Applying Spatial Augmented Reality to Facilitate In-Situ Support for Automotive Spot Welding Inspection

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Abstract

In automotive manufacturing, the quality of spot welding on car bodies needs to be inspected frequently. Operators often only check different subsets of spots on different car bodies with a pre-determined sequence. Currently, spot welding inspections rely on a printed drawing of the testing body, with the inspection points marked on this drawing. Operators have to locate the matching spot on the drawing and the body manually to perform the inspection. The manual inspection process suffers from inefficiencies and potential mistakes. This paper describes a system that projects visual data onto arbitrary surfaces for providing just-in-time information to a user in-situ within a physical work-cell. Spatial Augmented Reality (SAR) is the key technology utilized in our system. SAR facilitates presentation of projected digital Augmented Reality (AR) information on surfaces of car bodies. Four types of digital AR information are projected onto the surfaces of car body parts in structured work environments: 1) Location of spot welds; 2) Inspection methods; 3) Operation Description Sheet (ODS) information; 4) Visualization of weld locating methods. Various visualization methods are used to indicate the position of spot welds and the method used for spot welding inspection. Dynamical visualizations are used to assist operators to locate spot welds more easily. The SAR approach does not require additional special models in finding spot welds, but only needs knowledge of location of spot welds on the part. Our system allows operators becoming more effective and efficient to in performing proper inspections, by providing them the required information at the required time without the need to refer to paper-based manuals or computer terminals.

CR Categories: H.5.1 [Multimedia Information Systems]: Artificial, Augmented, and Virtual Realities; H.5.2 [Information Interfacesand Presentation]: User Interfaces.

Keywords: Spatial Augmented Reality, Spot Welding Inspection, Visualization Method

1 Introduction

Augmented Reality (AR) is a technology that integrates virtual objects into the real world [Azuma et al. 2001], by registering computer-generated images over a user's view of the physical world. With this extra information presented to the user, the physical world can be enhanced or augmented beyond the user's normal experience. Additional information that is spatially located relative to the user can help improving their understanding of the world in situ [Thomas et al. 1998]. AR interfaces enable people to interact with the real world in ways that are easily acceptable and understandable by users. For example, doctors may use the AR system to allow an intuitive real-time intraoperative orientation in image-guided interstitial brachytherapy [Krempien et al. 2008], and to guide the liver thermal ablation in interventional radiology [Nicolau et al. 2009]. Doctors can also use projector based AR for the intraoperative visualization of preoperatively defined surgical planning data. The potential of AR for industrial processes is also increasingly being investigated [Reiners et al. 1998].

Instead of body-attached displays (such as an Head Mounted Display (HMD)), Spatial Augmented Reality (SAR) detaches the technology from users and integrate it into the environment. SAR employs data projectors to superimpose computer generated virtual objects directly onto physical objects' surfaces. The user then views and interacts with the digital information directly projected onto the surfaces within a workspace in a natural manner [Bimber and Raskar 2005a]. SAR has been employed in a number of application domains, such as design [Porter et al. 2010], entertainment [Kojima et al. 2006], and museums [Bimber et al. 2005]. Due to the decrease in cost and improvements in availability of projection technology, personal computers, and graphics hardware, SAR is now a viable option for use in an industrial setting. This paper focuses on the projector-based SAR display and its applications in an industrial environment.

In automobile manufacturing, the quality of spot welding on car bodies needs to be inspected frequently. A typical car has thousands of individual spot welds. The spot welds are required to be checked in a predefined order, one individual spot weld at a time. For improving the productivity, operators often only check different subset of spots on different car bodies with a pre-determined sequence, instead of checking all spots on each body. When all spot welds are checked in a sequence, operators start a new spot sequence for checking. Currently, spot welding inspections rely on a printed drawing of the testing body, and the inspection points are marked on this drawing. The operator has to check the printed drawing and find the matching spot on the car body to perform the actual inspection. This manual inspection process suffers from potential problems: it is more likely for operators to make a mistake by checking wrong locations or wrong numbers of spot welding; it is also difficult for operators to remember the starting and finishing points on the checked body. This is especially true when the process is performed by an operator who does not routinely perform this task.

