Dynamic, Adaptive and Mobile System for Context-Based and Intelligent Support of Employees in the Steel Industry

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Summary

In order to fulfill the customer's requests for more product variety and quality, the processes in heavy industry companies are becoming shorter and more complex. These changes will also affect the demands on employees. At last, they make decisions within the diverse hierarchical levels that influence the production planning and the production process and thus ensure economic success. These decisions are increasingly based on a reliable, transparent and real-time provision of production and process data. This data should be provided in a simple and intuitive manner. To ensure this, it is important to recognize and consider the respective context. It must be decided who needs which data, at which moment and which place. The role of the user, the production situation and location must be recognized and evaluated.
In the research project "DamokleS4.0-Dynamic, adaptive and mobile system for context-based and intelligent support of employees in the steel industry" (1.7.2016-30.6.2019) explores how new technologies, like mobile and smart devices or augmented reality as envisioned in Industry 4.0, can be used to provide context-based and intelligent support to employees in the steel industry. The project, in which celano and the Hochschule Ruhr West - University of Applied Sciences collaborate, is funded by the European Union.
Exemplified by four scenarios derived from real situations in the steel industry the context-based data provision is described as well as the use of mobile devices and wearables with internal and external sensors and image processing methods. For interaction with the user the use of technologies like smart glasses are evaluated concerning usability and safety.

Key Words

Industry 4.0, celCAP 4.0, context-based model, smart devices, wearables, adaptive support of employees, user study

Introduction

The trend to an ever-increasing flexibility in production along with a broader product mix and smaller production lots is a recent challenge for the steel industry in Industry 4.0 scenarios. Growing customer requirements regarding product quality is another one. In addition to that, improving energy efficiency and reducing carbon dioxide emissions is becoming more and more important due to scarcity of raw materials, rising energy prices and higher environmental protection requirements. These changes will also have an impact on job requirements. Ultimately, the employees, along the value-added process and within different hierarchical levels, make decisions that influence the production process and production. These decisions will increasingly be based on a secure, transparent and real-time provision of production and process data. These data, however, must be made available to the employees in a simple, reliable and intuitive manner to meet security and usability criteria. To make this possible, it is important that the respective context is automatically recognized to provide the required data. It must be decided who needs which kind of data, when and where. Thus, the role of the user and the respective production situation and location must be recognized and evaluated.

Aim of the R&D project "DamokleS 4.0 – Dynamic, adaptive and mobile system for context-based and intelligent support of employees in the steel industry", which is presented in this paper, is to develop new scenarios and associated processes to support employees based on new, flexible, adaptive and smart technologies. For a reliable context-recognition the sensors of mobile devices and external sensor like beacons as well as image processing methods are evaluated. This is aggravated by the fact that in steel production plants are generally adverse environmental conditions for IT-systems that have to be taken into account. To find out how these systems can be used in this condition is an aim, too.
The first part of this paper describes the requirements of the project, followed by descriptions of celano's framework celCAP 4.0, which is the basis of the software development and the Rich Context Model (RCM). The development of the new methods is based on four scenarios, which are derived from real situations in steel production. These scenarios are described in the next part followed by the approaches of contextualization, localization and visualization for the user as well as a description of user experiments and new user concepts.

Requirements

The R&D project DamokleS 4. explores how new technologies like smart and mobile devices can be used to provide context-based and intelligent support to employees especially in the steel industry. The following requirements are taken into consideration when developing new methods.

a) Reliable context recognition
An essential requirement is the reliable recognition of the respective context. Mobile device sensors like acceleration sensors, gyroscope sensors, Bluetooth/Wi-Fi, etc. or image processing methods are evaluated to detect objects like persons, production devices or materials.

b) Safe and reliable data transmission
The attenuation of the electromagnetic waves by equipment, materials or interference of transmission makes it necessary to develop solutions ensuring a secure and interruption-free data transmission between the server and the mobile devices. Novel solutions are developed, such as reliable changes between Wi-Fi and mobile network.

c) Human-Machine-Interaction
New operating concepts will also change the requirements for human-machine interactions. Due to the need for flexible and transparent production, more and more activities with higher added value and creativity will be created. In this project, mobile devices and wearables are used for interaction. In contrast to the static use of desktop systems, mobile devices and wearables offer new dynamic interaction options.

d) Data security and privacy
With the advent of IT into production processes, the aspect of secure data handling has come to the fore more than ever before. It is particularly important for production companies to protect their own knowhow against unauthorized access.

