A Variable Low-cost Platform for Conducting Work Design Experiments

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***Abstract*—Due to the change of manufacturing work caused by the introduction of cyber-physical production systems (CPPS) further work design research is necessary. We propose to conduct work design experiments in order to design the future work places for the requirements of highly computational and cognitive tasks. Thus, we developed a low-cost experiment platform for an easy setup of experiments. First, we present a brief overview of work design research methods and recent experiments. Second, we present the experiment platform in detail and show how to setup work design experiments on it.**

I. Motivation

Many production resources and processes experience a change towards cyber-physical production systems. This means a combination of physical entities with computational elements in order to make them intelligent [1]. It leads to new products and processes, such as autonomous driving or smart homes, and also to smart production systems [2] [3]. These smart factories will change the way of working as well. There will be new work areas and a new task allocation between humans and machines. Besides, that development goes along with a highly-increased computerisation. Hence, for example, workers will have to deal with smart glasses, wearables, tablets, exo-skeletons, and more. To sum up, the human work will get more cognitive, more digitalised and less physical [4].

In order to facilitate and support this development, we need new work area design principles in order to enable a human-oriented work in the future factories. Therefore, our research deals with the primary research question: How do the work areas for human workers in the future factories have to be designed?

A suitable method to answer this research question is to conduct work design experiments [5]. By experiments, work design researchers are able to test different work design setups regarding their effects on key figures of interest, such as work performance, percentage of errors, work load perception, or motivation. In practice, when preparing experiments, a lot of preconditions and side effects have to be considered. First, implementing a work design experiment into the actual manufacturing process requires us to keep the production process ongoing. This leads to preconditions for the experiment setup which may influence the experiment outcome and subsequently biases the results. Second, running experiments in the actual manufacturing process are cost-intensive due to its disturbing effects on the previous production process and the incalculable outputs.

Therefore, a different way for conducting work design experiments is needed. We propose to use a variable, low-cost experiment platform to easily (pre)-test work design ideas without the mentioned harmful effects on the production key figures. The experiment platform shall be applicable to a wide range of work design starting points. Due to its separation from the production process and its re-usability, researchers are enabled to gain insights on the effects of particular work design ideas in an easier way.

In this paper, we present such an experiment platform from a technical point of view. Alongside, we focus on work design research experiments and how to run them on the experiment platform.

II. Work Design Research

What are the standard, classic approaches to design human work? From a human-oriented point of view work design deals with the creation of jobs, which enable a safe and neither physical nor mental exhaustive way of working [6]. For example, the tasks should be feasible, reasonable or satisfying [7]. Besides, work area design is concerned with the creation of varying and manifold tasks. Therefore, tasks should be as complete as possible. That means that tasks, for example, should have a clear objective, allow an autonomous decision about the tools to be used, and should provide a result review [6] [8].

But what about work area design for the future factories? We consider the standard work area design ideas as still being important but not fully sufficient anymore. Therefore, we suggest to add new work area design ideas to the previous ones. These new criteria focus on the design of the interface between the humans and the machines, such as use of assistance systems, illustration, robustness, or feedback [4]. In order to gain insights on their influence on work performance and perception further work design research is needed.

A. Methods

Work design research is mostly carried out by empirical methods. Two of the main options are observation and questioning. Observation can be distinguished by several criteria [5] [9]:

1) Open or hidden observation: Open refers to a situation where the observed persons are aware of being observed (due to the presence of an observer or a visible camera). Hidden refers to a situation, where the observed persons are not aware of being observed.
2) Participating or non-participating observation: In case of a participating observation the researcher is working with the test persons cooperatively. In case of a non-participating observation, the researcher stays passive.
3) Systematic or non-systematic observation: A systematic observation is performed following a fixed and standardized scheme and stays constant when repeated. A non-systematic observation is explorative and can vary if re-executed.
4) Artificial or natural situation: In case of an artificial situation, the investigated work design setup has been created for research purposes only. In case of a natural situation the investigation takes place on the job directly.
5) Self- or external observation: A self-observation is present, if the test person is observing him- or herself. In an external situation, the researcher observes the test person.

In human factors and work design research the mainly used method is an open, non-participating external observation [5]. For our experiment platform we therefore decided to stay with this proven setup. Further, we chose to perform the observations in a systematic way, which increases the reliability and usability of the results [5]. Finally, the observations shall take place within an artificial situation. As outlined earlier, that way we can separate the experiments from the ongoing manufacturing process.

Besides, we combined the observation part with the other main research method, the questioning. The experiment platform offers the possibility of including one or more questionnaires into the experiments at any time.

