A Digital Assistance System Providing Step-by-Step Support for People with Disabilities in Production Tasks

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Abstract. The use of Assistive Technology (AT) plays a significant role in the advancement of greater independence for individuals with disabilities in their work life. In particular, digital step-by-step support can enable people to perform production tasks that were formerly difficult to accomplish. In this paper, we focused on finding a solution for a specific production process. To this end, we set up a prototype assistive system for performing a cutting task which provides step-by-step support for people with disabilities. In an evaluation study with impaired people, we investigated how our assistive system affects the task efficiency as well as participants' subjective evaluation of perceived mental effort and system usability. Results show advantages for step-by-step support with regard to users' task efficiency and subjective evaluation.

Keywords: Assistive Technology · People with Disabilities · User-Centered Design · Human-Computer-Interaction · Production · Step-by-Step Instructions

1 Introduction

Approximately 15% of the world population are suffering from at least one disability. Unfortunately, this percentage is expected to grow rapidly in the coming years due to population ageing, chronic health conditions such as cancer and mental disorders [1]. In the industrialized countries, around 80 million people suffer from a disability (ranging from mild to severe) and face significant challenges in almost every area of society such as in employment [2,3]. People with disabilities are usually economically disadvantaged and experience higher rates of unemployment (17.4%) than people without disabilities (10.2%) [4,5]. On the other hand, technological advancement in recent years offers great potential in enhancing job opportunities for disabled people based on their abilities and resources [6]. In this context, assistive devices and technologies can play a key role in enabling the inclusion of people with disabilities as active and independent participants in the labour market.

In this paper, we introduce how such an assistive system can promote both quality of work and independence of people with disabilities by carrying out complex industrial tasks with great care and precision. In cooperation with an organization for handicapped people, we developed a hardware-based assistant system with a graphical user interface that supports people with disabilities producing high-quality jewelry boxes using step-by-step video instructions. Without an assistive system, disabled workers need stringent monitoring by attendants. Nevertheless, a significant proportion of jewelry boxes has to be sorted out because they are faulty, inaccurate or daubed with traces of glue. With the introduction of a digital assistance system we aimed at supporting workers in producing the jewelry boxes with absolute precision (see Fig. 1).

The paper is organized as follows: In Section 2 we give an overview of related work. Section 3 describes the prototype system and the methodology of our evaluation study. Results are presented in Section 4. Finally, we discuss the results and draw conclusions in Section 5.

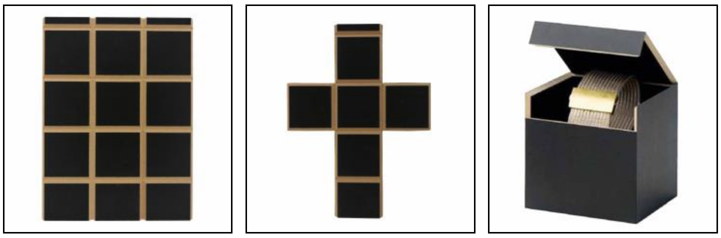


Fig. 1. Producing a jewelry box: raw material (*left*), cut material (*middle*), glued and folded material to a jewelry box (*right*).

2 Related Work

In recent years, a large number of assistive systems for people with special needs have been developed for supporting them in everyday life activities that rely on a variety of different technologies such as mobile devices [7,8], speech recognition [9,10,11], gesture recognition [12,13], augmented reality (AR) [14,15], virtual reality (VR) [16,17] and autonomous robot systems [18,19]. A general review about assistive technology systems for people with disabilities is provided by Sauer et al. [20]. However, assistive systems for inclusion of people with disabilities into the regular labour market have not yet been investigated to this extend. In the following, we present the related work regarding available assistance systems for impaired people in industrial environments.

