# Towards integration and management of contextualized information in the manufacturing environment by digital annotations

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**Abstract.** Advanced manufacturing promises an evolution of industrial production processes by increasing flexibility and specialization of work tasks to deal with mass customization. To maintain a high quality and efficiency despite this increasing customization or even improve them, intelligent assistance systems are required supporting the workers.
This paper describes how to integrate digital information in a manufacturing environment, where workers use assistance systems to access task related information. To explain requirements and constraints of assistance systems, a survey was conducted. Based on the results of this survey, a conceptual approach is specified that focuses on quick and easy access to relevant information via a tablet. To provide manufacturing workers with relevant information, a method is presented to measure information relevance based on an ontology. A demonstrative scenario describes the application of the conceptual approach.

**Key words:** Ontology, digital annotations, context, manufacturing

## 1 Introduction

Widen-Wulff [29] emphasizes the importance of knowledge sharing in organizations because of their increasing complexity and growing scale of information activities. One example concerns the advances of industrial manufacturing processes. To cope with the increasing mass customization the former rigid product processes are substituted by more flexible yet also more specialized processes. To maintain an equally high quality and efficiency despite the increased flexibility "information and knowledge are the firm's strategically most important resources today" [29]. At the same time the intellectual resources are difficult to manage and require intelligent assistance systems that support the individuals such as workers.

In this regard, knowledge can be defined as "information processed by individuals including ideas, facts, expertise, and judgments relevant for individual, team, and organizational performance" [28]. Even as the importance of information sharing is widely accepted [20, 28], motivation and communication barriers are still a great obstacle to sharing knowledge [7]. To identify these obstacles and possible motivators multiple studies have been conducted [7, 12, 28] depending on individual characteristics and situational perceptions. An important result of these studies is that especially people who perceive significant time pressure are less likely to share knowledge while perceived competition was not directly related to knowledge sharing.

Traditional knowledge management tools are often provided stand-alone and rely on the user to explicitly search for additional information due to a demand regarding his current work task [18, 28]. That means a user who is already under time pressure has to switch between different systems and perform further tedious interactions to gain information. We aim to integrate the knowledge management fully into their daily work so the user does not have to switch between systems to gain additional information. We propose the usage of ontology-based annotations as an intuitive way to integrate work task related information into an intelligent assistance system, enabling workers: (1) to access contextually relevant information based on the task that they perform and (2) to easily create and share useful information with their co-workers. Contextually relevant content is automatically recommended to the user based on an ontology modelling the domain.

After investigating necessary aspects of such a system in Section 2 by a survey, we consider related work in Section 3 especially in the area of digital annotations. Afterwards, we explain our concept in detail in Section 4 using the example of supporting an assembly worker and discuss key points of a visual integration of the annotations into an assistance system in Section 5. A conclusion summarizes our results.

## 2 Survey: general demands for assistance systems

A survey was conducted to enquire the general demands for work task related information as well as factors influencing the willingness to use an information assistance system.

### 2.1 Test subjects

31 test subjects from Germany participated in an online survey questioning their opinion regarding work task related information and support by an assistance system. The age of the test subjects ranged from 22 to 51. Most of them did not have much experience with information assistance systems. The background of the test subjects covers a variety of professions from medicine, economics, law, education, engineering, IT consulting, administration, research and manual work.

### 2.2 Questions

The subjects were asked to answer questions to the following topics:

System demands: The subjects were asked to evaluate the usefulness of different kinds of work task related information, such as an overview of the work task, a detailed work step instruction, information regarding involved tools and materials, and tips for improving the task itself.
Furthermore, the subjects were asked to evaluate different features of an information assistance system in respect to their significance to support the worker in his work task, such as usability, information quantity and quality, and transparency.

Usage factors: The subjects were asked to assess what kind of information they would share in what extent and to evaluate different concerns in respect to working with an information assistance system, such as lack of time or motivation and the averseness to being monitored.

