MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Acoustic feedback of a VR welding simulator

Sorrentino, Francesco[1]
Pascale, Aniello[2]
Pirozzi, Raffaele[3]
Immensive srls
Parete, Italy

Masullo, Massimiliano[4]
Maffei, Luigi [5]
Toma, Roxana Adina[6]
Department of Architecture and Industrial Design, Università degli Studi della Campania "Luigi Vanvitelli"
Abbazia di S. Lorenzo ad Septimum, Aversa (CE), Italy

ABSTRACT

Today the use of virtual reality for training and simulation of complex operations has become actuality with the Industry 4.0. Performing real actions in controlled environments allows learning in a quick and effective way, reducing the safety risk conditions and containing costs for materials or personnel.
Nevertheless, recreating real environmental conditions in terms of acoustic stimuli may help the trainee to carry out operations and perceive a real correspondence between action and sound. This is the case of welding procedures, where the sound of welding may help the worker to judge the quality of the welding itself. Popping or jerky noises for example may indicate an inconsistent arc or improper amperage. This work aims to assess the contribution of the acoustic feedback in welding processes by carrying tests out with a virtual welding simulator and involving expert welders. Welding simulation sessions with different amperages have been proposed to welders, in order to evaluate the quality of the acoustic stimulus in the VR environment.

Keywords: Welding, Virtual Reality
I-INCE Classification of Subject Number: 79

[1] francescosorrentino@immensive.it
[2] aniellopascale@immensive.it
[3] raffaelepirozzi@immensive.it
[4] massimiliano.masullo@unicampania.it
[5] luigi.maffei@unicampania.it
[6] roxanaadina.toma@unicampania.it

1. INTRODUCTION

In the last decades, Virtual Reality (VR) is progressively being used as a training tool in different application fields. The presence and immersion [1-3] of people into a virtual space, where they are able to interact with the surrounding environment creates a great opportunity for training skills. VR allows making mistakes in the virtual world, avoiding to harm anything or anyone in the real world. In this way, a trainee can experience several stress-free learning activities gaining skills more easily and measuring his progresses over time.

Firsts VR applications for training purposes took place in the military forces, where the technology was used for training soldiers in combat situations. VR is also used in health care, hospitals and surgery, for example, to help surgeons learning how to conduct an operation, before they have to operate in real life. In the industry sector, VR gives the opportunity to trainees to face most dangerous or critical working activities, limiting dramatically the costs and the risks of the real working activity. Among them welding activities took advantages from VR to improve the training effectiveness.

The traditional welding skills training has consumed a lot of manpower and material resources because of the high cost of material consumption, the difficulty of operation, the long training period and the pollution to the environment. Since 2004, welding simulator system has been created for simulating gas metal arc welding for use in training human welders [4]. The first system versions comprised of real welding torch attached to a force feedback device, a head-mounted display, a 6 DOF tracking system for both the torch and the user's head, and external audio speakers.

In order to enhance the perception of a real welding procedure, the addition of realistic simulated sounds, smoke, and sparks represents an important feature to help the trainee to carry out the operations by perceiving a real correspondence with the real world [5]. This is particularly true for the audio stimuli: in fact, acoustic feedback plays an important role for expert welders when performing Gas Metal Arc Welding (GMAW). According to Tarn, professional welders agree that arc-sound gives information concerning the process that the sight does not provide [6]. In GMAW, sound is generated from three sources: the arc, gas shielding and welding equipment. Welding sound reflects the behaviour of the arc and the welding pool, so the sound is an important feedback quantity for detecting arc stability, and welding quality [7]. Beside the information related to the arc column, the acoustic signals produced by the GMAW contain information also about the behaviour of the molten pool and droplet transfer [8]. Specifically, Grad [8] indicated that from acoustic signals it is possible to assess process stability and detect welding conditions resulting in weld defects: indeed, the arc sound exhibits distinct characteristics for each welding situation.

In order to verify the contribution of the audio stimulus on the perception of the global welding process, a virtual welding simulator, "Weld-VR", has been used to reproduce and assess different GMAW amperage conditions in a test involving expert welders.

2. METHODOLOGY

The virtual welding simulator has been used to reproduce the GMAW process at one visual condition (V0), corresponding to a single weld pool, and combining it with three audio stimuli, related to different current intensity levels: AL) Low: "Short Arc"; AM) Medium: "Intermediate"; AH) High: "Spray Arc".

Combinations of visual and audio conditions have been used during virtual welding tests to assess the ability of expert welders to recognize specific welding

conditions and to collect judgments about audio, visual and global aspects of the virtual welding experience.

