# Facilitating Collaboration with Laser Projector-Based Spatial Augmented Reality in Industrial Applications

Jianlong Zhou, Ivan Lee, Bruce H. Thomas, Andrew Sansome, and Roland Menassa

**Abstract** Spatial Augmented Reality (SAR) superimposes computer generated virtual objects directly on physical objects' surfaces. This enables user to interact with real world objects in a natural manner. This chapter investigates SAR techniques and summarizes advantages with the difficulties of SAR in presenting digital information to users. The chapter then presents a concept of portable collaborative SAR. The concept utilizes both projector-based SAR and Head-Mounted-Display (HMD) based Augmented Reality (AR) in a single environment to assist collaborations within multiple users. The concept combines advantages of both projector-based SAR for collaboration and HMD-based AR display in personalization to improve the efficiency of collaborative tasks. The presented concept is explored in a case study of industrial quality assurance scenario to show its effectiveness.

## 1 Introduction

Augmented Reality (AR) is a technology that integrates virtual objects into the real world [20]. It is the registration of projected 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 to improve their understanding of the world in situ. AR interfaces enable people

Jianlong Zhou, Ivan Lee, and Bruce Thomas
School of Computer and Information Science, University of South Australia, Australia
e-mail: {Jianlong.Zhou|Ivan.Lee|Bruce.Thomas}@unisa.edu.au

Andrew Sansome
GM Holden Ltd., Victoria, Australia
e-mail: Andrew.Sansome@gm.com

Roland Menassa
GM Michigan, North America

**Fig. 1** Example for a screen-based video see-through display. The locomotion of a dinosaur is simulated over a physical foot-print [3].

to interact with the real world in ways that are easily acceptable and understandable by users. For example, doctors can use the AR system to allow an intuitive real-time intraoperative orientation in image-guided interstitial brachytherapy [8], and to guide the liver thermal ablation in interventional radiology [14]. 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. However, the long tradition of AR systems has been based on systems employing Head-Mounted-Displays (HMDs) that involve complex tracking and complicated equipment worn by users. This can not meet industrial requirements. Additional disadvantages such as limitations in Field-Of-View (FOV), resolution, registration and bulkiness, make HMDs less attractive in industrial applications [4].

Instead of body-attached displays, the emerging field of Spatial Augmented Reality (SAR) detaches the technology from users and integrate it into the environment. SAR employs new display paradigms that exploit large spatially-aligned optical elements. Three different approaches exist in SAR, which mainly differ in the way they augment the environment either using video see-through, optical see-through or direct augmentation. Screen-based augmented reality makes use of video-mixing (video see-through) and displays the merged images on a regular screen (e.g. see Figure 1). Spatial optical see-through SAR generates images that are aligned within the physical environment. Spatial optical combiners, such as planar or curved mirror beam splitters, transparent screens, or optical holograms are essential components of such displays [4]. Projector-based SAR applies front-projection to seamlessly project images directly on physical objects' surfaces, instead of displaying them on an image plane (or surface) somewhere within the viewer's visual field [4]. Figure 2 is a projector-based augmentation of a large environment. Due to the decrease in cost and improvements in availability of projection technology, personal computers,

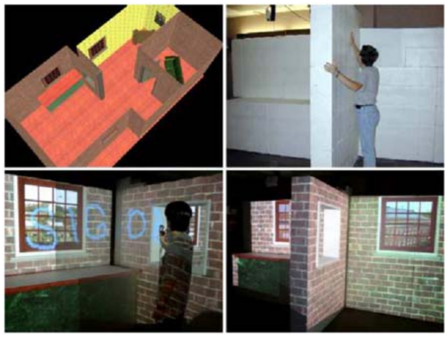


**Fig. 2** Projector-based augmentation of a large environment. Virtual model (upper left); Physical display environment (upper right); Augmented display (bottom) [10].

and graphics hardware, SAR is now a viable option for use in an industrial setting. This chapter focuses on the projector-based SAR display and its applications in a collaborative environment.

