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Context-awareness in industrial applications: definition, classification and use case

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Abstract

Context-awareness is becoming increasingly important as it allows to adapt the functionalities and user interfaces of applications based on environmental conditions or user preferences. While contextual adaption already plays a significant role in areas like mobile consumer applications (B2C market), the industrial domain still lacks a proper discussion. This paper is going to define the term context in the industrial environment and proposes a framework for the classification of the industry-specific context types. Using this framework, the most common contexts are determined, and it is shown how this classification supports the implementation of context-aware systems by discussing a use case.

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Keywords: context-awareness; context-aware computing; context-aware systems; context-aware information retrieval; shop-floor information systems

1. Introduction

With the increasing usage of smart devices and sensors over the last decades [1], the precise registration of changing environmental conditions became possible. This lead to the development of context-aware systems [2,3], in which the behavior of the application is influenced by contexts like the current location or user.

Due to the wide range of scenarios in which context-awareness can provide benefits, the possibilities and advantages of such systems have been investigated extensively for different domains [4,5,6]. As each research area proposes its own requirements, a general definition for context and context-awareness is especially difficult. Based on an analysis of a wide range of definitions, Perera et al. [7] even stated that it is not possible to develop a common definition that completely satisfies the demands of all domains equally, nor to apply one of another research area without modifications.

One area that did not receive much attention so far are context-aware systems in industrial applications due to several reasons like the diversity of data sources [8] or privacy issues [9]. Nevertheless, these applications offer a high potential, as they are able to adapt to changing user requirements that are caused by changing environmental conditions. One example could be a condition monitoring system that automatically notifies the proper maintenance worker based on parameters such as the detected error, the workers' current location, their skills, and their equipment.

The outline of this publication is as follows: Section 2 discusses the most common definitions in the subject area of context-aware computing that are stated in the existing literature surveys [7,10,11,12]. Further, the applicability of these definitions is analyzed for the requirements and challenges of the industrial domain and an adapted definition is introduced. Section 3 starts by analysing the context types that are stated in the literature reviews [13,14,15,16]. The raw data that makes up the context types is diverse, and its gathering and processing require different approaches. Working with data of many sources can be challenging. To resolve this issue, a framework for the classification of industrial context types is proposed that allows to classify these types based on the characteristics of the underlying data. As the retrieval of information and the analysis of historical data are common tasks at the shop-floor, the focus will not only be on the research

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area of context-aware computing, but also on information retrieval and pattern recognition. To support future developers in implementing context-aware systems, section 4 analyses a use case in which the proposed classification is used to identify present contexts. Section 5 finishes with a conclusion summarizing the different aspects and findings of this publication.

2. Context

2.1. Definition of context

Defining context is not a trivial task. As several research areas make use of this term, different definitions tailored to the specific domains have been proposed [4,5,13]. Based on the work of Dey [5], Perera [7] analysed the most common definitions in the domain of context-aware computing and stated that all of them can be divided into three groups:

- **Definition by example:** The term context is defined by providing examples [6,17]. While these definitions might be helpful for novice users, matching new situations can be problematic as it is not possible to state all potential examples.
- **Definition by synonyms:** Hereby the term is defined by its synonyms [18,19]. Like with examples, this can be helpful for new users but also be problematic in case of unseen situations.
- **Definition by aspects:** These definitions describe context by its aspects like who, where, and with whom the user currently is [20,21]. The advantage of this approach is that new situations can be included or excluded depending whether they satisfy the stated aspects.

In general, we acknowledge the definitions by aspects to be the most useful for industrial applications. Due to the diversity of shop-floor environments, the definition by example or by synonyms are not favorable as they would lead to discussions whether a specific circumstance can be considered as context or not.

As stated by [7,13], the generally accepted definition proposed by Dey [5] describes context as "*any information that can be used to characterize the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves*". We also consider the definition of Bazire and Brézillon [4] "*a set of circumstances that frames an event or an object*" and of Dey et al. [6] "*any information that characterizes a situation related to the interaction between users, applications, and the surrounding environment*" as useful.