2.1 Weld - VR software

Weld-VR is a proprietary software, developed by Immensive, that uses common VR mass-market hardware joint with real welding torches for training students on welding processes in total safety. The system detects user movements with high precision and it monitors the user's ability with various welding positions and typologies. Weld-VR provides the users with an immersive experience characterized by a high quality of the surrounding environment. In particular, the weld pool is recreated by simulating the physical droplet transfer (Fig. 1); as far as the acoustic stimuli, the software provides stereophonic audios commonly reproduced by headphones. The visual stimulus (V0) and the corresponding weld pool are related to the "Intermediate" amperage condition (AM).

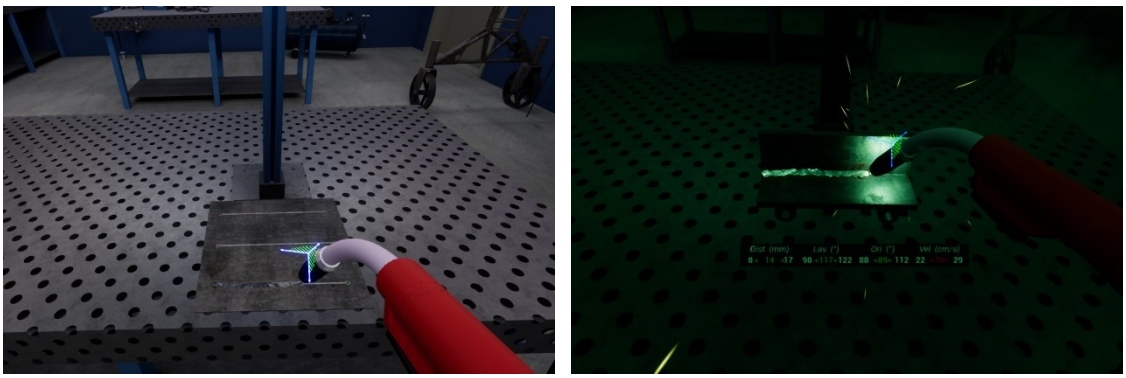

Figure 1 – Images of Weld-VR software during GMAW processes

2.2 Audio material

Audio recordings have been carried out in an industrial workshop with the assistance of expert welders. A 4-channel recording system SQobold (Head Acoustics) and a binaural headset has been used to carry out audio recording during different welding processes. Binaural recordings allowed to consider the effects of the operator head and of the welding shield on the existing sound field.

Figure 2 - Audio recordings of GMAW processes

Three audio recordings of the GMAW process have been carried out. They represent low (AL), medium (AM) and high (AH) current intensity levels. The amperages

of each level are showed in Table 1. Table 2 and Figure 3 show the A-weighted average sound pressure levels and the spectrogram (left/right channel) as a function of the GMAW conditions elaborated by Artemis.

	Welding typology	**Current Intensity [A]**
AL	Short arc	40
AM	Intermediated condition	80/100
AH	Spray arc	200/300

