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Situational Awareness Oriented Interfaces on Human-Robot Interaction for Industrial Welding Processes

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Abstract: Safety, efficiency and effectiveness are important characteristics for human-robot interaction in a factory. So, workers and operators are exposed to challenges of interacting with these systems, in particular with welding robots. Considering the complexity of the industrial context and of the welding process itself, an important factor for the operator is "to understand what is happening" or to obtain situational awareness (SA). The SA increases decision-making capacity, reduces errors, and adds features to improve the human-robot interface (HRI). In order to integrate SA into interfaces for human-robot interaction, this work proposes the mapping of important aspects of SA for the welding process, based on a literature review and a case study to identify SA on interfaces for HRI. Finally, comments which aspects should be included in situational awareness oriented interfaces in order to provide more intelligent interfaces.

Keywords: Human-Robot Interaction, Situational Awareness, Intelligent Interface.

1. INTRODUCTION

With the increase of technological changes, the complexity of industrial processes in robotic welding demand intelligent interfaces for human-robot interaction. An important characteristic to be acquired by welders and robots is the situational awareness (SA) or the "understanding of what is happening on the environment" during the welding operation. The increase of SA on environment elements helps rising the cognitive load for decision making in the right time and place, providing more intelligent levels of automation. According to Endsley (2011), the SA increases the decision-making capacity, reducing the occurrence of errors and significantly increasing the safety, efficiency and effectiveness of systems.

Operators are exposed to the challenges of interacting with larger data volume and systems, moreover different levels of automation are performed remotely. In this sense, interfaces for human-robot interaction (HRI) should be more efficiently designed in order to make its communication simpler for users (Argall and Aude, 2010). It is also important to study how and when the various types of robotic behavior's should be organized and presented to users (Kim et al., 2009).

In this context, the user interfaces have the important function of contributing to human interaction with robots. Among the tasks performed in industry, welding processes are paramount and require highly skilled workers, where minor imperfections in welding can lead to serious consequences. The use of robots guarantees important benefits for the quality of welding processes (Siciliano and Khatib, 2007).

HRI systems currently used in the industry provide support for users to take into account the purpose of the procedures from a technical point of view. However, they generally do not offer help for other relevant issues such as economic, legal, ethical and political. In this sense, the SA aims at providing a better understanding of the situation as a whole. The SA absence can produce an incomplete or erroneous condition which can cause problems and accidents (De Oliveira, 2016).

This work proposes the understanding of SA aspects required by a user who works with robotic welding in industrial environments. For this, it is presented the SA mapping about the environment of industrial robotic welding. The methodology consists of literature review about definitions and levels of human-robot interaction for a good situational awareness. Then a case study to identify the SA in interfaces for HRI is developed. Finally, comments which aspects should be included in situational awareness oriented interfaces in order to improve a human-robot interaction.

2. LITERATURE REVIEW

An industrial robot can be understood as a programmable machine whose main function is to manipulate parts or perform tasks (RIVIN, 1988). In the beginning robots were used in the industry to relieve humans from the risk of dangerous tasks. However their use today is related to the most diverse human needs (Garcia et al., 2007). Although these systems continue to evolve, completely autonomous systems are still far from being widely used. So it is necessary that human beings monitoring these systems intervene when necessary (Scholtz, 2002).

In the context of robotics, user interfaces have the important function of contributing to humans having a better interaction with robots. Human-robot interaction is conceptualized as "the study of humans, robots and the ways they influence each other" (Scholtz, 2003). As a discipline, it is composed of analysis, design, modelling, implementation and evaluation of robots. This field is strongly related to human-computer interaction (HCI) and human-machine interaction (HMI). However, it is distinct in some aspects of interaction since robots can present dynamic systems with varying levels of autonomy that operate in a real environment (Campana and Quaresma, 2017).

According to Moniz and Krings (2016), HRI research is facing great challenges and some of the most relevant issues are task complexity and intuitive interfaces. Making HRI more intuitive and intelligent can contribute to increased safety, productivity and help human operation in the industrial environment.