The subjects were asked to assess specific options of the topics with a four-level Likert scale. Furthermore, they were given the chance to give additional feedback as free text.

### 2.3 Results

In the following, the most important findings regarding the topics are summarized.

**System demands.** Figure 1 shows which content users want and expect of an assistance system. A process overview, a detailed explanation of the current work step, and an error detection were valued positively by 96.77% of the subjects. Tips for improvement and remarks by colleagues were valued by 87.1% each, and a technical discussion between colleagues was valued by 83.87%. Additional

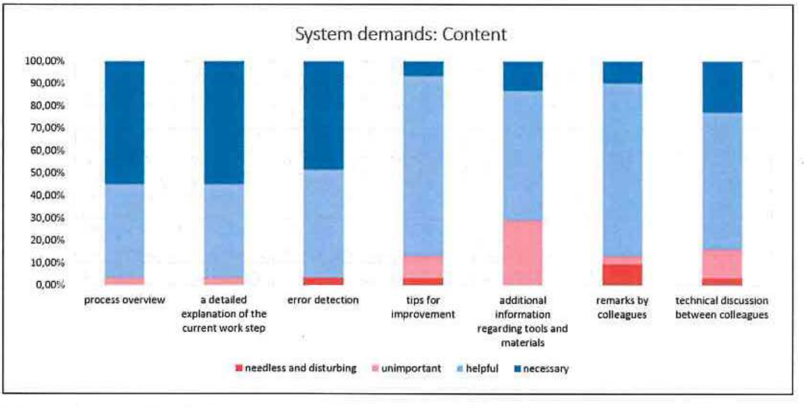


**Fig. 1.** Demands of the survey participants regarding the content of an assistance system.

information regarding tools and materials was valued the least with 70.96% of positive assessment.

When asked to evaluate specific kinds of additional information provided by experienced colleagues, remarks regarding the tool were estimated to be mostly "helpful" by 70.96%, "interesting" by 22.58% and "unimportant" by 6.45%. Nobody estimated this information to be "needless and disturbing". Remarks regarding the materials were estimated to be "helpful" (67.74%) and "interesting" (32.26%). Tips for improvement were estimated to be "helpful" by 45.16%, "interesting" by 48.39% and "unimportant" by 6.45%.

When asked about the importance of given system features (see Figure 2), the test subjects evaluated "providing relevant information of high quality" as most important (with the values of 83.87% "necessary" and 16.13% "important"), followed by an "easy and intuitive handling", "interactivity", "unobtrusiveness" and "sensible dealing with the data (anonymity)". "Quantity and multitude of information" was valued the least (12.90% "necessary", 58.06% "important", 16.13% "unimportant", and even 12.90% "needless and disturbing"). Additionally, the subjects named a reasonably small latency as very important.

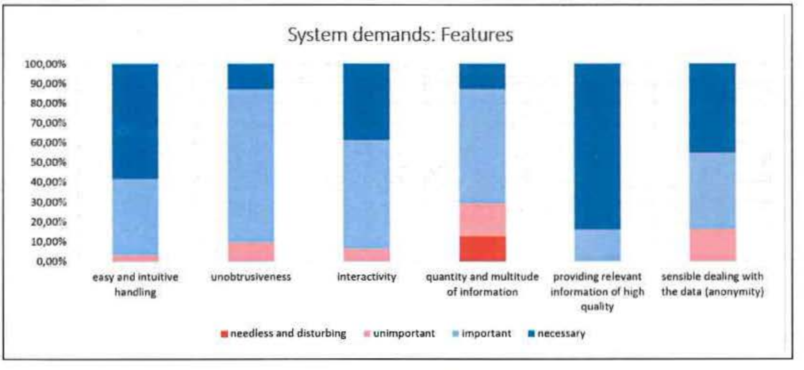


**Fig. 2.** Demand of the survey participants regarding the importance of features of an assistance system.

As further demands and nice-to-haves, the subjects named especially the possibility to give feedback (for correction or evaluation of the systems advice), integration of the support (by push-notifications, warnings), personal adjustment of the view and extent of support activities (more experienced users need less support), transparency (why did the system choose this; why should I follow its advice; what consequences are expected otherwise), and a display of remaining process time and how to save time (for a "smoke break").