This paper describes a system that projects visual data onto arbitrary surfaces for providing just-in-time information to a user in-situ within a physical work-cell. SAR is the key technology utilized in our system. Our SAR system provides a number of benefits to the spot welding inspection task in the automobile industry. SAR facilitates the presentation of projected digital AR information onto surfaces of car body parts. The projected AR provides *where-to-*

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act and *what-to-do* information, to assist operators performing spot welding inspections. Four types of digital AR information are projected on surfaces of car bodies in structured work environments:

1. Location of spot welds;
2. Inspection methods using various geometrical shapes, such as ultrasonic and destruction tests;
3. Operation description sheet (ODS) information; and
4. Visualization of weld find methods.

Various geometrical shapes are used to allow operators to identify the inspection method used for a specific spot weld. The animated visualizations guide operators to find the location of spot welds quickly and easily. Our system allows operators becoming more effective and efficient in performing the desired inspection task, by providing them the required information at the required time without the need to refer to paper manuals, terminals, or a laptop computer. Our system does not require additional special models in finding spot welds, but only needs knowledge of the location of spot welds on the part.

The paper is organized as follows: Section 2 presents the advantages of SAR, and a number of investigations into SAR for industrial applications. Section 3 shows the conventional approach of spot welding inspections and describes a SAR based system for automobile spot welding inspection. Section 4 describes our visualization methods used in the developed system. Some experimental examples are presented in Section 5 to demonstrate the features of our system. Finally, Section 6 summarizes and concludes the paper.

2 SAR and Its Industrial Applications

SAR allows digital objects, images, and information to be added as real world artifacts by projecting them onto surfaces in the environment with digital projectors. This section outlines advantages of SAR as well as its employment in industrial applications.

2.1 Advantages of SAR

A key benefit of SAR is that users are not required to wear HMDs; therefore, they are unencumbered by the technology. The user can physically touch the objects at the same position as the virtual images are projected onto. In SAR, the field of view (FOV) of the overall system is the natural FOV of the user, allowing their to use their peripheral vision. The range of the SAR system's FOV can easily be extended by adding more projectors or by using rotatable projectors. Ultimately the FOV can emulate the full physical environment with a higher level of resolution with what is determined to be the correct number and position of projectors. Projector-based SAR allows possibly higher scalable resolution and bright images of virtual objects, text or fine details, than traditional HMD or handheld display solutions. Since virtual objects are typically rendered near their real-world locations, eye accommodation is easier to achieve [Bimber and Raskar 2005a; Raskar et al. 1998].

2.2 SAR in Industrial Applications

AR technology was applied successfully in certain use cases in industries [Regenbrecht et al. 2005], and its major application areas include: servicing and maintenance, design and development, production support, and training. Similarly, SAR systems have the potential to improve processes in a variety of application domains [Bimber and Raskar 2005b; Raskar et al. 1998].

Bimber et al. [Bimber and Raskar 2005b] use conventional projectors that are calibrated in suitable locations to generate SAR scenes. They are able to show seemingly undistorted video and graphics on arbitrary surfaces in the environment, by means of pre-warping and color-adjusting the virtual data to counteract the reflection and perspective projection effects of the physical objects' surfaces.

In industries such as manufacturing, SAR may benefit a designer from the perceived ability to visually modify portions of a physically machined table-top model. The approach could also be used for product training or repair: one could set the product in the SAR environment and have the system render instructions directly on the product. Marner and Thomas [Marner and Thomas 2010] developed a SAR-based physical-virtual tool for industrial designers. Their system simultaneously models both the physical and virtual worlds. SAR is then used to project visualizations onto the physical object, allowing the system to digitally replicate the design process to produce a matching 3D virtual model. Olwal et al. [Olwal et al. 2008] use SAR on industrial CNC-machines to provide operators with bright imagery and clear visibility of the tool and workpiece simultaneously. This helps to amplify the operator's understanding and simplify the machine's operation. Schwerdtfeger [Schwerdtfeger 2009] uses HMD-based augmented reality to guide workers in a warehouse with pick information, which is named as pick-by-vision.