In order to better understand how human-robot interactions can occur, there are ways to classify these systems as proposed by Bdiwi et al. (2017) is by dividing them into four levels: Shared workspace without shared task; Shared workspace, shared task without physical interaction; Shared workspace, shared task; Shared workspace, shared task with physical interaction.

At the first level the human needs to work close to the robot due to limited work space or process flows. The human and the robot have their own tasks, however they are acting in a workspace with no shared effort. At level two, the human and the robot have a shared task, but the cooperation is very small. Also there is no direct contact between the human and the robot. An example of a shared task would be when the robot holds a component firmly while the human is performing a task (assembly, welding, etc.). On the third level, the task is shared and consists of a direct delivery between human and robot. An appropriate example of this level is given when the robot brings a necessary tool from the provisioning line and delivers directly to the human on the assembly line. At the last level the physical HRI is required to accomplish the task. For example, the robot can bring heavy components to the human worker (Bdiwi et al., 2017).

At any level or form of interaction, safety is a fundamental prerequisite in the use of industrial products, machines and systems. With the aim of develop effective and reliable control strategies for HRI, the concept of safety needs to be clearly understood (Najmaei and Kermani, 2010). When it comes to human safety, accident prevention can always be improved since any contact creates potential for an accident. Once hazards are known, they can be reduced or eliminated by design, protection, control and other methods (Vasic and Billard, 2013). To assist HRI, safety standards have design requirements and guidelines that help and simplify the development of new systems (Villani et al., 2018).

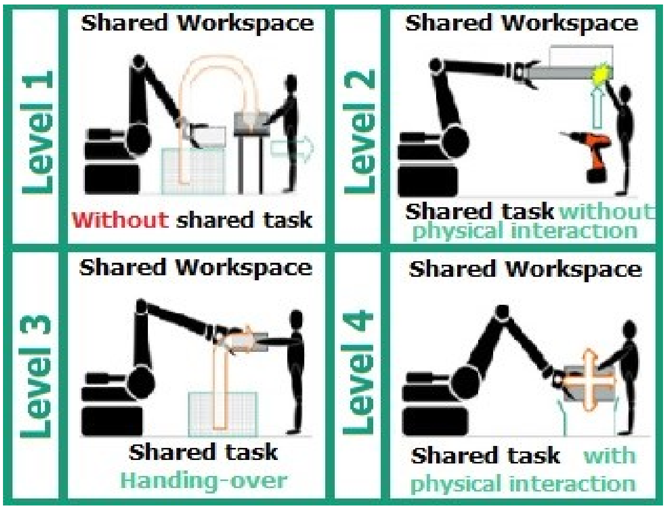

Fig. 1 Proposal of industrial HRI classification at four levels adapted (Bdiwi et al., 2017).

As reported in Villani et al. (2018) the main standards for robotic solutions can be classified into three categories, which are shown in Fig. 2. The first category, Type A standard, contemplates the basic safety standards for general requirements that can be applied to machinery. ISO 12100 and IEC 61508 are standards that address, respectively, the basic terminology and methodology used to ensure the safety of machines, such as the evaluation and reduction of risks in electrical, electronic and programmable machines. The Type B pattern class refers to generic safety standards and is sub-divided into B1 and B2. The third category, Type C, collects individual safety standards that define safety countermeasures for specific machines

As an application that requires safety and pose risks to the worker, welding represents one of the main uses of industrial robots and this process consists in using an equipment (robot, manipulator, etc.) to perform welding operations, after programming, without adjustment or control by the welding operator (Handbook, 1991). However, its effective application in practical production is still limited by the complexity and uncertainty of the welding process (Chen et al., 2004).