Framework celCAP 4.0

Driven by the "Internet of Things", "Internet of Services" and "Industry 4.0", the importance of using mobile devices is also increasing in industrial applications. This knowledge makes it necessary to select new technologies and to evaluate their use in terms of technical properties, economic viability, future development, possibilities and sustainability. In these investigations it turned out that a web-based presentation appears most suitable. This technique makes it possible to use it on desktop systems as well as on mobile and smart devices. The use of web-based clients also makes an extension of the system architecture necessary. The result is the new celCAP 4.0 infrastructure. The classical client/server division is extended by an additional layer, which includes the middleware (MW).
The new celCAP 4.0 structure thus forms the basis for integrating web-based clients, desktop systems as well as mobile and smart devices.

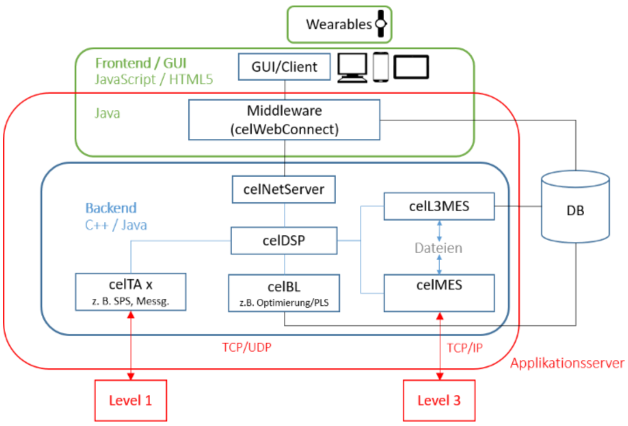

Figure 1: celCAP 4.0 structure for web-based clients and smart devices

Rich Context Model (RCM)

In the field of mobile devices, the sensors (e.g. acceleration sensors, gyroscope sensors and

Bluetooth/Wi-Fi) offer capabilities to collect information related the current situation of the mobile device user. Such information helps to determine the user's current context for recommending relevant information at the relevant time and location [7].Context could according to [2] (P. 4) be described as: "Context is 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 the applications themselves.". By the definition of Dey [2], the context information aspects vary depending on the application supporting contextualization. For instance, to recognize the context in mobile applications, it is necessary to access the sensors available in the mobile devices (such as accelerometers, gyroscope sensors, and Bluetooth/Wi-Fi). These sensors help, for example, to determine the position and direction of movement of a mobile device and therefore of a user. In many work environments, the context is used for various purposes. For such purposes, Context-Aware Recommendation Systems (CARSs) use context information to provide the user with points of interest [3] (tourism), learning resources [4] (mobile learning domain), interesting news [5] (news recommendation domain), etc. Context-aware applications utilize different approaches to modelling the utilized context information. The approach that we used in the presented project is a multidimensional context modelling approach [6]. A multidimensional approach provides benefits in comparison to other approaches in relation to the fulfilment of criteria (richness, flexibility, granularity and performance) [7]. Moreover, context models of this approach exhibit high performance and flexibility in presenting context information at different levels of detail [7]. In this approach, each dimension may represent different properties of an entity (e.g., device context, environmental context, personal context, etc.), whereby different context situations are represented as vectors in a multidimensional space. The model recognizes the current context because of its similarity to these vectors. Figure 2 presents an overview of context modelling in the multidimensional context modelling approach [8]. Rich Context Model (RCM) [7] is an example of this approach, which aims to model multiple dimensions of rich context provided by mobile users that are set in relation to task related content, e.g., in our case information about the current status of a machine or information on due tasks. The rich context term is used to describe data provided by different sensors on mobile devices that could potentially be enriched by external sources like Web services (e.g., weather API) or other user-defined algorithms, e.g., to streamline data gathered by sensors.

