A Flexible Context-Aware Assistance System for Industrial Applications Using Camera based Localization

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***Abstract*—Within a manufacturing system, a smart human-machine interface reduces the chances of human error and helps users to make informed decisions, especially in critical situations. This paper presents a concept for a flexible context specific assistance system for industrial applications using camera based localization. As a central element, a modular and service oriented context aware system aggregates relevant data from different sources. An object recognition service applies image analysis techniques on a video stream, captured from a top mounted multi-camera system to detect a person's location and associate it with a mobile device. A semantically enriched OPC UA server provides access to process data, and a web-service provides connection to a user interface hosted on a tablet PC. A case study provides an application of the proposed solution for the maintenance support and indoor navigation is implemented as a proof of concept.**

I. Introduction

Optical positioning systems are increasingly used in a wide field of applications, thanks to an increase in the data transmission rates and computational capabilities as well as profound development of algorithms in the image processing domain [1]. Normally, two approaches exist when using cameras as sensors; to locate moving objects in images captured by one or several static cameras (used in this paper), or to estimate the position and orientation of a moving camera itself [2]. Furthermore, with the developments in the Information and Communication Technologies (ICT), the functionality of factory monitoring systems have also evolved to more smarter Human Machine Interfaces (HMI). Traditionally, such HMIs are developed at design time and are not able of adaption at run time [3], [4]. In the future, topics like Internet of Things and Industry 4.0 require more flexibility, also there will be a need for mobile context-aware localization based HMI solutions [5], [6].

The main challenge for a vision-based positioning system is to correlate a detected user with an active mobile device (that hosts a HMI) within the automation system. Another challenge is to aggregate data from different sources and draw situational relevance to make contextual presentation decisions. This paper presents a concept for a flexible context-aware assistance system for industrial applications using a novel camera based localization. For the proof of concept, a case-study for a diagnosis and indoor navigation related use-case is implemented.

This paper is organized as follows: section II introduces the camera based localization system. In section III, the context aware framework is presented in detail. Section IV describes a case study based on an exemplary application. Finally, section V concludes this paper.

II. Camera Based Localization System

The ability to navigate persons and devices in indoor environments has become increasingly important for a rising number of industrial applications, a comprehensive survey of indoor positioning technologies is given in [7]. Low cost, extensibility and adaptability are some advantages for the provision of camera-based localization-context. In this section a novel camera based approach is described, which uses video analysis and image processing techniques to identify the physical location and trajectory of a person with a tablet in the Lemgo Smart Factory (LMF) [8]. 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.

Figure 1 describes the setup of camera based localization system in LMF, which is based on three cameras. To minimize

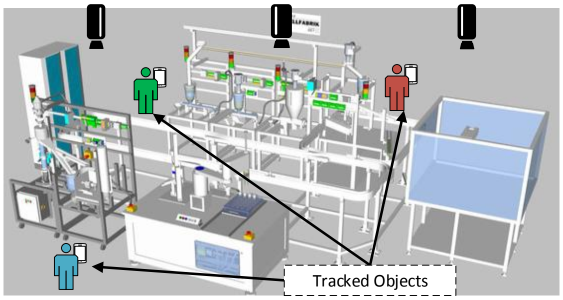

Fig. 1. Camera Based Localization System in Lemgo Smart Factory (LMF)

the cost of sensors, especially for large areas where multiple sensors are required, simple sensors like low resolution color cameras have been chosen. To reduce the number of required sensors as much as possible, the area of acquisition of each sensor had to be maximized. To achieve this, fish-eye lenses with a viewing angle of 170° have been used for all three cameras, which have been mounted to the ceiling, looking straight down to the floor. With this setup, each camera can cover an area of up to $6m \times 6m$. The area needed to be covered in the LMF is approximately $55m^2$. Besides the wide area of acquisition, a top mounted setup has the advantages of minimizing overlaps between persons and improved tracking quality compared to systems which use a side view.