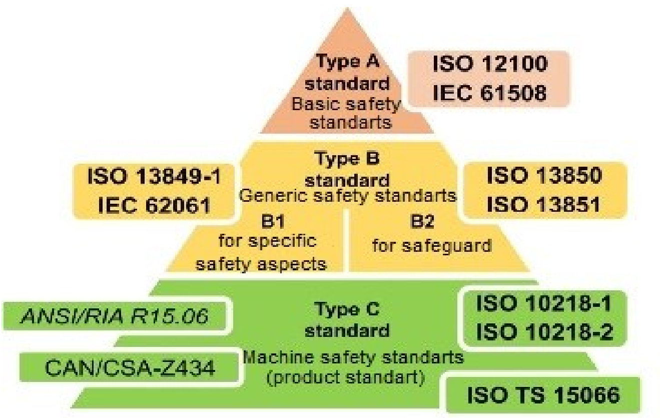

Fig. 2. Standards and safety standards for HRI in industry (Villani et al., 2018).

Considering the complexity of the industrial context and the welding process itself, an important factor for the operator is "to understand what is happening" or to obtain situational awareness. Thus, HRI starts with the need to deal with different levels of control and tasks, as well as to develop means of interaction that allow robot operators to execute and monitor their tasks in a clear and effective way (Perzanowski et al. 2001).

The SA concept is linked to the perception of elements in an environment considering a period and space, the understanding of what these elements mean and the projection of their current status in the near future (Endsley, 1995). This concept is then broken into three levels: perception, understanding and projection. At the first level the user must realize the elements that are occurring in the current situation. The level of understanding occurs when a person aggregates various suggestions of perception into a higher level of understanding. The third level is projection, which is about being able to predict the consequences of the situation that is taking place. Fig. 3 demonstrates the three level SA model, where people are active participants in creating their own SA, directing attention, communicating, using tools and changing strategies to process information (De Oliveira, 2016).

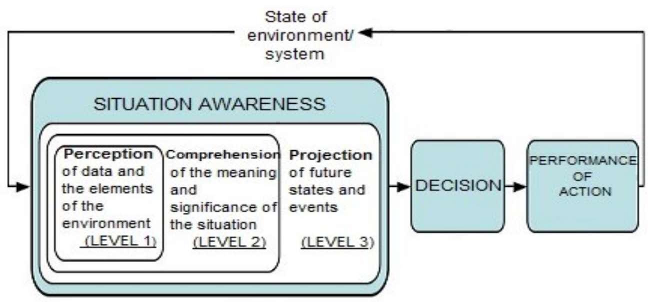

Fig 3. SA process model (Endsley, 1995).

According to environment Campana and Quaresma (2017), SA is an important human factor in HRI where there is supervisory control of remote applications, as it represents a continuous diagnosis in a dynamic environment. Being aware of the situation is an important factor in selecting the elements of interface design, designing an efficient interaction. The exact choice will then depend on the good SA, but the choice is not the same as the SA. Therefore, HRI's awareness focuses on the person who most directly controls the activities of the robot, which is the operator.

When SA is considered perfect, it induces and potentiates (but does not guarantee) that users choose the best possibility in the situation. Without SA support, users can still make the right decisions, but it is a product of pure guessing. By supporting SA, users can continue to make the wrong decisions because of lack of experience, lack of goodwill and other human and individual factors (stress, among others) (Endsley and Robertson, 2000). The next section proposes a map for SA in robotic welding.

3. SA MAP FOR ROBOTIC WELDING

An analysis of the human-robot interaction in the welding process was performed to identify local and global elements of situational awareness in order to propose a SA map for these characteristics.

The main information that must be considered in order to assist the welder in the decision making about the welding process was categorized. Even some that may be seem trivial, such as steps to perform a procedure. Their use through interfaces can reinforce criteria to ensure safe and effective work and allow non-expert users to operate the system.

The Fig. 4 shows important points to be contemplated in the SA map to application in industrial robotized welding operation.

The user-related aspect of consciousness encompasses the personal characteristics of each operator and the factors that may influence the individual's understanding of the situation, such as the level of technical knowledge, skills, and emotional factors. However, they are information that users do not need to know, but can be used to change the view of aspects in the interface. For example, using game techniques can increase user motivation. These individual particularities can generate SA problems, such as lack of experience and training at work or risk assessment.

The system aspect concerns the user, their knowledge about what functions are performed by the system autonomously or which the user can perform manually. So to maintain this aspect of consciousness, users must be informed about the automated functions of the system, or manual options to be used that can affect their work and cause risks to it.

