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Information provision utilizing a dynamic projection system in industrial site assembly

Patrick RUPPRECHT[a*], Hans KUEFFNER-MCCAULEY[a], Sebastian SCHLUND[a]

[a]*Human-Machine Interaction Group, Institute of Management Science, Technische Universität Wien (TU Wien), Theresianumgasse 27, 1040 Vienna, AUSTRIA*
* Corresponding author. Tel.: +43 664 5523442; *E-mail address:* patrick.rupprecht@tuwien.ac.at

Abstract

Today, industrial assembly of large equipment is often organized as site assembly. Information is provided on paper or stationary PC-terminals and employees have to walk long distances to receive information. An augmented dynamic projection system allows direct display of work-instructions and interaction on the component. The paper presents the results of an evaluation of a dynamic projection system compared to state-of-the-art information provision. The experiment is carried out using a demonstrator with a CFRP-layup site assembly for aircraft components. The results show that the augmented dynamic projection system brings significant advantages for process improvements and usability compared to PC-terminals.

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1. Introduction

The industrial assembly of large-scale equipment (e.g. carbon fiber reinforced polymer (CFRP) layup process for aircraft components, large machinery, gear boxes) is usually referred to as organized industrial site assembly [1] (Fig. 1).

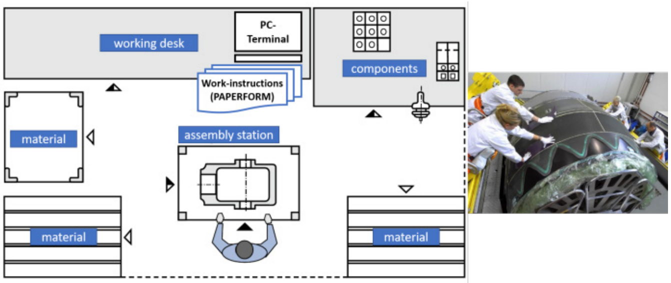

Fig. 1. Industrial site assembly (schematic) [1]

The part remains stationary during the assembly process and all sub-parts, tools, information and workers are transferred to the assembly station [1]. This type of assembly involves a lot of manual work and is automated at a low degree compared to other types of assemblies, as [1]:

- model variety is high; often different assembly-relevant variants are assembled
- due to the usually large work content the degree of repetition of assembly activities is very low
- (compared to single work assembly / flow line) the variety of geometries and dimensions is high
- the degree of industrialization (measured by the quality of documented processes) is low
- the dimensions of the working area are often too large for stationary solutions (both in the field of automation and digitalization)

In other kinds of assembly stations, such as single work assembly, flow assembly in the automotive sector or in manual assembly stations, there are currently already numerous research activities and industrial developments on assistance systems to support employees in production. For this low degree of industrialization, a high level of training and clearly structured instruction and work-information is needed [1]. The work information includes e.g. work-instructions, process descriptions, documents on norms and standards, supporting/learning instructions and other important

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documents for their use in process. Currently, different types of information provision systems are used in assembly stations and modern assistance systems are being developed. Fig 2. shows the approaches for providing information for assembly stations, and especially for site assembly.

Fig. 2. Different information provision systems

In site assembly, the state of the art system information being provided in paper-form or on centralized PC-terminals with standardized software e.g. MES Systems (Manufacturing Execution System) with the disadvantage that employees have to move long distances for interaction through a terminal, and in order to receive information in time. Further consequences with e.g. paper-documents are the high efforts needed for updating the information, a high error rate, documentation effort and traceability problems. The information provided is mostly text-intensive, nonintuitive and not context-sensitive, which complicates and reduces the speed of understanding [1]. These forms of provision result in high waiting and search times as well as coordination efforts for information procurement and clarification. In the field of cognitive activities, information search and clarification from e.g. information management systems directly on the shop floor, is of high importance and accounts for between 20-50% of effort, which has a high potential for increasing productivity [2,3,4].

This initial situation in site assembly results in a high economic potential for innovative assistance systems for support of the value-added assembly activities. Modern technologies and digital networking offer new possibilities of support to employees [5,6]. Many companies are currently developing these assistance systems for their use in production. The context of research on AR (Augmented Reality) is also becoming broader, particularly by addressing the challenges of implementing AR-solutions [7]. For the areas of support for cognitive work activities, intelligent wearables, mobile devices, (e.g. smartphones or tablets), data glasses and Augmented/Virtual Reality (AR/VR) systems are important [8],[9],[10]. Wearables, e.g. smartwatches offer the possibility to send information directly to the worker. The disadvantage is, that comprehensive information cannot be displayed in the small field of view, so they must be as brief and meaningful as possible [11]. Although wearables and data glasses are possible for use in production, and are often used in multi-machine operation or for service and e.g. maintenance procedures [12], they lead to significant problems in terms of manageability, limited field of vision, operation as they have to be worn on the body throughout the work process.

