A Context-Aware Assistance System for Maintenance Applications in Smart Factories based on Augmented Reality and Indoor Localization

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Abstract—**The term Industrie 4.0 carries the vision of smart factories, which automatically adapt to changes and assist the human as much as possible during operation and maintenance. This includes smart human machine interfaces, which reduce the chances of errors and help to make the right decisions. This paper presents an approach to equip the maintenance software running on a tablet PC with augmented reality functionality to be able to place virtual sticky notes at production modules. Additionally, these sticky notes are enriched with position information. The central element of this approach is an ontology-based context-aware framework, which aggregates and processes data from different sources. As a result, a tablet PC application was implemented which allows displaying maintenance information as well as live plant process data in the form of augmented reality. More than 100 of those sticky notes can be placed using this system, whereas each note requires a file size of 12 to 16 kilo bytes. After placing a sticky note, the system recognizes it even if the camera's position is not exactly the same as during the placing process.**

I. Introduction

The federal government of Germany defines the intelligent factory (= Smart Factory) as the vision of Industrie 4.0 comprising the fields of action versatility, resource efficiency and ergonomics / usability. In that case, the human should be supported to fully understand and control the complete production plant even if the complexity of production is increased. His skills should be extended by technical assistance systems in order to evolve from pure operator to controller, regulator, and designer [1].

The increasing complexity has a major influence on maintenance personnel. For them, there are increasing difficulties to execute maintenance tasks because they require the right data at the right time.

In order to assist during maintenance tasks, several augmented reality based approaches have been proposed [2], [3], [4], [5]. Augmented reality (AR) approaches are using digital or computer generated information and overlaying them in a real-time environment [6]. The approaches are mainly composed of three parts, a knowledge base as the intelligence of the system, a user interface, and an augmented reality module. The idea is that these systems show workers how to execute particular maintenance steps. Therefore, workers have to use head-mounted displays [2], [3], [5], mobile devices like smart phones [5], or small cameras in combination with laptops [4].

Several approaches have in common that the knowledge base is created and authored offline by the developer [2], [4]. Therefore, models of the augmented parts have to be created in advance, which causes some complex engineering effort. The approach described in [3] is based on an offline authoring, but supports some revisions by the user of the augmented reality system.

For maintenance assistance within complex production plants there are several limitations, which have to be considered. As a central issue, current systems are focusing on static information such as textual information, which is provided to the user by the AR system. Dynamic information like real-time data from sensors cannot be shown. However, especially this data is helpful for maintenance personnel to get production plants working.

Within production plants, often multiple production modules of same type are used. Since these modules can be based on a different internal configuration, maintenance tasks are specific for the particular instance. Common augmented reality based approaches cannot be applied here, because they cannot distinguish between objects of the same look.

In previous work, a smart assistive system has been developed [7], [8]. The proposed architecture is based on a modular and service oriented paradigm that aggregates relevant data from different sources, like PLC data via OPC UA, or person's position via a camera-based localization system. As a case study, a maintenance app for tablet PCs was implemented. After logging on to the app, a map of the plant is shown. If the maintenance employee moves in front of a machine, the system shows all relevant process data elements for that machine. The set of relevant information is dynamically generated by querying the contextual knowledge-base and applying reasoning techniques. So far, augmented reality based applications are not part of this approach.

This paper presents an approach that is based on virtual sticky notes, which can be used for information exchange within an augmented reality environment. These virtual sticky notes represent static maintenance information, dynamic maintenance information and recurring maintenance tasks. As an user interface, mobile devices such as tablet PCs or smart phones are used. These are integrated into a platform for context-sensitive services, which supports access to real-time production data and indoor localization.

This paper is organized as follows: section II briefly introduces the relevant technologies. In section III, the concept for the augmented reality based assistance system is presented in detail. Section IV describes a case study. Section V presents the results of this work. Finally, section V concludes this paper.

II. Basic Technologies

A. Augmented reality

Augmented reality means to take digital information such as audio, video, touch or haptic sensations and to overlay them over in a real-time environment [6]. Most commonly, the signal of a digital camera is used, allowing the user to see the real world equipped with virtual objects. Since the computing performance of mobile devices such as smart phones and tablet PCs has increased significantly over the past years, augmented reality is more and more used on those devices. To develop augmented reality applications, a variety of software development toolkits is available. A comparison of such SDKs can be found in [9]. Since the application is meant to be used in a production environment, much emphasis is placed on the stability of the tracking process. The Metaio SDK [10] does not only rely on image processing, but also evaluates the state of the device's acceleration sensors to improve the stability.