In the industry of automobiles, SAR can be used in quality assurance, material handling (e.g. bin picking and kitting of parts) and maintenance as well as other applications. The quality assurance of spot welding is one of typical applications in the automobile industry. Schwerdtfeger et al. [Schwerdtfeger et al. 2008a; Schwerdtfeger and Klinker 2007; Schwerdtfeger et al. 2008b] set up an AR system that uses laser projectors in the quality assurance of welding points. In this system, a hybrid information presentation approach is used: the laser projector is used to locate and display the position of welding points to be checked; an additional computer display is used to show complex what-to-do information to users. The system still requires users to read the computer display while focusing on the welding points, thus affects the work efficiency. In addition, SAR can also be used for training in automotive manufacturing.

3 SAR in Spot Welding Inspection

As mentioned above, SAR may be applied to improve industrial quality assurance. This section describes our new system which facilitates SAR for in-situ support of spot welding inspection in automobile manufacturing, where SAR is used to highlight the location of the spot welding and type of inspection on an unpainted metal car part. The use of SAR can help operators to improve the efficiency of spot welding inspection in an automobile industry. The approach aims to remove the need of holding a paper-based operation description sheet and relieve some of the user's cogitative load by displaying cross-referenced information readily, in a suitable location and at the required time, in order to improve the accurateness and efficiency of the inspection of spot welding.

3.1 Conventional Approach of Spot Welding Inspection

In a typical automotive manufacturing process, the quality of spot welding on car bodies needs to be inspected at regular intervals. For example, a typical car has thousands of individual spot welds. In the process of making a vehicle, sub-assemblies are made and these assemblies can have between 30–200 spot welds. The spots have to be checked with a randomised sequence, even if the same type of part is checked — this has statistical reasons for dealing with the occurrence of false negatives. Instead of checking all spots on each body, operators only check different subsets of spots on different bodies. When all required spot welds are checked in a sequence, operators start a new spot sequence and repeat the inspection process. A variety of different methods are used to check spot welding: visual inspection, ultrasonic test, chisel test, and destruction test.

The current procedure that operators use to check spot welding is as follows (see Figure 1): the operator has a drawing, which shows the welds to be checked on a sample body. First, the operator has to find the spot in the drawing; subsequently, the operator has to locate the matching point on the body; after this, he has to choose the corresponding control method to perform the inspection.

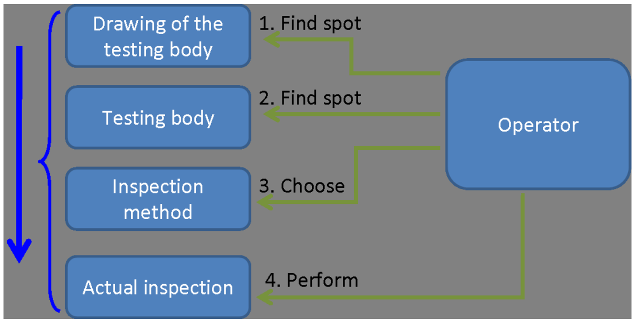

Figure 1: *Conventional operating procedure of spot welding inspection.*

This manual inspection process suffers from potential problems: it is possible that the operator identifies wrong locations and wrong numbers of welding spots. The operator is required to take time to interpret the drawing and find the corresponding spot on the raw body frequently. This process is also difficult for the operator to remember where to start and where to finish the checking on the checked body. Skilled operators are therefore required for performing manual inspections.

3.2 Projector-Based SAR in Spot Welding Inspection

SAR can be applied to lower the skill-level requirement for spot welding inspection by projecting digital AR information onto surfaces in structured work environments. Specifically, SAR projects visual data onto arbitrary surfaces for the express purpose and providing just-in-time information to users in-situ within a physical work cell.