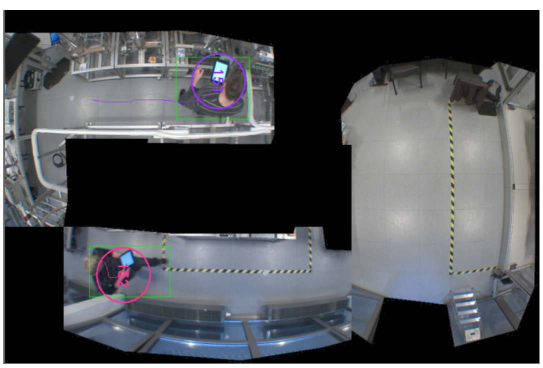

Fig. 2. Results from Camera Based Localization System

A major challenge is the combination of multiple camera views. Due to the fish-eye lenses, the views are highly distorted and cannot easily be calibrated. A manual transformation of each view into a common coordinate system provides a stitched overview of all views as depicted in figure 2. The detection of persons within the coherent view is accomplished by a statistical modeling of the background. By analyzing differences between the background and the dynamic foreground in current frames, potential candidates can be identified. Secondary properties, like movement or size, are used in addition to estimate the likelihood of candidates representing a person. Candidates with low confidence are eliminated to avoid false positives [9].

The visual tracking system provides continuous motion data for each person along with their position at the factory floor. To be able to link a recognized object to a user, this motion data is correlated with the accelerometers from tablets to assign tablets to person tracks and therefore predict the location of the tablets. As the motion data from tablets cannot only be explained by a walking person but also by movement of just the tablet, the correlation observes all motion data from tablets and visual tracker continuously, waiting to identify combinations that allow to update the assignment of tablets to tracks. Figure 3 shows the magnitudes of both the sensor data from the tablet (in red) and the person tracker (in blue) for an example implementation. Here magnitude represents the fluctuation between steady and moving states over time. Due to the various ways a tablet can be carried, it is unlikely that sensor data on tablet and tracker can be correlated based on a trajectory alone. The rest phases, when a person stands still, are more helpful to get a correlation, because different phases of activity and inactivity can be detected reliably. While all persons can stand still at certain times, a rather long window of one minute is used to correlate tablet and tracker data. The data in this window creates a fingerprint that allows to differentiate between different persons and tablets.

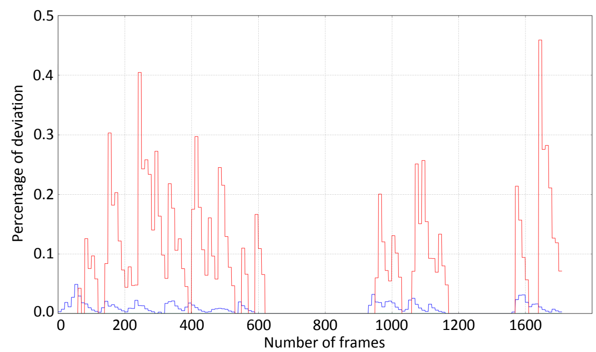

Fig. 3. Correlation between sensor data of a tablet and the tracking data of the person carrying that tablet.

III. Context Aware Software Framework

In the new generation of automation systems, due to the rising complexities of technical processes and the large amount of underlying data, plant employees need more sophisticated and useful HMIs that should be context aware [10], where a context will represent 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 [11]. Normally, for plant monitoring and maintenance systems a HMI is created by integrators and developers at design time, which does not support on-line adaptation according to a user's context.

Over the years, many frameworks (including web-based technologies) for context-based applications have been evolved [6]. In this work a service oriented architecture based flexible approach is used, which supports user-context centric adaptation of HMIs. Here, the primary context is the user's physical environment (e.g. location, orientation) and the secondary context is his role (e.g. operator, maintenance).

Figure 4 shows a generic framework for context aware assistive systems, it is comprised of several components that include:

