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Study of the impact of projection-based assistance systems for improving the learning curve in assembly processes

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Abstract

With the introduction of Industry 4.0 the use of worker assistance systems is getting more and more important. Assistance systems should support operators to increase efficiency and to reduce physical and mental stress and thus increase ergonomics of the work. In this paper, we investigate the impact of a projection-based worker assistance system conducting lab experiments simulating a ramp-up situation of a new product in assembly. The specific aim is the investigation of the impact of such systems in assembly for improving the learning curve, when products are changing. The study shows the results of a comparison between the assembly process with traditional worker instructions and the use of cognitive assistance systems to project instructions on the workplace.

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Keywords: Assistance system; Manufacturing system; Assembly system; Smart manufacturing; Industry 4.0; SME

1. Introduction

By looking at the current situation in the manufacturing industry, someone can realize that the manner we are manufacturing products is promptly changing. On the one hand, we can observe a trend in a growing automatization of repeated activities. On the other hand, a lot of products can be made in a wide range of variations, which consequently results in a smaller size of different products [1]. The increased diversity in products results in an increasing number of product changes for workers doing manual assembly in production and higher complexity of the tasks that need to be done [2]. In other words, the nowadays industry is changing from "mass production" to "mass customization" in addition to a shorter product life cycle, which means in consequence, that the manufacturing systems must be flexible enough for fast product shifts [3]. The mentioned trends show that not only manufacturing systems are changing but also the traditional role of human in production. Just a few years ago, the idea of digitization and automation in factories has terrified many people. There was a fear of employees that the human will be replaced by tireless and much more precise robots, leaving the worker in the long run on the track [4]. Today, experts assume that exactly the opposite will happen and that a human-centered production system will be sought, which adapts to the requirements and needs of the employee [5, 6]. Human work will also be required in the future, but it will concentrate more on ambitious tasks. As a result, the research on human machine interaction (HMI) is getting more and more important. During production processes, machines will focus more on standardized and automated tasks and the human concentrates more on those assembling tasks, that cannot be solved by machines due to the complexity and uniqueness, which results from the products [1]. In this context, assistance systems are getting interesting for the production. Research about human operators in Industry 4.0 show the usefulness of assistance systems [7] and digital information [8] as solutions for the accretive complexity of

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production systems. Within Industry 4.0, assistance systems are classified as one of five main branches of research [9]. One approach of cognitive assistance systems, investigated in this paper, is the projection of work instructions on the workplace.

2. Theoretical Background

In the following, we show a literature review to summarize the state of the art of learning curve effects and projection-based assistance systems in production. Based on this, we formulate the research question for this work.

2.1. Learning Curve Effects in Assembly

Modern assembly deals with technology developments and changes within the scope of Industry 4.0. The future worker is expected to work in the most efficient way with Industry 4.0 technologies and master the utilization without a long period of training. This means, operators need to learn very quickly. Hence, every assembly production line should have an effective learning process. The learning curve is a model to describe the capability of gaining knowledge within the process and consequently accumulate experience [10]. Initialized by Wright in the late 1930s it was firstly used in aircraft industry. Nowadays it is a concept, which is widely used in many branches of industry. The definition of a learning curve is a nonlinear regression model, which associate the performance of workers to task characteristics [11]. After Wright's initialization, a huge amount of other learning curve models had been developed, that can be divided in multivariate and univariate models [12].

In Fig. 1 we see a log-linear learning curve, that has an 80% learning rate. Each doubling of production volume results in a 20% reduction in unit time or cost. The curve can be divided in a learning zone and a so-called standard zone. As it can be seen in the Figure, the efficiency in the learning curve is very conspicuous. The steady state is reached in the standard time zone [13].

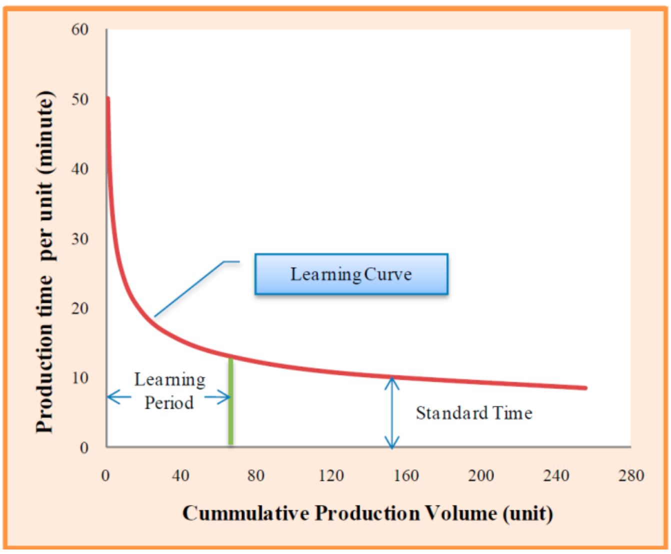

Fig. 1. Learning curve model [10].