This chapter firstly investigates SAR techniques and summarizes advantages and problems of SAR in presenting digital information to users. Specifically, the chapter outlines laser projector-based SAR in various applications, as we are investigating the use of laser projected SAR in the automotive industry. The chapter then presents a concept of portable collaborative SAR. The concept utilizes both projector-based SAR and HMD-based AR displays in a single environment to assist collaborations within multiple users. In this concept, a portable projector (e.g. laser projector) based SAR is used to project 3D digital information onto the physical object's surface. Meanwhile, each individual user utilizes an HMD-based AR to receive customized information about the position on the physical object's surface marked by the projector-based SAR. The concept combines advantages of both projector-based SAR and HMD-based AR display to improve the efficiency of collaborative tasks. The presented concept is used in a case study of industrial quality assurance scenario to show its effectiveness.

The chapter is organized as follows: Section 2 investigates advantages and problems of SAR, and presents typical applications of SAR in industries. Section 3 outlines laser projector-based SAR and shows that it partially solves problems of conventional projector-based SAR in presenting digital information to users. Section 4 presents a concept of portable collaborative SAR. Section 5 gives a case study which uses the presented concept in spot welding inspection in automobile industries. Finally, Section 6 summarizes and concludes the chapter.

## 2 Spatial Augmented Reality and Its Industrial Applications

SAR allows digital objects, images, and information to be added as real world artifacts by projecting onto surfaces in the environment with digital projectors. Bimber et al. [5] 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. SAR benefits from the natural passive haptic affordances offered by physical objects [13]. This section outlines advantages and problems of SAR. Industrial applications of SAR systems are also discussed in this section.

## 2.1 Advantages of SAR

A key benefit of SAR is that the user is not required to wear a HMD and is therefore unencumbered by the technology. The user can physically touch the objects onto which virtual images are projected. In SAR, the FOV of the overall system is the natural FOV of the user, allowing him to use his peripheral vision. The range of SAR system's FOV can easily be extended by adding more projectors. Ultimately the FOV can emulate the full physical environment with a greater 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 [4, 18].

## 2.2 Problems of SAR

Like most of techniques, SAR also has some problems besides advantages in applications. The crucial problems with projector-based SAR are as follows [5, 18]:

- **Dependence on properties of display surfaces**. A light colored diffuse object with smooth geometry is ideal. Rendering vivid images on highly specular, low reflectance or dark surfaces, is practically impossible. The ambient lighting can also affect the contrast of images. This limits applications of SAR to controlled lighting environments with restrictions on the type of objects with which virtual objects will be registered.
- **Restrictions of the display area**. The display area is constrained to the size and shape of the physical objects' surfaces (for example, no graphics can be displayed beside the objects surfaces if no projection surface is present). Multi-projector configurations can only solve this problem if an appropriate display surface is present.
- **Shadow-casting**. Due to the utilisation of the front-projection, SAR has the problem of shadow-casting of the physical objects and of interacting users. This can be partially overcome by employing multiple projectors.
- **One active head-tracked user**. SAR also allows only one active head-tracked user at any instant in the environment because images are created in the physical

environment rather than in the user's individual space. Time multiplexed shuttered glasses may be used to add more users that are active and head-tracked, but this requires the user to wear technology.

- **A single focal plane**. Conventional projectors only focus on a single focal plane located at a constant distance. It causes blur when projecting images onto non-planar surfaces. Multifocal projection technology [2] can solve this problem by employing multiple projectors.
- **Complexity of consistent geometric alignment and color calibration**. When the number of applied projectors increases, the complexity of consistent geometric alignment and color calibration is increased dramatically.

A major issue for SAR is the determination of suitable projection areas on the object itself. This limits the amount and complexity of information that can be presented [27]. Meanwhile, since the diffuse reflection is very small, only a minimal amount of light is reflected omni-directionally towards arbitrary viewer positions. Therefore, the projected and 3D aligned augmentations on the surface are not clear to viewers and have to be kept simple. So the main challenges include: How to project onto arbitrary surfaces; Where to mount the projectors; and How to provide adequate accuracy. Part of problems caused in conventional projector-based SAR can be finely solved by utilizing laser projectors as discussed in following sections.

### *2.3 SAR in Industrial Applications*

AR technology was applied successfully in certain use cases in industries [19]. Several major application areas are identified: 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. For example, doctors could use the SAR to jointly visualize and discuss virtual information that is projected onto a patient or mannequin, while simultaneously visualizing remote collaborators whose imagery and voices are spatially integrated into the surrounding environment [5, 18].