One line of research addresses in-situ projection for workplaces [21]. For instance, Korn et al. [22] investigated the potential of thereof in a sheltered work organization. They used a toolkit for measuring the performance of impaired persons and built a prototype system projecting work instructions directly into the workplace [23]. Subsequently, they analyzed the effect of in-situ projection on participant's work quality and acceptance of the system. Results with regard to work quality were heterogeneous: some participants could reduce their assembly time and error rates through the system, while others were overwhelmed by using the prototype and performed worse. With respect to system acceptance, however, all participants indicated that they would like to retry the system. Furthermore, Baechler et al. [24] evaluated different pictogram visualizations for order picking tasks with cognitive disabled employees. In a comparative wizard-of-oz study, 24 employees tested four picking visualizations: pick-by-projection, pick-by-paper, pick-by-light and pick-by-display [25]. Dependent variables such as picking time, error rate and participants' perceived mental effort in using the system were measured. In contrast to other methods, participants made almost no mistakes with the pick-by-projection.

With regard to picking time and subjective mental effort, pick-by-light was the first, pick-by-projection the second-best method. Funk et al. [26] investigated the impact of in-situ-projection instructions on workers with disabilities in an assembly scenario. In a user study with 64 participants, they compared a contour-, a video- and a pictorial-visualization to a control group using no visual feedback. They found that participants made fewer errors and were faster using the contour-visualization in an assembling task.

These "conventional" assistive systems in production environments focus mostly on technical aspects of the assembly. To make work more attractive and to increase motivation of impaired workers, different design approaches of motion-controlled gamification[1] have been recently introduced for disabled workers in production (e.g. the tetris design [28], the circle design [29] and the pyramid design [30]). The results reveal that there is a common tendency towards higher work speed and motivation of workers with disabilities, when gamification components are integrated for future implementations into the production process.

In spite of the fact that there are various research projects about augmented-based assistive systems for impaired people, there is no previous work combining a computer-based system with manual support for specific tasks like cutting, folding and gluing. In this paper, we explored how to find a reliable solution that can be also transferred to similar production tasks in a modified form. Subsequently, we tested the prototype in an evaluation study with disabled workers from a sheltered work organization.

3 Materials and Methods

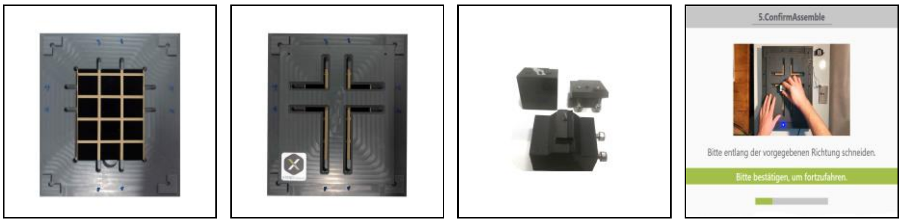
3.1 Prototype System

The prototype system was developed with user-centered design methodology. First, thinking-aloud tests were conducted with three disabled users and two attendants producing jewelry boxes using conventional methods such as scalpel, wood glue and manual folding. On this basis, user requirements, needs and problems were analyzed as a starting point for the novel prototype. Based on this input we created a hardware-based prototype which supports users in three different stages: cutting, glueing and folding. The following paragraphs describes the general approach and implementation concept in more detail.

In a first step, the cutting process was analyzed and adapted to the needs of people with special needs. The requirement analysis led to the creation of a 3D mould (see Fig. 2a) with a hard plastic template that workers can place on the fiberboard to cut it precisely along the line (see Fig. 2b). As a cutting tool, we printed two 3D handles which allows for interchangeable blades (see Fig. 2c). The user can choose between a

[1] "[...] the use of video game elements in non-gaming systems to improve user experience (UX) and user engagement." [27]

45° and -45° angle blade depending on which line they are cutting. The mould is equipped with remote controlled LEDs using Arduino and Bluetooth technology in order to guide the worker through the cutting steps by presenting video instructions on a mobile device. The video instructions were recorded from a bird's-eye view in HD resolution. A brief interruption of one second was added to the end of each step to enable users getting a better temporal orientation while cutting the fiberboard. To facilitate the user playing the instructions in a simple manner, we implemented a software with a user-friendly graphical interface using C++ and Qt (see Fig. 2d). With the click of a button integrated in the mould, the user can skip to the next step after performing the current subtask. Blinking LEDs before each step support the user finding the right position to cut quickly. Furthermore, the software allows attendants to edit or create new work instructions.