2.2. Projection-Based Assistance Systems for Assembly

The idea of using projection-based assistance systems was already tested in the year 2010, in which a study was published about the comparison of (i) contact analog highlighting of parts position, (ii) projections on working areas and (iii) monitor instruction presentations. In addition, an experimental setup was tested to create an overlay of the workplace with additional instructions at the exact position where it was needed. The results showed potential for the development of projection-based assistance systems [14]. An important point, which is addressed by Mueller et al., is the fact that those systems can take into account the level of education, while providing information [15]. The implementation of the system in form of a "Smart Workbench" was realized to aid assistance directly on the workplace and hence increase the quality of the products [16]. Experiments confirmed the helpfulness of the system and the authors share the opinion that such systems show a huge opportunity during industrial manufacturing scenarios [3]. This is especially necessary due to the significant flexibility in modern manufacturing. The traditional paper-based instructions cannot meet the needed requirements [17] and by using projectors, the low comfort of wearables and the limited field of view of smart glasses, such as augmented reality (AR) or mixed reality (MR), can be eliminated. The invented systems show assembly instructions as well as picking information in the workspace [18]. A comparison between paper-based instructions with in-situ projections and head mounted display (HMD) showed that in general HMD was ranked lower in terms of helpfulness and easiness [1]. Instead, the comparison between in-situ projection and HMD showed, that with the latter, the participants are measurable slower, and they make more mistakes [19]. Later on, experiments were conducted in order to compare Microsoft's Hololens with projection-based displays. It showed a great improvement on the constraints of HMD based systems, but due to the low battery life and the weight, such projection-based displays are not used yet in industrial practice [20]. The system can also be used for reassembling in order to place the deconstructed components in the defined position. Therefore Hinrichsen et al. built up a flexible design of such an assistance system, which can be moved and carried to any workstation [21] Projection-based assistance systems can not only be used as worker support. Equipped with a laser, the projector can be used for quality assurance and hence eliminate high expenses for measuring systems [22]. It is also possible to indicate places where tapes have to be placed through projection mapping systems by using color projection [23]. Apart from the technical advantages, this informative assistance system can also be used to support worker with a lower educational level [11] and provide intuitive additional information. Therefore, a study was conducted with experienced, freshman and cognitive disabled workers. While for the latter the continuous support is useful, for the others an additional support in form of information is useful only during the learning phase [24].

2.3. Research Question

The literature review showed that there are already some papers regarding projection-based assistance systems. Most of them are discussing the technology itself. What lacks, are empirical studies about the effect on the learning curve and hence the improvement of the learning period in batch productions. This makes the area interesting for further investigation and leads us to the following research question:

How is the learning curve of workers in assembly influenced by the transition from traditional, paper-based manual instructions to digital, projection-based instructions, and can it be seen as an advance in modern production?

In order to answer this research question, tests in a laboratory environment have been conducted accompanied by a questionnaire filled out by the test persons. The detailed research methodology is explained in the following section.

3. Research Methodology

The research methodology used in this research is illustrated in the scheme in Fig. 2. First of all, a systematic literature review (SLR) was conducted in order to pursue the purpose of providing a state of the art, on which it is possible to build on. Subsequently, the research question could be formulated as contributing to a clearly specified study rather than an "all about" study. Afterwards the planning of the test scenarios was done, which consists of an assembly test and a questionnaire. What follows is the setup and conduction of the experiment in a laboratorial environment.

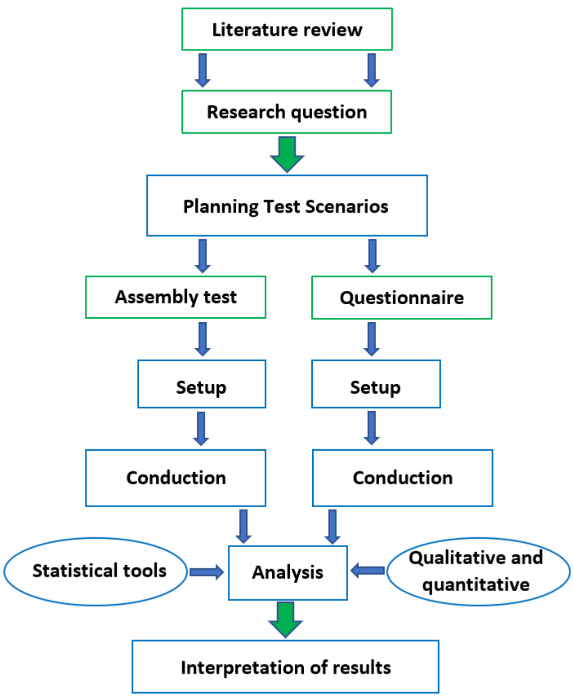

Fig. 2. Research methodology.