**Usage factors.** When asked about their willingness to share their own experience with their colleagues, almost all of them (96.77%) were willing to share information about tools and materials in a digital way where everyone could access the information. They were a bit more reserved with information about found errors in the manual and tips for improving the work task. Here, 12.90% and 19.35% respectively would only share these information verbally.

29% of the subjects commented on their choice. All comments to this topic were like-minded: They would share their knowledge, because sharing of knowledge promotes the working atmosphere and helps everyone to improve themselves and the processes. They share as they want their colleagues to share their knowledge, too. The sharing is no problem if it does not result in further work. Sharing a more subjective opinion (such as improvements) only feels comfortably to them when performed verbally to prevent being negatively perceived as a "know-it-all".

When analyzing the evaluation of different concerns regarding the assistance system (See Figure 3), the greatest concerns are the fear of being surveilled (by the system 51.62%, by my supervisor 58.07%) and the concern of not having the time to maintain the system (51.62%). The other concerns scored significant less agreement: lack of willingness to maintain the system (25.8%), lack of motivation to deal with the system (19.35%), fear of being more distracted by the system than supported (19.35%), and fear of being replaceable, when they share their knowledge (19.35%).

Further concerns are that the system might not work correctly and that the supervisor is not really supporting the additional efforts of using the system. They fear requiring additional time and thus extra hours to maintain the system.

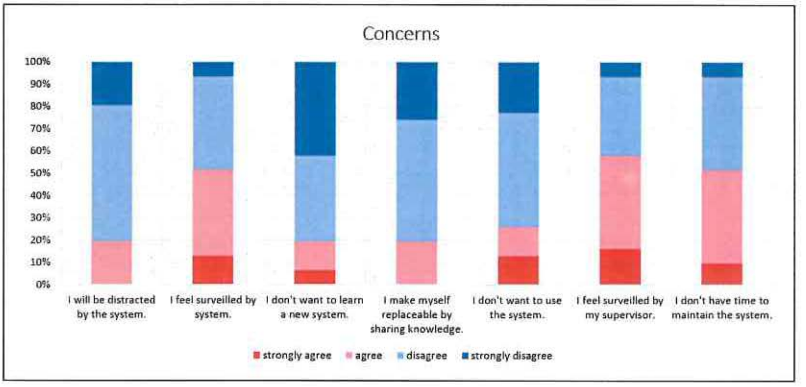


**Fig. 3.** Agreement of the survey participants to concerns regarding an assistance system supporting the work task.

### 2.4 Conclusion

Due to the rather small number of participants and their different qualifications, we cannot claim that the survey is representative, but a few general insights are still gained. We found out that the participants were generally open to a system that provides them with information. If the benefit is recognized, they would also share information in order to promote the team. We want to particularly emphasize that the highest ranked system features were "providing relevant information of high quality" followed by features alleviating the usage of the system. Furthermore, the greatest concern besides the averseness against being monitored was not having the time to maintain the system.

In summary, it can be stated that it is of great importance that the perceived benefit is greater than the perceived disadvantage. Consequently, additional efforts and especially the time required for using and maintaining the system have to be minimized. This tendency seems to be universal since participants of various fields agreed, so that an approach to solve this problem could also be of use for instance regarding workers in a production environment.

For this reason, a simple and intuitive information communication means is desirable. Digital annotations make this possible as we will show below.

## 3 Related Work

The digitization and accessibility of contextual relevant information is a broad field where diverse approaches are applied. Traditional knowledge management systems rely on the user to explicitly search for additional information by himself due to a demand regarding his current work task [18, 28]. But as our survey has shown the users require a more easy and intuitive means that minimizes this additional effort to get to the information. Consequently, we are focusing on ways that more automatically provide relevant information as it is typically done by recommender systems.

