Vision-based Positioning Enables Scalable User-Context-Aware Services for Industrial Applications

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Abstract. In this paper, a concept for a flexible context specific assistance system for industrial applications using camera based localization is proposed. Such a smart assistive system would reduce chances of human errors and it could increase the productivity and efficiency of maintenance persons. The architecture proposed a modular and service oriented paradigm that aggregates relevant data from different sources. Furthermore, it applies image analysis techniques on a video stream, which is captured from a top mounted multi-camera system to detect a person's location and associate it with a mobile device. It uses an OPC UA based access to process data, and a web service that provides connection to a user interface hosted on a tablet PC. For the proof of concept, a diagnosis and safety related use case is implemented.

1 Introduction

Optical positioning systems are increasingly used in a wide field of applications, due 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 has also evolved to 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 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 a safety related use case is implemented. This paper is organized as follows: section 2 introduces the camera based localization system. In section 3, the context-aware framework is presented in detail. Section 4 describes a case study based on an exemplary application. Finally, section 5 concludes this paper.

2 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 the camera based localization system in the LMF, which is based on three cameras. To minimize 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 x 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.

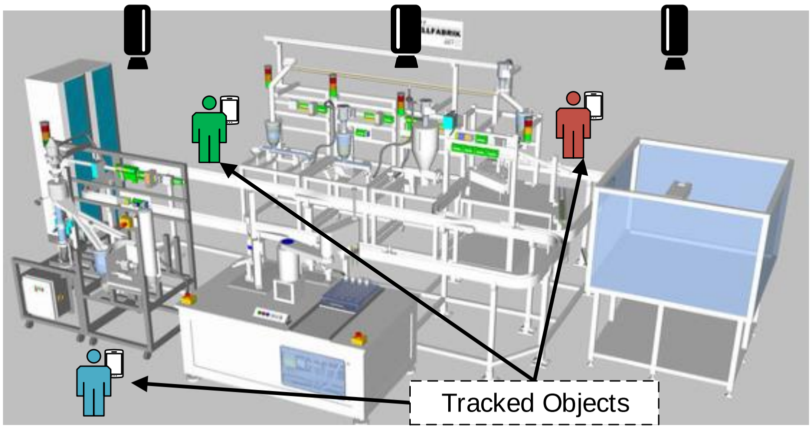

Fig. 1. Camera-based Localization System Approach

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].

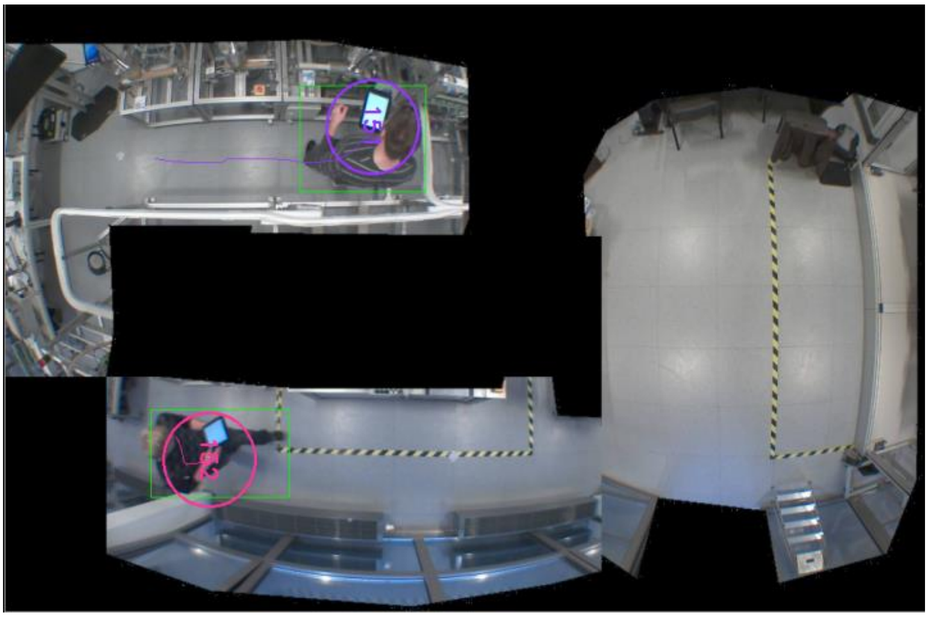

Fig. 2. Results from the Camera based Localization System

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 updating 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 exemplary 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 differentiating between different persons and tablets.

