The Comparison Study of Different Operator Support Tools for Assembly Task in the Era of Global Production

Citation for the original published paper (version of record):
Gong, L., Li, D., Mattsson, S. et al (2017). The Comparison Study of Different Operator Support Tools for Assembly Task in the Era of Global
Production. Procedia Manufacturing, 11: 1271-1278. http://dx.doi.org/10.1016/j.promfg.2017.07.254

(article starts on next page)

Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 11 (2017) 1271 – 1278

Procedia MANUFACTURING

27th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM2017, 27-30 June 2017, Modena, Italy

The comparison study of different operator support tools for assembly task in the era of global production

Liang Gong[a,*], Dan Li[a], Sandra Mattsson[a], Magnus Åkerman[a] and Åsa Fasth Berglund[a]

Chalmers University of Technology, Hörsalsvägen 7A, Göteborg 41258, Sweden

Abstract

As part of a global production strategy, many manufacturing companies locate their assembly plants in different countries around the world. While outsourcing final assembly closer to key markets has competitive benefits, these companies face new challenges with communication and dissemination of information. Concerning shop-floor operators specifically, these challenges affect the initial training and continuing improvement work instructions in particular. Emerging information and communication technology (ICT) have created new opportunities for supporting operators cognitively. In this paper, an immersive virtual reality (IVR) training environment for LEGO gearbox assembly was developed and tested. IVR technologies offer new opportunities where operators can access training and work instructions in an immersive environment, which could potentially improve and influence the operator performance and emotion. Both objective performance and subjective emotion were measured and the impacts were analyzed. The results were compared with four different operator support approaches and it was seen that IVR technology has the potential of improving operator and that further studies on integration, information, communication design and development of measurement methods are needed before the industry can benefit from the full potential of IVR technology.

Peer-review under responsibility of the scientific committee of the 27th International Conference on Flexible Automation and Intelligent Manufacturing

Keywords: Virtual reality, operator support, assembly, global production

* Corresponding author. Tel.: +46-729820225.
E-mail address: liang.gong@chalmers.se

Peer-review under responsibility of the scientific committee of the 27th International Conference on Flexible Automation and Intelligent Manufacturing
doi:10.1016/j.promfg.2017.07.254

1. Introduction

The globalization and mass customization trend pose great challenges to the manufacturing industry [1]. While automation is increasingly incorporated for the production process to improve productivity and quality, there are still many tasks need to be carried out by human operators [2]. Highly skilled operators become more and more important in this transition. At the same time, the shortage of manual skills are reported throughout the world in manufacturing industry [3]. In this context, appropriate operator support tools are needed to cope with the challenges. For the different support tools, there exist both advantages and disadvantages for these three factors. When evaluating different support tools, it is important to consider the support tool's prospective purpose [4]. As the advancement of information and communication technologies (ICT), the computer-based training is playing an increasingly important role in future factory [5]. Several studies have shown that virtual training has positive effects on supporting operator in assembly tasks [6], [7], [8]. With the latest advancement of immersive virtual reality (IVR) technology, it promises the "real-life" experience which can be beneficial to assembly training. Therefore, an IVR approach for operator support is developed, evaluated and compared with four other support tools, namely the text-picture, face to face, movie and augmented reality (AR) approaches.

2. Challenges of global production

The shift towards global production gives companies the possibilities of growth and cost reduction. At the same time, it brings higher requirement to maintain an efficient global production network (GPN) [9]. The increase of customization in industry implies that more and more product variants need to be produced in factories. This increase of product variants also increase the complexity of work for the shop-floor operators, as work variance is the largest contributor to a perceived complexity and imply that better support tools are needed [10].

The production complexity and the product variants are accompanied by information; such as work instructions. Information can be shared in numerous ways, but two Knowledge Management approaches are predominant: personalization that emphasizes a face-to-face show and tell, and codification with its explicit documentation [11], [12]. However, the global setting and increased product variants diversifies the process of creating work instruction, hence would hinder the establishment of efficient and stable GPN. While implementation of personalization approach has certain pedagogical advantages because of a rich two-way communication, it is dependent of more people at the same place, at the same time [13], which may not be very easy to accomplish, especially if the production is in a global setting. In this global production setting, the codification approach and its pre-defined work instructions make information sharing more flexible regarding the variation of time and place concerning the presenter and the receiver of the information [14]. When implementing the codification approach, presentation of information can be regarded with two categorizes: the carrier that considers the medium of information (e.g., paper, monitor, touchpad, or IVR goggles), and the content that contains the mode of information (e.g., text, pictures, video, or interactive 3D models) [15].