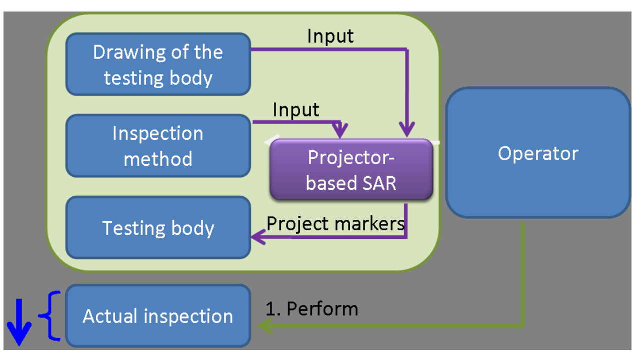

Figure 2: *Spot welding inspection using SAR.*

In this paper, a projector mounted on a movable stand is employed to view and interact with digital information projected directly onto surfaces within a workspace. Figure 2 shows the procedure of spot welding inspection using the SAR system described in this paper. In this system, the 3D CAD drawing of the test body part is used as an input of the SAR system, and it is stored in the SAR system as a geometrical model. The location of spot welds can be obtained from the geometrical model. The SAR system projects digital markers on top of spot welds with various geometrical shapes. The various geometrical shapes are used to inform operators what inspection method is used for a specific spot weld. As a result, operators are only required to perform the actual inspection in a inspection session, but not required to read the drawing of the test body from time to time to find spot welds on both the drawing and the test body. Figure 1 and Figure 2 illustrate how the SAR system effectively remove conventional operating steps before actual inspection. Figure 3 shows the main components of the system in our configuration, projector, control pad and computer.

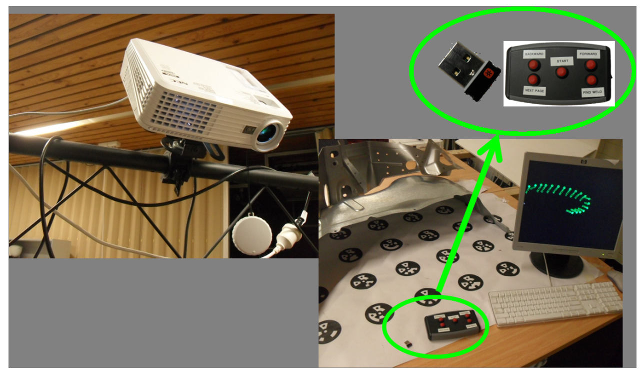

Figure 3: *Projector, Control Pad and Computer are the main components of the system.*

In order to simplify user interactions with the system, a wireless control pad as shown in Figure 4 was developed. The wireless control pad provides the operator to access the next/previous spot weld, find the current spot weld, go to the next page of spot welds, or go to the beginning of the spot welds list only by pushing one button on the pad.

Figure 4: *The wireless control pad is used for user interactions.*

4 Visualization in Spot Welding Inspection

SAR has the flexibility to provide various visualizations in the scene to augment information displayed to operators. This section presents different visualization methods to show the position of spot welds and assist operators locating spot welds easily.

4.1 Visualization of Location and Inspection Method of Spot Weld

In our approach, the location of the spot weld is visualized directly on the physical surface of the test body part with a colorful geometrical shape. Meanwhile, the inspection method of the spot weld is encoded into the geometrical shape. Various geometrical shapes are used to indicate that a spot weld is to be tested using a specific inspection method as shown in Figure 5. In addition, ODS information is displayed along with the spot weld marker together to assist operators performing the actual inspection (see Figure 5(c)).