Through statistical tools and qualitative and quantitative research approaches, the analysis was performed, which opened the opportunity to interpret and describe the resulting data.

4. Setup of the Test Use Case in the Laboratory

As described before, the experiment consists of (i) a quantitative part, which is represented by an experiment and (ii) a qualitative part for which a questionnaire had to be completed by the participants. 10 volunteers in total participated at the experiment and the completion of the questionnaire. All of them have a technical background and the age ranges from 23 to 31 years. The participants had to assemble a commercially available pneumatic cylinder, which can be seen in Fig. 3. Five of them used the traditional, paper based, and the other five test persons worked with the projection-based assistance system Ulixes Der Assistant A600. In Fig. 3 the setting of the workplace for the experiment can be seen (left side: traditional; right side: digitalized projection-based assistance system).

The cylinder is assembled out of 22 parts, which are tidied up in boxes and grab trays in front of the worker on the worktable. On the left image in Fig.3, the paper-based working instruction is fixed in front of the participant at eye level. On the right image, the assembling instructions are projected on the worktable directly in the point of view of the worker and can be switched through virtual buttons.

For the qualitative part, a questionnaire had to be completed by the participants, which consists of questions about the level of difficulty of each step of assembly and additional, more general, questions (see Table 1).

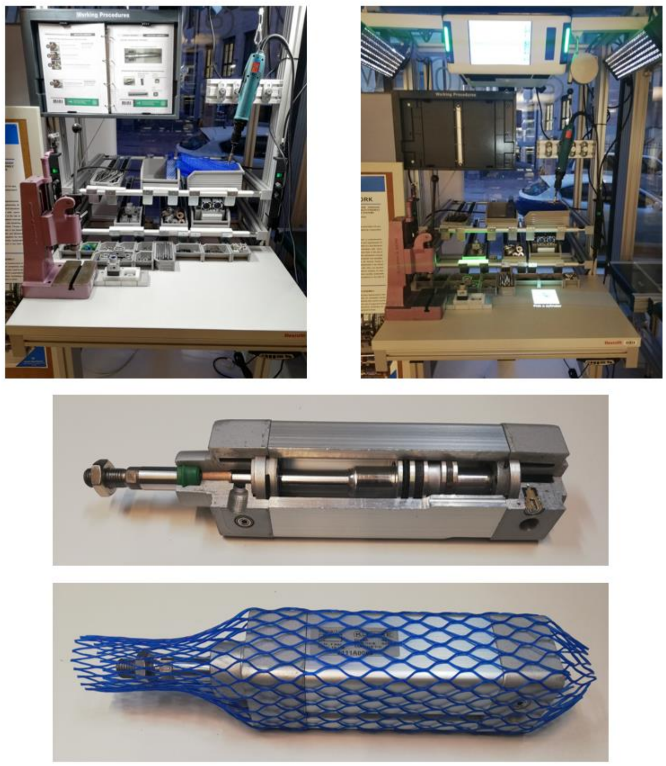

Fig. 3. Traditional workplace (left), projection-based workplace (right) and the cylinder to be assembled (below).

Table 1. Questionnaire.

#	Traditional, paper-based instructions	Projection-based assistance system
1	Did you understand what to do after the introduction was given?	Did you understand what to do after the introduction was given?
2	Did you overall feel comfortable with the paper-based instructions (e.g. were they clear enough?)	Did you overall feel comfortable while working with the Ulixes assistance system?
3	/	Do you have some suggestions for improvements of the assistance system?
4	/	Do you think this system could be useful in industrial practice?
5	/	Do you think that this system could be an assistance system to involve also disabled or elder people in the production of industrial companies?

For the questions 1, 2 and 5, the participants had to answer with a number between 0 and 5, where 0 represents "not at all" and 5 stands for "fully". Questions 3 and 4 were open questions, at which each participant could answer with full sentences.

5. Conduction of the Test

5.1. Conduction of the Assembly Tests

Before starting with the experiment, all participants got a short introduction. In order to simulate a real training scenario, a single cylinder was assembled together with each candidate and the individual components were explained. After the participants had no more questions, they were told to independently assemble cylinders for a defined time of 45 minutes. The participants who had to work with the paper-based instructions were told to check the instructions in case of assembly instruction questions or insecurities.