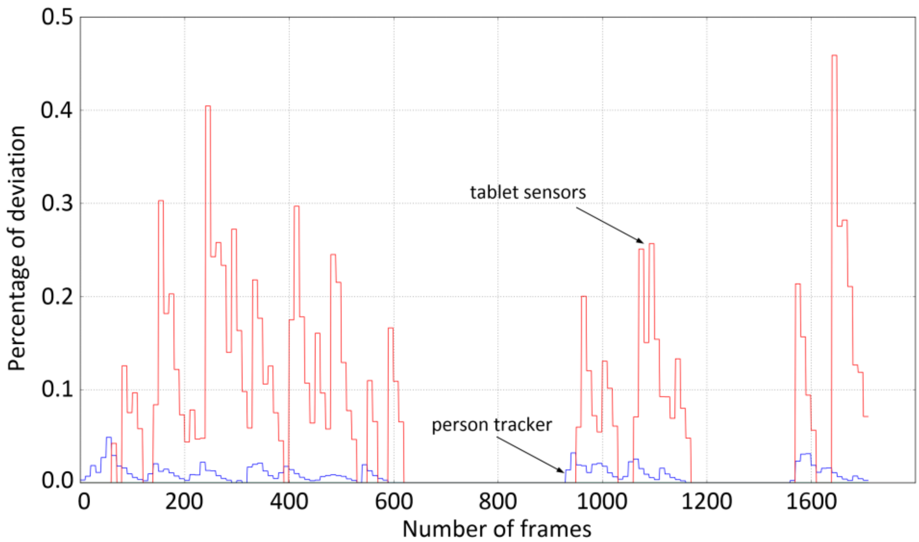

Fig. 3. Correlation between tablet sensor data and the camera tracking data of a person

3 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 online 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:

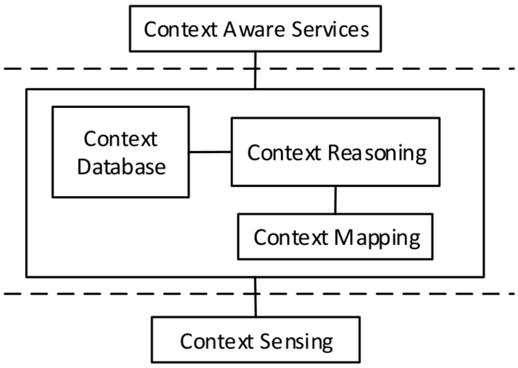

Fig. 4. Generic Framework of Context-Aware Assistive System

- **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 to him. He might also need to navigate his way using a floor plan service according to his localization context.

Figure 5 shows the core components of the implemented service oriented and context-aware assistive application architecture. It consists of mainly four components: a camera-based localization context provider; an OPC UA-based data source with semantically enriched ontologies representing the plant and its automation process; context-aware hand-held devices which present relevant HMI to the user which is specific to its context; as well as a floor plan of the plant. The fourth and the most important pillar is the middleware that binds all these components together and orchestrates a context-aware assistive system in real-time.

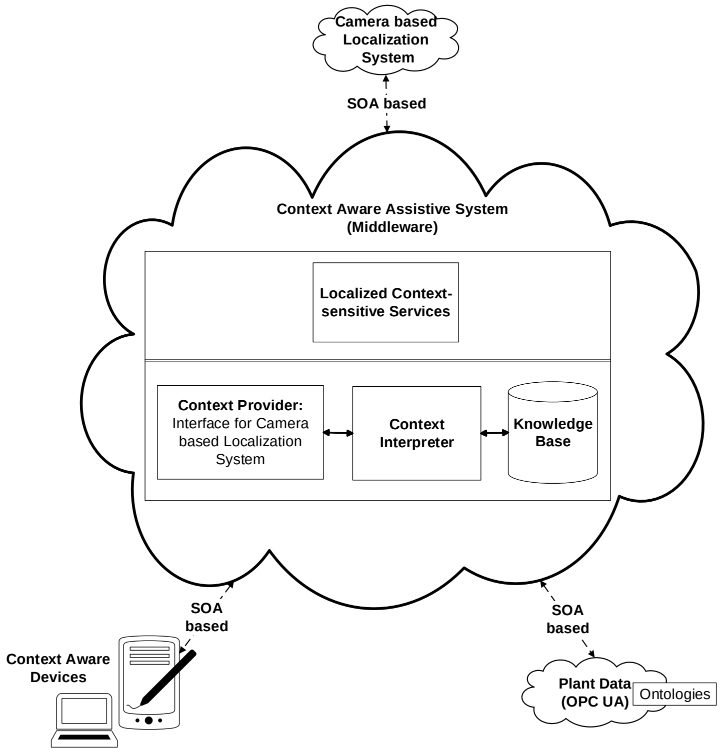

Fig. 5. Architecture of the Context-Aware Assistive System

4 Case Study

The environment for the given case study is described in section 2. The LMF is equipped with a 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 level covers 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 level one, a level two service technician who has deeper technical knowledge about the relevant machine will be called. If they cannot solve the problem either, a level 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.