In manufacturing area, various operator support approaches are identified, such as work instruction, training seminar, monitoring, and learning by experience. Dehnbostel categorize them as formal and informal training [16]. According to Mura et al. the different approaches can be distinguished as on the job training, face to face training and computer-based training [17]. Training is seen as one of the main factor to the successful establishment of new production unit abroad [18] and global production need be improved with good infrastructure of information and communication [19].

3. Experiment setup

With the challenges poses in global manufacturer, an experiment was setup to test various operator support approaches and to identify their characters,

A LEGO gearbox model consists of 21 components was developed to be used in the experiment, see Fig. 1. All of the tests are conducted in lab facilities at Chalmers University of Technology. Test subjects were invited to assembly the LEGO bricks into the designate gearbox by using one of the five different operator support approaches. The whole experiment can be divided into three rounds of tests. The first round was carried out in spring 2014 and tested the face-to-face instructor and text-picture based instruction. The second round was in autumn 2015 and tested the remote guidance with augment reality (AR) and movie-based instruction. In December 2016, the IVR training approach which is the focus of this paper was developed and tested. All the tests for the four scenarios were conducted with the similar setup for the assembly station as shown in Fig. 2c, except that the test subjects were provided with different assembly support. In general, the instructions were developed with regard to information quality to support cognitive automation. Text-based instruction was developed based on an empirically tested guidelines [13] and movie-based instruction was inspired by the same guidelines and was used when applicable. However, while these two types of instructions are unidirectional, test subjects can have feedback when tested with face-to-face instruction and remote guidance with AR. The development of IVR training followed the guidelines as much as possible, so that the five different operator support approaches can be analyzed and compared.

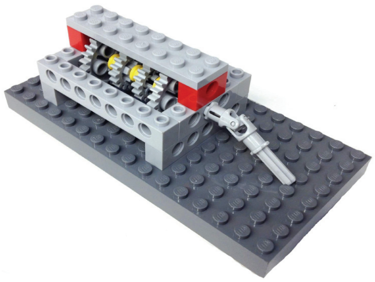

Fig. 1. The LEGO gearbox used in the experiments.

3.1. Prior tests

In the first test round of face-to-face instructor and text-picture-based instruction scenarios, there were 30 test subjects participated in this round of test and they were randomly assigned into two groups, Group A for the face-to-face instruction and Group B for the text-picture-based instruction. Each test subject was introduced to the test separately and was asked to assembly the gearbox five times. For test subjects in Group A, they were shown how to assemble the gearbox by an expert. They can to ask questions and get feedback at their own behest. Test subjects in Group B were asked to assemble the gearbox according to the text-picture-based instruction displayed on a tablet at the assembly station. They can swipe through the images with the steps to complete the assembly.

In the second round of the test, there were 16 test subjects participated. They were also randomly assigned into two groups to test the two proposed operator support approaches, Group C for the remote guidance with AR and Group D for the movie-based instruction. Group C were first introduced and got familiar with how to use the AR goggles. Then each of them were guided by an expert stayed in a different room, through the AR goggles. The expert can see what the test subject see at the assembly station and provide instructions which will be overlaid to the test subject's view of the AR goggles. The remote instructor and test subjects can have real-time feedback on the ongoing assembly process. Test subjects in Group D were provided with a touch screen computer at the assembly station, where they can watch the movie-based instruction and choose to fast forward or rewound. Fig. 2 shows the test setup for Group C and D.

