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Worker information systems: state of the art and guideline for selection under consideration of company specific boundary conditions

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Abstract

Due to customer specific products, the number of product variants and the complexity of assembly processes increase. To meet these challenges, worker information systems are used to manage information diversity in manual assembly and to provide the right information at the right time in a lean way. Such systems are available in various types and their classification depends on a particular point of view. In order to enable a holistic overview of the existing diversity, this paper summarizes such systems and their benefits. For this purpose, available categories are shown. Accordingly, this paper serves as a summarizing report for the state of the art. Furthermore, the implementation and configuration of worker information systems depend on company specific boundary conditions. Considering them, a guideline is presented for the selection of worker information systems.

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Keywords: Assembly; Information; Worker information system

1. Introduction

With the beginning of industrialisation paper-based workshop drawings have already been used for communication. Meanwhile, the standardisation, the methodological design of products and the computer support are established in engineering processes. [1]

These developments have even found their way into the design of paper-based work instructions for production tasks. This paper-based provision of worker information results nevertheless in different problems [2–4]. The IT-based provision of worker information – in the following named worker information systems (WIS) – minimises the problems due to the paper-based provision of worker information and supports the worker in dealing with the diversity of information needed in today's manufacturing areas [5].

This paper serves to obtain an overview over existing WIS and to support the selection of such systems. For this purpose the state of the art is reflected firstly. Afterwards, company-specific boundary conditions with focus on WIS are mentioned. Considering this, a guideline for selection of WIS is presented after all.

2. State of the art

WIS are available in manifold embodiments. Knowledge originates by cross-linking of information [6]. Consequently, differences in knowledge occur by qualitative and quantitative differences in the information itself and / or in its kind of networking. Similarly, the information needs of the worker varies depending on the task, so WIS are classifiable by their purpose respectively their area of application, e.g.: single part manufacturing, manual assembly, maintenance, quality inspection or logistics.

The selection of appropriate WIS is indeed mainly task-oriented and to be performed accordingly the worker needs, but company-specific constraints are also taken into account. Both aspects narrow down the selection of WIS. Correspondingly different perspectives on describing WIS are possible. This will be followed by describing the state of the art in an analytically way. For this purpose, WIS are viewed

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from different perspectives. Each perspective means an individual class of the classification. It is noted that some WIS can belong to the same class, but they can still differ to each other qualitatively and quantitatively in the information content provided. Thus for example GUSTAFSSON point out different design contents of visual process instructions, in which e.g. textual or acoustic information can be complemented [7].

2.1. Used means of communication to provide worker information

HAUF & DREISSIGACKER illustrate in 1991 an electronic WIS, which uses a numeric display to provide part numbers of the components to be assembled in a way clock-synchronously to the assembly flow [8]. Today's state of the art enables the provision of worker information for manual assembly in a multimedia way via **screen** [9–14]. The screens considered in this context provide only two-dimensional and / or quasi-three-dimensional contents which are based on perspective views. The stereoscopic view of three-dimensional contents is assigned to the virtual reality.

Pros. Enables multimedia, so information representation is scalable [15]. A common IT infrastructure for implementing screen-based WIS is sufficient. *Cons*. Changing between different viewpoints – between screen and object of assembly – is necessary. Tracking the assembly state is usually not given, so the worker must control the information provision by himself.

In **augmented reality** (AR), the user's field of view is enriched with computer generated data appropriate to the situation and for real-time interaction [16,17]. However, AR generally includes the addressing of all human senses [16,18,19]. Within literature, however, there is to be found no consistent uniformity regarding which sensory perceptions are to be included in the build-up of AR systems. As pointed out in [20] the feedback of haptic and force in AR applications has been considered. AZUMA describes in 1997 possible AR scenarios which include acoustics respectively haptics. [18]. For the purposes of the industrial application of AR only the visual aspect of sensory perception is considered often [16] [19]. EVERSHEIM ET AL. present in [21] an AR-scenario in single and small series assembly. REIF [22] and GÜNTHNER ET AL. [23] represent AR for Pick-by-Vision in logistics.

Pros. No view changes because the worker information is projected directly on the observed assembly object. Less modelling effort and information to be generate computerised compared to virtual reality [24]. *Cons*. IT-Effort for build-up because of necessary enabling technologies and components: e.g. tracking-system [21], activators [25], vision devices [25], high demands on calibration and tracking accuracy since proper placement of digital information into the real world is essential [16,24], which applies to the AR Software [25] or its algorithms at the same. By wearing e.g. head-mounted display or any activator, the worker is possibly impaired.