(a) (b) (c) (d)

Fig. 2. Prototype system: (a) 3D mould, (b) hard plastic template, (c) cutting tool, (d) graphical user interface.

For the glueing task, we used an automatic glue dispenser (Drifton 2000-D)[2] with timer control and foot pedal. It regulates the dosage of the adhesive with the air pressure and thus enables accurate application of the glue (see Fig. 3). To facilitate the last stage of folding, we printed a 3D folding aid that allows the user to form the glued fiberboard into a box shape. The aid consists of two identical moulds, only differing in height, that are mounted directly one above the other: Firstly, the glued fiberboard is placed the enclosed square on the one mould and is pressed carefully down with one finger until the desired box shape is achieved. Subsequently, the other mould is fitted to the top side of the box. A soft cloth is used to avoid scratching and to achieve a more stable fixation of the box (see Fig. 3).

In the present study we focus on the cutting process which turned out to be the most demanding and complex subtask of the production process. First solution approaches of glueing and folding tasks are described and discussed, however they are not included in this study.

[2] http://www.drifton.eu/

Fig. 3. Automatic glue dispenser (*left*), folding aid with a soft cloth (*middle*), folding process (*right*)

3.2 Study Design

Next, we conducted an evaluation study applying a within-subject design with two experimental conditions. The hardware-based assistance system was used either with or without the step-by-step support as described in the previous section. As dependent variables we measured the following:

- *Mental Effort:* Participants' perceived mental effort in conducting the specific tasks, was assessed with the SEA scale ("Subjectively Perceived Effort" [31]). The one-dimensional scale ranges between 0 ("no cognitive effort") and 220 ("maximum cognitive effort").
- *Usability of the system*: To assess systems' usability, we employed an adapted version of the standardized ten-item SUS questionnaire ("System Usability Scale" [32]) for people with impairments. Ratings on ten items are given on 5-point Likert scales ranging from 1 ("strongly disagree") to 5 ("strongly agree"). Bangor and colleagues suggested the following interpretation of SUS scores [9]: <50: Not acceptable; 50-70: Marginal; >70: Acceptable

Finally, we also investigated participants' efficiency in performing tasks. To this end, we measured how long it took them to complete the tasks (time on task), whether they succeeded or failed at a task (task success) and whether they solved the task without help (task accuracy).

3.3 Procedure

The study was conducted as part of a workshop for handicapped people. First, participants were welcomed by the experimenter. Prior to participation, all participants were given a brief description about the aim and procedure of the study. Then, the experimenter demonstrated how to use the system with and without step-by-step support and clarified all outstanding issues until the participants felt confident in their understanding and handling of the prototype. The demonstration phase was carried out to ensure that all participants have an equal foundation of experience in using the prototype. The order of experimental conditions was randomized. Subsequently, participants were asked to conduct the same cutting procedure with and without step-by-step support (see Fig. 4). The condition with step-by-step support contained 17 subtasks (see Tab. 1).

Table 1. Overview of the 17 subtasks in the condition with step-by-step support.

Step-Nr.	Description
01	Please check your work material.
02	Please put the blank into the mould.
03	Please place the template on the mould.
04	Please take the scalpel with the digit 1. (blade with a inclination of 45°)
05-08	Please cut the blank in the specified direction (the corresponding LEDs are blinking)
09	Please take the scalpel with the digit 2. (blade with a inclination of -5°)
10-14	Please cut the blank in the specified direction. (the corresponding LEDs are blinking)
15	Please put the scalpel back.
16	Please remove the template from the mould.
17	Please remove any residues from the mould.

After finishing the task, participants gave a post-task rating of their perceived cognitive workload on the SEA scale and were then asked to fill out the SUS questionnaire. Finally, participants were debriefed and thanked for their time.