Augmented static projection systems are state of the art systems used in site assembly, e.g. stationary laser systems with 532nm green diode pumped solid state lasers, for displaying 2D-contours of the CFRP-mats onto the workpiece in an assembly station of aircraft components [13], or developments of static AR-projection systems at Skoda, which support employees in loading pallets [14]. The advantage of these projection systems is that, unlike AR-glasses or other wearables, they can be operated hands-free and no devices have to be worn on the body during the whole working day.

Static projection systems are mostly suitable for displaying two-dimensional information on a planar surface, because they do not have the possibility to move the information dynamically in a large spatial area, as it is necessary in the case of a large site assembly. Therefore, not all necessary work information can be displayed in the room, which in turn requires central terminals or paper. In industrial site assembly, state of the art assistance systems for providing digital information carry a number of advantages with them, but also present difficulties. Quick changes, warnings or individual, context-sensitive messages and information, which are dynamically moveable, changeable and oriented to the employees position are difficult to implement through static projection or terminals. A special new and innovative system of spatial augmented dynamic projection is presented in the following.

2. Spatial Augmented Dynamic Projection System for site assembly

In current projection technology, projectors with low maintenance laser-bulbs, a brightness of 6200 ANSI Lumen, a high resolution of Full HD or 4K, a contrast of 10,000:1 and an expected lifetime of 20,000 hours, fall below a price limit of 10,000 EUR, which renders their use for assembly conceivable. Usually, work-instructions (e.g. CAD-data) in high resolution is available with a combination of relevant assembly information. Furthermore, a new dynamic projection system with a high-performance moveable mirror system used for displaying projected information (e.g. pictures, videos, animations) on large surfaces is currently used for media installations in the event sector [15]. This system consists of a professional laser bulb projector from Panasonic (PT-RZ660BE) with motor driven lenses, a digitally controlled mirror head to ensure the dynamic component of the projection, a small accessible desktop computer to control the projector via web interface and a desktop PC (Ubuntu Linux) with a media content management system including a mapping engine (specially developed for the mirror head) to import content and map it correctly on any surface without distortion. A single projector can be used for display ranges of up to several hundred meters [15].

The dynamic projection system for the display of work-instructions in an intuitive way, in combination with the advantages of the state-of-the-art accurate solid state laser system for precise display of contours, results in an innovative spatial augmented reality system, which has great advantages for process optimization and the usability of the employees in site assembly station. Fig. 3. shows a schematic overview of the augmented projection system. Prepared work-information and augmented media, such as pictures, learning-videos and CAD-data can be provided through a desktop PC (Ubuntu Linux) with a media content management system. The mapping engine translates the information and combines them with the position where it should be displayed.

The digitally controlled moveable mirror system allows for an adjustable spatial position of the work-information projection, making a non-planar and distortion free display of the images possible through a mapping function.

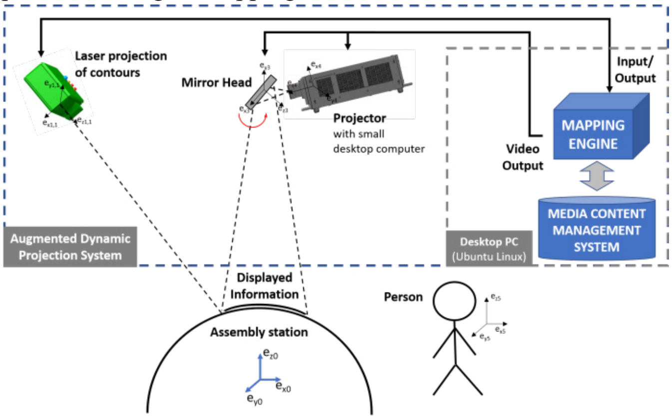

Fig. 3. Schematic overview of augmented dynamic projection system

It is thus possible to project work-information directly onto the component, floor or wall in a three-dimensional manner. This allows for the use of dynamic projection systems, e.g. for CFRP-layup assembly processes on non-planar applications and rotationally symmetric contours, such as they are used in site assembly for the production of aircraft parts. The intuitive interaction and the individual extended information such as videos and 3D elements can be used in user-centered workstations for assembly and bring more advantages with them compared to a static system and one-size-fits-all system [16].