In contrast, to the candidates with the projector-based instructions it was told, where to reset the system instructions in order to restart the system if they get stuck in one place during the cylinder assembly. All participants in the given time could assemble a total amount of 13 cylinders. After the 45 minutes of cylinder assembly, each candidate had to complete the aforementioned questionnaire.

Fig. 4 shows a participant during the assembling process with the traditional paper-based instructions inserted in an information board from Bosch Rexroth. Quality checks were indicated in the instructions and explained before the start of the test.

Fig. 5 shows a participant using the projection-based assistance system to project instructions in form of pictures, text or videos directly on the work bench. In addition, the projection-based test setup included also quality checks that were assisted through the integrated multi-sensor camera (RGB sensor, infrared sensor and depth sensor for 3D recognition).

Fig. 4. Participant while assembling with the traditional instructions.

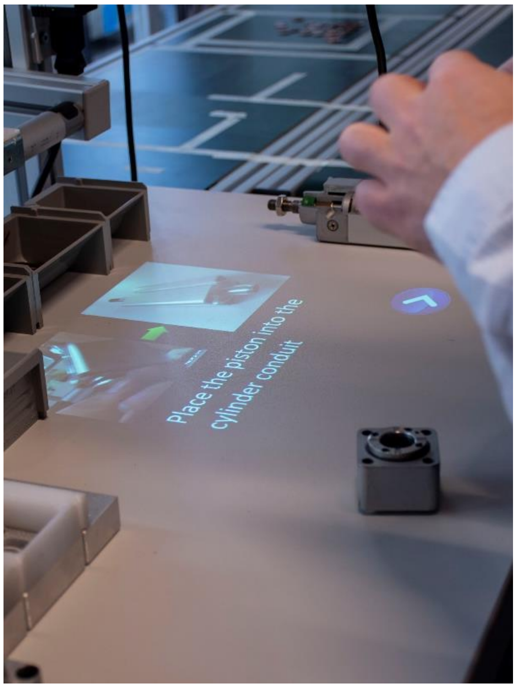

Fig. 5. Participant while assembling with the projection-based system.

5.2. Questionnaire for Qualitative Research

The questionnaire represents the qualitative part of the experiment. This part of the investigation was very important in order to receive additional information about the feeling of the participants with the two alternatives that cannot be captured through the experiment itself.

The questionnaire showed, that in both experiments, the traditional one as well as in the assisted one, the participants were overall satisfied with the introduction that was given by the research team. The arithmetic mean on a scale that ranges from 0 to 5 showed a value of 4.4.

Regarding the question if the participants felt comfortable while working with the paper-based instructions, an arithmetic mean of 3.6 resulted, while the projection-based system showed the slightly higher value of 4.0.

The questionnaire contained also an evaluation of difficulty of each step of the cylinder assembling. What turned out to be interesting is that the participants working with the paper-based instructions felt more difficulty during the assembly of some parts compared to the participants working with the projection-based instructions. This leads to the conclusion, that the participants with the assistance system felt more stress-free compared to their colleagues with the traditional instructions.

To the question if the digital assistance system could be useful in industry, the participants answered very positive (arithmetic mean of 4.4), but the suggestion was to create two parallel working instruction systems. The first one for beginners during the training phase should include each step and a detailed instruction together with the quality checks during the assembling. The second one is for advanced workers where it should be possible to switch off the instructions of each step and concentrating to the integrated quality checks by the aid system.

To the question if according to the participants the system could assist also disabled or elder people to improve the inclusion in production, each candidate answered very positive with the highest answer, which gives an arithmetic mean of 5.0.

6. Analysis of Quantitative Test Results

In Fig. 6 a comparison of the learning curves with the traditional and the assisted setup is illustrated. The blue curve represents the traditional, paper-based approach and the orange one shows the learning curve of the assembling with the help of the projection-based assistance system. The x-axis represents the 13 cylinder that could be assembled by all participants in the given time period.

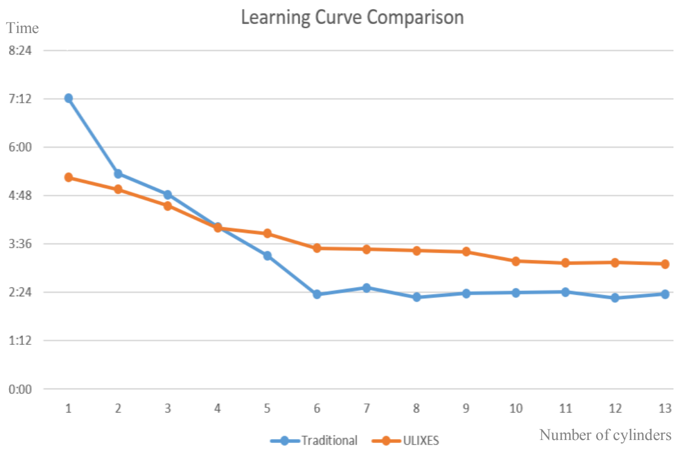

Fig. 6. Learning curve comparison.