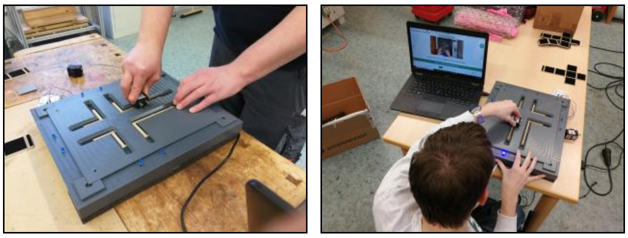


Fig. 4. The evaluation study: Demonstration of the cutting process (*left*), participant performing the cutting task (*right*).

3.4 Participants

Five German speaking male participants with different levels of cognitive disability took part in this study. They ranged in age from 20 to 21. The participants mean age was 20.6 years (SD = 0.55). One of the participants had a physical disability and used a manual wheelchair. The study was conducted at the Werkstätte of Lebenshilfe Detmold e.V., a German sheltered work organization supervising about 890 workers with cognitive and motoric limitations. Neither of the participants had previous experience with our supporting system.

4 Results

In the following we report results regarding the effect of experimental conditions on (1) measures of task efficiency, (2) subjective evaluations (measured with standardized inventories). Due to the small sample size, we could only use descriptive statistics to assess general trends in both conditions. Therefore, the statistical findings can not be used to infer significance.

Task Effeciency

Here, we investigated participants' efficiency in performing the cutting task with regard to *time on task*, *task accuracy*, and *task completeness*. All three variables were noted by the experimenter who observed the participants' activities on cutting fiberboards. Results are visualized in Figure 5.

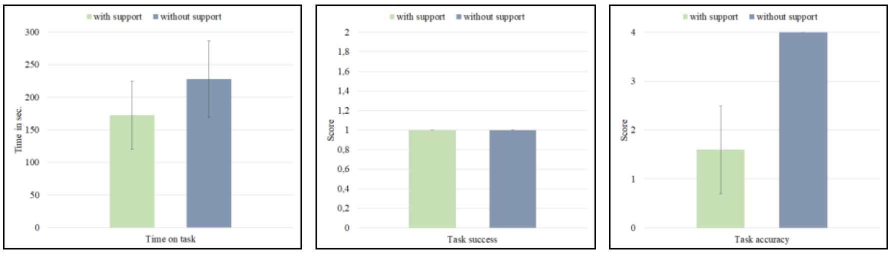


Fig. 5. Comparison of mean values and standard deviation for the variables time on task (*left*), task success (*middle*) and task accuracy (*right*).

Time on task: We compared the sum of participants' completion time for finishing the cutting task across experimental conditions. The mean task completion time in the "with support"-condition was 161 seconds while tasks performed without support took about 218 seconds on average.
Task success: Task success measures whether participants succeeded or failed at a task. A score of 1 was given for "full success" on a task, 2 for "partial success" and 3 for "no success" (see Fig. 2). In both experimental conditions, participants' success rate was maximal (*M*= 1, *SD*= .00).
Task accuracy: Participants' accuracy in task performance was measured as follows: 1 for "participant solved the task without help", 2 for "participant solved the task with trial & error", 3 for "participant solved the task with a single hint of the lab member" and 4 for "participant solved the task with constant support of the lab member". On average, participants' accuracy in the "with-support"-condition (*M*= 1.6, *SD*= .894) was higher as in the "without-support"-condition (*M*= 4, *SD* = .00).

Subjective Evaluation

Participants' subjective evaluation of the interaction was measured with standardized inventories in the dimensions of perceived mental effort and usability of the prototype (see Fig. 6).

Mental effort: We measured participants' perceived mental effort in task performance after the cutting task with the SEA scale ranging from 0 ("no effort") to 220 ("extremely high effort"). On average, participants judged their cognitive effort in the "with support"-condition lower (*M*=30.0, *SD*= 10.00) than in the "without support" condition (*M*= 54.0, *SD* = 19.49).

