OPTIMISATION OF MANUAL WELDS USING VIRTUAL AND AUGMENTED REALITY

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ABSTRACT

This paper presents first results of an interdisciplinary research project for the development of an "intelligent" welding helmet. Contrary to conventional welding helmets the system allows a detailed observation both of the welding process and the environment. By methods of virtual and augmented reality additional information can be supplied to the welder. The system can be used for welding preparation, welding process observation and quality assurance.

KEYWORDS

Virtual and augmented reality, manual gas metal arc welding, welding process observation, quality assurance

1. Introduction

Manual gas metal arc welding is still an important industrial manufacturing method. It is often used for production of unique pieces where an automation is impossible or uneconomic, e.g. in shipbuilding with its complicated hull geometry. Because of the extraordinary high brightness, infrared and ultraviolet radiation of the welding arc an observation is only possible with a welding helmet and suitable protective glasses. These glasses darken the entire scene homogenously, so even experienced welders can hardly recognize details of the welding pool, the welding seam and the environment. Figure 1 shows the view of the welder simulated with a CCD camera and standard protective glasses.

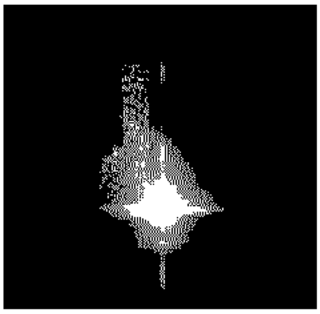

Fig. 1 View of the welder with standard protective glasses

Moreover, the welder has no additional information about the actual welding process, e.g. the current parameters of the welding power supply like current, voltage or wire feed. And the welder receives only insufficient feedback about the quality of his work and the creation of manual welds with constant high quality becomes difficult. Furthermore, an online quality control of the welding process is not possible. To increase the manufacturing quality and economic efficiency a support system for the welder is required. This can be achieved by improving the visual information for the welder and by supplying additional information with methods of virtual and augmented reality.

2. Virtual and Augmented Reality

Virtual reality is a new technology, which uses a computer model to generate and present an artificial environment to a person. The simulated environment responds to human movements evoking the impression of actually moving in this environment. A virtual reality system usually consists of a computer capable of real-time animation, a position tracker and a closed-view head-mounted display for visual output. A closed-view head-mounted display is one of two basic types of head-mounted displays. It does not allow any direct view of the real world. The second type is a so-called see-through head-mounted display. See through head-mounted displays use optical combiners to mix the real world's image, and the virtual image from monitors. In contrast to closed view head-mounted displays, see-through head-mounted displays let the user see the real world, with virtual objects superimposed by optical or video technologies. They are generally used in optical see- augmented reality, which is a variation of virtual reality. With virtual reality, the user cannot see the real world around him.

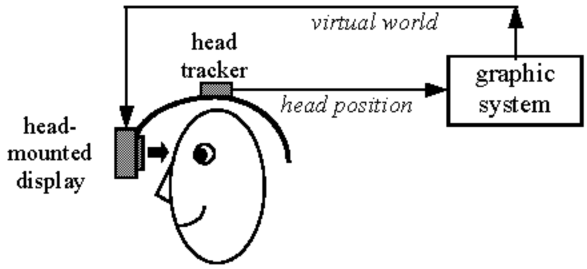

Fig. 2 Principle of virtual reality

In contrast, optical see-through augmented reality allows the user to see the real world with virtual objects superimposed upon or composed with the real world. The insertion of virtual objects is context dependent, i.e. compatible to or derived from the observed scene. E.g., the real field of view of a mechanic can be extended by the insertion of instruction sheets.

This technique is only partly suitable for observation of welding processes. Because see-through head-mounted displays do not protect against ultraviolet and infrared radiation and the high light intensity of the welding process, protective glasses are still necessary. The combination of a head-mounted display and protective glasses would enable the insertion of additional information for the welder. However, his view on the environment would not be improved.