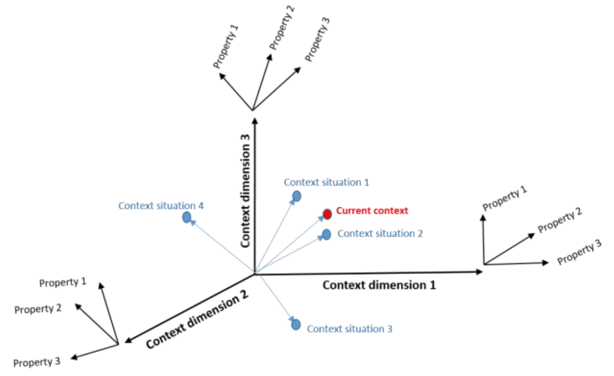

Figure 2: Context representation in multidimensional context modelling approach

Development of Scenarios

Together with the stakeholders and associated partners of the steel industry real production situations were collected and categorized in four different scenarios. Furthermore, the scenarios were abstracted and anonymized. The stories in the scenarios, which all describe the need of context-based data support, are the basis for the further development of solutions in the project. Imaginary employees in the scenario are Frank and Petra.

a) Workplace safety
Frank has been with a steel company for 15 years and is responsible for various machines. He comes to work early in the morning, puts on his smartwatch, couples it to his smartphone and authenticates himself with the "locksmith" role in the system. Petra works for a company that offers external services, including machine maintenance. She has received an order from her superior in a company in the steel industry and meets her contact person Frank in his office there. Petra receives a short safety briefing, a smartwatch and a smartphone. The smartwatch is already connected to the smartphone and the steel company's factory app has already been launched on the phone. Petra authenticates herself to the system with the role "external locksmith", puts the smartphone in her pocket and puts the smartwatch on his left arm. Afterwards, she goes to the workplace and enters Hall 11. Petra makes her way to the machine, which she is supposed to maintain. She will leave the safe area on her way there. The secure and insecure areas are stored in the system to which Petra has logged on. The system repeatedly compares Petra's position data with the area data and determines that Petra is in the unsafe area. Petra's watch is vibrating and she can now read a warning message. She is offered navigation that can lead her out of the unsafe area in the shortest and safest way. She is also given the opportunity to call her contact Frank.

Frank’s smartwatch vibrates and he receives a message from the system that an ”external locksmith” is in an unsafe area. He takes his smartphone out of his pocket and has Petra’s position data displayed on his mobile phone.
Petra has read the warning message, rejects both options and goes back until the warning message disappears again. She knows now that she has left the unsafe area and chooses another way to the machine. Frank has walked a bit in Petra’s direction but then gets the all-clear from the system that the ”external locksmith” has left the unsafe area.

b) Production
Frank goes to the cooling bed. He has received the information from one of his colleagues that a plate from one of his machines has not been properly processed and wants to take a closer look at the plate. Arriving at the plate, he first holds the camera of his smartphone on the plate. The system determines the temperature of the sheet and informs it with a warning that it is too hot to enter. Since Frank cannot inspect the sheet, he goes back to the machine, that is said not to have processed the sheet properly in order to examine it.

c) Maintenance
When Frank arrives at the machine, he notices that oil spills out of the machine. He suspects that there is no danger to other employees, but he is not 100 percent sure. Therefore, he marks the area around the machine and also a part of the adjacent machines as unsafe on his smartphone. He then receives a message on his smartphone that there is still one external and one internal employee in this new insecure area.
Frank checks his machine by holding his smartphone in front of the machine. On his smartphone, Frank selects the data that are important for his review from the available machine data. These are then added to the image of the machine. Frank notes that due to the lack of oil one part already has a high temperature. He stops the machine so it will not be damaged. Frank now checks where the oil came from and sees that he can easily fix the mistake himself. He closes the leak, restarts the machine and releases the area of the machine.

d) Warehouse management
After his machine has lost a lot of oil, Frank opens the warehouse management app on his smartphone and determines how much oil is left in the warehouse for this machine. Based on the app, he sees that several barrels are available. He goes to the warehouse and fetches a barrel to refill his machine. The warehouse management system determines that a barrel has been removed from the store and calculates that there is enough oil. Frank refills the machine with oil.