2.2. Context in industrial environments

After comparing the different definitions, we consider the one of Dey [5] as best fitting for the industrial domain. Nevertheless, we propose two slight changes to improve its applicability.

First, not only the situation of an entity but also the entity itself including its characteristics are important for context-aware shop-floor applications. If we consider a globally deployed information provision system operating in different countries with different languages, a context-aware system would need to automatically adapt its user interface to the native language spoken by its user. Therefore, the workers' language skills can be considered as context even though they do not characterize the situation of an entity but instead the entity itself.

Secondly, we highlight the distinction between material objects (like a part or machine) and immaterial states (like 10am or failure). While the definition of Dey [5] only states objects, we consider immaterial contexts as even more important for industrial applications especially since the first context-aware systems in the industrial domain have been condition monitoring systems. Therefore, we feel the need to highlight this context class in our definition.

With these adaptions in mind, we propose the following, modified definition: *Context is any information that can be used to characterize an entity, its condition, or its surrounding situation, if the information is considered relevant to the interaction between a user and an application. An entity can be a person, place, material object or immaterial state, including the user and the application themselves.*

3. Context types

3.1. Classification of context types

Several researchers have identified and classified the different context types based on their perspective [22,23,24]. One of the most popular classification was proposed by Dey [5], separating contexts in primary and secondary types. He stated that with the primary contexts time, identity, location, and activity it is possible to fully capture any given situation. Furthermore, he highlighted that all other contexts are secondary and can be derived from the primary ones.

While we agree with the importance of the primary contexts, we do not consider this classification useful. One contradictory example are machine conditions, such as the temperature of a machine, which would be considered secondary even though they cannot be derived from any of the stated primary contexts. This shows that the distinction between more and less important contexts is not always possible as it highly depends on the use case. Considering the information provision at the shop-floor, it can easily be shown how the importance of a context depends on the current situation. Let us therefore first consider a worker inspecting a product drawing on his smart device. In this case, the device and its screen size are of importance to the user as using a screen below a certain threshold complicates the information intake massively. If the same worker must navigate to a certain location, the screen size is not as important, since most smart devices are able to provide navigation in an adequate format. If we consider a situation in which the worker records his working hours using a chip card, the device will not even be considered as it will not be part of the interaction.

To resolve this issue, we prefer the classification of Chen and Kotz [23] dividing contexts into active and passive groups. Active contexts are all contexts that are needed to identify the current entity and its conditions. Passive contexts are all other contexts. As stated, only the current situation is relevant for the classification so that in the same use case a context can be active and passive, depending on the current situation. This concept can be demonstrated by considering a context-aware information system. If the system intents to provide only the maintenance team with an error notification, the users' roles are important and represent an active context. If the system provides all users with a general information, their roles are not of interest and therefore represent a passive context.

3.2. Context classification framework

In the following, we propose a framework for the classification of contexts types in industrial applications. The framework lists the context types and highlights the characteristics of the underlying data. It compares the different aspects of contextual data and identifies similarities. To help readers to get an overview of this complex topic, the following paragraphs provide a description of the different aspects the framework addresses. Additionally, table 1 provides a summary in tabular form.

