Development of the Human-Robot Communication in Welding Technology Manufacturing Cells

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Abstract. Currently, approx. 29 % of all industrial robots are installed working on the welding processes, the vast majority of them in the automotive industry. They are mostly mounted in the lines of arc welding or spot welding, which are joined with the automated system of handling and transport. In such a configuration, HRC is less important, because the entire manufacturing installation manages the master control system of the line, the hall or the whole plant. In the near future industrial welding robotics await big changes. Clearly it increases interest in robotics among SMEs. The allow for operation of robotic installations through workers with limited physical efficiencies and cognitive abilities is inevitable. It refer elderly and disabled people. It becomes more and more real to put a man in the working area of robots – the idea called collaborative robots. The implementation of these concepts is often dependent on the development of effective, efficient, "user friendly" Human-Robot-Communication system. The paper presents the development and current state of HRC for welding robots. On this basis the trends and anticipated developments of HRC solutions in the robotic welding installations are described.

Keywords: Robotics welding · Human-Robot communication

1 Introduction

In the development of the robotics different phases can be indicated. Modern robotics, during its formation in the 50 s of the XX century, had an industrial face. The general aim of designers of the first robots, was to replace the human when working hard, in difficult or dangerous conditions [1]. Therefore, the greatest progress during that phase has been made in the area of mechanics, drives and motion control. In the 80 s the new branch, service robotics has started [2]. In the first commercial models, many solutions well proved in the industrial environment were used. Then specific field was developed especially intensive and reached higher level. Constructors of the next industrial robots are willing to use these best practices from service robots. One of such areas was Human-Robot Communication.

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According to recent data from International Federation of Robotics IFR approx. 29 % of all robots installed in industry today operates in the welding processes [3]. There is no indication that the situation is changing in the near future. Among the robots launched in 2013, 28 % were also used in welding. These are primarily the position of lines and arc welding and spot welding, working mainly in the automotive industry.

This situation is especially observable in the Central and Eastern Europe [4]. During last 20 years many manufacturers of cars and subassemblies for them, have moved their plants to the countries like Poland, Slovakia, Czech Republic, Hungary, Romania. These factories are generally heavily saturated by robotics & automation technique, mainly in the welding technologies. Robotic cells and lines are often operated by unskilled workers, trained for a new job on the short, intensive courses. Many of these people don't know foreign languages very well, especially English. In this situation good, effective Human-Robot Communication is very important from efficiency of the manufacturing plant, quality of production and safety of employees point of view.

2 Communication of Human with Environment

Communication is the process of organizing messages in order to create meaning [5]. The message, that is information, is stored and encoded using different types of signals. Organizing involves converting messages, according to the used transmission channel and the physical transfer between at least two objects. Such a participant of the communication process can be in general a living creature or device. When one of them is the human it is referred to as personal communication. In general, six possible variations, when it comes to the type of communication participating sites, can be recognized:

- man ↔ man
- man ↔ animal
- man ↔ machine
- machine ↔ animal
- machine ↔ machine
- animal ↔ animal

Man-machine communication includes also communication between human and robot. Important feature of this communication process is the number of participants. In general, there are four cases [6]:

- one man ↔ one robot
- one man ↔ many robots
- many people ↔ one robot
- many people ↔ many robots

Way to communicate depends on the type of the signal that is used to transmit information. One of possible classifications of signals, used in communication of the human with the environment considerations, is presented below:

- mechanical signals,
- chemical signals,
- sound signals
- optical signals,
- electrical signals,
- electromagnetic signals (radio waves).

In addition to the character of the signal to describe the communication it is necessary to specify a method for producing the signal (generator) and its reception (receiver). People use their senses to receive communication signals. In relations with other people or animals in a natural way a man uses a voice (sound signals), for which the sense of hearing is needed.

Very often a man uses optical signals, using the sense of sight. This happens when a person has a weakened hearing apparatus or effective voice communication is not possible, because of the distance between the interlocutors or existing distortions. This method of information exchange can be called visual communication.

The men use also the mechanical signals to communicate, using their sense of touch. Usually the scope and complexity of the content, in this case is much less than with the voice or visual communication. Typical message, like suitable nudge, pat or stroking usually means assessment (acceptance, opposition) or the feelings that one wants to convey to another (praise, reprimand). However, it cannot be forgotten, that the sense of touch is used when reading the Braille. Individual characters (letters are encoded by dots arranged in the correct order) are recognized by the touch of one's fingers. This way of exchanging information, can be called touch communication. The communication using chemical signals is also possible. It involves the sense of smell (olfactory communication), and the sense of taste (flavor communication). This type of communication very common in the animal world, but is rarely used by people.