The system presented in this paper is based on the so-called video see-through augmented reality. This technology uses a closed view head-mounted display as known from virtual reality. Cameras are mounted on the user's head and provide his view of the real world. The images obtained with the cameras are overlaid with additional information created by a computer. The resulting images are sent to the head-mounted display.

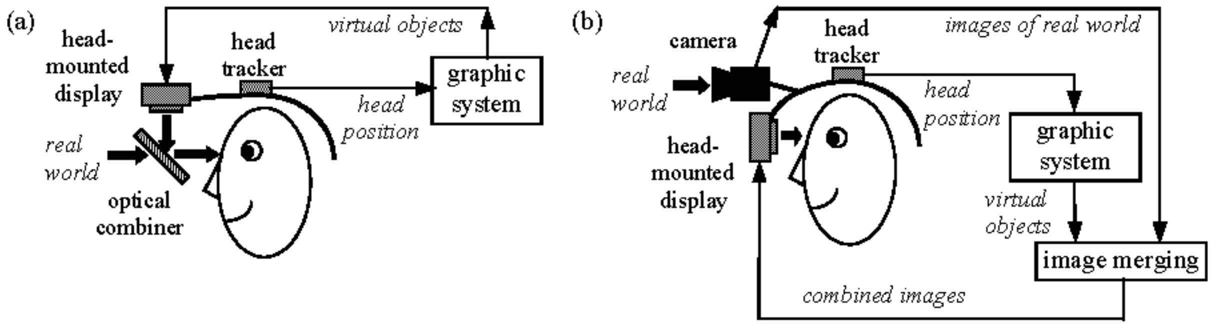

Fig. 3 Principle of: (a) optical see-through augmented reality; (b) video see-through augmented reality

Because the welder observes the welding process only with the help of the cameras, he has no direct view on the welding process and is protected against its high brightness and radiation intensity. Due to the use of High-Dynamic-Range-CMOS cameras (HDRC) he receives a substantially more detailed view on the process as with conventional protective glasses.

3. System

A welding helmet is combined with two HDRC cameras and a stereoscopic closed-view head-mounted display. Each camera is coupled with one half of the head-mounted display in order to provide three-dimensional images. The recorded images are sent to the portable computer (in a backpack), processed and displayed on the head-mounted display. By methods of virtual and augmented reality additional information can be inserted depending on the application. This information can be derived from the welding power supply (e.g. electrical welding parameters or consumption values), directly extracted from the images (e.g. dimensions of the arc or inclination angle) or transferred by another computer (e.g. constructional details or material type). The basic set-up of the system is shown in figure 4(a).

Figure 4(b) shows a schematic sketch of the welding helmet. For safety-relevant reasons it is to take into consideration to use an head mounted display which can switch between closed view and see-through mode. During the welding process, the system operates in video see-through mode. The welder observes the scene only by the use of the head-mounted display and the cameras. Before and after welding and particularly in case of camera failures the system can switch to optical see-through mode which enables the welder to recognize his environment through the protective glass of the welding helmet.

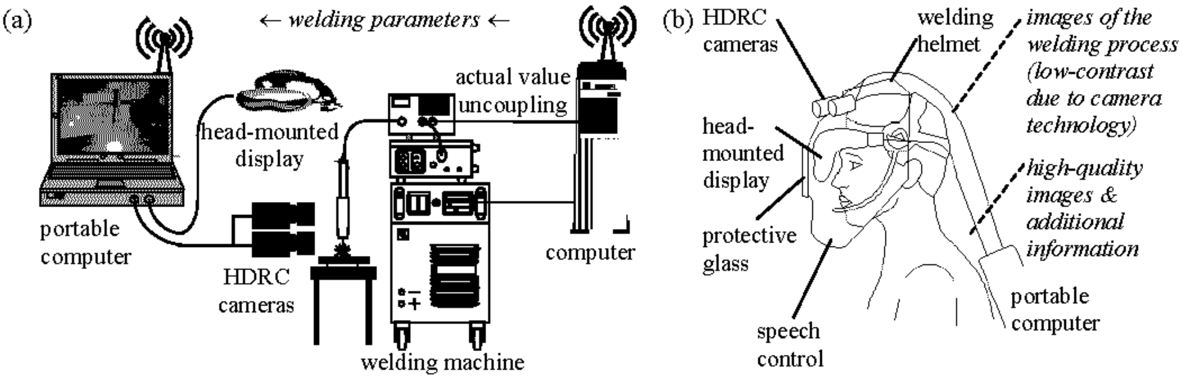

Fig. 4 (a) Principle sketch of the system, depicted without welding helmet; (b) Welding helmet

