. In: NINTH INTERNATIONAL CONFERENCE ON COMPUTER TECHNOLOGY IN WELDING, 1999, Detroit. p. 11.
10. MANSOOR, A.M.; HUISSOON, J. P. Acoustic Identification of the GMAW Process. In: NINTH INTERNATIONAL CONFERENCE ON COMPUTER TECHNOLOGY IN WELDING, 1999, Detroit. p. 12.
11. MASON, A., et al. Real Time Image Processing of Electrode Profile in Resistance Spot Welding. In: GERI ANNUAL RESEARCH SYMPOSIUM 2005, 2005, Liverpool.
12. NATIONAL INSTRUMENTS INC. **Data Acquisition Fundamentals**, in APPLICATION NOTE 007. Available on <www.ni.com>. Access date: 08/02/2005.
13. NATIONAL INSTRUMENTS INC. **Intuitive Graphical Programming Language for Engineers and Scientists**. Available on <www.ni.com>. Access date: 06/03/2005.
14. NATIONAL INSTRUMENTS INC. **SCC Signal Conditioning Overview**, in PORTABLE MODULAR DAQ SYSTEMS. Available on <www.ni.com>. Access date: 20/02/2005.
15. NATIONAL INSTRUMENTS INC. **Signal Conditioning Fundamentals for Computer-Based Measurement Systems**, in APPLICATION NOTE 048. Available on <www.ni.com>. Access date: 20/02/2005.
16. THE LINCOLN ELECTRIC COMPANY. **The Procedure Handbook of Arc Welding**. Cleveland: Lincoln Electric, 1994. ISBN 9994925822.
17. WIDGERY, D.; BLACKMAN, S. **Pipelines for Stranded Gas Reserves: Cutting the Cost**, 2001. Cranfield University, UK, 2001. p. 11.
18. YAPP, D. **Trends in Data Acquisition for Weld Monitoring**. Cranfield University, UK, 2004. p. 14.