Another important factor in automated systems is to provide some level of control for the user. For example, the possibility of interrupting the welding process when something is wrong with it.

The awareness of the environment makes the user aware of the working conditions, risks and problems present at the time of the task and can obtain a future projection of the same.

One factor to consider in the environment is the risk. Examples of such are issues such as noise, visibility and temperature present in the environment (De Oliveira et al., 2015). The impact caused by factors such as noise can affect tasks based on concentration and knowledge, such as task tracking or equipment diagnostics.

Also, according to Parsons (2014) extreme conditions can reduce physical and psychological functions. Heat can cause sweating (affecting grip), distractions, and psychological tension. Already the cold can induce a loss of sensitivity, stiffness of the fingers, general discomfort and tremors, causing distractions that can increase the stress of the user.

Another important point for interaction in the industrial environment is group awareness, which is directly impacted by the SA of each user. Establishing a communication channel in the group, which allows transparency and visibility of the point of action, is one of the goals for SA to become viable.

According to De Oliveira et al. (2015), communication is the main factor in teamwork, but adverse environmental conditions can make this difficult. Keeping that awareness through the interface can suppress this problem.

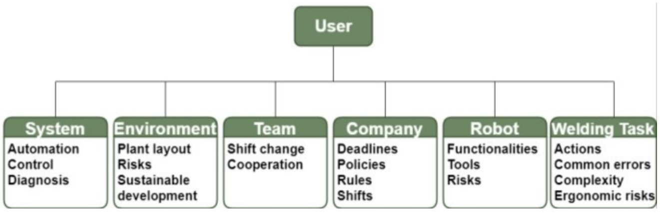

Fig 4. Main aspects of awareness for the robotized welding operation (adapted from De Oliveira (2016)).

Equipment is the consciousness related to the devices used in the industrial process, relating behavior and risks. In this work equipment refers to the welding robot.

It is important to have clear the features of the robot and how to use them through the interface, as well as a help menu for novice or non-expert users. Also, the risks inherent in the use of the robot, such as failures in carrying out welding, can occur when the diagnosis is not made. The health status can be verified through the sensors present in the robot and maintenance can be scheduled as necessary.

Welding task refers to the awareness that user must have about the procedure or action to be performed. The experience helps to develop the task automatically, but according to Endsley (2016), when using the working memory the user is subject to a limitation of the SA. Therefore, systems and their interface need to support this awareness.

The aspect of robotic welding also depends on the complexity of the task, i.e. the difficulty inherent in the welding procedure. Then, the complexity factor can be used to change how the parameter setting or task progress information will be viewed to compensate for the user's lack of experience or the high complexity of a procedure (De Oliveira et al., 2015). Common mistakes are recurring problems that the user needs to be aware of, such as weld defects or sheet position. Therefore, information about ergonomic risks is also necessary, since some procedures need to be done over a long period of time in a posture that could harm users.

4. CASE STUDY

The case study goals identify the aspects of the operator's SA supplied by interface of the robotic equipment, type MDS-1005 from BUG-O System. The BUG-O robot performs the welding process autonomously or manually. The robot is arranged in rails parallel to the plates to be weld, being of the tractor type. It carries out the torch movement and the parameters are configured through computer vision. However, the parameters can be adjusted by the user whenever necessary. The control unit coupled to the upper part is responsible for controlling the robot according to Fig. 5.

A mobile digital interface to operate the robot was developed by Schott (2018). This interface presents the configuration data for initial positioning of the robot, in order to place it in the center of the chamfer to begin the manual or autonomous parameterization. It is possible to visualize the parameterization variables of the robotic equipment and three forms of seam for welding. The feedback functionality informing the operator the welding progress, with data referring to robot speed and welding machine configurations as well as images of welding progress.