As it can be seen in the graph, especially at the beginning the participants with the paper-based approach needed more time (+27%) compared to the ones using the assistance system. By considering the last six cylinders, in which the time is commuted in, the difference in assembling time is 37,7%. Between the 3rd and the 4th cylinder the participants working with the traditional approach were assembling the cylinder faster than the others. That is because after a while the persons with the traditional approach were able to assemble the cylinder without looking to the instructions and therefore becoming very fast. The persons with the assistance system received very good support at the beginning but after they were able to produce the cylinder without help, they still had to follow the given instructions and confirm each step by clicking the virtual button.

By looking at Fig. 7 we can see, that the curve with the traditional approach shows much more the expected learning curve compared to the assisted system. The curve with the assistance system shows advantages during the learning period, while at the end of the curve the standard time is higher compared to the traditional approach.

Regarding the quality of the assembly process there occurred some problems and peculiarities during the cylinder assembly using the traditional approach. The candidates with the paper instructions sometimes forgot small seal rings or used them in the wrong direction. Especially in the assembly of the fourth or fifth cylinder, it was more common that such careless mistakes happened. This suggests that errors occur/increase as soon as participants feel safe without instructions. These errors have not happened with the projection-based instructions, because this system has implemented quality controls and thus forgetting the sealing rings would not be possible.

Another observation was that with the paper-based instructions, after a few cycles, the candidates changed the steps in the cylinder assembly process, setting their personal course of action. One candidate even wanted to redesign the worktable during assembly. The people who worked with the projection-based system could not change their order and were always tied to the programmed process.

Regarding the paper-based instruction, it was recognizable that especially at the beginning the participants were referring quite often to the user's manual. It can be noted that some time is lost also because they need to first get familiar with the instructions, since those are not personalized. This led to the situation that some of the participants preferred to try the assembling on their own before looking into the manual instruction and also tried to reposition the worktable with the boxes. The projection-based assistance system projects the working instructions directly on the workplace in the field of view of the worker, therefore it is not possible to reposition the boxes.

Further, the projected instruction is very detailed. That means, after the assembling of some cylinders, the worker already knows the simplest steps. As a result, the participant works faster and the system changes from assistance to barrier, which should not happen under any circumstances. Another problem was the sometimes not well working virtual button as well as the quality control, in which the cameras compare the current object with one previous, in birds eye view, saved 3D object. The problem that occurred here was that the system already showed an error if, for example, small dust rested above an object even though the object itself was assembled in the right way.

7. Critical Discussion

Summarized, it can be said, that the projection-based assistance system got a positive feedback. At the beginning the instructions must be programmed into the system, which results also in a not negligible effort. Although it is time consuming, once created, it can be used as often as wanted. During the experiment it could be seen, that the detailed instruction on the workplace in form of the projection was very helpful especially at the beginning during the learning phase. This not only to guide the participants through the assembling process but also to reduce the stress factor and to make the worker feel more comfortable. In this learning period the projection-based instruction was much more accepted by the participants than the paper-based instructions. This changed when people were trained enough to assemble the product without detailed instructions. Then the comprehensive, interactive instructions turned out to be prevenient. This was also confirmed by the analysis of the quantitative learning curve data. A suggestion is here to create two kinds of instructions, one very detailed for beginners and the other one for advanced staff. The quality checks by the aid system resulted to be an additional advantage of the system.

8. Conclusion

The present study exemplifies two ways of providing instructions in a production environment and shows the results of an experiment that was conducted by comparing traditional paper-based instructions with a projection-based digital assistance system. In conclusion it can be said that the digital projection-based assistance system showed much potential and could be used in a useful way. Based on the tests conducted as well as the feedbacks from the questionnaires we are able to answer the research questions as follows. Digital and projection-based assistance systems affect the learning curve positively in that sense, that the period of learning and achieving a "steady state" situation can be shortened with such systems. In addition, we could see that this kind of assistance systems show also an advantage in the daily use also of advanced operators. The advantage here is not based on the projection of assembly instructions on the worktable, but much more on the fact, that such systems often dispose also of sensors to integrate in-process quality checks leading to a higher product quality, more quality reliable processes and a reduction of the scrap rate.

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