B. Indoor Localization

Since AR is based on image processing, two components of same type cannot be distinguished. Indoor localization can be used to solve this task. In [11] a survey about indoor localization technologies is given.

C. Context-Aware System

The definition of context-aware systems proposed by Abowd et al. is commonly accepted and will be adopted in this work [12]:

> *"A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task."*

A service provides relevant information, like PLC data and localization to the user. To enrich the sensed data with semantics and to provide it in a machine processable form, a context model is needed [13]. This model formally describes concepts and relations between real world objects and sensed context data. By the use of an ontology-based model, most of the requirements explored by [14] are fulfilled.

A context reasoner sends queries to deduce more meaningful knowledge from the context model. For example, raw sensed coordinates from the localization systems can be inferred to an assembly group on top of the relations defined in the context model.

D. Communication

To provide access to the machine's process data, OPC UA is used. OPC UA is a platform-independent communication standard, which is based on the client-server model [15]. The data is represented by nodes in the address space of an OPC UA server. OPC UA offers a variety of features, like Subscription, which allows the client to monitor a node and to be notified in case of a value change. Furthermore, security plays an important role, which offers sign and encryption functionality. Because of these and more features, OPC UA is increasingly used in industrial applications.

III. Context-Aware Software Framework

Allowing users to dynamically place and attach digital information within augmented reality based environments is a well-known concept [16]. The idea is to support communication and information exchange via virtual sticky notes.

The approach presented in [17] is based on virtual sticky notes and supports maintenance personnel to place site-specific annotations with semantic and machine processable content for documentation of services as a location based service. The approach in [17] mainly focuses on semantics. Neither AR nor connection to PLCs are supported.

A. AR based Approach

This AR based approach uses sticky notes as a platform for communication between workers within smart factories. These notes can be attached to components without predefined markers nor predefined tracking samples, eliminating the need of setting up the AR system. The attachments can be placed anywhere.

Figure 1 shows the architecture of the context aware system. Plant data and localization information are sensed and provided to the context aware assistive system. Both are stored in a knowledge base. A context interpreter deduces higher level knowledge from the raw sensed information. This higher level knowledge is sent to the context provider, which offers the information to applications.

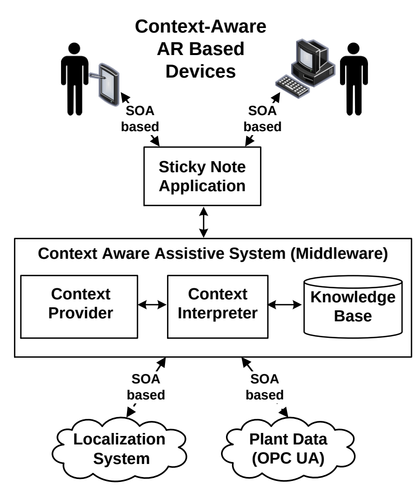

Fig. 1. System Architecture of Context Aware System

When a sticky note is created by a user, a text can be left on it or the sticky note can be mapped to a specific information resource. Such mapping to resources offers the opportunity to combine different information resources in a single location. Figure 2 illustrates this combination of information resources. Apart from the information container there are several context information (namely: identity, timestamp, location, user groups) which are sensed and need to be modeled to enable deducing knowledge. The information container comprises three different types of virtual sticky notes, which are described as follows:

- ***Static:*** Static information represent information which usually does not vary, for example reminder messages, component documentation and manuals. These differ in subtypes like audio, image, video, text et cetera. When creating static information, a relation between the sticky note and the static resource can be drawn. The sticky note then refers to this specific resource.
- ***Recurring:*** In addition to static information, recurring information has a periodical attribute. For the purpose of cyclic maintenance tasks, which occur periodically, such an information type can be defined and attached to the relevant component.
- ***Dynamic:*** Dynamic information refers to PLC data, which represent physical or logical values of the related components. When creating dynamic information, the user has to draw a relationship between the sticky note and the OPC variable which is representing the physical or logical value of the related component.

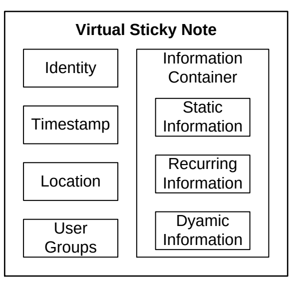

Fig. 2. Virtual Sticky Note Information Types

B. Communication Infrastructure

On field level, a PLC is used to control the process and to manage the process data. Communication between OPC UA and the PLC is established, which allows clients to read process data. Since OPC UA is an increasingly used standard, more and more PLC producers offer suitable OPC UA servers respectively to their products.