3.1. High-Dynamic-Range-CMOS Camera (HDRC)

The principle of HDRC cameras can be described as follows. The intensity levels in an image are essentially dependent on the irradiance and reflection properties of the observed objects. The information content of an image only depends on the contrasts resulting from varying reflections, and fewer on the absolute intensity values caused by irradiancy because the reflection property of a surface is independent of the irradiancy. A CCD-camera maps the absolute intensity values caused by the irradiance of an object. The light intensities may have a relation of up to 10^6:1, i.e. in high-energy processes as welding. Due to the technology, the dynamic range of a CCD camera is approximately 4000:1. The characteristic curve of a CCD camera can be moved by modification of the aperture. Figure 5 shows that, independently of the aperture value, the dynamic range of a CCD camera is not sufficient in order to represent the high light intensities of the welding process. The image sensor of the HDRC camera consists of CMOS transistors. The input signal is compressed logarithmically in every transistor of the image sensor. Due to this compression the HDRC camera maps the contrast caused by different reflections between two side-by-side object points and the information content of the image is not reduced. Thus, the dynamic range of an HDRC camera is approximately 10^6:1, which corresponds to the light intensities of the welding process.

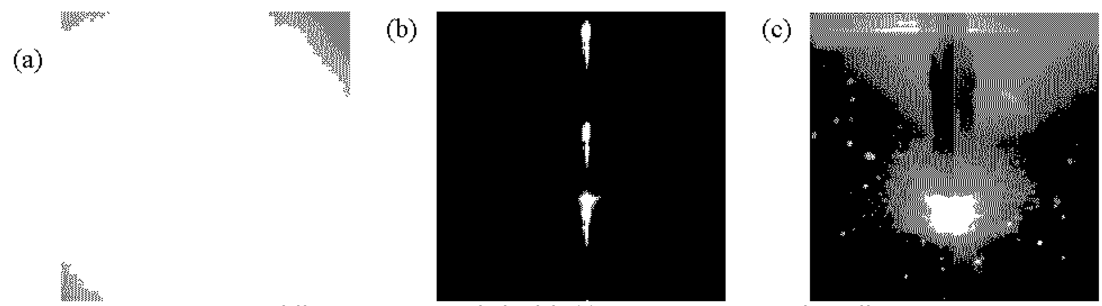

Fig. 5 Welding scene, recorded with (a) a CCD camera and small aperture;
(b) a CCD camera and large aperture; (c) an HDRC camera

3.2. System Architecture

As described above, the tasks of the portable computer are image recording, image processing and representation of the images together with the overlaid information on the head-mounted display. During the image processing application the image quality is improved and relevant features for object recognition or tracking are calculated from the image data. Due to this tasks the requirements on the portable computer are very high. Attention must be paid to a high image refresh rate or respectively to a small latency. The image refresh rate has to be at least 25 images per second because only starting from this frequency movements appear flowingly. Latency can be described as the lag between the user's head position or orientation changing and the updating of the displayed view to reflect that change. An effect of too high latency is the so-called „motion sickness" which occurs when the brain's expectation of orientation and position is not matched by the visual input. Present portable computers (e.g. laptops or notebooks) cannot fulfill these requirements because of their insufficient performance. Thus, the portable computer is a combination of three single board computers with one Pentium III 850 MHz processor each. The portable computer has an evidently higher performance than conventional systems. Each camera is connected with one computer, in the following mentioned as "camera computer". Thus, each camera has its "own" processor for image processing. The tasks of a "camera computer" are image recording, image quality enhancement, insertion of additional information into the images and the representation on the head-mounted display.