- **Contextual category:** Categories are high-level clusters of contextual types and can be seen as reference to the aspect the contexts are focused on. For example, the widely used category "user" clusters all contexts related to a user such as his/her personal information, location, or tasks.
- **Context type:** As categories are too vague to be applied usefully, context types cluster contexts in groups with related properties like the data source or base type. Having a reasonable level of abstraction, they are used most commonly for defining and analyzing context-aware systems. An example would be the location that covers the user's position, but also his orientation, movement, or viewing direction.
- **Data source:** This category specifies the origin of the contexts. Possible options are internal system occurrences (internal), external inputs by a user or other system (external), or sensors-based measurements (sensor).
- **Base type:** The base type characterizes whether the contexts originate from physical or virtual entities. In most cases the data collected from physical entities (physical) requires sensing and processing or a manual input. Originating from virtual sources (virtual), the data is mostly in the correct format for further processing. A clear separation is not possible for all contexts types. In that case, the particular contexts must be classified individually (dependent). Considering server-related contexts, the computing power can be derived from the physical hardware, whereas the current workload is only virtually measurable.
- **Durability:** The durability describes if the contexts are exposed to change. In case of static contexts (static, e.g. name), variations are impossible or very unlikely. In contrast, dynamic contexts (dynamic) change over time. Thereby, the durability only describes if variations are possible, but not their frequency or velocity. If we consider a condition monitoring system, most of the time the observed machine is working regularly, but sudden changes are possible. Therefore, the machine's durability must be seen as dynamic, even if there has not been a change in years. The same as for the base type, it is not possible for all context types to specify this characteristic (dependent). For instance, in case of the location, resting entities (e.g. machines) are defined by a static context while moving entities (e.g. products) are described by a dynamic context.
- **Change:** In case of dynamic contexts, this category describes if context types change instantly (instantly) or over time (continuously). Again, it is not possible for all types to make such a strict division (dependent). If we consider physical conditions, visual stimulations can change continuously and discretely. For static contexts, it is not useful to make this differentiation.
- **Usage:** Based on the review of a wide range of context-aware applications, the usage states how likely it is that a context-aware system uses a context type. The likelihood is stated in the three levels: high – medium – low.

While the framework covers the most important aspects of contexts in the industrial domain, it is not possible to provide a complete list due to the diversity of shop-floor environments. Therefore, we encourage future users to extend or adapt the classification framework depending on their specific needs.

3.3. Industrial application specific categories

In general, the contexts can be divided into core contexts and domain-specific contexts. While core contexts are common in most context-aware applications, domain specific contexts appear mainly in specific environments. In the following we are going to introduce the three core categories user, environment, and system. Additionally, we look at the two domain specific categories information retrieval and pattern recognition as these contexts are common in industrial applications.

- **User:** This category clusters all contexts related to the users of the context-aware system. As in most cases each user is an independent entity, each one requires a separate context model. The degree of overlapping between the models strongly depends on the context. While some contexts are identical for larger groups (e.g. role), others are mostly unique (e.g. name, date of birth).
- **Environment:** The environmental category clusters all contexts that surround the user.
- **System:** This category summarizes all contexts related to the usage of the system. Therefore, they mainly appear when the system is used actively.

Table 1. Contexts classification

Contextual category	Context type	Data source	Base type	Durability	Change	Usage
User	Personal information	External	Physical	Static	-	High
	Personal condition	Sensor	Physical	Dynamic	Continuously	Low
	Location	Sensor	Physical	Dynamic	Continuously	High
	Task	External	Virtual	Dynamic	Instantly	High
Environment	Date & time	Internal	Virtual	Dynamic	Continuously	High
	Resource	External	Physical	Dependent	Continuously	Medium
	Resource condition	Sensor	Physical	Dynamic	Dependent	Medium
	Physical condition	Sensor	Physical	Dynamic	Dependent	Medium
System	Software	Internal	Virtual	Dependent	Instantly	Low
	Device	Internal & External	Dependent	Dependent	Dependent	Low
	Network	Internal	Dependent	Dependent	Dependent	Low
	Server	Internal	Dependent	Dependent	Dependent	Low
Information retrieval	Content	Internal	Virtual	Dynamic	Instantly	Medium
	Search	Internal	Virtual	Dynamic	Instantly	Medium
Pattern recognition	Historical data	Internal	Virtual	Static	-	Medium
	Pattern	Internal	Virtual	Dynamic	Instantly	Medium

- **Information retrieval:** This domain specific category clusters all contexts related to the information provision. This includes all contexts arising from the workers information needs and the approaches to fulfill them.
- **Pattern recognition:** This category summarizes all contexts that are based on past data or the information that can be extracted

Even though we discussed the most important contextual categories for industrial applications, it is not feasible to provide a complete list due to the vast amount of possible special situations. The same as for the classification framework, we encourage future users to expand the domain-specific contexts.