3 Development of HRC in Industrial Robots

The control system of the robot is responsible for the external communication, especially with the human/operator. Since one of the basic tasks of communication is to create and enhance application (utility) program of the robot, the way (organization and technical realization) of programming and then memorizing and storing these programs has a significant impact on the organization and technical implementation of the communication.

The control systems of the first industrial robots cooperated with an external memory block, in which the program that specifies the robot action had been stored. In the beginning different solutions were used. These included storage drum and perforated tapes, in which a change of the program was followed by the replacement of media. There were also systems programmed by changing the electrical connections.

This generation of robots was characterized by a very limited ability to communicate with the operator. In general, there were the buttons (e.g. "START/STOP") and lamps (e.g. "OPERATION/PAUSE"). So it was a communication through the exchange of digital (two-state) signals. For their handling, a special communication block was introduced in the control systems. Its task was also to control the cooperating devices (e.g. open/closure of the gripper).

In subsequent years, robot control systems were equipped with special, separate devices to communicate with the operator: teach pendant (TP) or programming unit. They were used to operate the robot and to create/change of the application programs. This involved further development of the robot control systems. In the early 70 s of last century the microprocessor controllers were introduced. They were equipped with the integrated internal electronic memory, in which main (system) control program of the robot, as well as current utility program have been stored. In addition, control systems of the robots have had external memory, which served as a storage of utility programs. These programs can be exchanged by uploading them to the internal memory of the control system. The use of external memory, from which users required durability and the ability to make and store the copies, forced introducing new solutions. The tape memory was very well fitted for this purpose. Other external storage solutions, also called mass storage, were based on those used in computers, consecutively EEPROM memory card, battery-backed RAM and different types of floppy disks (FD).

Next breakthrough in storage solutions for robots, was associated with the introduction of computer control system structures, which included hard drives (HD). It meant the end of the problems with lack of memory. The capacity of HD has enabled storing everything: system, current utility program, as well as entire libraries of other procedures and programs on a single device. An external data store functions were taken over by standard computers. Today they are usually working in the structures of local area networks (LAN) of the manufacturing plants. Then a USB Flash memory is used to transfer the program from/to the robot as a standard. At the same time, today's control computers of the industrial robots have the ability to directly connect to the network through digital communication channels used in office computers (RS, USB, Ethernet) or in industrial networks (Profibus, CAN, DeviceNet, etc.).

Like the storage solutions, devices for communication with the operator have gone through the long evolutionary path. In the first models of robots only digital signals were used. Even the first teach pendants with digital displays were still controlled using 2-state (digital) signals. The manual movement of the robot was realized using buttons. Usually a pair of buttons was assigned to each axis, realizing the movement to " + " and "–". The TP was equipped with a number of light-emitting diodes, which informed about the selected robot statuses. Information on displays were coded. For example, the programming unit of IRB-6/60 robots (ASEA) had a display, which consisted of four digital, 7-segment modules, which practically allowed displaying only digits and some letters. An operating panel (OP: buttons and lamps on the control cabinet door) was also used to operate this robot. Such a human-robot communication system, that uses OP on the cabinet and TP, which enabled to reach the vicinity of the mechanical part of the robot, has become a standard used by all manufacturers of industrial robots for many years (Fig. 1).

The next phase of communication between robot and human development, was associated primarily with the development of hardware and software of robot controllers. A major step was to equip TP with the alphanumeric displays. This allowed presenting the information in natural language. Further improvement was to extend the screens, giving two lines of information. This in turn helped to implement a