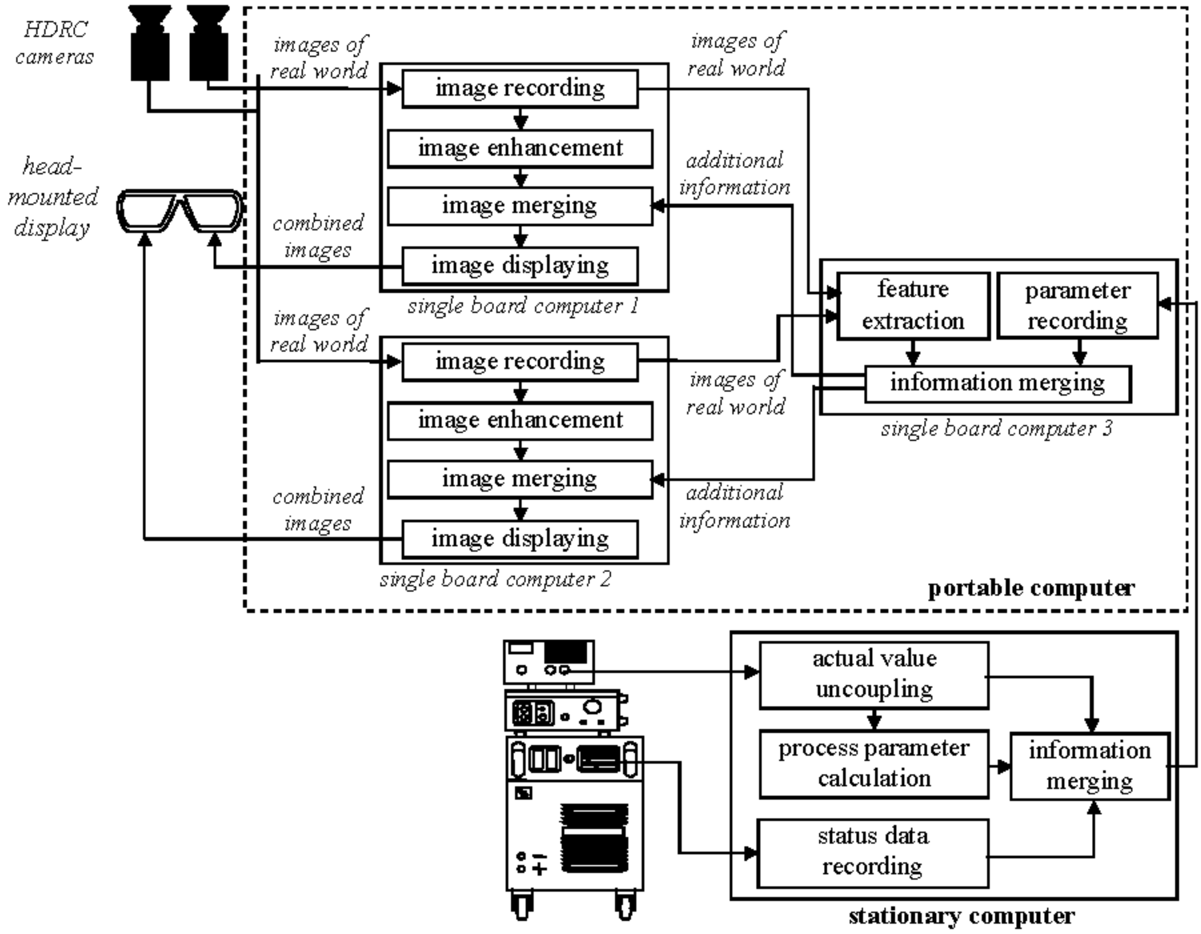

Fig. 6 System architecture

The additional information can be derived from the welding machine or directly extracted from the images. Because the image features do not change fast, the image rate can be lower than 25 images per second. Thus for feature extraction images are transferred in certain time intervals from the camera computers to the data computer. Additionally the welding machine data are transmitted to this computer. These data are combined with the data extracted from the images and transferred to the camera computers, where they are combined with the images of the real world. The welding machine data are processed by a stationary computer. Via an interface the current settings of the welding machine can be directly transmitted to this computer. This allows the measurement of electrical welding parameters and the calculation of characteristic welding process parameters. All data are transmitted to the data computer and combined, as described above, with the data extracted from the images.