Contextualization and Localization

In all of the above-mentioned scenarios, localization of staff and machines as well as context specific awareness information and system notifications are essential for facilitating task fulfilment.
As one element of the arrangement, at least one device is needed that interacts with the user and conveys the relevant information. Virtual Reality (VR) devices have been excluded from the start because a full awareness of the surroundings and interaction with machines is necessary to ensure safety in a steel industry setting. Because VR-devices intend to isolate users from their current environment in order to ensure immersion in a virtual world, they might be useful for training scenarios in industry settings, focusing on e.g. real machine functionality, maintenance processes or production steps [1] but should not be used in human-machine-interaction in heavy industry scenarios. Several glass-devices that are currently on the market have been tested for their eligibility in steel industry environments that is characterized by varying temperatures, noise and filth and dust. Many proved to be uncomfortable for the test users, evoked sickness, had problems with quickly flattening batteries or heat development. The AR-device HoloLens from Microsoft was finally used for further development and testing. One of the distinctive features of the HoloLens compared to other evaluated devices was its holographic display. Instead of a static screen, similar in use by other mobile devices such as smartphones, the HoloLens uses two light projectors that send light waves onto a lens, that is specifically designed to distribute the light right into the eye, where it manifests as the displayed object. This allows the user to see its environment. Albeit slightly darkened, the eye focus of the user is always in the distance, avoiding focal dissonance effects, a major factor for inducing sickness in sensible people that often emerged with the other evaluated AR-devices. Another crucial factor is the requirement of indoor navigation. Outfitted with an array of cameras and infrared sensors, the HoloLens is able to recognize its surroundings. Although normally used for placing AR-content into the environment, the spatial tracking was adapted for the indoor navigation purposes. Mesh data generated by the HoloLens were combined into a map that fully covers areas of interest, e.g. those prepared for the user tests. This allowed to anchor several navigation points in the mesh, enabling the comparison between the tracked data and the stored data holding the predefined walking path. If the device classified both as a match, the navigation point was displayed in the field of view of the participant including the calculated distance. In order to ensure both datasets were aligned a calibration process was introduced at the start of each test session.

To investigate whether an automatic in-door navigation may be achieved using camera images only in an industrial environment, we recorded video data in experiments with users and conducted corresponding digital image processing experiments. To record our video footage, we have mounted five AVT GE1650C cameras and two FLIR cameras, namely AX655sc and AX5. Our AVT colour cameras feature a resolution of 1600 by 1200 pixels different focal lengths from 6mm to 12.5mm. Our thermal camera images feature a resolution of 640 by 480 pixels, where each pixel contains thermal information. We have calibrated the intrinsic and extrinsic camera parameters using the standard approach described in MATLAB [12]. In order to calibrate our thermal cameras, we have designed a chessboard pattern with aluminium foil, which we have heated up and recorded. The contrast in the thermal images suffice for a successful calibration with the standard procedure.

On all of our images, we detect a person's foot point using the OpenPose network. Compared with other approaches, the OpenPose architecture has proven to be most suitable for our application [11]. Even on our thermal images, OpenPose manages to detect persons quite reliably.

With the intrinsic and extrinsic camera parameters obtained by our calibration process, we transform the persons foot point into world coordinates. With an adaptive histogram equalisation pre-processing and a rule-based post-processing procedure, we maintain real-time applicability while minimizing the need for additional tracking algorithms like Kalman filtering. Running our system in real-time requires as many running OpenPose instances as recording cameras, which may consume up to 6GB GPU memory per camera. Increasing the frames per second results in higher accuracy at the cost of additional computational resources. Figure 4 shows the results of our real-time detection method, compared to the internal coordinates used by the AR application (Figure 3). Although the positions used in the AR application look very precise, they do not necessarily correspond to the true positions of the person in the environment, as the AR application may need to reorient itself in the course and may then distort the actual position. The paths obtained by camera-based person detection and tracking may therefore yield more realistic position estimation but is exposed to false detections, induced by blinding light or mirror effects. In our experimental setup we recorded the camera images with eight frames per second and the AR positions with two positions per second.

Beacon is a transmitter or receiver based on Bluetooth Low Energy (BLE) or Bluetooth Smart technology.

Basically, this is a radio technology that can be understood as a further development of Bluetooth [9].