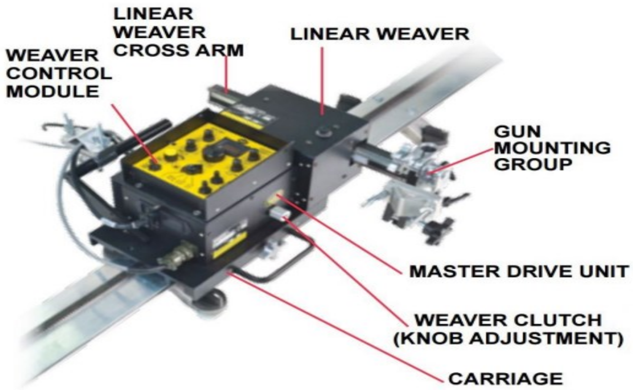

Fig. 5. Layout of the BUG-O System linear welding robot MDS-1005 (Steffens et al., 2015).

From the interaction with the interface used to control the robot and the understanding of its functionalities, the SA aspects that the interface has were highlighted.

The system aspect found in the screen of Fig. 6, makes the operator aware on the car and arm position configuration can be made automatically by the system, from a computer, or manually by the buttons on the screen. This configuration possibility is also associated with the welding task aspect. It is still possible to identify the place of robot through image, informing to the user the position it is, on the plates that are being weld.

In Fig. 7 the same aspects of system, welding task and robot are identified. The user has the information that the parameterization, or configuration of the robot is being performed. It is possible to follow through the image this configuration and the position where the tractor is.

In the parametrization interface, Fig. 8, there is no direct information about the robot's status. However, it is possible to understand the parameters that have been configured by the system to perform the welding task. It is also possible to the user to modify these settings before starting the welding.

In the Fig. 9 the welding task, the system and robot aspects are again present on the screen for help monitoring the welding process. The user can understand the information provided and monitor the progress through the image.

One way to understand the relationship between the aspects present in the system is to perceive the way the functionalities interact. In this case study, a simple example of this interaction is the way the user needs to accomplish the operations on the robot to perform the welding task. The Fig. 10 contains a simplified use case diagram for this HRI functionality.

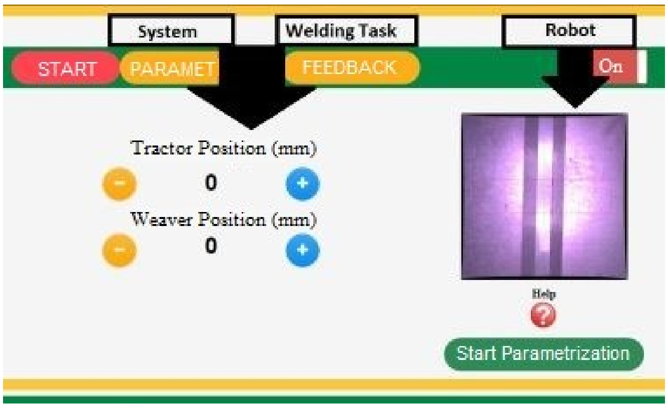

Fig. 6. Aspects presents in the initial interface.

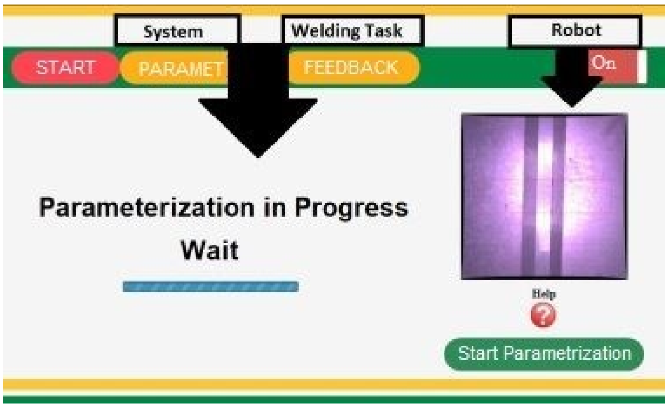

Fig. 7. Aspects identified in the parameterization monitoring interface.