4. Application Possibilities

The system can be used for several stages of the welding process. In the following the possible application areas of the system are presented. To avoid distraction of the welder his field of view may not be overloaded with too many or insufficient virtual objects. The usual working method of the system must be retained in order to achieve a high acceptance of the system. Most suitable is the use of symbols, which can be easiliy interpreted. The insertuion of text during the welding process is not suitable, because the welder can not read and weld at the same time. However, the insertiuon of text before and/or after the welding process is reasonable since the welder does not have to concentrate on the welding process, but he can read the inserted information.

4.1. Welding Preparation

The first application possibility is the use during welding preparation. In this phase constructional details can be displayed, e.g. the material type, joint type or welding machine settings. The information about the work piece and the welding seam is stored on the stationary computer and can be accessed via the work piece number.

4.2. Welding Process

Depending upon the application, different information can be supplied to the welder, e.g. the welding machine settings (current, voltage or wire feed speed), constructional details (instructions sheets or design drawings) or features directly extracted from the image data (arc length, welding speed or inclination angle).

4.3. Quality Control

One disadvantage in manual arc welding is, that the welder recieves no feedback about the quality of his work. With the presented system an online-monitoring of the welding process is possible by the continuous comparison of actual and desired values. The actual values can be extracted directly from the image data or be determined from the electrical welding parameters. If the values threaten to leave a certain tolerance range, a warning is transmitted to the welder. If the current values exceed their tolerance range, the image data and the corresponding electrical welding parameters are stored automatically and are available for an analysis. Figure 8 shows the principle of online monitoring corresponding to the system architecture in figure 6.

4.4. Weld Inspection

With conventional procedures, the weld quality is estimated after the welding process for example via radiometric or ultrasonic examination, which is very complex and expensive. Furthermore, the optical inspection of the welding seam is separated from the inspection of the electrical welding parameters. This method does not allow any conclusions on occurrences during the welding process. Based on the system described in [4] during safety-relevant welds the images can be stored together with relevant welding parameters, which can be easily assigned to each individual picture. It can be examined as shown in figure 9, whether the splashes are caused by a too high welding current or by other effects.

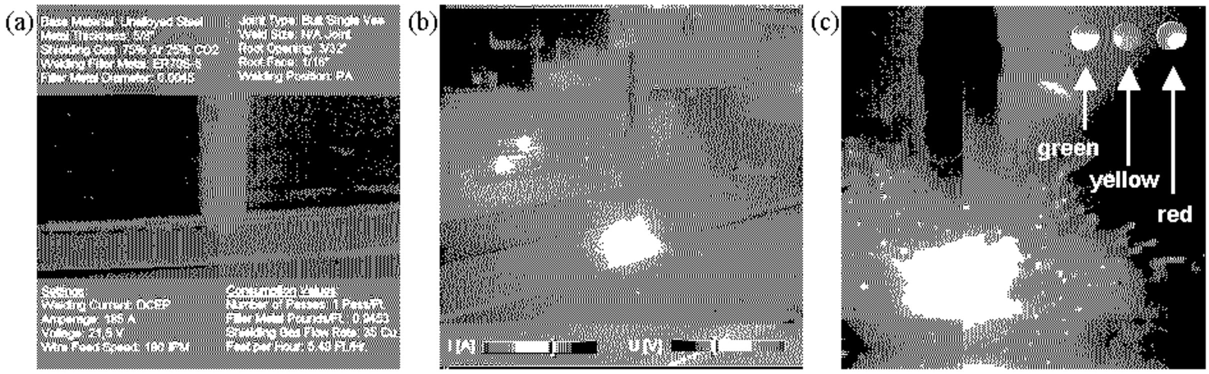

Fig. 7 Possible insertions: (a) material type, joint type and welding machine settings; (b) welding current and welding voltage; (c) "traffic light" for process monitoring (green = everything ok, yellow = values threaten to leave tolerance range, red = values out of tolerance range)