In **augmented virtuality** (AV), the virtual scene is enriched with real images [26]. AV is not widespread applied in WIS for assembly, but a scenario could be implementing pictures of real but not virtual existing assembly devices into a fully virtual designed assembly workstation shown while providing worker information. *Benefit:* merely real existing assembly objects must not be fully virtualised or digitised in an upstream process. The *Drawback* is similar to the virtual reality ones.

The **virtual reality** (VR) is a simulated reality in which the VR user is involved acting and controlling and feels (ideally) like integrated in a real environment [27]. Human beings can be passive, exploratory or interactively involved [28]. Main features of VR are interactivity (the artificial environment responds directly to the inputs of VR user), immersion (the VR user feels as part of the virtual environment) and imagination (the specific problem-solving benefit of the VR scene depends on the human imagination of the VR user and not solely by the placement of the VR scene) [27,29,30]. In the technical implementation of VR the realisation of spatial vision (stereoscopy) is of significant importance. To differentiate the terms AR, VR, AV and Mixed Reality in relation to each other reference is made to Reality-Virtuality Continuum in [31].

Benefit. No real environment is necessary, whereby VR is useful if the real scenario needs e.g. too much effort for build-up or it is risky [32]. *Cons*. Effort for modelling [24], because the environment needs to be present fully virtual respectively digital. There is no on-the-job-training, whereby practical knowhow is not acquired in a fully manner [32].

Light-guided WIS provide worker information via light signals. Pick-by-light respectively put-to-light applications use signal lights to inform about positions for removal or storing of components [22]. Also projected light signals (e. g. via laser [33]) are possible. In **pick-by-shutter** applications locking mechanisms attached at component containers open specific to the product variant [34] and thus inform about components to be used. Guiding the worker by voice output (**pick-by-voice**) is also available [22].

Pros. The benefits of AR are transferable to light-guided WIS. Pick-by-Shutter prevents picking-up the wrong component. Pick-by-Voice exempts eyes and hands from operating the WIS. *Drawback*. The systems are often limited to removal and storage information, which is why they are supplemented by screens [5].

The above mentioned types of media for providing worker information can occur in **mixed forms**. For example, head-mounted displays are given in AR-applications [18]. The degree of mixed forms depends also on the working task content.

2.2. Degree of mobility: stationary versus mobile WIS

Considering the procedural organisation linkage of worker and job content, non-stationary assignments of worker and workplace can be realised [35]. A worker can perform work contents at different workplaces. Likewise, different workers can be allocated to one stationary work place. The provision of worker information correctly arranged to the workplace is constantly required. Taking this into account, WIS can be divided according to their degree of mobility into stationary and mobile WIS. A stationary WIS implements for example LANG in [15]. GRAFE, MATYSCZOK & PARISI [36–38] use mobile devices. Schenk et al. describe in [16,17] mobile AR-systems beside stationary ones.

An advantage of mobile WIS is the minimisation of necessary WIS stations, since these now depend on the number of workers, instead depending of the number of workstations. Usually less workers than workstations are there. An advantage of stationary WIS is the not necessary effort for worker localisation, since the individual WIS are stationary rigidly installed. But at minimum one hand is not able to perform the assembly since it is occupied by holding the mobile device, if there is no adequate ability for positioning the device at the workstation in a view ergonomic manner.

2.3. Cognitive load of worker: static versus dynamic provision of information

The provision of worker information serves to support the execution of the production task. To make this possible in an efficient manner it is necessary to prepare the worker information understandable and ergonomically [15]. Adequate hereto is to minimise the cognitive load of the worker during information acquisition.

WIS can provide information in a static and / or dynamic way. Static information representations – such as images and text – are time-invariant. They can't directly represent temporal sequences. The worker must extract those – e.g. the sequence of individual process steps – from the static description by using a cognitive process by himself. In this case, the operator converts the external presentation of information into an internal model representation. The cognitive load is minimised when temporal sequences are immediately extractable from the external representation, e.g. by using videos, movies or animations. Because of their time variance, however, the dynamic representation of information requires to adapt the duration of information presentation adequate to the (individual) worker needs. [39]

2.4. Degree of flexibility: deterministic versus adaptive worker guidance

WIS describe individual working steps. Classically, these follow a rigid concatenated sequence. This deterministic kind of worker guidance requires frictionless processes, because if one single production step cannot be completed – e.g. in the case of missing process inputs such as parts or tools – the process chain is interrupted. The following steps are therefore not executable.