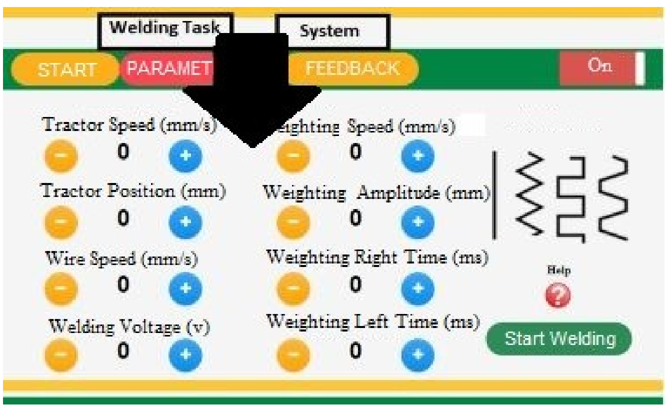

Fig. 8. Aspects identified in the configuration interface.

In the HRI interface used in this case study the SA aspects map can be reorganized to better understanding of the situation. The HRI is made through the system and the welding task is performed by the robot. The aspects of group, company and environment are not included in this interface.

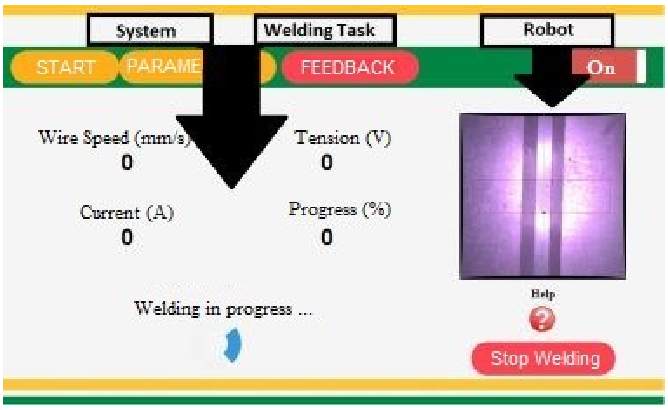

Fig. 9. Aspects present in the weld monitoring interface.

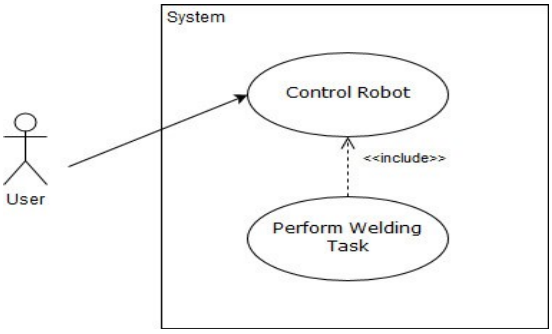

Fig. 10. Simplified use case diagram where the actor has the HRI through the system to perform the welding.

5. DISCUSSION AND FUTURE WORK

This paper broach the aspects of situational awareness for improve the human-robot interaction. The interaction form addressed was that human needs to work close to the robot because of a shared space but without sharing the task. So the human and the robot have their own activities. The HRI is made through the control interface of the robot during welding process.

In an overview of the robotic welding process was described to highlight the functionalities that ensure the parameters are accurately configured and that they allow to follow the process, being able to avoid several defects in the weld by the correct parameterization and control of the equipment.

Another factor to be mentioned is that an SA for HRI, through its operating interface, can prevent the operator from positioning itself near the sparks, smoke, electrical risks and high temperatures generated by the welding. These operational risks make the environment unhealthy by jeopardizing the safety of the operator.

The mapping carried out to support the situational awareness of the operators connects the information that compose the user's consciousness in the industrial environment and provides intelligence for industrial environment through this awareness. The structure was adapted from a literature review in the fields of HRI, welding and SA.

The aspects addressed by interfaces of case study to inform the operator about: welding task, system and robot (equipment). There is no information such as environmental conditions or the possibility of sharing the situation in a group. It is necessary that the interfaces contemplate more aspects to increase the SA of the operator and facilitate the process of HRI.

Providing SA support for a user working with HRI from the defined factors creates a context for analyzing and executing operating processes in the industry, improving their efficiency and also reducing the number of errors and their impacts on the production environment.

As future work should be developed to measure the gains from inclusion of SA in interfaces. Methods of evaluating the interface generated for HRI with aspects of SA such as usability also should be elaborated.

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