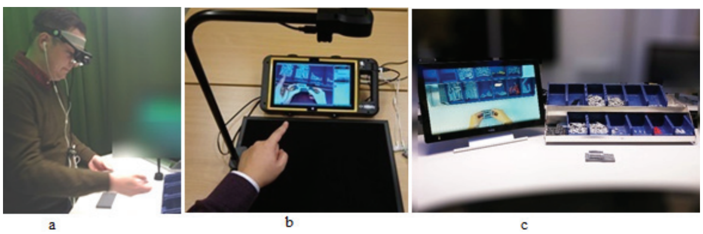

Fig. 2. Remote guidance environment trainee side (a) and expert side (b), movie-based test environment (c)

3.2. Development of IVR assembly training

An IVR assembly training tool was developed for the same gearbox. Unity game engine was chosen as the development platform for the IVR training tool [20]. The individual CAD models of each LEGO bricks that consist the gearbox were imported into Unity. Then a virtual workstation which similar to the ones in the previous test rounds was modeled as the IVR training environment. HTC vive was selected as the head mounted display and a handheld controller for the test subjects to visualize and interact in the IVR training environment [21].

The IVR training session was developed based on the pick-to-light principle [22]. One working but not optimal assembly sequence was provided. During the training session, the container with the right bricks to pick up for assembly will be highlighted according to the predefined order, and visual aid is provided for the precise assembly position of that selected brick, , see Fig. 3. After test subjects have correctly place the brick to the assembly position, the system will move on to the next one until the completion of the gearbox.

Fig. 3. Immersive virtual reality training view (left), VR test environment view (right).

3.3. IVR test procedure

In the IVR test round, there were 11 test subjects in total, seven male and six female participated and they are referred as Group E in the rest of the paper. All of them are engineering students from bachelor to postgraduate levels. The average age is 25, with an age span between 19 and 32 years old.

Before the start of the IVR assembly training, each test subject filled in a pre-test questionnaire about their basic information as well as their previous experience of assembly work, LEGO and IVR technology. After that, a warm up session was followed to make sure everyone gets familiar with the HMD and handheld controller to eliminate the potential noise factor, which may cause by the lack of experience with the presented tool.

When the test subjects are completely comfortable of controlling the IVR device, the IVR assembly training starts. Each test subject followed the pick-to-light instruction and assembled the virtual gearbox twice. They are free to navigate around the virtual workstation by foot and pick and place LEGO bricks by the controller. They can also decide the pace of their assembly training.

After the training, the test subjects were asked to assemble the LEGO gearbox in real world for three times. A similar workstation with the required LEGO bricks was set up in another room. The boxes that contains the bricks has the same layout as in the IVR environment. Similar to the previous test rounds, an overview picture of the gearbox was available while they were performing the assembly task.

At the end, test subjects gave their qualitative feedback about the IVR assembly training in general through a short interview.

3.4. Measurements of the tests

In all the three test rounds, the test subjects were measured both with their objective performance and subject emotions.

The performance is mainly about whether they complete the assembly correctly and the completion time, which are referred as assembly quality and time respectively. In the first test round, each test subject need to assembly the same gearbox five times, while in the second test round, they had four assembly attempts. For the IVR-based test round, every test subject had two virtual assembly and three physical assembly. If all the bricks were assembly in the correct position, then the gearbox is considered as adequate. Otherwise, any error with the mounting position is considered as inadequate. The completion time starts from the pick-up of the first brick till the correct placement of the last brick and is recorded in seconds. Additionally, in the IVR test round, whether the test subjects followed exactly the same sequence as in their virtual training were recorded as assembly precision.

The subjective emotions were measured through a picture-based questionnaire called self-assessment manikin (SAM) [23], [24], see Fig. 4. Psychologically, three dimensions of emotion represent the human responses when assessing environmental perceptions and experiences of test subjects:

- valence; unhappy – happy,
- arousal; calm – stressed
- dominance; little control – full control

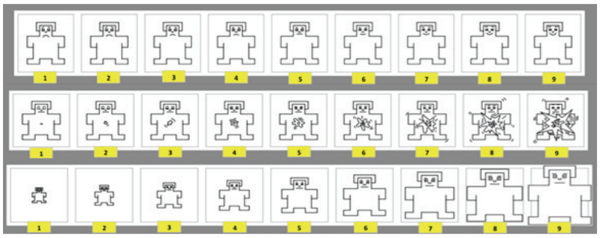

Fig. 4. Self-Assessment Manikin (SAM) questionnaire [24]

By asking the test subjects to fill in the questionnaire, these three emotional dimensions and the changes are recorded and later evaluated. All test subjects filled out the SAM questionnaire before and after the assembly task and the absolute value change in between the two self-assessment is calculated. This procedure enables the evaluation of the assembly situation's impact on the test subjects.