Recommender systems are a subclass of the information filtering systems that attempt to predict a "rating" or "preference" that a user would assign to an item. Traditional recommender systems neglect/disregard the notion of "situated actions" [26], the fact that users interact with the system within a particular "context" and that preferences for items within one context may be different from those in another context [2]. They simply produce a list of recommendations by collaborative or content-based filtering. Hence, context-aware recommender systems [2] define a context in order to create more intelligent and useful recommendations. Contextual factors such as time, location, purchasing purpose are then also taken into account.

Yet, recommender systems are mainly used for providing relevant information. They rarely provide intuitive and simple ways to create and integrate new information. However, as the survey has shown such an intuitive and simple access is necessary to reduce the time a user requires to share his knowledge. Regarding this demand for a simpler means of communication, basic forms of knowledge sharing are already performed using annotations by diverse groups of people. Students are writing annotations in their textbooks or people are putting sticky notes at objects to annotate them; the activity of annotating is easily done and useful to support information sharing and processing by human beings [6]. Therefore, it is not surprising that annotations are also used in the digital environment to enrich digital content with additional information [3].

The concept of digital annotation is not uniformly defined, but can be summarized as follows: *An Annotation is an object that contains information about one or more related entities.* Digital annotations are usually used for classification, documentation or communication. They can be provided in various forms to integrate different media depending on the purpose, e.g. as text, image, audio, video, etc. In general, two different kinds of digital annotations can be differentiated: Annotations for machine interpretation (often referred to as "semantic annotation") and annotations for human communication.

### 3.1 Annotations for Machine Interpretation

Most often, annotations are used to semantically enrich digital documents to support computers in processing and interpreting the information context [16]. Here, annotations classify documents or document sections by a word or word group using a standardized vocabulary. In this way, they support activities like searching for information, structuring and shaping a document as well as enabling service interoperability. Accordingly, they are of importance in semantic information retrieval [6].

In order to include the semantic context, various approaches use an ontology formalizing domain knowledge. Kara et al. [14] present an ontology-based information extraction and retrieval system applied to the soccer domain, while Nakatsuji et al. [21] use ontologies to index and classify a user's blog entries to derive the user's interest. The benefits of an ontology are widely recognized, but its biggest weakness is the complexity and expense of its creation and maintenance. Hence, Euzenat [8] proposes an ontology-based annotation approach in which the ontology should be expandable on the fly. Recently, Zhao and Ichise [30] proposed a Framework for InTegrating Ontologies (FITON), a semi-automatic system to integrate large and heterogeneous ontologies.

These annotations are very limited regarding their ability to carry information and thus cannot be used as a means for communication. Yet, this kind of annotations may support the automatic identification of context-relevant information.

### 3.2 Annotations for Human Communication

But annotations can also be used as a tool to support collaborative information exchange [16]. Known applications are different document readers (such as Adobe PDF Reader), that allow the user to add comments or notes (annotations) to the documents, or the collaboration features of MS Word (or similar software products) that enable the tracking and discussion of changes. Lortal et al.[17] describe a cooperative annotation tool used by a mechanical engineering team to discuss design drafts. These approaches often lack in indexing and annotation recall [16]. For most applications it is also not advisable, as the annotations are mostly valid for a very specific subject (e.g. an exact passage in a text). This annotation might not be of great use in another context.

Regarding repetitive "situations" such as work tasks which can be integrated in a broader context, we see advantages in retrieving associated annotations. Here, abnormalities in one work task are most likely also of interest regarding related or similar tasks. The classification of the annotations for re-usability in other contexts is interesting, but in the research area of annotations largely untreated. In [4] we presented a first concept for the use of contextualized annotations that are semantically enriched human annotations for an integrated visualization of heterogeneous manufacturing data. We extend this concept by applying these contextualized annotations within an assistance system as a communication medium for situation relevant information.