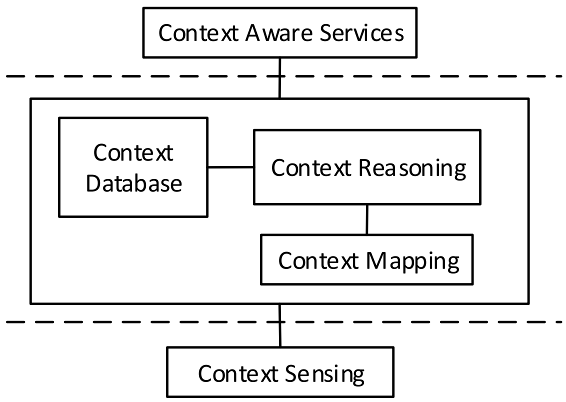

Fig. 4. Generic Framework of Context Aware Assistive System

- ***Context Sensing:*** this component is used to learn the contextual information from the surrounding about a user or any entity. In this work, a camera-based localization is used to sense the primary context.
- ***Context Mapping:*** this component is responsible for mapping the contextual information in an appropriate format so that it can be shared or reused by other components.
- ***Context Reasoning:*** this component provides a decision making mechanism. It interprets the localization information associated with an object in the system; it queries a database accordingly and uses inference rules to generate a set of relevant information.
- ***Context Database:*** a knowledge-base that stores rules, logical expressions and the historical information. One approach to structure this database could be to define an OPC UA-based information model including ontologies for the given automation system. The main challenge that needed to be addressed is how our knowledge-base can be enriched with necessary spatial and role-based relevancies to data elements coming from various sources [12]. Furthermore, data-mining approaches could also be used to learn such an information model using historical data, by means of data analysis to identify hidden patterns in the parameters that control manufacturing processes.
- ***Context Aware Service:*** this component is responsible for providing the services to the user. It incorporates information about the current location of a mobile user to provide more relevant services to him. For example, a user is allowed to interact with the automation plant for maintenance reasons, so a role-specific GUI service is relevant for him. He might also need to navigate his way using a floor plan service according to his localization context.

An ontology-based approach offers a way of incorporating structured syntactic and semantic knowledge into a context-aware application [12]. This work uses ontology-based reasoning for asserting relevancies and/or relationships among different system entities. Figure 5 shows an example of the ontology-based approach for modelling a context for the case study described in the next section, which identifies two application scenarios that are implemented for a proof of concept.

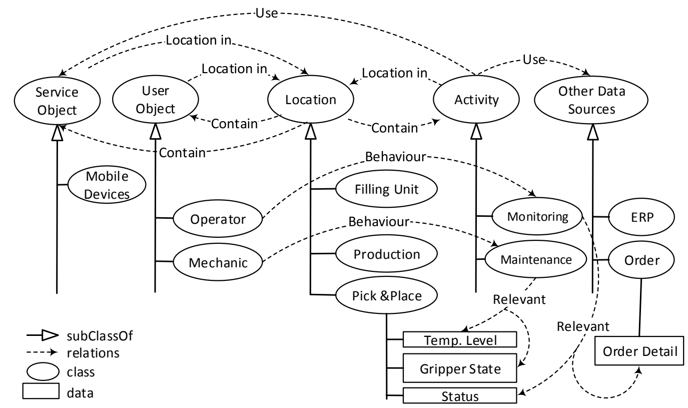

Fig. 5. Example of Ontology-based Approach for Modelling Context.

IV. Case Study

The environment for the given case study is described in section II. The LMF is equipped with a high-performance Wi-Fi network. This work uses Android-based tablets as end user devices with connectivity to the backed infrastructure. These tablets are used to assist the maintenance procedures for the LMF. An Android HMI app was implemented and installed on each tablet. This app provides user access to the implemented context aware HMI. A MySQL-database with spatial extensions is used to store the indoor geographical dimensions of the LMF (a virtual map). In addition, it stores spatially marked machine locations on that map. Spatial relationship of different system elements can be generated and spatial queries, to determine the distance of an object to a module or if two objects intersect, can be performed. The OPC UA based knowledge-base provides access to the process data together with needed meta-data. A PHP based scripting language is used to do the necessary processing for context determination and to generate a user specific GUI.

In the LMF like other plants, there are three levels of maintenance services. The first tier is machine operators and mechanics who are responsible for keeping it functional. Both user groups contribute in the early stage of fault detection and its resolution. In case of a malfunction that cannot be resolved by tier one, a tier two service technician who has more deeper technical knowledge about the relevant machine will be called. If they cannot solve the problem either, a tier three machine builder needs to be contacted. Depending on the current level of the service, the maintenance personnel's context-specific information has to be presented on the relevant HMI at his mobile device.