In industries such as manufacturing, SAR could 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 [13] set up a SAR-based physical-virtual tool for industrial designers. The 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 designing process to produce a matching 3D virtual model. Olwal et al. [15] 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 [24] 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 [26, 27] in automobile industries. In addition, SAR can also be used in job training in the automotive industry.

## 3 Laser Projector-Based SAR

Laser projector-based SAR has special properties compared with conventional projector-based SAR. This section shows related work on laser projectors and applications in SAR. Advantages of laser projectors are also discussed in this section.

### *3.1 Related Work*

Wearable laser projectors have already been presented by Maeda et al. [12]. Kijima et. al [7] develop a hand-held laser projector to enhance the annotation of a barcode with additional information. Glossop and Wang [6] develop a laser projection AR system for computer-assisted surgery. The system uses rapidly scanned lasers to display information directly onto the patient. A well established industrial application of laser projector uses a table top system that mounts a laser projector to indicate directly on a circuit board where to place the next item [22, 27]. A laser can also be used in a remote collaboration AR system for annotation in the real workplace the user is focused on [9, 16].

There are other approaches toward using laser projectors in industrial applications. Zaeh and Vogl [28] use stationary laser projection to visualize tool trajectories and target coordinates in a robots environment by SAR technology. The system is arranged and calibrated for a specific, static scene. The surfaces onto which information is projected may not be moved. MacIntyre and Wyvill [11] developed a laser projector that augments chickens in a processing line with automatically generated slaughter instructions. Schedwill and Scholles [23] develop a laser projection system for industrial uses, such as distance measurement and AR applications.

Schwerdtfeger et al. [25, 26, 27] set up an AR system that uses laser projectors. Figure 3 shows an example of this system. The system is used 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.

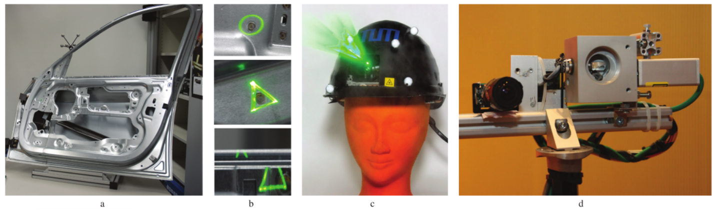


**Fig. 3** (a) A white body of a car door, with about 50 welding points; (b) Projected images onto the white body; (c) First prototype of a laser projector: head-mounted, integrated into a helmet; (d) Second prototype: tripod-mounted, consisting of a wide angle camera for optical tracking, a galvanometer scanner and a 1 mW laser (from left to right) [27].

## *3.2 Advantages of Laser Projectors*

The problems of the conventional projector-based SAR can be solved partially by the utilization of laser projectors. The laser projector-based SAR has following advantages:

- **Self calibration**. Both the laser projector and the conventional projector need to be calibrated to the environment in which it will work. During the laser projector calibration process, the user only needs to specify rough positions of calibration points on physical surfaces of objects. The laser projector will then automatically search exact positions of calibration points on physical surfaces. However, for the conventional projector calibration, the user needs to specify the exact position of each calibration point on physical surfaces precisely, there is no automatical mechanism to search calibration points on physical surfaces in the conventional projector;
- **High bright laser beam**. The laser projector uses high bright laser beam and allows the user to perceive information from a large view and complex lighting conditions (even when viewed through an HMD);
- **Unlimited depth of focus**. The laser projector has "unlimited" depth of focus. The projected image on the object is in focus at any time.

Because of these advantages, information presentation systems using the laser projector based SAR are getting widely used in various applications, such as the aerospace industry.

However, the laser projector also has disadvantages.These mainly include safety issues related to the laser projector. Because of safety issues, the laser projector has additional requirements for work places and has to be limited in specific work places.