4. Results

In terms of assembly quality, it is evaluated as whether the test subjects have correctly assembled every LEGO bricks onto the designated positions to form the complete gearbox. The quality of each assembly attempts in all the test scenarios are illustrated in Fig. 5a. In the previous test rounds, Group C and D achieved a high assembly quality of almost 100% correct completion. Group B had a lower quality in the first two assemblies but quickly improved to the same level as other groups in the later attempts. For the IVR test round, the assembly quality is better than the average of other scenarios and it is interesting to note that assembly quality dipped to 81.8% in the transition from virtual to real environment, but climbed up again to 100% right after the first physical assembly.

The completion time for each assembly was measured in seconds from the first move till the placement of the last brick of the gearbox. The average time for the five assemblies in all scenarios are illustrated in Fig. 6. It is clear that the first assembly in all five scenarios took the longest time, then quickly shorten in the later attempts. Group D spent the longest time of 414.9s for the first assembly, but gradually improved to 83.5s in the last attempt, which is as fast as other groups. The IVR group spent 130.7s and 140.9s in their first virtual and real assembly respectively. The switch from virtual to reality was not smooth as the completion time increased from 87.2s to 140.9s in the transition. In the final assembly round, Group E achieved the shortest average completion time (80s) of all.

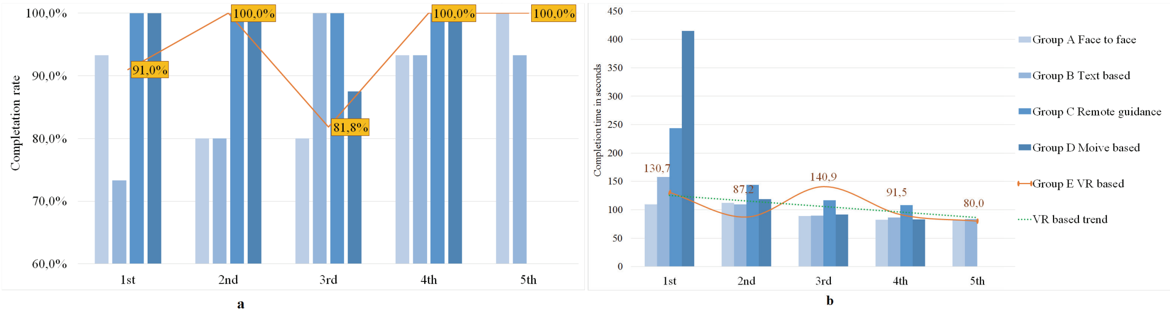

Fig. 5. Assembly quality (a) and average completion time (b).

The SAM questionnaire was used for the test subjects to assess their valence, arousal and dominance before and after each test scenarios. The average change of the absolute values are shown in Table 1. It shows the tendencies where emotional changes are happening. Face to face scenarios had great influence on test subjects' valence and dominance, while movie-based scenario impacted most in arousal. The IVR scenario had a medium impact on the self-assessed emotions compared with the other scenarios.

Table 1. Average change of absolute values in two SAM questionnaire.

Scenarios		Valence	Arousal	Dominance
Group A	Face to face	0.86	1.46	1.26
Group B	Text-based	0.33	1.13	0.60
Group C	Remote guidance	0.50	1.13	1.38
Group D	Moive-based	0.63	2.00	0.88
Group E	IVR	0.64	1.36	1.00

In the feedback session at the end, most of test subjects were positive and felt that IVR is suitable for assembly training, while one test subject noted that the IVR glass caused a little motion sickness. Some of the reoccurring themes were identified and listed below:

"The tasks become live and interesting to learn in VR."

"It is not as easy as I thought when switching from VR to real world assembly."

