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Evaluation of 3D printing approach for manual assembly training

Abdulrahman Al-Ahmari [a, b], Wadea Ameen [a, b, *], Mustufa Haider Abidi [b], Syed Hammad Mian [b]

[a] Industrial Engineering Department, College of Engineering, King Saud University, Riyadh 11421, Saudi Arabia

[b] Princess Fatima Alnijiris's Research Chair for Advanced Manufacturing Technology (FARCAMT Chair), Advanced Manufacturing Institute, King Saud University, Riyadh 11421, Saudi Arabia

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A B S T R A C T

Assembly is an important aspect of the manufacturing process. Proper assembly training plays a vital role for efficient operations. Therefore, this paper suggests a new assembly training approach based on 3D printing technology. The proposed approach is compared to existing assembly training methods including conventional drawing (CD) and virtual reality (VR). Different size scales of product are considered to evaluate and validate the suggested 3D printing approach. The training performance is evaluated based on completion time of assembly task, number of assembly errors, number of frustration points during the task, and completion percentage. The experiments have been conducted on 25 participants using the three assembly training approaches. The obtained results show that the 3D model performed better than the other two conventional methods. The results also illustrate that there is no significant effect from the 3D model scale variation on the assembly training performance.

1. Introduction

Assembly processes have been considered a necessary tool in several industries, such as manufacturing, biomedical industry, and construction (Groover, 2007; Tang et al., 2006; Simpson and Durbin, 2010). Increase in product complexity pose significant challenges for manufacturing industries, and demands more skilled assembly operators. Because assembly has a great impact on production efficiency and cost, it is necessary to identify new methods for assembly training which can improve the performance of the operators.

Several existing approaches can be used for assembly training, including the traditional engineering (TE) approach using paper drawings or blackboard teaching, desktop-based methods, and virtual reality (VR). Two-dimensional (2D) paper-based drawing is widely used to guide the assembly operators. The drawing provides a list of components and their associated assembly steps. Three-dimensional (3D) computer aided design (CAD) is another way of guiding and teaching product assembly tasks. Moreover, VR based training methods are also used in assembly teaching and training (Hou and Wang, 2013). Many companies have used CAD model based simulation for assembly planning and training to improve efficiency and minimize the issues of their assembly processes (Leu et al., 2013).

3D printing or rapid prototyping (RP) have been applied in many fields, such as engineering (design and manufacture), biomedical, construction, and medicine (surgical planning). Generally, the technology finds its application in the field of prototyping and design, aesthetics, features analysis, or direct fabrication of the product. However, in this study, 3D printing is used for the novel application of the manual assembly training process. Furthermore, the effect of scale size on training performance is also studied. This proposed method is evaluated and tested using an assembly prototype that is fabricated using 3D printing with different scales. The suggested approach is also compared against the conventional assembly training and VR approaches based on several performance measures, including completion time, number of errors, and number of frustration points during assembly operations.

2. Previous related work

Measuring the performance of manual assembly has been an area of interest for many researchers and practitioners. Dencker et al. (1999), investigated the potential of a production-integrated video learning system (PVL) in the assembly of car

* Corresponding author.Industrial Engineering Department, College of Engineering, King Saud University, Riyadh 11421, Saudi Arabia.
E-mail address: wadeaameen@gmail.com (W. Ameen).