The current difficulties in the implementation of dynamic and digital systems often do not concern the hardware available today (sensors, image processing and actuators), but the difficult integration and interoperability of hardware and software [17]. Here the big challenges are that different systems e.g. dynamic projection systems should automatically interact with solid state lasers and other information systems (e.g. Enterprise Resource Planning systems (ERP), and MES). From a technical point of view the challenge is that the movement of the mirror has to be tracked and mathematically calculated to perform the coordinate transformations of the various systems. Initially, high authoring efforts are required for manual preparation, adjustment and calibration of the mirror system and digital data preparation.

3. Experimental comparison of information provision systems

In order to gain deeper understanding about the opportunities and obstacles in assembly operations we carried out an experiment with state-of-the-art information provisioning and the dynamic projection system in relation to process time and usability. The research question of the paper is:

"Which added value does dynamic provision of information and interaction at the assembly station offer compared to the provision and interaction via terminal and static projection?"

For this purpose, the state-of-the art system, which includes the interaction and provision of work-information via PC-terminal and display of the layup-contours by means of an accurate solid state laser projection, was set up for the experiment analog to its application in industry. This "PC-terminal" experiment is shown in Fig.4..

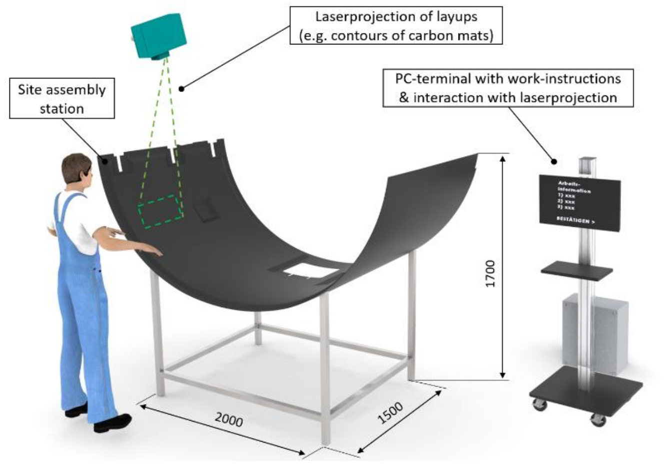

Fig. 4. PC-terminal experiment - information provision by PC-terminal

The compared experiment is the spatial augmented dynamic projection system, where the work-information is displayed directly on the assembly-tool (with projector and mirror head) and the interaction with solid state laser (displayed contour of mats) and content management was executed by touching projected buttons (Fig. 5.).

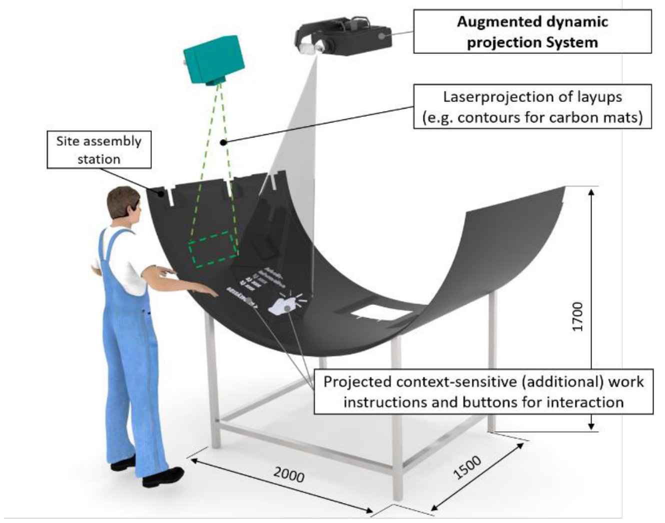

Fig. 5. Spatial Augmented Dynamic Projection System - experiment

At the stage of the experiment, the technical implementation, that an interaction is automatically triggered when the projected buttons are touched, was not completely functional yet. Therefore, when the user has touched the button, we proceeded to the next process step manually via PC.

The experimental process is a CFRP-layup assembly, which corresponds to an industrial site assembly station. Here, carbon mats are bonded layer by layer until a finished aircraft product is created. The challenges of site assembly, such as long distances, manual work and information provision are illustrated.