## 4 Conceptual Approach

Our objective is to provide the user with a quick and easy way to access and capture additional information about their current task (e.g., a worker assembling a certain machine). So, the overall team can benefit from an exchange of their experiences. For this purpose, we combine several ideas from the field of digital annotation to benefit from their advantages. By relying on the freedom of "annotations for human communication", the user should be able to digitally capture all sorts of information in a fast and easy way. This simplicity will minimize distractions from his primary task and thus motivate him to document his thoughts and experiences.

Yet, to present only context-relevant parts of this information to a user requires further steps. First, the information has to be put in its right context to make it versatilely reusable. We therefore apply the indexing mechanisms especially the underlying ontologies used for "annotations for machine interpretation" to the human readable annotations. Second, from this ontology modeling real-world objects and their relationships only that information has to be extracted that is actually relevant for a user's current task (such as information about the machine or necessary tools). Hence, we utilize recommendation mechanisms working on the structure of the ontology for this context-relevant information extraction. In summary, the following three steps have to be performed:

- Formalize domain and context knowledge as an *ontology*.
- *Capture additional information* as annotations and match them with corresponding ontology concept(s).
- Provide *contextually relevant* information for a given situation.

In the following, these steps are explained in more detail using the example of an assembly worker.

### 4.1 Modelling the Ontology

All relevant contextual elements of the work domain (such as work tasks, tools, parts or materials) are modeled by semantically interrelated concepts in a domain ontology. An ontology describes a shared conceptualization which formally represents a set of concepts and their relationships [10]. Since we want to extend the assistance of a worker using the ontology, it makes sense to represent the context of the work environment, in particular the work tasks. We are guided by the classical definition of context by Abowd et al. [1]. Here, a work task is defined by its relations to people, places and things. Accordingly, our ontology consists of four interrelated sub-ontologies:

- The *people* subgraph of the ontology formalizes the roles with their corresponding responsibilities and skills (e.g. planning engineers assign workers).
- The *places* subgraph of the ontology summarizes the local arrangements of the work places (e.g. the production hall contains different working groups).
- The *things* subgraph of the ontology summarizes all production-related materials such as tools, parts or products, and also encodes their composition as specific interrelations.
- The *work tasks* subgraph formalizes the different work tasks, from general work tasks such as monitoring, planning, and assembly to more specialized work tasks such as sticking and soldering. Moreover, the concepts of the *work tasks* subgraph connect all subgraphs.

The assembly *work task* in particular relates to all other subgraphs as it is performed by a worker (*people*), at a work station (*places*), and consumes parts to produce a product (*things*). In this way, all subgraphs of the ontology are interrelated through diverse work tasks. Figure 4 illustrates an example ontology.

### 4.2 Capturing Additional Information

To best support the worker in capturing additional information while minimizing the perceived disturbance, we adapt the metaphor of a sticky note. These sticky notes give the worker the ability to intuitively capture information in various forms, such as text, photo, audio, etc. To make this information widely available, they have to be assigned to ontology concepts describing those real world objects that the information annotates. As we are extending an assistance system with work task related information, this assignment can be done semi-automatically. The assistance system already knows about the current work task and can thus select those concepts of the ontology that represent the current work task and its context which are most likely to be annotated by the worker. In this way, the worker does not need to choose the corresponding concepts from all concepts of the ontology, but the specific concepts relevant to the current work tasks