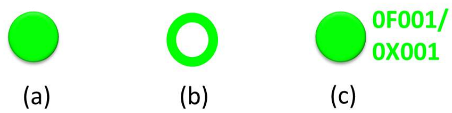

Figure 5: *Visualization of location of spot welds: (a) Destruction test; (b) Ultrasonic test; (c) Spot weld marker with the ODS information.*

4.2 Visualization of Weld-Find Method

If the test body part to be inspected is large or complex, operators may need to spend significant time to locate the spot weld during the inspection process. In order to assist operators to easily locate a spot weld to be inspected, this section describes a set of visualization approaches that project various dynamically changing geometrical shapes on the physical surface of the test body part. Three types of visualization approaches to assist in the task of weld-find are used in this paper (see Figure 6):

- **Shrinking concentric circles:** A size-changing circle centred on spot weld location is dynamically reduced from a radius about the size of the inspected part to the radius of the spot weld marker to guide operators locate the spot weld to be inspected.
- **Moving arrow lines:** Multiple arrow lines pointing to the spot weld are displayed. These arrow lines are initiated from approximately the edge of the part to the location of the spot weld dynamically to guide operators locate the position of the spot weld to be inspected.
- **Arrow line between two spot welds:** An arrow line pointing from the previous spot weld to the current spot weld is displayed. This arrow line directly guide operators to locate the next spot weld to be inspected along the arrow line.

The process of rendering the SAR data requires 3D graphical objects to be created. In the case of spot weld identification marks, individual graphics files (in .obj format) were developed. This is required to obtain perspectively correct rendering which is very important for the readability of text. The weld-find animations were developed that did not require as accurate positioning and could be generated on the fly in real time. Each of the three weld-find visualisations only requires at most two 3D positions in the part's coordinate system.

5 Results and Discussions

This section presents examples of applied SAR in an industrial quality assurance scenario, where SAR is used to highlight spot welding to be inspected on an unpainted metal car part. Our approach removes the paper-based operation description sheet by displaying cross-referenced information readily, on top of target loca-

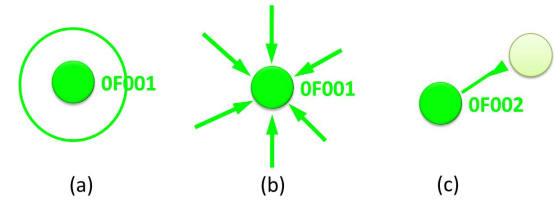

Figure 6: *Visualization of weld-find method: (a) Shrinking concentric circles: A size-changing circle gathering from far to the centre of the spot; (b) Moving arrow lines: Arrow lines gathering from far to the centre of the spot; (c) An arrow line pointing from the previous spot to the current spot.*

tions at real-time, in order to improve the accuracy and efficiency of spot welding inspection.

Figure 7 shows an example of projecting AR information on top of a spot weld on the surface of a car part. The ODS information is also displayed with the AR information. In our system, various formats of digital information (e.g. text, image, video, geometrical shapes) can be projected on the surface of a car part.

Figure 7: *ODS information is displayed beside the marker.*

In Figure 8, multiple spot welds are identified with AR information at the same time. This allows operators to access and inspect multiple spot welds concurrently. It also shows the distribution of spot welds on the surface of the test body part.

Figure 9 to Figure 11 give different examples of weld-find methods for spot welding inspection. Figure 9 shows an example of visualization of the weld-find using shrinking concentric circles. A series of concentric circles shrinking towards the spot weld are rendered dynamically to guide operators locate the position of the spot weld to be inspected. Figure 10 shows an example of visualization of weld-find using multiple moving arrow lines. The arrow lines are gathering from the edge of the part to the spot weld dynamically to assist operators locating the spot weld. Figure 11 shows an example of visualization of an arrow line from the previous spot weld to the current spot weld. The arrow line provides a direct guidance for operators in the process of spot welding inspection.