C. Indoor-Localization

The sticky notes are tagged with position information. This is necessary, to distinguish similar looking sticky notes in different locations. Furthermore, this has the advantage to be able to show at which modules of a production plant sticky notes are placed. Therefore, the position of the tablet PC must be known. As described in [7], a camera-based localization system serves this purpose. It can recognize objects in the room. By correlating the acceleration of these objects with the tablet PC's acceleration sensors, the position of the tablet PC is determined. The camera based localization system provides the 2D position information, i. e. the X and Y coordinates in the room. These coordinates are then mapped into the context model.

IV. Case Study

The case study described in this section takes place in a Smart Factory called "Lemgoer Modellfabrik" (LMF) [18]. The LMF represents a plant for storing, transporting, processing and packing bulk material. It has a modular design, i.e. it consists of eight process modules, namely: a storage system, some transportation systems, a weighing station, a bottle filling mechanism, a production facility, a product packing system, a bearing robot, and a lid robot.

This work uses Android-based tablet PCs and desktop-PCs as end user devices with connectivity to the backend infrastructure. These devices are used to manage the maintenance tasks in the LMF. An app is implemented on each tablet PC, it enables the interaction with virtual sticky notes including reading, writing and modifying them. The HTML-based interface on the desktop-PCs is used to control and monitor maintenance tasks and can be used from any browser compatible devices.

The LMF is equipped with a Wi-Fi network, in which the end user devices act as clients communicating with a Linux Server. This server is responsible to provide data to clients and inform them about changes with the aid of a socket, developed in Node.js. Due to possible connectivity issues in harsh environments, the system provides an event-based online and offline data management. Automatically sensed context information provided by the context provider can be set manually.

V. Results

The following section describes the results. As shown in Fig. 3, a user is able to create a virtual sticky note which is described in section III.C, and attach it to a component. Therefore, a tracking is needed to learn the environment, in which the sticky note has to be attached. This tracking can be done within a camera view during the runtime of the app.

In this case, one information container has the type of a recurring information (Inspect) and the other one of a dynamic information (346 °C). Once a recurring information is created, it appears on-again in a user defined period. This period can be reset manually when the task described with this sticky note is finished. The dynamic information represents the temperature from the heater seen in the picture. More detailed information can be obtained by touching the sticky note. Authorized user groups receive the information on their desktop-PCs and their tablet PCs. As this attachment contains information respective to the location, authorized users know where this attachment can be found.

This section presents some measurements, which were conducted with a Samsung Galaxy Tab S and a Samsung Nexus 10. The distance when an AR object gets detected is

Fig. 3. Augmented Reality App

measured from a reference line, which represents the distance from where the AR sticky note was created. This distance is fluctuating in several measurements between *584 mm* to *750 mm* from the reference line and depends on factors as light level, back- and foreground and the used camera.

On both tablets more than 100 sticky notes were created without leaking resources. The file size per sticky note differs from *12 KB* to *16 KB* and depends on the environment.

An initialization has do be done once while starting the app to draw relationships between tracking files and coordinate systems of the camera and sticky notes in the scene. This initialization takes *3.18 seconds* on the Samsung Galaxy Tab S and *5.41 seconds* on the Samsung Nexus 10 with more than 100 sticky notes.

VI. CONCLUSIONS

The paper presented an augmented reality application built upon a context-aware system, which provides a communication platform for maintenance workers. It enables attaching virtual sticky notes, representing digital information to components within a smart factory. Besides textual information, these sticky notes are able to refer to different information resources like plant process data, manuals, audio, video and so on. The approach supports information resources to be reviewed by selecting the sticky note. Similar looking components can be distinguished by utilizing localization information. Further, there is no need to configure the AR system, since it is learning the environment by using object recognition during runtime.

The results show that a fairly large amount of sticky notes can be placed without affecting the stability of the tracking process, while requiring little storage space. Furthermore, the object recognition is stable even if the postion differs from the original point of view.

As a further work, a maintenance coordinator could make use of the desktop interface, for the purpose of planning maintenance tasks. In contrary to the maintenance scenario described in section 4 this interface would allow attaching augmented reality objects to a model representing a plant. Other clients with mobile devices would be informed respective to this attachment.

While finishing a task related to a sticky note, a history log could be extended by maintenance personnel, so that a history log can be shared related to its components location.

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