B. Experiments

Conducting experiments as a way of applying observations and questioning is a common research method in human factors and ergonomics science. Their topics and research goals cover numerous different aspects. In the following, we provide a brief overview of topics of interest and experiments conducted recently:

Jeske et al. did a study on the influence of different task descriptions on the learning process of workers. They showed a relationship between the design of task descriptions and work performance and mental work reception [10]. Another study dealt with the workers acceptance of head-mounted displays. The authors described a relationship between technology acceptance and wearing comfort or view restrictions [11]. An experimental investigation by Ganßauge was concerned with the light conditions for surveillance tasks. They showed the impact of different light conditions on human vigilance [12]. More studies further investigated topics around the mental stress related to cognitive tasks [13], on trust issues towards autonomous systems [14], or on the examination of mental stress in factories [15].

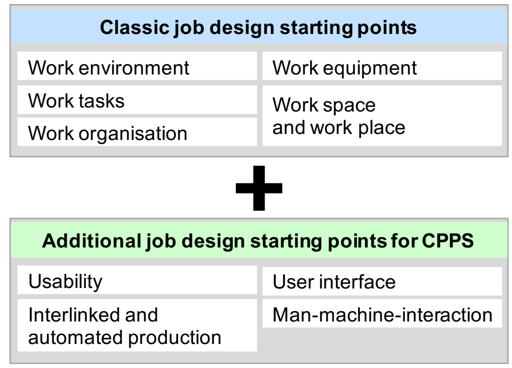

Fig. 1. Work design starting point in CPPS

The topics of these studies show some work design starting points (i.e. aspects of work design, which are necessary for human-oriented work design). As also discussed in [4], most contributions in work design research have been made prior to the rise of modern, cyber-physical production systems. Therefore, they are mainly dealing with partially obsolete understandings of manufacturing work. For example, highly physical-related work design actions such as the consideration of required brawn, which is necessary for executing specific tasks, are mentioned. However, since the majority of physical work tasks will be automated in cyber-physical systems, this topic might not be as important for the major part of future work places as it was before. Thus, additional work design actions, which fit the new situation of cyber-physical production systems, have to be considered. Figure 1 shows a summary on work design actions for future production systems.

III. EXPERIMENT PLATFORM

A. Technical and functional description

The experiment platform is mainly based on a Raspberry Pi 2 B microcontroller in combination which a 7 inch touch display. The experiment software is a self-developed Python program, running on a regular Linux operating system for Raspberry Pi. The test person is able to communicate with the system via the touch display. Prior to the experiment, the investigator sets up the work task or the work setup to be investigated. During the experiment, the system automatically collects data about the test person's performance (observation) and records answers in the questionnaires (questioning). After

Fig. 2. Experiment platform

the experiment, a results file is provided to the investigator. Figures 2 and 3 show the system and its functional diagram.

The Raspberry Pi (1) is mounted to the touch display (2) and to a display case (3). Further, that component is mounted on a cubical box (4). In order to fit the budget, we used a plastic lottery box as a basis and a case for the experiment platform. It came with a prefabricated horizontal slot (which is meant to be used as an opening for lots or sheets), which we use for cable feedthrough. Inside of the cubical box a battery, an XBee unit,

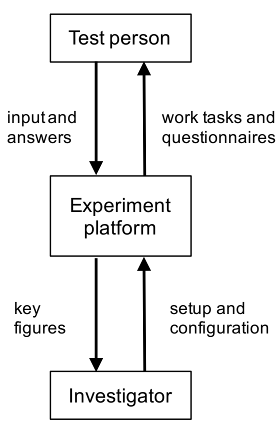

Fig. 3. Functional diagram of the system

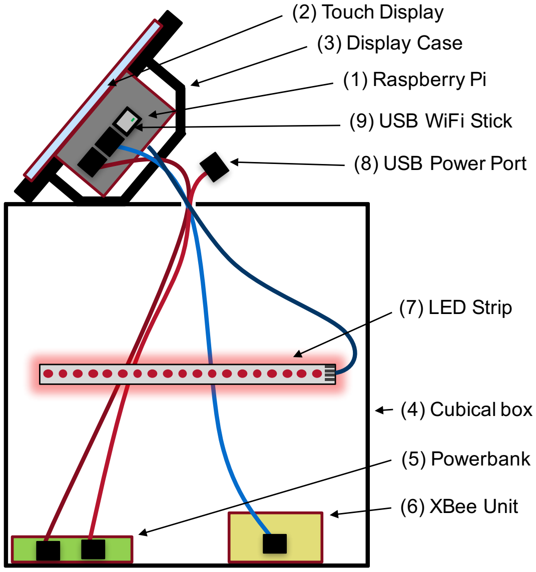

Fig. 4. Cross section of the experiment platform

an LED strip, and wires are stored. We use a standard USB powerbank (5) for power supply of the whole system. The XBee unit (6) is a radio module for a reliable data transfer and meant to be used for an optional communication between two or more experiment systems. Additionally, the LED strip (7) is used for illuminating the experiment system and can be used as a part of the experiments, e.g. as a supporting visible effect. All components can be controlled by the Python program. Besides, we installed an USB power port (8) outside of the box to have an easily reachable charging option. A USB WiFi stick (9) is used for setting up the experiment and for data exchange with the investigator's computer. Figure 4 shows a cross section of the system.