5. Discussion

From this study, it shows that IVR training could serve as an operator support to help cope with the challenges posed by global production. At the same time, the problems that we've encountered in the development process of the IVR training are worth noting. Due to the complexity of implementing precondition-check of the assembly sequence, only one fixed sequence of assembly was available in this training. Test subjects had to follow the pick-by-light order precisely in order to complete the assembly, even though there are more working assembly sequence. This requires better integration started from product design phase to smooth later development of the IVR training. Also, the transition from virtual training to real assembly was not smooth as both the assembly quality and completion time dropped in the first real assembly. This indicates that some gaps exist in between the presented virtual reality and reality. For example, a controller was used for test subjects to interact with the virtual components to complete the assembly. The controller is equipped with precise motion tracking and programmable vibrating to mimic the real hand movements, however, future development of real hand movement tracking would make the IVR training experience even close to reality.

In comparison of the test results among the five operator support approaches, it is difficult to conclude one is superior to the others. The five operator support scenarios tested in this study all showed certain advantages and disadvantages. Face to face scenarios provides customized real time feedback and interaction between operator and instructor, but requires an expert to be at the same place and same time while the task is being carried out, which is difficult and experience in practice. It is also worth noting that operators experienced a higher pressure which are consider negative to their overall performance. Remote guidance provides more flexibility by eliminating the need to be at the same place, but still need an available expert. Text-based support showed the least impact to operator emotion, but had the poorest assembly quality. Considering the complexity of the assembly task and the ceiling effect, for more complicated assembly task, this approach would not be suitable. Movie-based support achieved a high quality, but showed a steep learning curve with regard to the time parameter.

The IVR approach turned out to be above average, but not necessary the best in all the measurements. One of the reason is that the presented IVR training is only a prototype with one fixed sequence of assembly. Even though test subjects are positive about the potential, it lacks the flexibility in providing feedback and customized support. Based on the codification approach described earlier [15], the carrier, which is the immersive IVR technology in this case is merited, but the content that are the information and communication design is missing. As Fox pointed out in the previous study [24], particular attention of information and communication design are needed before this approach to be proven a superior for operator support. Another factor can be the relative low complexity of chosen assembly task, the small differences of performance in all scenarios can also be the result of the ceiling effect.

In the context of the increasing global production, it is necessary to have further studies to better understand various operator support solutions and their characteristics. Hence, operators can be better supported to cope with the posed challenges.

6. Conclusion

In this study, the importance of operator support in concurrent manufacturing is emphasized. The IVR operator support approach was tested and compared with four conventional approaches. It has shown that IVR technology has the potential of improving operator support to meet the challenges arised from the changes of global production and mass customization in manufacturing. However, further studies on integration, information and communication design, as well as the development of measurement methods are needed before the industry can benefit from the full potential of IVR technology.

Acknowledgements

The research was conducted as a part of the project GAIS funded by VINOVA. The research has been carried out within the framework of the Sustainable Production Initiative and the Production Area of Advance at Chalmers University of Technology. The support is gratefully acknowledged.