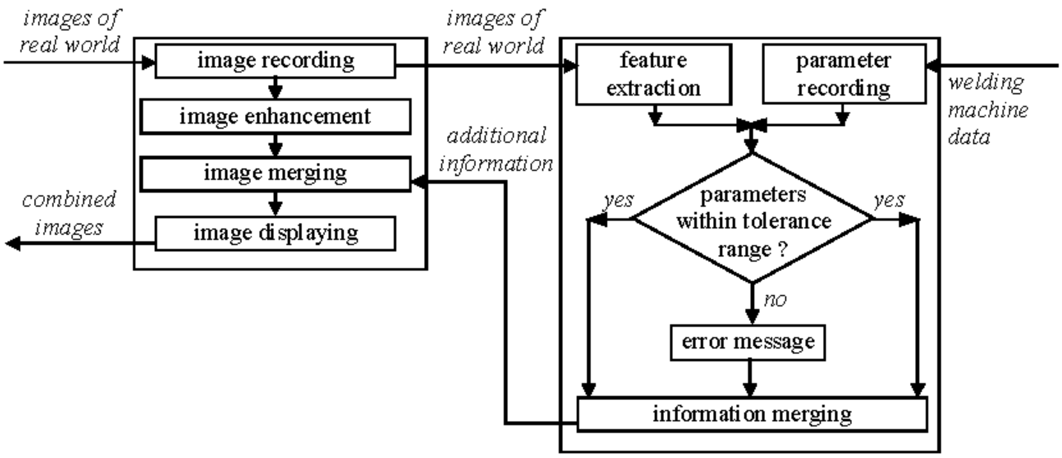

Fig. 8 Principle of the online-monitoring of the welding process

(a) (b)

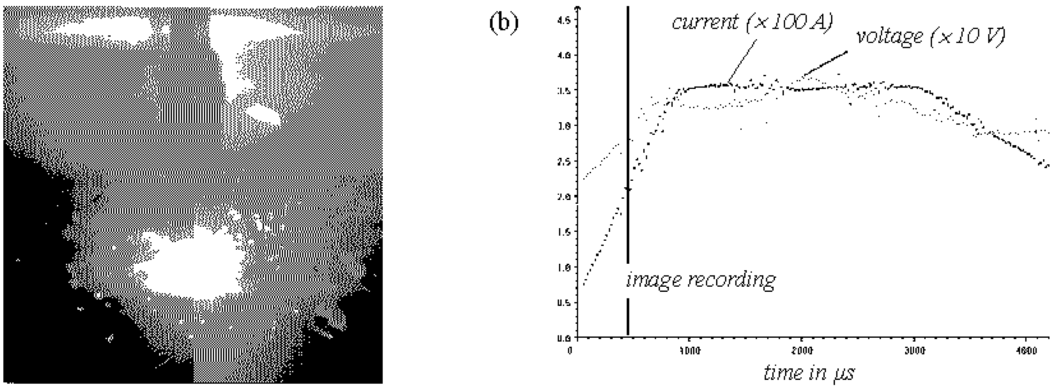

Fig. 9 (a) Image of the welding process; (b) synchronized and simultaneously measured electrical welding parameters current and voltage including the time of the image recording [4]

5. Summary

The presented system combines a welding helmet with a head-mounted display and two HDRC cameras. The welding scene is observed with the cameras. A portable computer provides further enhancement of the image quality and displays the images on the head-mounted display. The welder has a detailed view on the welding pool, welding seam and his environment. By methods of virtual and augmented reality, additional information (e.g. welding parameters or constructional details) can be inserted depending upon the application. The system can be used for getting information about the welding task before the beginning of the welding process, for the observation of the welding process including online quality control and for weld inspection.

6. Conclusion

By the visual observation of the welding process in combination with the representation of relevant welding parameters, the welder receives new information and will be able to enhance the weld quality using this information. Thus the simplification of manual welding and an improvement of the welding result are achieved, leading to a better and more constant quality and therefore to a reduction of the inspection expenditure in quality control.

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