The process sequence was defined and simplified, and all participants had to complete it for both experiments. (Fig. 6.).

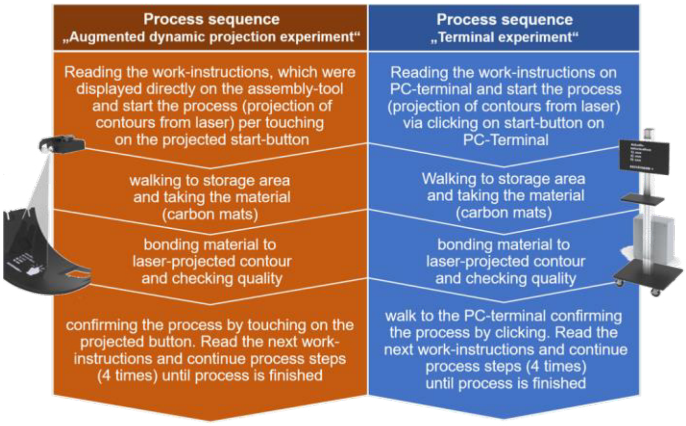

Fig. 6. Process sequence for both experiments

4. Evaluation and results

The differences of the two systems as well as the added value of this dynamic provision was evaluated from a process optimization and usability point of view with 16 participants, which were students and interested laymen with a technical background. The gender allocation of the participants was such that 4 participants were female and 12 were male. 12 participants were between the ages of 20 and 29 and 4 between the ages of 30 and 39. On average 11 people had no experience with augmented reality or virtual reality, but smartphones are used by all participants on a daily basis. In order to evaluate the process optimization, the process time of each participant and experiment was determined using a stopwatch and then the average for the respective experiments was calculated and compared. The clarity of the understanding of the work information and performance of the work was also queried to contribute to the optimization of the dynamic projection system. Tab. 1./Fig. 7. shows the results of the process time of the two experiments.

Table 1. Comparison of process time (1)

Experiment sequence/total	Average process time [min]	Improvement projection to terminal [%]
Terminal experiment 1st	02:35	/
Dynamic projection experiment 1st	02:29	+3%
Terminal experiment 2nd	02:17	/
Dynamic projection experiment 2nd	02:11	+4%
Terminal experiment 1st&2nd	**02:25**	/
Dynamic projection experiment 1st&2nd	**02:19**	**+4%**

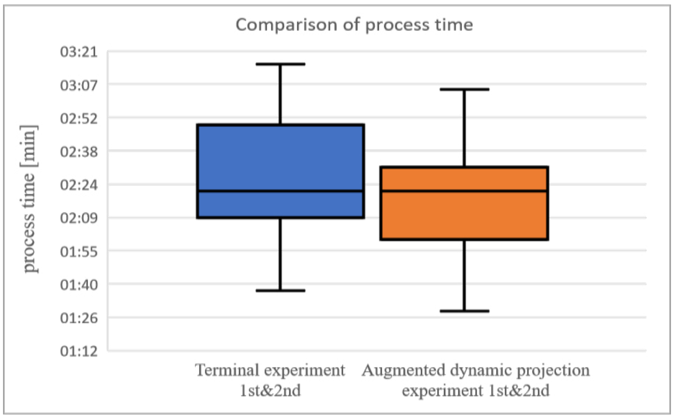

Fig. 7. Comparison of process time (2)

The amount of time to complete each process was timed and it was discerned that the dynamic projection experiment requires on average throughout each round six seconds less than the terminal experiment. In the first round, regardless of starting the experiments the process times were higher than the second round. Core statements from a process optimization point of view are:

- With a dynamic projection system the paths to retrieve information are shorter and the interaction is faster
- Dynamic projection system needs less process time

Usability is very important for users in order to achieve acceptance and improvement of human working conditions and to ensure appropriate learning opportunities to improve qualification and work quality [18],[19].

To evaluate the usability and acceptance [20],[21],[22], the "Structured System Usability Scale (SUS)" and the "Technology Acceptance Model (TAM)" were used as usability questionnaires. After each experiment a usability questionnaire was filled out by the participants and a short interview about their insights into the process was conducted. Brooke [23] developed the structured usability scale (SUS) specifically towards industry needs. The questionnaire consists of ten items that are answered on a five-point Likert scale. The result is a value called “Total SUS Score”. 100 % is therefore a perfect product or service perfectly designed according to usability. The adjective rating scales can be used to interpret the total SUS score [24].