Table 1 – GMAW *conditions*

	AL	**AM**	**AH**
L95(A)	83,0	86,5	89,1
L(A)	87,0	88,1	91,1
L5(A)	89,5	89,5	92,5

Table 2 – Average Sound Pressure Levels for GMAW *conditions*

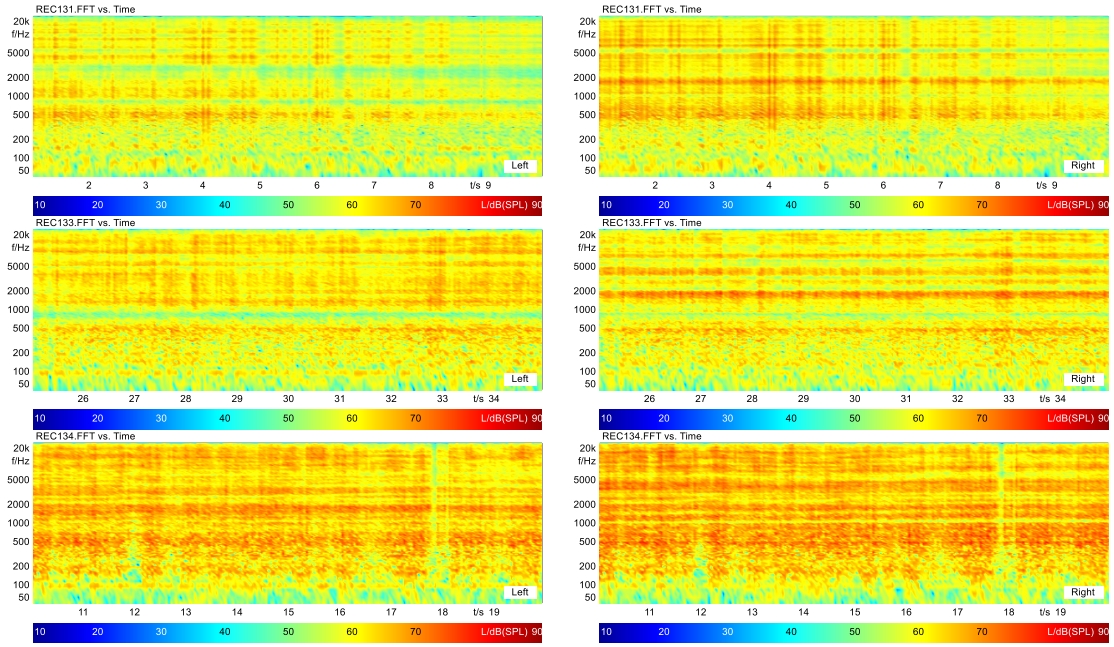

Figure 3 – Left and right spectrograms for GMAW *conditions*

Afterwards, the recorded audio signals have been implemented in the Weld-VR software and then played back when the torch was in touch with the weld seams. Moreover, fade-in and fade-out effects have been introduced to emulate realistic audio reproduction. The sound pressure levels of the audio signals, as reproduced by the whole system (workstation, software, reproduction headphones), have been calibrated by means of a Mk1 Cortex mannequin connected to a Symphonie 01dB card.

2.3 Questionnaire

To assess on the welding process experienced in Weld-VR, a subjective questionnaire has been prepared. It investigates on the subjects' ability to distinguish among AL, AM and AH conditions (Q0) and on the similarity of the auditory (sound intensity, sound spectrum, sound spatial localization), visual (weld pool) and global

experience of the virtual welding with the real one. Table 3 shows the English translation of five questions administered during the test session.

	Not at all	Slightly	Moderately	Very	Extremely
Q1 - How similar to real is the weld pool in the virtual simulation?	☐	☐	☐	☐	☐
Q2 - How similar to real is the sound intensity in the virtual simulation?	☐	☐	☐	☐	☐
Q3 - How similar to real are the sound spectral characteristics in the virtual simulation?	☐	☐	☐	☐	☐
Q4 - How accurate is the sound spatial localization in the virtual simulation?	☐	☐	☐	☐	☐
Q5 - How similar to real is the global welding process in the virtual simulation?	☐	☐	☐	☐	☐

Table 3 – Questionnaire

3. TEST SESSION

The test has been carried out by 5 expert welders (Fig. 4) that used the Weld-VR system in order to experience the 3 prepared GMAW conditions. The tests were performed in a factory hall. Before the test, each welder had a short training session aiming to make him confident with the VR tool.

Figure 4 – Virtual reality test session

4. RESULTS

By analysing the answers related to Q0 (Tab. 4), it is possible to observe that, in general, welders show a high ability to distinguish among the three different GMAW conditions, and the global recognition rate is high (more than 85%).

	Q0-Recognition rate
AL	4/5
AM	5/5
AH	4/5
Global	13/15

Table 4 – Q0 results

By considering the answer, separately, for each condition, it can be noted that for the AM condition, the only one that shows a correct correspondence between audio and video stimuli, all the welders were able to recognize the proposed amperage condition. In the other two conditions (AL and AH), four welders have been still able to distinguish the shown amperage condition by relying their judgement just on the audio feedback.

Regarding the similarity questions, the results have been normalized, as it can be observed in Tab. 5.

	Q1 Weld pool quality	Q2 Sound intensity	Q3 Sound spectrum	Q4 Sound spatialization	Q5 Global welding process
AL	50%	81%	88%	100%	88%
AM	88%	94%	94%	100%	88%
AH	56%	69%	69%	100%	75%
Global	65%	81%	83%	100%	83%

Table 5 – Average rating of welders' answers

Generally, it may be observed that the processes show high scores for all aspects investigated (higher than 75%), excepting for the visual aspect (weld pool quality, Q1). Moreover, it is noted that welders consider perfectly similar to the real the sound spatial localization (Q4) in each one of the three simulation.

The data for each welding conditions are shown in Fig.6. It can be immediately observed that AM condition shows the best score among the three welding conditions, with a similarity judgement higher than 85% for all dimensions of the experience (visual, auditory and global). The coherence between the auditory and visual stimuli of AM seems could be lead to a positive perception of the welding process.