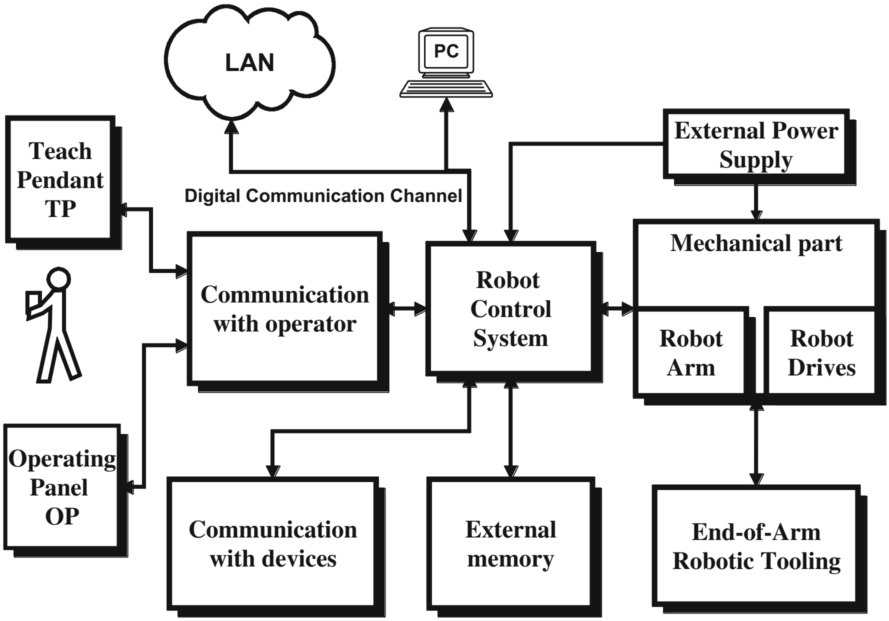

Fig. 1. General block diagram of an industrial robot

conversational system of communication between operator and robot. One line was used as the so-called command line, and the second as a menu line. At the same time the way to manually control the movement of the robot was changed. Joystick control was used with increasing frequency. The first such solution has been presented by ABB in TP of IRB robots, working with S3 control system. Today, both approaches are in use: the buttons and the joystick.

Subsequent changes in the HRC devices were related to the display of TP. The larger screen was introduced, which contained several lines of text. It turned out to be very comfortable, especially when viewing and editing the robot's program. The next step was the introduction of a graphical display, which enabled the implementation of environment modeled on Windows operating system, popular in the world of PCs. The first TP of this type implemented in the mass-produced robot, has been introduced in the KUKA robots, equipped with control systems of KRC family. For manual control of movement, the set of keys, placed next to the screen or a special joystick, called "space mouse" can be used. To activate the manual movement of the robot, the operator must press so-called authorization button (located on the rear panel). This is one of the solutions which improve the safety of the robot. In general, in recent years safety issues, in addition to the requirements of technological processes, are the most common cause of changes and modifications of robots, their controls and interfaces including communication with the operator.

It seems that only the introduction of the possibility of joint work by a man with the robot, and therefore operation of man in the workspace of robot, will force the introduction of new methods and solutions for human-robot communication. Discussions on this type of organization of interaction between human and robot in the implementation of tasks in manufacturing processes, have been taking place for several years. It is getting closer to a modification of current restrictive safety regulations, which in existing form practically make the common action impossible. The first step was the publication of technical specifications for robots cooperating with humans in the beginning of 2016 [7].

4 Communication in the Robotized Welding Cells

The configuration and construction of the robotic welding cell depends on many factors. The cell must be tailored to the task of production and meet the specific requirements of the recipient. They are related to the overall layout of the installation (the conditions in the hall, the organization of transport), the size and weight of welded parts, machines cooperating, etc. In general, it can be assumed that the typical robotic welding equipment includes the following:

- Industrial robot with control system, adapted to cooperate with a set of welding,
- Welding set containing current source, cooling system, wire feed, burner, control system, designed to cooperate with the robot,
- Cell controller – usually PLC in the proper configuration, often with graphical display as an operator panel,
- Positioner in configuration and with parameters suitable for the executed task,
- Fixing device, often equipped with sensors for recognize the presence of welded elements,
- Safety fences, equipped with sensors for access control,
- The security system (light curtains, door locked, the system of "emergency stop" safety controller),
- Fields of storage/warehouses for details in/out,
- Auxiliary equipment, e.g. a system to verify the tool definition, sensory systems, burner cleaning machine, filtering unit, etc.

Today most of these devices are equipped with an intelligent control, providing communication with other machines or industrial local area networks (LAN) via transmission channels. This enables the exchange of content-rich information, e.g. diagnosis of the state of the devices themselves, as well as the process as a whole. These solutions also enable connection of the robotized cell controller to the global Internet network, either directly or through a network of the factory. Thereby access to the robotic installation is available from any place in the world. It is big advantage for maintenance and service. Then, supervision, monitoring and sometimes the service of such an installation in remote mode can be performed from anywhere at any time, by the integrators, consultants, suppliers or high-level control systems. The figure below shows a schematic flow of information in the typical robotic welding cell (Fig. 2).