4.1 Safety Scenario

In production sites, many areas have to be secured to ensure proper functioning. For example, there are moving parts which may be error-prone if handled incorrectly. By using a localization system, unauthorized individuals can be tracked. This allows ensuring that danger caused by those individuals is prevented, for example by turning off the machine.

In this project, this safety mechanism is implemented by defining three safety zones around each machine, as shown in Figure 6. These safety zones are represented by variables in the PLC, which, if set, trigger further actions. If an unauthorized individual moves close to the machine, he first enters *Safety Zone 2*. In this zone the system informs him that he just entered a restricted area by turning on a light. If he moves closer, i.e. *Safety Zone 1*, the system flashes that light, asking him to step back. If he moves even closer, reaching *Safety Zone 0*, which is very close to the machine, the system turns off that machine.

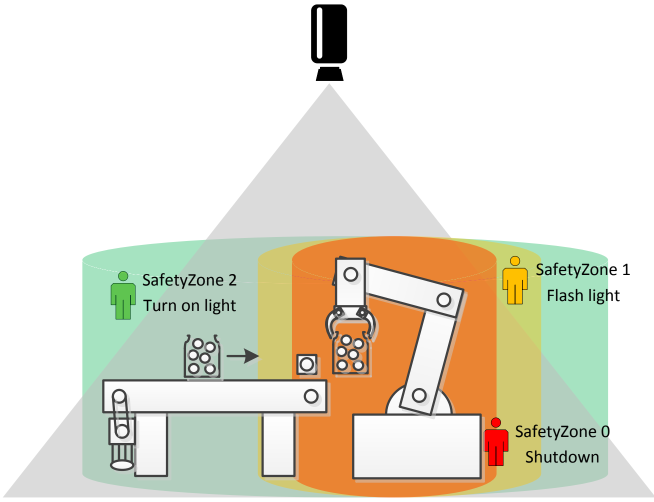

Fig. 6. Safety zones around a machine

4.2 Context-Aware UI Application for Maintenance Scenario

The main purpose of the HMI app is to provide relevant information to the maintenance personnel based on the situational context. 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. Besides that, his own location is shown. If he 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 role. The set of relevant information is dynamically generated by querying the contextual knowledge-base 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.

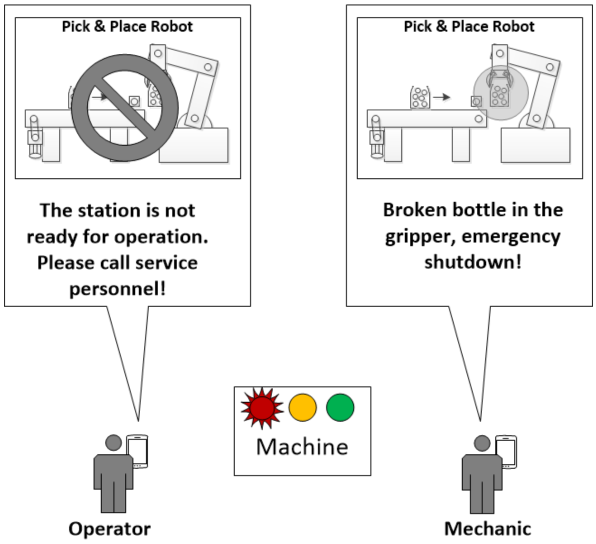

Fig. 7. Tablet showing context relevant information

4.3 Results

The area of the LMF could be fully covered by use of three cameras, which were mounted to the top of the ceiling. The cameras send their data as a continuous JPEG stream to a centralized Linux server, which we set up. Furthermore, the tracker software is implemented on this server. It was developed in C++ using different libraries such as Okapi and OpenCV. The tracker merges the images of the three cameras into one image, on which the algorithm is performed. The tracker software then provides coordinate data of the recognized objects.

As a central element a MySQL database was implemented on the Linux server. It is used to store not only the spatial information and the user credentials; it also acts as an interface between the HMI and OPC UA, which in turn allows access to the PLC.

With the Android app, the user can move around in the LMF, finding his position as well as the position of the objects in that environment. He can move from module to module, while being provided with the module's details regarding to his current position and user role. To implement the security features described in section 4.1, a service was developed using C++, which performs cyclic spatial queries to the database. This query returns the distances of all unauthorized persons. The respectively shortest distances are used to decide whether a safety zone has to be set or not.

5 Conclusion

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 the maintenance personnel in a smart factory. The result shows that a context-aware and proactive decision support system, 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 enriching the user experience through application of augmented reality by using the camera of the tablet. In addition, another important topic for further investigation is to reduce the engineering effort needed to configure spatial and behavioral relevance between different system entities and data sources.

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