Due to the use of popular electronic components, such as the raspberry pi or a USB powerbank, the total price (234 euros) of the experiment platform is very affordable. It is within the range to standard tablet computers, which could be seen as an alternative solution. But, based on its modular design, the Raspberry pi based platform can be modified and extended

TABLE I
MATERIAL LIST

Component	**approx. Price in €**
Raspberry Pi 2 B	40
7 Inch Touch Display	75
SD Card	12
WiFi USB Stick	8
Display case	22
Cubical box	30
USB Powerbank	20
USB cables	10
Jumper cable	2
LED Strip	15
Total	**234**

more easily. Therefore it increases the fit of the system to the desired experiment. Table 1 gives an overview on the used parts and estimated retail prices.

B. Setup of experiments

One of the main goals while creating the experiment platform was to include the option to easily change the experiment setup. This way, the subject of the experiment can be varied in order to test the effects of these variations. Further, main parts of the software can be re-used for another investigation with a different subject of the experiment.

Therefore, an experiment process follows a sequence of pages, which are shown on the touch display. A sequence consists of questionnaire pages, text and information pages, and task pages. They can be arranged in any order. The test person faces these pages step by step and can move back and forth along these pages (with restrictions). Depending on the page type, the test person receives instructions, is asked to answer questions, or is asked to fulfil a task or solve a problem. These answers, results, and solutions are recorded by the experiment system. Further, several key figures such as the time spent on every page or the number of touches on every page are measured. All data is stored in a results file.

Exemplary, an experimental investigation on the influence of work design elements in cyber-physical production systems shall be presented. The investigation will be conducted using the experiment platform. First, the test persons fill out a general skills questionnaire. This information is used for a general classification of the test persons. Second, test persons get to the task description and the task illustration. Further they are asked to perform the task execution, i.e. to solve a given scheduling problem. Third, the test persons answer a second questionnaire. The questions deal with their reception of the tasks regarding motivation, task complexity, or task difficulty. Fourth, the test persons get to a results page. Here they see a comparison of their solution and the optimal solution. Via the experiment setup, particular work design elements can be switched on or off in order to test their impact. Figure 5 illustrates this process. Finally, figure 6 shows a situation during the experiment execution.

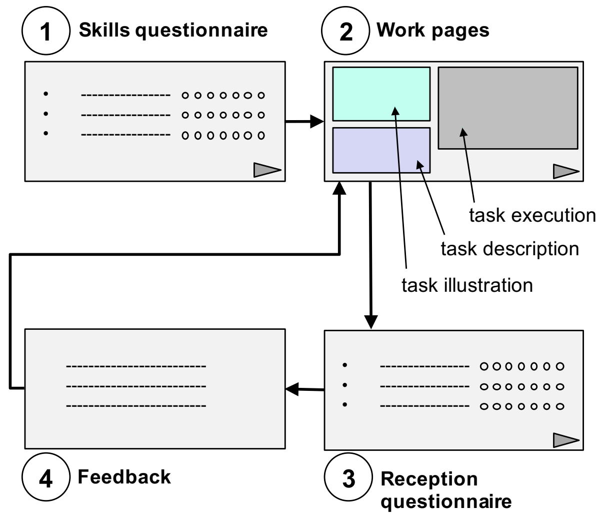

Fig. 5. Exemplary sequence of pages

Fig. 6. Experiment platforms in use

IV. Possibilities and Outlook

Besides the exemplary experiment setup presented earlier, the experiment platform can be used for other experiments or purposes as well. Here, both the work design elements of interest and the tasks to work on can be varied. For example, alternatives to the scheduling tasks could be the creation of batches. Via the touch display the test person could be asked to pool orders or production resources in order to optimize the material flow and subsequently the logistical key figures. Moreover, one or more experiment platforms could be used to model picking tasks. Then, for instance, a touch display represents a shelf compartment. In this case, the test person is asked to mark the requested items of a bill of materials.

Further, the experiment platform is suitable for non-investigative purposes such as training of workers. Here, the several experiment platform can be combined by using the radio module function and arranged as a group work exercise. Thus, skills in collaborative work can be enhanced. Besides, job-related training can be carried out by using the experiment platform. Instead of introducing changes in the manufacturing work on the job, the platform enables a decoupled test environment.

As already outlined earlier, the experiment platform contains a xBee unit to enable communication among two or more platforms. This component has not been integrated into the software yet. We plan to include this function in the next research steps in order to make experiments and training with multiple test persons or platforms available. Additionally, after finalization of experiment platform, we plan to provide the software under an open source license for interested researchers and practitioners.

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