3.4. Industrial application specific context types

Even though the classification approaches are vast, most of them only provide a high-level perspective or are focused on specific categories [7]. In the following, a deepened description of the different context types, their characteristics, and common examples is provided.

- **Personal information:** As one of the most used context type, it characterizes the user. This includes elements like the name, age, date of birth, nationality, language skills, or habits. Besides, the user's position and role in the company are of high importance for context-aware information provision systems as different user groups require different information.
- **Personal condition:** While the personal information represents static content, this type covers all contexts related to the physical condition of the user. This can include his/her heart rate or stress level.
- **Location:** Together with the personal information, the location is one of most used context type as it has the advantages of being easily obtainable and providing a lot of information. In addition to the current position, this type includes contexts like the orientation, movement, or viewing direction of the user.
- **Task:** This type includes the users work tasks. Further it includes the user's agenda covering the past and future activities.
- **Date & time:** This type normally includes periods and events like daytimes, weekdays, or calendar entries. They are of high importance in industrial applications as most activities are linked to specific dates or times.
- **Resource:** The work space resources summarize all physical, non-human entities that are present on the shop-floor and relevant for the user. This typically includes machines, tools, products, or other inventory used in the production, assembly, or maintenance.
- **Resource condition:** Related to the resources this type classifies their conditions. Examples are machine states like working or faulty, or product states like in progress or finished.
- **Physical condition:** Physical conditions include all conditions that are imposed by the environment excluding the resource conditions. The temperature, lightening, or humidity level are commonly used examples.
- **Software:** Describing an internal data source this type summarizes all contexts that are related to the software of the context-aware system. Among others this includes its scope, functionalities, and usability.
- **Device:** This type includes all device-related contexts like the screen size, computing power, or battery lifetime. As the information, which can be presented, strongly depends on the used device, this category is of high importance for information provision systems.
- **Network:** The network includes contexts like its capacity, connectivity, or bandwidth. While in most publications,

these contexts are considered as basic prerequisite rather that as input, we want to highlight their usefulness. As an example, let us consider a system with a varying bandwidth trying to transmit larger files. In case of a slow connection it might be useful to reduce the information to a smaller format than trying to transmit the larger file.

- **Server:** This type includes contexts like the processors, computing power, or availability. As with network types, most systems rather see them as prerequisite than as usable context information.
- **Content:** The content type is specific to information retrieval tasks and refers to all contexts related to the searchable data. Depending on the information need, this commonly includes the data type or search categories.
- **Search:** Building a key aspect of information retrieval, this type covers all contexts that are not related to the content itself, nor to other contexts like location or personal information. This normally includes aspects like verbal search versus keyboard search.
- **Historical data:** Strictly speaking this type does not represent distinctive contexts but rather it includes the historical contexts of the types stated above. Historical contexts have high value as they offer the possibility to gain new insights using machine learning algorithms.
- **Pattern:** The most recently introduced context type are patterns as they require mature machine learning algorithms and high computational power. This type covers all contexts that arise from identified patterns or events with importance to the user. An example would be a system triggering a warning if a resource condition exceeds a certain threshold.

4. Use Case

To validate the accuracy and completeness of the proposed framework and the derived classification, we are going to consider a use case. By doing so, we will give a short introduction, show that contexts are an inherent part of most activities and demonstrate how they can be used to support the user.

The Spanish company Thermolympic S.L. is a tier one supplier of injection molding parts for the automotive industry. The production is automated to a high degree, but workers are still responsible for setting up the machines, performing visual quality controls on each part and preparing the parts for dispatch. As partner in the EU H2020 research project FACTS4WORKERS, the company is upgrading its software systems by - among other things - implementing a context-aware information provision system assisting the shop-floor workers in their daily tasks. As the system is going to be aligned to existing workflows, this use case shows a brown-field solution in which the company-specific characteristics must be considered.