Adaptive worker guidance, however, can determine work contents in a situation specific manner and is able to adjust work sequences dynamically by using state-based graphs. For this purpose cognitive skills are involved in the generation of work instructions. [40–42]

2.5. Source of worker information: local versus web-based handling of worker information

Today's product creation is segmented into individual phases and is characterised by a Global Cross Enterprise Engineering, in which engineering and production activities are carried out globally and across companies in a distributed way. Consequently, the worker information which feed into and is to be processed by the WIS can be company-own or -foreign and local or global origin. Due to different engineering workflows different information standards and data types may be present. This information diversity needs to be controlled and integrated by the WIS. [43]

As a result WIS can be integrated into a local respectively intranet-based [44] and / or a web-based [43] network.

2.6. Time of information provision

Considering the timing of the provision of information, information can be provided synchronously with the (assembly) process or in a prior training. In the case of synchronous provision, the worker information is provided simultaneously to the real assembly process and its state. This requires the synchronisation between worker information needs and offer. In the simplest case, a situation-specific query of information by the worker himself at the WIS is sufficient. However, if the worker information provision should run simultaneously to the real assembly process, the latter must be continuously tracked. Or the worker must comply with the given speed of information provision by the WIS. In the case of an upstream training worker information are presented for example by assembling a demo product. As the result does not subject to the series production, assembly errors have rather a teaching effect than negative consequences. However, the upstream provision of worker information claims capacities of the worker and increases therefor non-value-added time slices. There are combinations of both types possible.

2.7. Access to worker information: centralised versus decentralised provision of information

Beside workplace-specific WIS also working group related information terminals are possible. This centralisation of information retrieval and provision minimises on the one hand the number of necessary WIS. On the other hand, non-value-adding walking distances of the production staff with congestion and waiting time at the terminals are possible.

2.8. Real versus virtual worker information

WIS can provide really documented and / or digitally created information. Realistic images reflect the assembly activities in a natural way. However, they require real objects to be present. In addition, relevant object details may be obscured. Consequently, real objects are to be destroyed in certain cases to make details of the assembly object visible. At digital objects this is easily possible by using for example removing features of the CAD-Software. [5]

2.9. Ability to dialogue

By integrating ability to dialogue – possibly by means of multimedia forms of communication [45] – also workplace or process-related operating data is collectable [46]. As a result, states of the process and worker specific needs are traceable. Also, motion recognition [47] functionalities can be integrated for error prevention.

3. Guideline for selection of worker information systems based on company specific boundary conditions

Only reasonable combinations of the above-mentioned properties build practicable solutions, thus some

- properties are dependent on each other (e.g. fully digitalised respectively virtual objects are needed for VR),
- expressions of the properties can be represented by the same WIS (e.g. static and / or dynamic provision of worker information on the same screen) and
- properties are optionally available, so it enables to expand WIS in a manner of modularity (e.g. ability to dialogue to feedback problems by the worker as an possible extension).

In addition, from a practical view on possible combinations some properties are mutually exclusive (Fig. 1). In [16] mobile AR systems are described as attached to the worker and thus accompanying his movements. Consequently transferring the description of mobile AR systems in general to mobile WIS, light-guided and pick-by-shutter WIS are not assigned to mobility since their components are fixed to the work place. Pick-by-shutter applications are used to indicate a removal sequence so it is to be regarded as a kind of dynamic WIS. Additionally, pick-by-shutter counts as not adaptive, since opening other shutters containing alternative parts to compensate e.g. missing parts is usually not practicable. During engineering processes defined parts are to be used in a fixed working step. Applying AV and VR to provide worker information synchronous to the work task means changing the real view into a virtual one. This implies switching from a real task into a virtual scene at the same time, what is not a manner of synchronicity. Using AR and light-guided WIS at a centralised terminal leads to integrating all real work stations and their individual objects into one central AR station. This means a lot of effort for retooling the centralised WIS for each single information request. In contrast, installing VR at every work station has the consequence of replacing this real work station by VR for each single information request. VR is limited to fully virtual information by its definition, so no real information is provided. On the contrary, light-guided and pick-by-shutter WIS provide real information from a physical view of point.

		2.1						
	expression	screen	AR	AV	VR	light-guided	pick-by-shutter	pick-by-voice
2.2	stationary							
	mobile							
2.3	static							
	dynamic							
2.4	deterministic							
	adaptive							
2.5	local							
	web-based							
2.6	synchronous							
	up-stream							
2.7	centralized							
	decentralized							
2.8	real							
	virtual							
2.9	dialogue							

Fig. 1. Example for combination restrictions generated by a today's practical point of view.

Beside this above from a technical perspective driven restriction of property combinations, also company specific boundary conditions restrict some combinations or even the use of properties. Examples are:

- The decision of necessity of movements between workers and work stations [35] determines to what extent mobile or stationary WIS are required.
- The complexity of the work task to be performed determines to what extent static or dynamic information representation are useful.
- The degree of digital product and process development determines to what extent real respectively virtual information are usable.