## 4 Portable Collaborative SAR

In a natural face-to-face collaboration, people mainly use speech, gesture, gaze, and nonverbal cues to communicate. The surrounding physical world and objects also play an important role, particularly in a spatial collaboration tasks. Real objects support collaboration through their appearance, physical affordances, and ability to create reference frames for communication [1]. SAR technology promises to enhance such face-to-face communication. SAR interfaces blend the physical and virtual worlds, so real objects can interact with 3D digital content and improve users' shared understanding. Such interfaces naturally support face-to-face multi-user collaborations. In the collaborative SAR, co-located users experience a shared space that is filled with both real and virtual objects. Moreover, wearable computer based AR interface, such as HMD-based AR, in a collaboration makes the power of computer enhanced interaction and communication in the real world accessible anytime and everywhere [21]. HMD-based AR offers the flexibility for the personalization of information. HMD's allow for a customized AR visualization for each individual user in a collaboration.

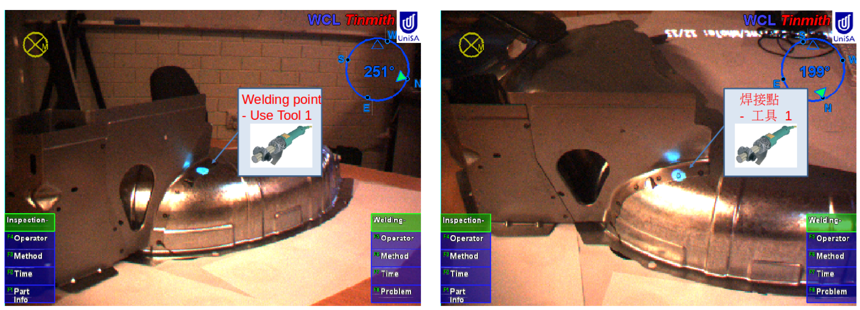
This section presents a concept of portable collaborative SAR which utilizes both SAR and HMD-based AR to support collaborations within multiple users. In this concept, a portable projector (e.g. laser projector) based SAR is used to project global and positioning 3D digital information onto the physical object's surface. Meanwhile, each individual user utilizes an HMD-based AR to receive customized information about the position marked by the projector-based SAR on the physical object's surface. The portable laser projector and thus the portable collaborative SAR allow flexibility for locations of work places.

Figure 4 shows an illustration of this concept. The concept combines advantages of the projector-based SAR and the HMD-based AR at the same time: SAR projects digital marks onto the physical object's surface. These marks serve two purposes, 1) to provide a global physical world context for users to understand the problem space and 2) a fiducial marker for the HMD-based AR visualizations. Various users who wear the HMD-based AR system can receive personalized information on the marked points. In the case of automotive welding applications, it is conceivable that different users can wear the HMD-based AR system where one user is reviewing welding schedule parameters and another user reviewing weld specification and in different languages to enable global collaboration.

As an example, Figure 5 shows that two operators view the same SAR projected digital mark (light blue disk), with personalised welding and inspection information displayed by the HMD screen for each individual operator. These light blue AR displayed graphical objects provide global overall information for both users. These can indicate graphically the position and type of weld. This acts a universal means of providing a "grounded" frame of reference for both users. Critical positions and information are physically common between the users, and therefore this removes any uncertainty due to tracking errors. The HMD AR displays are created using Tinmith Wearable Computer [17]. The operator who is an English speaker receives operation information in English, while the operator who is a Chinese speaker receives oper-

**Fig. 4** Concept illustration of combining laser projector-based SAR and HMD-based AR for collaborations.

ation information in Chinese. In this figure, spot welding on a mechanical part are inspected. Each operator receives information on different aspects of the welding spot. The light blue laser projected disk is treated as a tracking marker and global information. The marker-based AR is used to identify the marker as the reference point, and place the personalised instructions through the user's HMD according the reference point.




(a) Viewpoint from operator 1

(b) Viewpoint from operator 2

**Fig. 5** Concept illustration of combining projector-based SAR and HMD-based AR visualisation for different operators.

This concept has potential applications in various areas. First, it can be used in a collaborative training environment. The collaborative training environment allows trainees with different backgrounds (e.g. language) work together without additional help. For example, a company has multiple factories in various countries. Operators doing the same task in different countires need to be trained. Users training in their own languages is preferred to improve the effectiveness of the training. Of course, operators can be classified into groups according to their languages. Multiple training sessions are then necessary for various groups based on languages. By using the collaborative training environment, one single training session is only used for all operators from different backgrounds. This is achieved by each trainee having a personalized interface while viewing the same target. The collaborative training environment not only improves effectiveness of the training session, but also allows trainees with different backgrounds to learn with each other in a single environment. Second, the concept can be used in military, diplomatic and other similar situations where participants have different backgrounds and need to collaborate with each other. Third, the concept benefits various industries in production support, designing and maintenance. Last but not least, similar to Chapter 11, the concept could be extended and used in remote collaborative tasks such as remote guiding, training and maintenance. Section 5 shows an example of using the presented concept in the automobile industry.