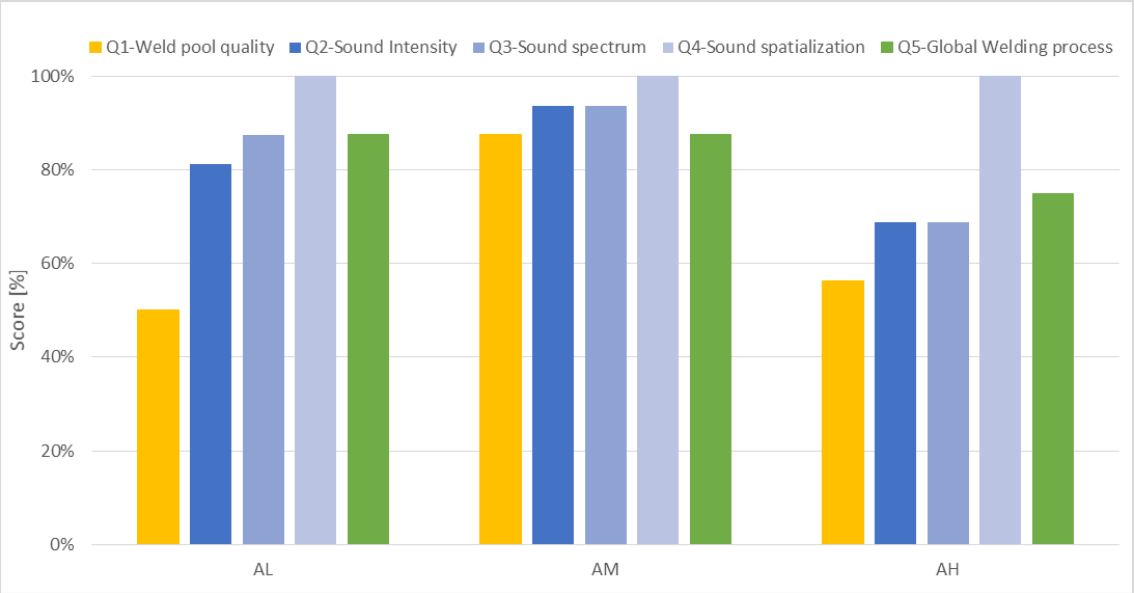

Figure 6 – Test session

As far as the other two conditions, it is possible to observe that weld pool quality (Q1) shows the worst score in the similarity judgement, as expected. Nevertheless, it

seems that this aspect does not affect, alone, the perception of the global welding process (Q5), that appear to be influenced by the sound character (sound intensity, Q2; sound spectrum, Q3) of the audio stimuli. This is particularly true for the AL condition, where despite the low rating for the weld pool quality, the global judgement on the experience appears highly positive.

5. CONCLUSIONS

This study aimed to investigate the importance of the acoustic feedback contribution in the welding processes. For this scope, an experiment has been carried out with expert welders using a virtual welding simulator, by fixing the weld pool visual stimuli and combining it with three different audio stimuli corresponding at as many GMAW amperage conditions.

Preliminary results highlighted that expert welders show high abilities in recognition of the different virtual welding amperage condition when they rely on the audio contribution of the welding process. This ability has been confirmed in the similarity questions provided to the participants, that showed good results for all visual, auditory and global aspects at the intermediated amperage condition (AM). Sound character has showed to have a potential influence on the global perception.

6. ACKNOWLEDGEMENTS

We acknowledge gratefully the welders of the companies Parricelli srl, Piscitelli Infissi snc and TriboTech srl for having contributed at this paper by participating in the test session and our Giovanni Ciampi for his kind support.

7. REFERENCES

1. Mihelj M, Novak D, Begus S (2014) Interaction with a virtual environment. Virtual Reality Technol Appl. Springer, Dordrecht, pp. 205–211

2. Iachini T, Coello Y, Frassinetti F, Senese VP, Galante F, Ruggiero G (2016) Peripersonal and interpersonal space in virtual and real environments: effects of gender and age. J Exp Psychol 45:154–164

3. Sanchez-Vives M, Slater M (2005) From presence to consciousness through virtual reality. Nat Rev Neurosci 6:332–339

4. K. Fast, T. Gifford, R. Yancey, "*Virtual training for welding*", In Proceedings of the 3rd IEEE/ACM International Symposium on Mixed and Augmented Reality, IEEE Computer Society, 298-299 (2004)

5. C. Choquet, "*Arc+: Today's virtual reality solution for welders*" Internet Page, 1-6 (2008)

6. J. Tarn, J. Huissoon, J. "*Developing psycho-acoustic experiments in gas metal arc welding*", In Proceedings of Mechatronics and Automation, IEEE International Conference 2, 1112-1117, (2005).

7. M. Čudina, J. Prezelj, I. Polajnar, "*Use of audible sound for on-line monitoring of gas metal arc welding process*", Metalurgija, 47(2), 81-85 (2008)

8. L. Grad, J. Grum, I. Polajnar, J.M. Slabe, "*Feasibility study of acoustic signals for on-line monitoring in short circuit gas metal arc welding*", International Journal of Machine Tools and Manufacture, 44(5), 555-561, (2004)