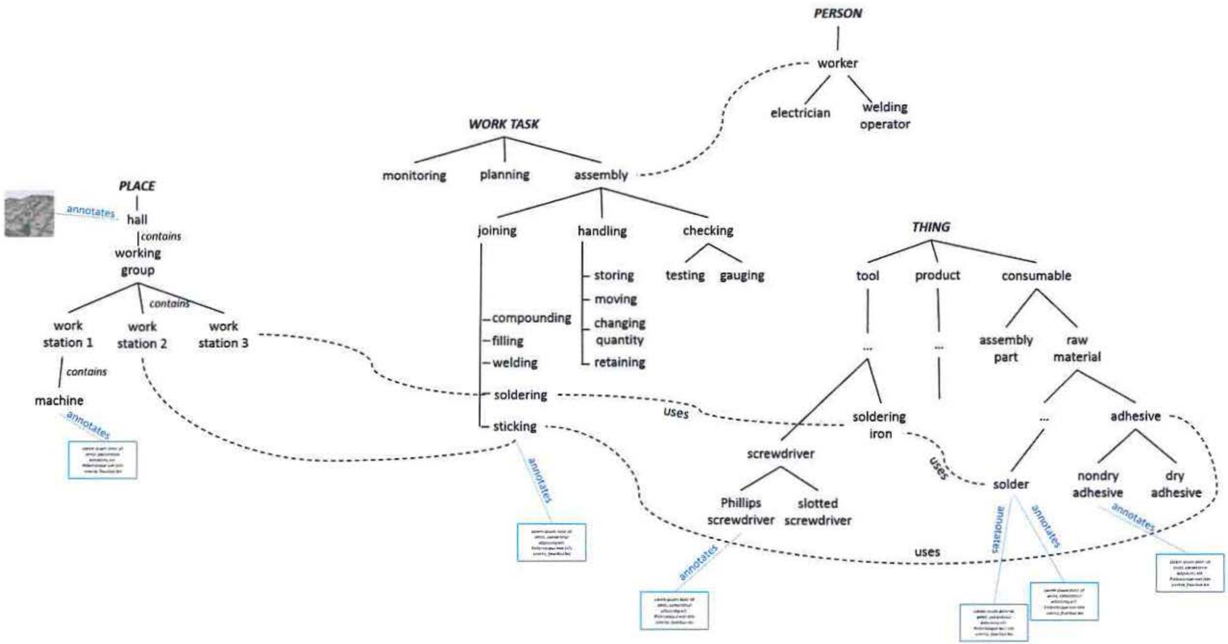


**Fig. 4.** Excerpt from a sample domain ontology. Straight lines represent hierarchical relationships, broken lines represent context-relationships, especially between the sub-ontologies (modelling the context between work tasks, people, places, and things). Annotations are displayed as blue boxes that are linked to at least one ontology concept.

are already available. From this preselection, the worker can then choose the concept(s) to annotate, for instance restricting it only to the machine and/or a used material.

### 4.3 Measuring the Information Relevance

For extracting context-relevant information to support a user in his current task but also for capturing additional information as described in the previous step, a measurement is necessary that indicates the relevance of an information to a specific "situation". In our case, such a situation describes a worker's current work task. As the ontology represents work tasks and their context, this situation can be identified as an ontology concept. Starting from the initial work task concept adjacent relationship paths (the edges of the ontology) can be followed to find related concepts annotated with additional information. Therefore, a relatedness measure can determine the degree to which a pair of concepts are related considering the whole set of semantic links among them [25]. We aim to adapt this notion to measure how relevant an annotation of a related concept is to the current work task.

Many publications cover special cases of semantic relatedness, the (semantic) similarity between objects [23]. They basically differ in which relationships they utilize for measuring relatedness in ontologies. Most often the hierarchical structure of the ontology is used to determine the semantic similarity between concepts [5, 27]. More recent research in the area of semantic relatedness consider different relationship types and thus also the non-hierarchical relationships in ontologies [19, 11, 22, 9]. That means starting from the initial work task concept, three types of relational directions can be identified that lead to information relevant to the situation and are shown in Figure 5:

1. **Upwards:** Path leads to more *general information* that annotates a parent concept. This information is more general and not restricted to our specific situation but still valid.
2. **Horizontal:** Path leads to *contextual information* that annotates concepts that are related (directly or indirectly) by contextual relationships (non-hierarchic relationships, especially cross-connections between subgraphs).
3. **Downwards:** Path leads to more *specific information* that annotates a child concept. This information is more specific, but under circumstances not relevant for the initial situation. It makes sense to choose the initial concept already as specific as possible (preferably a leaf concept) or to gradually specify the concept.