Usability of the system: We employed the SUS questionnaire to measure the usability of our prototype on a 5-point Likert scale from 1 ("fully disagree") to 5 ("fully agree"). Mean values and standard deviations are visualized in Figure 6. On average, participants rated the "with support"-condition (*M*= 80.5, *SD*= 11.096) better than the "without support"-condition (*M*= 47.5, *SD* = 9.519).

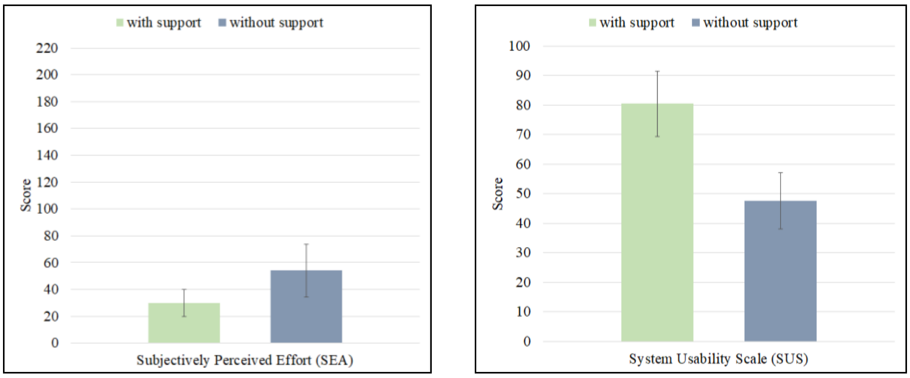


Fig. 6. Comparison of Subjective Perceived Effort (SEA, *left*) and of System Usability Scale (SUS, *right*) in "with-support" and "without-support"-condition.

5 Discussion

In this paper, we investigated the potential of step-by-step support for people with disability using an assistive system in production. We applied a user-centered methodology and implemented a prototype which enables disabled workers to perform a specific subtask of cutting a square fiberboard for producing jewelry boxes. In an evaluation study, we compared our assistive system being employed either with or without step-by-step instruction. Our results can be summarized in two major points.

First, participants' efficiency on using the prototype was assessed with regard to *time on task, task accuracy* and *task completeness*. Along the dimension *time on task* and *time accuracy*, the "with-support" condition was rated more efficiently than "without-support" condition. However, we could not observe any difference between both conditions across the *task completeness*.

Second, participants' subjective evaluation of the interaction was assessed with regard to *mental effort* and *system usability*. Again, our results showed a clear advantage for the interaction "with-support". Participants' perceived cognitive effort using the assistive system with support was lower as compared to the condition without support. The advantage of the "with-support" condition was also found in terms of system usability: Here, the “with-support”- condition was rated higher than “without-support” condition.

Overall, our assistive system *with* step-by-step support showed to have several benefits over the assistive system *without* support. That is, the supportive technology we developed seems to be a helpful aid for disabled workers. Nevertheless, our pilot study has some limitations we plan to overcome in future work.

First, due to the small amount of five participants, only trends could be seen regarding differences in both conditions. Therefore, we conclude that the same study should be repeated with a larger amount of participants. However, there are major discrepancies between individuals with cognitive disabilities. Thus, it will significantly complicate to obtain accurate and reliable evaluation results.

Second, based on the fact that the regular SUS questionnaire could be too complex for participants with disabilities, we used a modified version of the questionnaire in our study. Nonetheless, the participants didn´t have the cognitive ability to read, completely understand and fill in the questionnaire. Therefore, the experimenter read out each question from the questionnaire and noted participants’ answers. In some cases, participants gave uninterpretable responses to the experimenter which may affect the results. The same applies to placing a check mark on the SEA scale to measure participants’ mental effort. Future research includes a study with special questionnaires for people living with cognitive impairments.

Even if there are still a few obstacles to overcome, we could show in this paper that an assistance system can enhance the quality of work and thus improve job opportunities for people with disability to employment. Our assistance system can be seen as a successful reference project for other companies and organizations planning to employ handicapped people and thereby offers new possibilities for inclusion.

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