References

[1] H. A. El Maraghy, “Flexible and reconfigurable manufacturing systems paradigms,” *Flex. Serv. Manuf. J.*, vol. 17, no. 4 SPECIAL ISSUE, pp. 261–276, 2006.
[2] Å. Fasth-Berglund, J. Stahre, and K. Dencker, “Level of automation analysis in manufacturing systems,” in *Advances in Human Factors, Ergonomics, and Safety in Manufacturing and Service Industries*, CRC Press, 2010, p. 233.
[3] J. Katz, “Engineering Jobs Top U.S. Skills Shortage List,” *IndustryWeek*, 2008.
[4] T. Fässberg, “Cognitive Automation in Mixed-Model Assembly Systems – Current and Future Use in Automotive Industry,” Chalmers University of Technology, 2012.
[5] D. Gorecky, K. Mura, and F. Arlt, “A vision on training and knowledge sharing applications in future factories,” in *12th IFAC/IFIP/IFORS/IEA Symposium on Analysis, Design, and Evaluation of Human - Machine Systems, HMS 2013*, 2013, vol. 12, no. PART 1, pp. 90–97.
[6] S. Jayaram, H. I. Connacher, and K. W. Lyons, “Virtual Assembly Using Virtual Reality Techniques,” *Comput. Des.*, vol. 29, no. 8, 1998.
[7] L. Malmsköld, R. Örtengren, B. E. Carlson, and L. Svensson, “PREPARATORY VIRTUAL TRAINING OF ASSEMBLY OPERATORS : AN EXPLORATIVE STUDY OF DIFFERENT LEARNING MODELS,” in *Proceedings of Swedish Production Symposium 2007*, 2007.
[8] R. J. Adams, D. Klowden, and B. Hannaford, “Virtual Training for a Manual Assembly Task,” *Electron. J. haptics Res.*, vol. 2, no. 2, 2001.
[9] P. E. C. Johansson, L. Moestam, and Å. Fast-Berglund, “Use of Assembly Information in Global Production Networks,” *Proc. 25th Int. Conf. Flex. Autom. Intell. Manuf.*, vol. 1, no. 0, pp. 258–265, 2015.
[10] S. Mattsson, M. Tarrar, and Å. Fast-Berglund, “Perceived production complexity – understanding more than parts of a system,” *Int. J. Prod. Res.*, vol. 7543, no. February, pp. 1–9, 2016.
[11] M. T. Hansen, N. Nohria, and T. Tierney, “What’s Your Strategy for Managing Knowledge?,” *Harv. Bus. Rev.*, vol. 2, no. 77, pp. 106–116, 1999.

[12] D. Li and J. Samuelsson, "Improve Reuse of Engineering Knowledge – Investigating a Method for Capturing Actionable Knowledge in Manufacturing Engineering," Chalmers University of Technology, 2015.
[13] D. Li, S. Mattsson, Å. Fast-Berglund, and M. Åkerman, "Testing Operator Support Tools for a Global Production Strategy," *Procedia {CIRP}*, vol. 44, pp. 120–125, 2016.
[14] R. M. Baecker, "Groupware and Computer-Supported Cooperative Work.," in *Readings in Human-Computer Interaction – Toward the Year 2000*, Morgan Kaufmann Publishers, San Francisco, 1995, pp. 741–753.
[15] Å. Fast-Berglund and J. Stahre, "Concept model towards optimising Levels of Automation (LoA) in assembly systems," in *Proceedings of the 3rd CIRP Conference on Assembly Technologies and Systems*, 2010, pp. 1–3.
[16] P. Dehnbostel, "Informelles Lernen: Arbeitserfahrungen und Kompetenzerwerb aus berufspädagogischer Sicht," in *Proc. of the 4th Fachtagung Schule-Wirtschaft/Arbeitsleben*, 2003, pp. 18–19.
[17] M. D. Mura, G. Dini, and F. Failli, "An Integrated Environment Based on Augmented Reality and Sensing Device for Manual Assembly Workstations," *Procedia CIRP*, vol. 41, pp. 340–345, 2016.
[18] P. E. C. Johansson, F. Delin, S. Jansson, L. Moestam, and Å. Fast-berglund, "Global Truck Production - The Importance of Having a Robust Manufacturing Preparation Process," *Procedia CIRP*, vol. 57C, pp. 631–636, 2016.
[19] Y. Gong, *Global Operation Strategy*. 2013.
[20] UnityTechnology, "What is Unity?," 2017. [Online]. Available: https://unity3d.com/unity.
[21] HTC, "VIVE™ | Discover Virtual Reality Beyond Imagination," 2017. [Online]. Available: https://developer.viveport.com/eu/develop_portal/.
[22] L. Goss, "Manufacturing system and method for assembly of computer systems in a build-to-order environment." Google Patents, 2001.
[23] I. Bakker, T. van der Voordt, P. Vink, and J. de Boon, "Pleasure, Arousal, Dominance: Mehrabian and Russell revisited," *Curr. Psychol.*, vol. 33, no. 3, pp. 405–421, 2014.
[24] R. Mollard, M. Wolff, N. Couture, and A. Clay, "Développement d'une plate-forme d'évaluation personnalisable et adaptable pour létude du comportement émotionnel en situation de multisollicitation," *Trav. Hum.*, vol. 75, no. 3, pp. 253–277, 2012.