A common and very intuitive way to describe relatedness in a graph is based on the distance between two nodes which is basically the number of edges (relations) between them in the shortest path. In this sense, the shorter the path and thus the distance between two nodes, the more related they are. The problem with this approach is the assumption that the edges represent uniform distances within an ontology; i.e. the semantic connections are of equal weight [23]. Furthermore, the perception of similarity between concepts differs regarding the

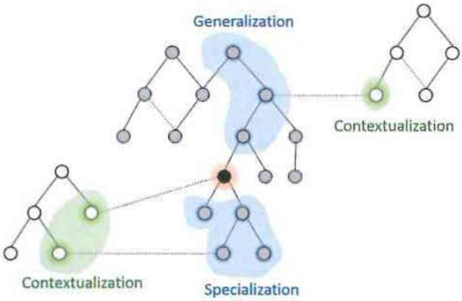


**Fig. 5.** Abstract ontology example highlighting which ontology concepts are of interest when looking for additional and relevant information.

relational directions as well as the types of relation. That means they have different influence on the measure and are often assigned weights to capture their importance.

Regarding hierarchical relations (upwards and downwards) especially path length and depth are of importance to get similarity results that compare to the human perception of similarity [15]. Since concepts located hierarchically deeper in the ontology are more specialized, the distance between those concepts is perceived as shorter than a distance of the same path length between concepts near the root. For instance, the path "Phillips screwdriver PH2 " - "Phillips screwdriver" - "screwdriver" is perceived shorter than the path "screwdriver" - "assembly tools for screws and nuts" - "tools" despite that both paths contain the same number of nodes and edges. Hence, the path depth should be included in the distance calculation. Jiang and Conrath [13] define an edge weighting that uses Resnik's [23] notion of a concept's information content implicitly containing path length and depth. We use this notion to weight upwards and downwards directed paths between two concepts $c_1$ and $c_2$:

$$W(path_H(c_1, c_2)) = |IC(c_1) - IC(c_2)| \tag{1}$$

The information content $IC$ is defined as $IC(c) = -\log_2 p(c)$. The probability $p(c)$ of the occurrence of a concept is calculated by the count of concepts summarized by a parent concept as frequency $freq(c)$ and the count $N$ of all concepts of the ontology with $p(c) = \frac{freq(c)}{N}$ [23]. The probability of a concept's occurrence decreases with hierarchical depth, while the information content increases.

As the information content is calculated according to the hierarchical structure of the ontology, a different weighting approach is needed for the horizontal non-hierarchical relations. Regarding this direction considering the relation type is of even higher importance compared to the upwards and downwards direction [19, 11, 22, 9]. For instance, the path "soldering"-*needs*-"soldering iron" should be ranked higher than the path "soldering"-*is located at*-"work station 3" as a worker knows where he actually is but could need additional information regarding specifics of the tool to use. We therefore adopt the formula by Mazuel and Sabouret [19]. They associate an individual weight $TC_X$ to each relation type $X$ to represent its semantic cost. The weight of a path between two concepts $c_1$ and $c_2$ is defined by:

$$W(path_X(c_1, c_2)) = TC_X \times \frac{|path_X(c_1, c_2)|}{|path_X(c_1, c_2)| + 1} \tag{2}$$

Both formulas only consider a single relationship type. Hence, to calculate the distance to any concept in the ontology the path which might contain mixed relationships has to be broken down into sub-paths with only a single relationship type. The weight of a mixed relationship path is then the sum of the weights of the sub-paths:

$$W(path(x, y)) = \sum\nolimits_{p \in path(x,y)} W(p) \tag{3}$$

In this sense, concepts whose paths to the current work task score a lower path weight (are semantically closer) are assumed to be annotated with more relevant information than concepts scoring a higher path weight. Yet, some path constraints have to be considered to exclude non-relevant concepts that would possibly score a small path weight. While following upwards and downwards directed relationships (such as "is-A", "include") no change of direction should be performed. Other child concepts of the same parent concept (sibling concepts) are negligible for our retrieval even if they measure a short distance to the origin concept from an information theoretical point of view [23, 24]. As these concepts do not relate to the specific situation, considering them is expected to provide no meaningful improvements to our information retrieval. Hence, hierarchical paths are restricted only to direct ancestors or successors.