Workers on the shop-floor can be separated into three groups: operators, team leaders, and quality managers. Operators build the main workforce and are responsible for visual control inspections. Additionally, they prepare the parts for dispatch according to the customer specifications. For these tasks, they need to be supplied with visual and written descriptions of the products including the characteristics and common errors.

Team leaders are the operators' supervisors. They are responsible for supplying the machines with the correct raw material, setting up the machine by adjusting the machine parameters and performing maintenance and repair activities. Team leaders need to be aware of the currently produced products including their raw materials. Additionally, they need extensive information about the machines.

The quality managers are responsible for performing extended quality controls. They need to be supplied with the quality information of the operators and additional data like the product dimensions and tolerances.

A context-aware system is deployed to automatically provide the workers with the needed information. Based on the current situation, the required data will be identified by using the following context types:

- **Resources:** The available machine park defines which products can be produced and which maintenance activities must be performed.
- **Task:** The task assignment specifies which machines are producing which parts.
- **Personal information:** The role of the user defines the activities he/she has to perform and therefore which information is needed.
- **Location:** The specific information about the different machines and parts can be derived from the worker's location. If he/she is close to a predefined location, the related data is provided. This allows the workers to easily switch between different machines or help colleagues if needed.
- **Physical condition:** As the injection molding process is temperature and humidity dependent, changes of these parameters require changes of the machine settings.
- **Search:** The search can be personalized by allowing the user to select from different search categories. Additionally, other context types like the user's role or location can be used to specify the results.

For example, an operator (*personal information*) at a machine (*location*) is mainly responsible for performing visual quality checks (*task*). Therefore, information about the part characteristics and possible errors are provided. As one worker can be responsible for different machines or can help a co-worker, going to a different machine (*location, task*) results in the adaption of the displayed information. After production, the operator also packages the parts for dispatch (*task*). The system automatically provides the required instructions on entering the packaging area (*location*).

If the team leader (*personal information*) is in the warehouse (*location*), he/she needs information regarding the raw materials of the produced parts (*task*). The system displays the needed data based on the identified contexts. As the injection molding process is temperature and humidity dependent (*physical conditions*), the team leader must react on changing conditions by adapting the machine parameters (*resource*). During the production start of a new product, the team leader must also set up the production place and adjust the machine parameters (*task, resource, location*). As the team leader can decide on his/her own, which activity he/she wants to do first, it is not possible for the context-aware system to precisely identify the needed information. Therefore, the system provides an easy-to-use user interface to select the required information.

The quality manager (*personal information*) is responsible for performing detailed quality controls on random sample (*task*). He/she will be supplied with the required part dimensions by arriving at a machine (*location*).

Independent from the user, the search results (*search*) are specified by defining search categories, and by taking the users location (*location*) and the currently produced parts (*task*) into consideration.

Due to the high number of tasks, contexts and information available it is not possible to review the whole use case. The stated examples should rather provide an insight about how the contexts can be identified, classified, and how they influence the information provision. Further it can be seen that not all contexts are equally important, and neither are all used in each situation.

5. Conclusion

Context-aware systems have gained a lot of attention over the last decade due to the extended personalization possibilities they offer. They can identify current situations and act accordingly. One domain that can benefit significantly from this development are industrial applications due to reasons like the predictability of the work situations or the vast ability of sensors.

With the proposed framework and the derived classification of industrial contexts future system designer and developer have the toolkit to easily identify complex situations and implement systems that can act upon. Rather than starting from scratch, developers now have the possibility to build their systems upon the stated contexts.

As seen at the use cases, not all context classes and contexts are equally important for industrial applications. Whether a context is currently or generally needed strongly depends on the application. Thereby, an important issue is to not disregard any contexts as they might play a crucial role in another situation.

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