A. Indoor Navigation Scenario: Getting to the Target Machine

After logging on to the app, a map of the LMF is shown. The maintenance personnel can see the status of different machines at a glance. Beside that, his own location as well as the distance to the machine that requires some sort of maintenance is shown. In large production sites, it often becomes difficult to quickly find the way to the faulty machine. Therefore, in order to assist them, an indoor navigation function was implemented as part of the app. Figure 6 shows the navigation view of the implemented app for an example scenario, where the weighing module of the plant is not working (drawn in red color). If the operator asks the app to guide him to that module, the system dynamically calculates, draws and updates the feasible path (dotted directed line).

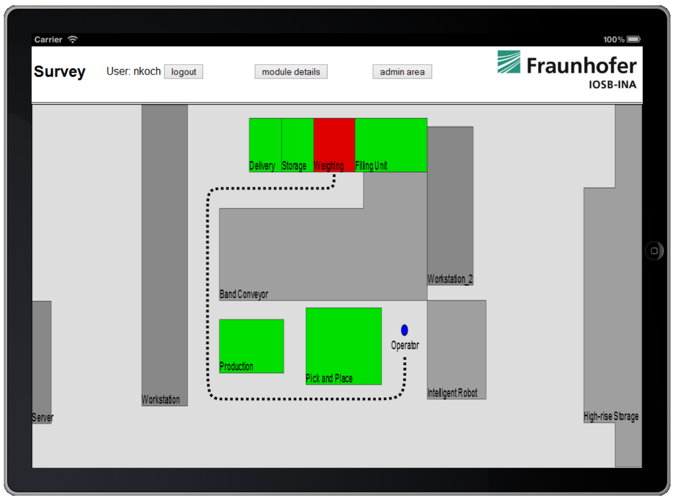

Fig. 6. Indoor navigation system

B. Context Aware UI Application for Maintenance Scenario

Another function of the app is providing the relevant information to the maintenance personnel based on the situational context. If an operator moves in front of a machine, the system shows all the relevant process data elements for that machine and/or information coming from other sources deemed relevant in relation to his location and user's role. The set of relevant information is dynamically generated by querying the contextual knowledge-base (ontological representation as shown in figure 5) and applying reasoning techniques. For different user groups, some signals may have respective contextual meanings. In an example shown in Figure 7, a machine is not functioning properly and therefore flashing a red light. The operator and the mechanic are both close to this machine but due to different user roles, the same red light on the same machine results in different messages displayed on the respective user's tablet. To the operator, a flashing red light just means that the station is not ready for operation. Whereas to the mechanic, it provides more specific information such as "the bottle is broken in the gripper that caused an emergency shut-down". The HMI also enables the maintenance personnel to execute certain corrective procedures.

V. Conclusions

The paper presented an architecture that offers context-sensitive services using a camera-based tracker, and an OPC UA based knowledge-base to estimate a situational context of a maintenance personnel in a smart factory. The result shows that context-aware and proactive decision support system,

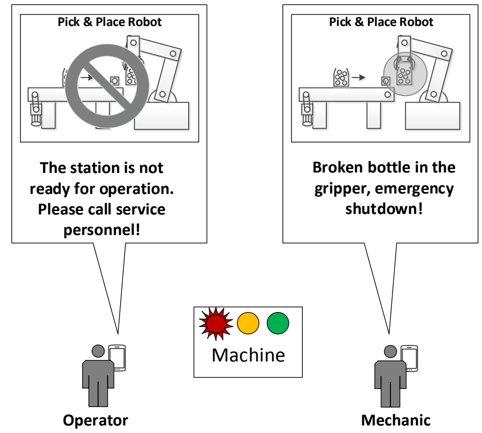

Fig. 7. Tablet showing context relevant information

which provides only the right amount of relevant information at the right time, using a vision-based localization system is possible. The video based approach can be integrated into any production plant, which supports suitable lighting conditions and physical installation of top mounted cameras. Future work will focus on implementing safety related applications and enriching the user experience through application of augmented reality by using the camera of the tablet. In-addition, an other important topic for further investigation is to reduce the engineering effort needed to configure spatial and behavioural relevance between different system entities and data sources.

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