How this extracted context-relevant information can be represented to support a worker in fulfilling his current work task is discussed in the next section.

## 5 Integrated Presentation

Our application scenario is located within a networked factory. We envision that for assistance the worker or the assembly station is equipped with a tablet that provides him with information on the current assembly order and current process step. An example of such an assistance system is the assembly assistant of the Fraunhofer IGD[1]. We already emphasized the importance of integrating the communication of additional information directly into the work flow, as we found out that users prefer to not switch between different systems. Figure 6 shows a first design of how to integrate the annotations into the user interface of an assistance system.

[1] `https://www.igd.fraunhofer.de/en/Institut/Abteilungen/IDE/Projekte/PlantHand-Assembly-Assistance-Production`


**Fig. 6.** An exemplary design of an assistance system showing multiple steps of an assembly work task on the left and a detailed description of the current step in the center. Annotations for the work task are embedded directly in the center view as sticky notes (see the two red annotations on top of the image) and summarized below. Additional relevant information regarding related concepts (such as reports to the machine and its parts, specifications of tools and materials) is integrated in a virtual clipboard on the right.

The main part of the interface is still dedicated for the current work tasks with the different steps on the left and a detailed representation of the current step in the center. Additional information regarding the task itself is directly embedded in the main view where applicable (see sticky notes on the image) and summarized below. Further information regarding related concepts are listed on the right and are ranked according to our explanation in Section 4.3.

Regarding the support of a worker to fulfill his current work task, horizontal relations to tools and materials are most likely of high interest to him. Yet, connections to person concepts are probably not so interesting for the worker himself (but may be for a planning engineer assigning the different workers). Hence, relationship types are assigned different weights according to their importance (the more important the smaller the weight). As these weights have to be determined relative to the overall information content of the ontology (as used to weight the hierarchical relations), and of the persona to be supported (worker, planning engineer ...) no general recommendations for these weights can be given at this point. Therefore, further investigations are necessary.

Based on these weights, annotations for concepts scoring the lowest path weights are retrieved. As annotations can be assigned to more than a single ontology concept, they can be retrieved more than once with different rankings (corresponding to the rankings of the ontology concepts). Our survey showed that users prefer quality of information over quantity, so recurring occurrences of one and the same annotation are filtered out.

To create new annotations the worker can simply select a concept by clicking in its area (in the center or on the right side) and choosing a type of annotation he wants to add (text, photo, audio ...) which opens a corresponding widget. He can either point in an empty part of a concept if he wants to annotate the concept in general, or he can select for instance a position in a text or image if he wants to annotate a specific part of its description.

## 6 Conclusions

As confirmed in our survey, one of the biggest barriers to knowledge sharing supported by a technical system is the fear that use and maintenance is too cumbersome and especially time-consuming. To address this problem, we presented a concept that integrates the knowledge sharing intuitively into the workflow. We have shown that annotations for human communication are an intuitive and simple means for this purpose and how to support the annotation's re-usability using a domain ontology. For a ranked retrieval of the annotations, we proposed a relatedness measure weighting paths within this ontology.

In future, we want to put our enhanced system in operation and conduct a user study with workers in production. Based on their feedback additional factors regarding the weighting of concepts can be evaluated. One aspect is the novelty of information, for instance the older the information the less important it might be. But also personal feedback may be an important aspect to steer which information will be shown. An assessment of the information rating relationship types in general but also individual annotations (from very helpful to wrong) could be integrated in the ranking of the information. Finally, it will be of importance to address the user's averseness of being monitored.

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