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manufacturing. The evaluation results were promising and showed the effectiveness of a PVL system in the training of car assemblies. Boud et al. (1999), investigated whether augmented reality (AR) and VR offered potential for better assembly training, compared to conventional media when the performance measure was completion time of the assembly tasks. The VR and AR offered the benefits of improved performance of assembly training over the conventional approach (2D drawing). Ye et al. (1999), also investigated the potential benefits of using VR in assembly planning compared to the TE environment and a non-immersive desktop VR environment. Their results showed the advantages of the two VR environments over the TE environment by improving the overall performance of the assembly planning and minimizing the handling difficulty. Adams et al. (2001), evaluated the benefits of force feedback for virtual assembly training in a real manual assembly task. The trainers received virtual training with haptics and virtual training without haptics. The result of the completion time of the real task showed that the performance of training with force feedback was significantly better than training without it. Brough et al. (2007), proposed an assembly training system in which the users were trained using the following three modes: interactive simulation, 3D animation, and video. The results indicated that the system was able to support training for assembly operations. Abdel-Sayed et al. (Abdel-Sayed and von Segesser, 2011), identified RP as a promising technique for training cardiovascular surgeons (surgical operations planning and implant designing). The authors also suggested that the RP technique has serious potential in biomedical and academic fields besides cardiovascular surgery. Webel et al. (2011), evaluated the performance of the AR-based training and traditional training technologies in the context of training in complex machine maintenance procedures. They used the performance measures of number of errors and performance time. Oren et al. (2012), compared the transference of training from VR environment versus real world. The results showed that the group who used the virtual environment for assembly training was faster than the group trained using a physical puzzle. However, the training time to complete a complex assembly in a VR environment was three and a half times longer than the training time using the physical components. Abidi et al. (2012), compared the performance of training transfer to the actual assembly using three training means: TE, computer aided design environment (CADE), and immersive virtual reality (IVR). They used two performance measures, namely, the time to complete the tasks and number of frustration points during the assembly. The results showed that the participants of the IVR training condition performed better than those of the other two conditions. Hou et al. (Hou and Wang, 2013), considered the gender factor in the evaluation of the assembly training. AR and the 3D manual training were used for assembly training in which male and female groups participated. The result showed that AR helped both female and male trainees to learn the assembly methodology faster than the 3D manual, whereas training using the 3D manual was more effective for males than for females. Ahmad et al. (2015), proposed RP as a useful tool for manual assembly training and validation. There has been no research so far, which has evaluated the performance of RP assembly training as well as studied the effects of different scales of the RP model.

To the best of our knowledge, the work presented in this paper is a novel approach which has employed 3D printing as an assembly training method, taking into consideration the effect of scaling down the assembly parts. This method will lead to more applications of 3D printing because there is a rapidly growing demand of applications and technology for additive manufacturing. The suggested approach provides solutions to overcome the limitations encountered in the existing assembly training methods.

3. Proposed 3D printing approach

Currently, there is a noticeable trend towards more applications and technologies for 3D printing systems. This paper suggests the use of 3D printing as an assembly training approach, utilizing the capabilities of RP machines for producing complex parts. The methodology of the proposed approach is illustrated in Fig. 1. This methodology involves the following steps:

- Step 1 Select the assembly to be used for the training assembly.
- Step 2 Identify assembly components based on part structure or bill of materials.
- Step 3 Develop CAD model for the selected assembly.
- Step 4 Produce prototypes for the parts using different scales, develop a VR environment for the assembly, and provide the design denomination required for manual assembly.
- Step 5 Perform the assembly process using the conventional and suggested method.
- Step 6 Compare the assembly methods and select the most efficient method based on the selected performance measures.

The above methodology steps were used to conduct an experimental study using different scaled models of the selected assembly.

3.1. Participants

Twenty five male university students from King Saud University with a mean age of 22.5 ± 3.5 years were randomly selected for this study. All participants were right handed (self-reported) with normal vision (medical test) and none of them had any health problems.

3.2. Performance measures

In order to investigate the learning transfer performance in different training environments, objective and subjective measures were employed. The objective measures involved time to complete the assembly task, number of assembly errors, number of frustration points during the task, and completion percentage. The NASA TLX questionnaire developed by Hart and Staveland (1988) was also used as the subjective measure for determining the workload.

3.3. Experiment procedures

Fig. 1 illustrates the experimental procedures that were used in this study. The participants were divided randomly into five groups. The first group was assigned to assembly training using conventional drawings (CD), the second group was assigned to assembly training using a VR assembly environment, and the remaining three groups were assigned to assembly training using the RP model of different scales (1:1, 1:2, and 1:4). Before the start of the training, all the participants were required to complete the demographic questionnaire to provide their personnel information as well as ability differences. The trainers provided the same instructions and information to all the participants of a group. Adjustable mid-bearing (containing 13 components) was selected as a case study for carrying out the assembly process. SolidWorks software was used for creating the CAD model parts and assembly. During the CD training, the adjusted bearing assembly and individual parts drawings were presented using A4 hard-copy papers. Drawings contained both composite and exploded views of the product assembly (see Fig. 2(a) and (b); Fig. 3).

The assembly steps were also provided to each participant during the training. The selected product was assembled using the