As illustrated in the examples above, SAR can provide effective guidance to attract the operators' attention to the next set of spot welds for inspection. The data items are projected onto the car body, providing instructions to operators. This removes the need

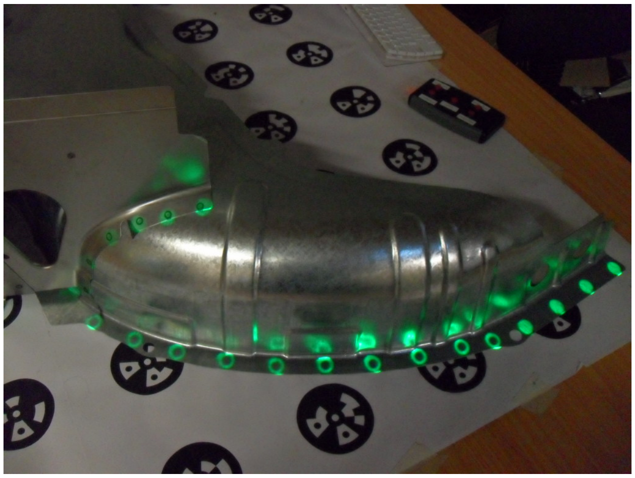

Figure 8: *Multiple welding spots are displayed at the same time.*

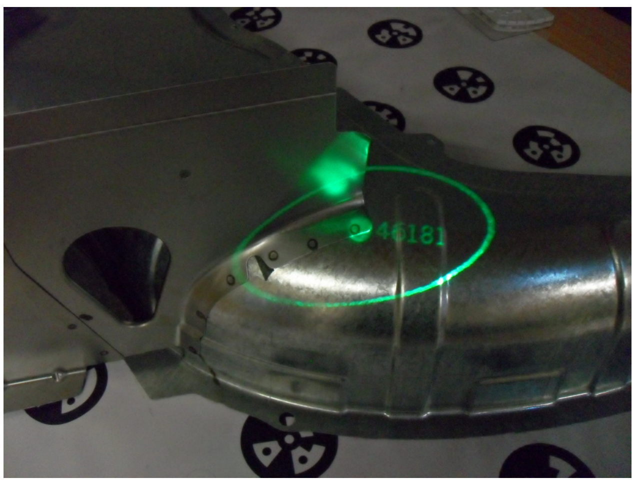

Figure 9: *Shrinking concentric circles helps operators to locate the spot.*

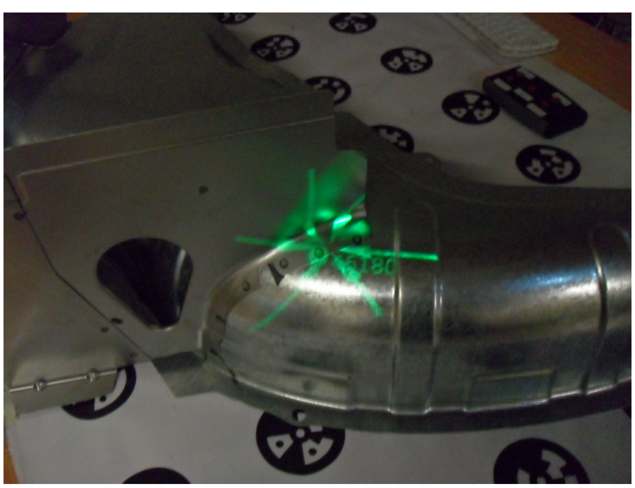

Figure 10: *Moving arrow lines pointing to the spot help operators to locate the spot.*

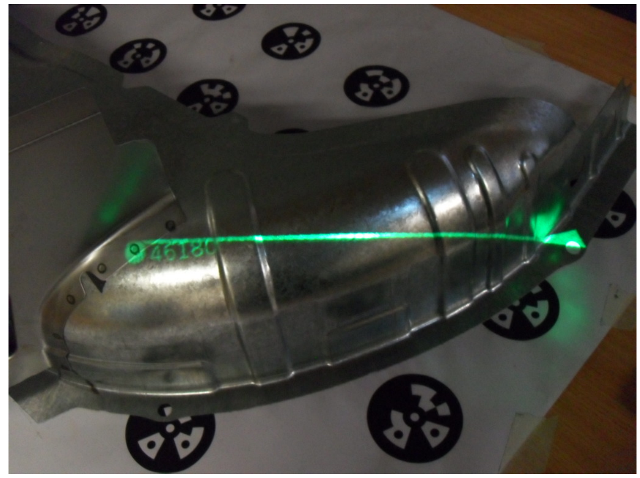

Figure 11: *An arrow line from previous spot to the current spot helps operators to locate the spot.*