Following this together with other company specific boundary condition and continuing for the other properties, Fig. 1 can be used as a form to document

- properties which are not to be implemented (striking out of expressions) and
- restrictions in property combinations (grayed-out fields)

with the result of remaining those means of communication (see chapter 2.1) which are able to fulfill the company specific boundary conditions. If there is no system, which is able to perform the required properties, combinations across the means of communications are possible. It should be noted, that the systems *screen*, *AR*, *AV* and *VR* are considered as not to be combined to each other, whereas they are combinable with light-guided, pick-by-shutter and / or pick-by-voice. As a result, possible combinations of the means of communication are shown, which enable to perform the required properties.

Summarizing the above mentioned aspects, a guideline to select a suitable WIS is proposed in Fig. 2.

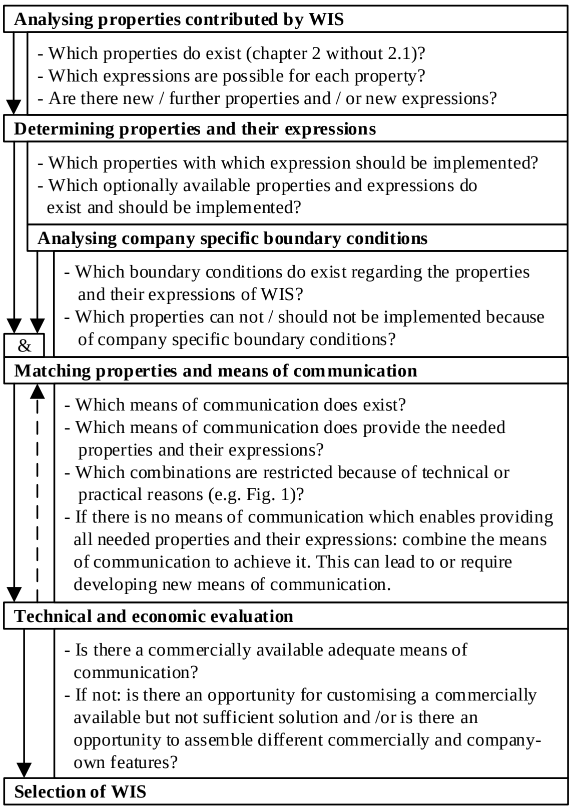

Fig. 2. Guideline for selection under consideration of company specific boundary conditions.

4. Selected examples of practical implemented WIS

Four examples of WIS are presented in table 1.

The first both systems are equal concerning a lot of properties. Typical applications are in assembly and logistics. A monitor for displaying the contents of each WIS is installed at an assembly workstation with a swivel arm. Both systems are connected to the company specific intranet. Differences result in the data formats for content, whereas photos, screenshots and text are applied on one side and video sequences of little parts of assembly on the other side. The first option is expandable to e.g. the field of logistics in form of consignment and can also integrate engineering data, which are not available in a physical way. A tool for problem reports is known for option one.

The third variant directs to the area of maintenance which includes assembly tasks where required. A real situation including machine or device is continuously recorded by a tablet camera. The live picture on its display is enriched with servicing relevant information. Thus, this variant is a typical AR system. Virtual and real world are drawn together in this case and automatically calculated animations for this situation are possible. All data should be offline available though, because an internet connection can't always be ensured.

The fourth variant directs to a not yet commercially available, but beneficial combination based on prototypes in the field of scientific research. One approach mainly regards the application of open source web technologies to reduce software costs. Besides, particular conclusions of an electric risk assessment are included and strategies for avoidance shown to a worker. This system also applies to apprentices by integrating further educational contents. A scientific system can be brought to industrial maturity by a downstream commercial development.

Table 1. Selected examples of practical implemented WIS.

chapter	commercial 1	commercial 2	research 1	research 2
2.1	screen & light guided	screen	AR	screen
2.2	stationary	stationary	mobile	stationary
2.3	static (text & picture)	dynamic (video)	dynamic (animation)	static & dynamic (animation, text, picture)
2.4	deterministic	deterministic	adaptive	adaptive
2.5	intranet	local / intranet	local	webbased
2.6	upstream & synchronous	upstream & synchronous	synchronous	upstream & synchronous
2.7	decentralised	decentralised	decentralised	decentralised
2.8	real & virtual	real	virtual in real	virtual
2.9	feedback	steady improve-ments by (expe-rienced) worker	---	feedback

5. Conclusion

This paper gives an overview to the field of worker information systems in a lean manner. Typical properties which arise from different perspectives on describing such systems are declared in detail. The proposed guideline considers company specific boundary conditions as well as properties which are due to future developments in the field of WIS. Especially in the steps of matching required properties and providing means of communication the need for developing new WIS can occur.

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