The results from the SUS score of the two different experiments are displayed in Fig. 8.

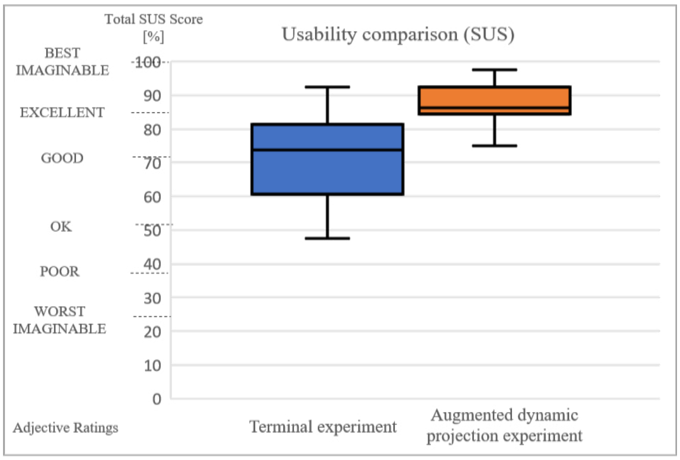

Fig. 8. Results of SUS-Score

We can derive from the results, that independently of the order in which the experiments were conducted, the dynamic projection experiment scores a higher “Total SUS Score” compared to the terminal experiment, with a mean of 85.3, which translates to an adjective acceptance rating “Excellent”. The terminal experiment exhibits an average of 71.1, which corresponds to an adjective acceptance rating of “GOOD”.

The second usability questionnaire was TAM, with which we have the possibility to determinate user acceptance, which has practical value for evaluating systems.. Davis [25] developed the “Technology Acceptance Model” (TAM).To better predict, explain and increase user acceptance, we need to better understand why people accept/reject computers. Fig 9. is a representation of the TAM results.

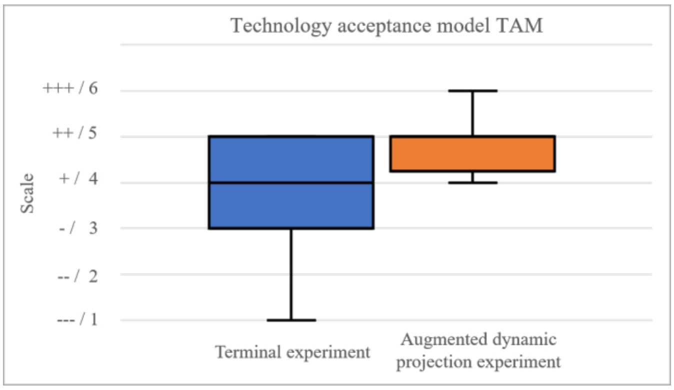

Fig. 9. Results of TAM

With dynamic projection system shows a median of 5, which corresponds to an acceptance of ++. The first quartile lies at 4.75 and the second quartile at 5. With the terminal system the median is 4, which corresponds to an acceptance of +. The first quartile lies at 3, where the second lies at 5.

In this experiment the participants were also observed and filmed during the process and problems and obstacles were noted. The participants had to speak out loud in order to determine their impressions and feelings. The think-aloud test is well suited to catch users thoughts and feelings in the experiment [21]. In a final interview after the experiments, the participants were asked which system they felt more comfortable with, which one they would prefer and where information was more clearly visible. Following (Tab. 1.) are the findings/statements to the experiments:

Table 2. Findings and statements to the experiments

Findings/Statements to the PC-terminal experiment
Long paths to PC-terminal to confirm the process step is cumbersome
Important information was overlooked in the vast amount of text (e.g. say "Process complete" out loud) at the end of the experiment
No flexibility due to fixed position of the PC-terminal
Orientation of the displayed information on the PC-terminal hard to picture on the real work piece
Considerable amount of information is hard to memorize and requires frequent returns to the PC-terminal
Confirmation of work steps on the PC-terminal is cumbersome
One of the participants noticed that they felt more comfortable with the terminal system because the participant felt more comfortable using the PC.
Findings/Statements of the augmented dynamic projection system experiment
Information and interaction directly at the work piece is convenient
No long travels to PC-terminal
Easy to use and comprehend
At the beginning a higher amount of information is required, then later in the process only arrows or less and more concrete information is needed
It would be useful if the information would orient / align itself to the worker
Projections on individual features are hard to read
Easily comprehended and in direct vicinity of operation
Information „Process complete" was not overlooked as it was displayed in an effective way
For professional (trained) users it is necessary to enhance the displayed information, e.g. less but more practical information compared to novice users

With the aid of the lead questions it was discovered that 14 of 16 subjects found the dynamic projection system and the direct display of information/interaction more preferable and would feel more comfortable with the projection. One of the two subjects, which thought that the dynamic projection was not that comfortable, said that the PC is more preferable because one is already familiar with it. The other subject said that they already had more experience with layup processes and therefore needed more concrete and a reduced amount of information displayed. Tab. 3. shows the overall comparison of process time, SUS and TAM-Score and also the preferences of the participants.