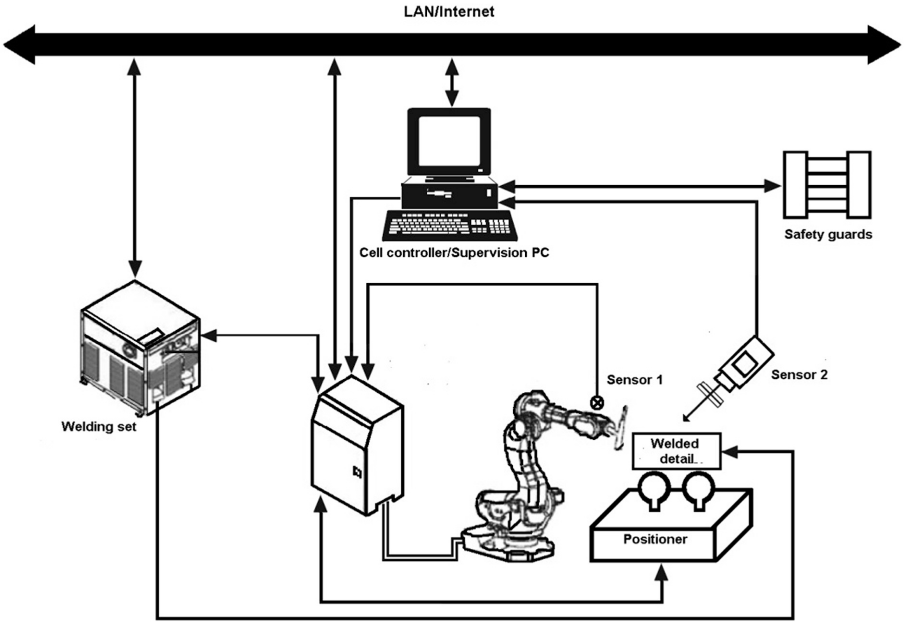

Fig. 2. The flow of information in a typical socket welding

5 Challenges of the Near Future and Consequences for HRC in Welding Applications

Until recently, robotic welding systems worked mostly in large factories that could provide funds for investment and adequate technical staff for operation and maintenance. Today an increase in interest in robotics among SMEs is obvious. Such companies generally do not have, and are unlikely to hire specialists with extensive knowledge and experience in the field of robotics. Maintaining such a specialist for several robots will not be profitable. Therefore, the communication system must be extremely 'user-friendly', so the person with the general technical competence and a very superficial knowledge of the robot can effectively supervise its work, modify the program and carry out basic maintenance and checks.

Another clear trend is the release for operation of robotic installations through workers with limited physical efficiencies and cognitive abilities. It refers to the elderly and disabled people. As the average life span becomes longer, prolongation of the professional activity is inevitable. It can be expected that people older than now will be employed to operate the robotised welding installations. These people will often have limited locomotion, manipulation or cognitive possibilities. Also, for many years there has been a strong trend to activate the people with disabilities, congenital or acquired as a result of illness or accident. Such individuals may also be employed at workplaces, where cooperation with the robot will be required. Robots working with elderly and disabled people must be able to adapt to the specific characteristics of its partners i.e. operators, as the other way is impossible. One of the conditions of successful cooperation is using the proper HRC.

The third very clear trend is to put a man in the workspace of robots. This concept emerged only a few years ago, but it already has many supporters. For a long time, it had been considered that the best way for the human to cooperate with the industrial robot is to isolate him from the device, at least when the robot is in automatic operation mode. Therefore, the typical robot working cell is equipped with a variety of covers, fences, locks, etc. As the result, there are separation standardization documents on safe installation of robotic [8–10]. They imposed very stringent requirements for security on the design, both on the side of protective devices, as well as their monitoring and control. At present, these rules are being changed. The initiators are often companies producing robots. They see a chance for new fields of application in the admission of robots to work in the vicinity of people, and thus a chance to increase sales of robots. Also, standardization bodies recognize these trends and have already started working on relevant standardization documents. Apart from changes in the design of robot manipulators, equipping them with new sensory systems, practical implementation of this new approach will require the development of modified or completely new solutions in the field of HRC. After all, working together is not possible without mutual communication.

6 Summary and Final Conclusions

Considering the future development trend of HRC in robotic welding systems, the direct interaction and remote access should be treated separately.

Currently, HRC which is the most widely used in industrial robots for direct interactions, is the type using a graphical user interface. It meets today's requirements of robotic production systems. A way to communicate human directly with industrial robots will become increasingly similar to the communication with service robots. Ultimately, both variants will aim to the human-to-human type of communication. The first step in the realization of this vision is to equip robots working in industrial installations, in particular welding, with more than one sense and additional communication channels. Because of development of the collaborative robots' concept, it can be the sense of touch.

The reasons for the remote access development can be presented in two groups. The first one includes efforts for purpose of assuring effective maintenance and servicing. The second is directed at remote programming and training. In both cases the technical development of robotic welding cells will be required. It refers to installation of advanced vision systems, with possibility to observe the cell from different points. Also new solutions connected with Internet of Things will be introduced (direct access to the welding equipment, sensors). On the remote stands, especially for programming and training, the virtual reality looks very promising. Systems which will enable remote training in virtual environment will be useful not only for workers but also for vocational schools and technical universities.

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