# 5 Case Study: Using Collaborative SAR in Automobile Industries

This section presents an application example that uses the presented concept in a training session of an industrial quality assurance scenario, where SAR is used to highlight spot welding to be inspected 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 paper-based operation description sheet from operators' hands and relieve some of the work 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.

## *5.1 Spot Welding Inspection in Conventional Ways*

In the industry of automobiles, the quality of spot welding on car bodies needs to be inspected at regular intervals. For example, in an automobile company, a typical car has thousands of individual spot welds. In the process of making the vehicle, subassemblies are made and these assemblies can have between 30–200 spot welds. The spots have to be checked randomly from one to the next, even if the same type of part is checked — this has statistical reasons dealing with the occurrence of false negatives. Operators are not required to check all spots on each body. Instead, they only check certain number of spots on different bodies in a sequence. When all required spot welds are checked in a sequence, operators start a new spot sequence for checking. 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: the operator has a drawing, which shows the welds to be checked on the sample body.

First, the operator has to find the spot in the drawing. Then he has to match it on the body. After this, he has to choose the corresponding control method to finally perform the inspection. This manual inspection process has potential problems: the operator can easily check the wrong locations and/or wrong numbers of spot welds; it is also difficult for the operator to remember where to start and finish the checks on the body.

### 5.2 Using Laser Projector-Based SAR in Spot Welding Inspection

SAR benefits spot welding inspection in the automobile industry. It facilitates presentation of projected digital AR information onto surfaces in structured work environments. Specifically, the portable laser projector-based SAR allows to project visual data onto arbitrary surfaces for the express purpose and provides just-in-time information to users in-situ within a physical work cell. It enables operators to do the spot welding inspection efficiently and effectively.

In this example, a laser projector mounted on a movable stand is employed to view and interact with digital information projected directly onto surfaces within a workspace. SAR provides guidance to operators to the next set of spot welds to inspect. The data items are projected onto the car body, providing instructions to operators. This removes the need to constantly refer to the instruction manual such as the operation description sheet, thus speeding up the operation and reducing errors.

The concept of portable collaborative SAR can be used in a training program of spot welding inspection. With the proposed technique, a typical training session can be conducted as follows: an instructor performs the spot welding inspection according to the digital marker pointed by laser projector-based SAR, and trainees wear HMDs to inspect operations. HMD-based AR allows trainees to access different information (e.g. welding method, welding time) of the same welding spot marked by the laser projector concurrently. For example, some trainees may want to know the welding method for the inspected spot and put this information on their HMD's screen, while others may want to display the inspection information in their own native languages. Because each trainee gets personalised information with HMD-based AR, each trainee can learn spot welding inspection from different aspects. This may improve the training efficiency for both the individual trainee and the overall training session.

Perhaps one the biggest advantages to the concept of portable collaborative SAR can be used to assist operators in manual welding stations and to help the weld inspectors evaluate discrepant welds in automated welding stations. Quality is paramount and in the case of manual welding a SAR based system can help the operator to ensure that all the welds have been applied to the part, 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 maintain the fidelity between the welding databases and the actual welds that are being performed by the robots on the factory floor. Cycle time optimization long continues after production launches and in many case 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.

There are benefits for providing in-situ data presentation for the 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, it improves the inspection accuracy and efficiency greatly.

## 6 Conclusions

This chapter reviewed SAR techniques and summarized advantages and problems of SAR in presenting digital information to users. The chapter then presented a concept of portable collaborative SAR. The concept utilizes both projector-based SAR and HMD-based AR displays in a single environment to assist collaborations within multiple users. The concept combines advantages of both projector-based SAR for collaboration and HMD-based AR display in personalization to improve the efficiency of collaborative tasks. The presented concept was used in a case study of industrial quality assurance scenario to show its effectiveness.

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