Table 3. Comparison of the results

	PC-Terminal experiment	**Augmented dynamic projection experiment**
process time	**02:25 min**	**02:19 min**
total SUS Score	71,1	85,3
adjective rating SUS	OK	Excellent
TAM Score	4 +	5 ++
preferences of participants	#2/#16	#14/#16

5. Conclusion

In this paper we presented the results of an experiment to compare a dynamic projection system as a new spatial augmented reality assistance system for information provision in industrial site assembly with state-of-the-art technology. Therefore, we compared industrial concepts of providing information in site assembly. Starting with the provision of paper-documents, the use of PC-terminals, wearables, data glasses and also the use of static projection systems were discussed. The advantages and disadvantages of the existing systems were described and a new augmented dynamic projection system was demonstrated. To answer the research question, a comparison of state-of-the-art provision with PC-terminal and the new augmented dynamic projection system was conducted.

This paper has shown the practical comparison in terms of process optimization and usability. The results show that the spatial augmented dynamic projection system has a shorter process time, a higher SUS and TAM-Score and the participants felt more comfortable and prefer this system compared to the PC-terminal system. Furthermore, qualitative feedback supports that the augmented dynamic projection system offers new possibilities in the display of information, such as the usage of images, videos and context sensitive information directly at the workplace and oriented in correspondence to the sight and position of the worker according to where it is needed in the process.

In the comparison of the process time, it can be considered that the time using the dynamic projection system is about four percent faster. The investment of the projector is between 10,000-15,000 EUR including all components. However, it should be pointed out that if information is digitally available and can be delivered quickly to the workplace, this will provide an added value in terms of query time, etc. Also the updating of paper documents or "pdf" takes a lot of time in the traditional system, which will justify the investment. Nevertheless, future work will emphasize a more significant decrease in process time as improvements of more than 10% in the assembly process is required for a business case. The results serve as an input for future research in information provision systems for site assembly. The general statements are restricted due to the limited number of participants, but since this was the first test of the system, the statements of the participants helped to derive further development steps and to bring the system to a higher technological readiness level, which will then be tested with more participants. More subjects would have brought even more data in terms of process time and feedback in terms of usability. Nevertheless, valuable qualitative insights were gained, and the usability scores strongly support further research towards a hands-free and context-adaptive assistance systems without having to wear markers for tracking. As such, information can be more effectively and quickly perceived and there is no need to walk long distances to PC-terminals. The interaction with projected buttons (e.g. confirming and proceeding to the subsequent process step) is also intuitive and can take place directly on the component, which saves a lot of time and the usability rates positively. Also most of the participants mentioned from their statements that despite the black and shiny surface of the component, the information was well readable, but perhaps the readability could be improved by displaying information at special positions on the part. We conclude that the process optimization, the usability and acceptance was clearly improved when displaying information directly on the product. However, it is still necessary to adapt the projected information to the requirements and qualifications of the employee and to display information in a more targeted manner with signs and pictograms than in text form, even while the process is running.

The future work in this research area should incorporate the experience and feedback of this experiment into the design of the user interface of the projection system as well as into the form and granularity of the displayed intuitive information for different user groups (novices, professionals). Especially for projected information, specific pictograms and symbols are designed for use in site assembly and tests are carried out with different graphic styles (colour, font size, shapes) for several surfaces of the component. The automated digital data preparation and the development of interfaces between the various systems also remains to be solved. Future developments are supposed to trigger the interaction of the projected buttons by image recognition and machine learning algorithms instead of switching manually via the PC. Further concepts with 3D cameras and image recognition for tracking employees and aligning the projected information according to their position and viewing direction will expand and improve the augmented dynamic projection system. At the end of the experiment the first results have already been implemented with some users and have provided positive feedback. The projection system for applications outside site assembly has also to be evaluated and tested.

Acknowledgments

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