to constantly refer to the instruction manual such as the ODS, thus speeding up the operation and reducing errors. There are benefits for providing in-situ data presentation for spot welding inspection. First is the reduction in cognitive load of forcing people to remember specific tasks and the order they are required in. Second, the vehicles coming down the line are individually built (each car is different as they come down the line), and this requires unique information for each vehicle. Third, changes to the production information can be directly sent to the production line and displayed to the user. Last but not the least, the use of SAR can improve the inspection accuracy and efficiency greatly.

One of the biggest advantages of our approach is that it can be used to assist operators in manual welding stations and to help the weld inspectors evaluate discrepant welds in automated welding stations. In the case of manual welding, a SAR based system can help the operator to ensure that all welds applied to the part are in the right sequence, in the right pattern, and at the right location. In cases of automated welding stations often time recovery from a welding related downtime is lengthened due to the lack of knowledge of what welds belong to what groups of welds to determine the proper corrective action. The SAR based system can help to quickly assess this condition. Another major advantage to a SAR based system is to help maintaining the fidelity between the welding databases and the actual welds that are being performed by the robots on the factory floor. Cycle time optimization process is usually continued for a long time after a production is launched. In many cases robot programmers move welds from robot to robot and from station to station in order to optimize cycle times. In many cases these welds are not reported properly. A periodic SAR based auditing system can help to facilitate this important check in order to assure the product design intent.

A major constraint of SAR based spot welding inspection system is the reliance of suitable projection areas on the object's surface. Limited amount and complexity of information that can be presented depending on the shape and size of the object [Schwerdtfeger et al. 2008b]. Meanwhile, since the diffuse reflection is very small from surfaces of car bodies, only a limited amount of light is reflected omni-directionally towards arbitrary viewer positions. Therefore, the projected and 3D aligned augmentations on the surface are sometimes not clear to viewers at specific angles; although, when this issue occurs, the viewer can usually adjust his/her positions slightly to find an improved viewing angle as a workaround.

When the system is used in a real-world environment, additional design factors need to be considered: 1) lighting condition of the work-cell; 2) tools for simplifying and automating the system operation (e.g. automatic projector calibration); 3) a control system which is able to identify and track moving objects and facilitate SAR projection on an assemble line. For the first issue, the allowed work-cell brightness is mainly determined by the physical properties of surfaces and the projector used in the system. The high luminous projectors could be used to project high contrast augmentation in a bright work-cell. Regarding the second issue, the project in our system is manually calibrated, and an automatic projector calibration approach will be a desirable feature for adopting our system in a real-world environment. Since this paper is mainly focused on the employment of SAR in the spot welding inspection, automated projector calibration will be considered as a future work. For the third issue, we have developed an approach to project augmentations on objects moving on the assemble line. Synchronization between the SAR system and the control of the assemble line could be used to recognize various parts on the assemble line as well as to manage the display information.

6 Conclusions

This paper described an SAR-based system for automotive spot welding inspection. SAR facilitated presentation of projected digital Augmented Reality information on surfaces of car bodies. The digital AR information including ODS information on surfaces of car bodies directly indicates the location of spot welds. SAR avoids the problem of operators taking time to read a drawing and find the corresponding spot on the raw body frequently as usually taken in manual inspection process. Various geometrical shapes are used to allow operators to identify the inspection method used for a specific spot weld. The animated visualizations in the system assisted operators to easily and quickly locate the spot welds. Our approach did not require special models but only required knowledge of location of spot welds on the part in finding spot welds. Besides the problems discussed in the previous section, the future work of this research will focus on the extensive evaluation of our approach. The operation information in other formats (e.g. movies, pictures) could also be projected onto physical surfaces of objects to assist operators.

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