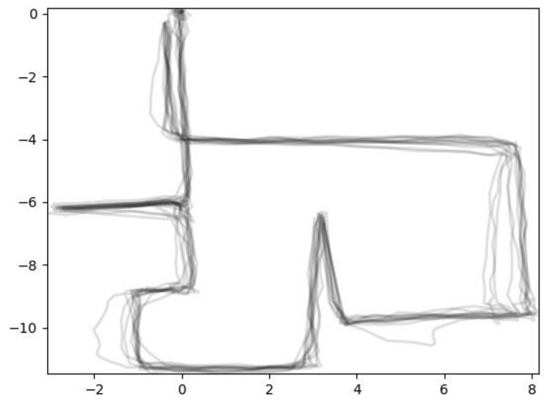

Figure 3: The internal positions used by the AR application

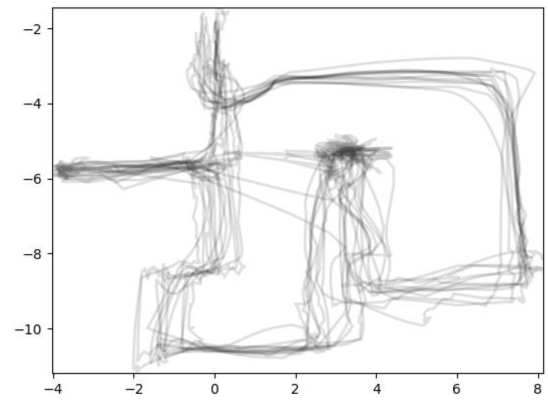

Figure 4: Camera-based person tracking

Their range is approximately 50 meters. Data transmission between devices consumes far less energy than with the predecessor Bluetooth, which results, for example, in low battery consumption for smartphones. The transfer costs also remain low. Large amounts of data are not suitable for exchange because the transfer rate is relatively low. The beacons themselves are operated by battery or rarely by direct power connection.

Beacons are installed in different positions in the building. They transmit signals to mobile phones via Bluetooth. In this way, it is practically possible to determine their position at any time and forward it to the indoor navigation system. In DamokleS 4.0 project, we use a trilateration for the positioning [10]. In short, trilateration is a geometry technique to calculate your position based on the physical position and the relative distances of three referenced locations. The trilateration approach works with at least three beacons and the signal strength of the beacons needs to be stabilized. The problem we are currently facing is the instability of signals from beacons. For this purpose, suitable filters should be used to filter these signals.

Developing new User concepts

Navigation with smart glasses
So far, devices like the HoloLens have not been used in steel industry environments, nor have they been widely used in other contexts so that best practices are not available. Interaction concepts have still to be designed and tested that meet usability criteria and are accepted by the users (e.g. in the sense of high ease of use and usefulness in work settings). As a first approach, different visualisations for an indoor navigation have been designed that should not impair vision while walking, allow the user to estimate the distance to a next machine or task by showing the distance in meter and guides the ways using familiar visual elements known from Google maps or navigation systems in cars (line vs. arrow). Apart from supporting indoor navigation, the system gives instructions to the users at the different stations, e.g. asks to find a serial number on machine elements and check whether cables are plugged to the right socket, asks for identification, remembering a number and type it in a computer, warns users when entering a danger zone and initiates an evacuation supported by navigation in the HoloLens.

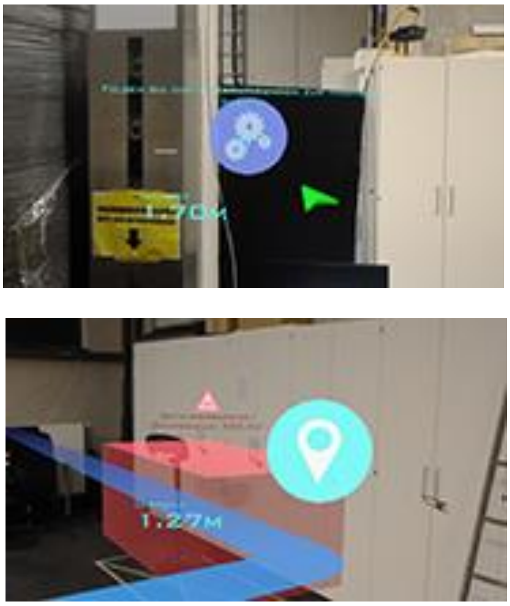

Figure 5: Indoor navigation with HoloLens

Notification with smart watches
In addition to the use of smart glasses for navigation new applications for a smart watch were developed based on the use cases described in the scenarios and integrated in the celCAP 4.0-framework. Free configurable notifications, e.g. entry in an unsafe area, can be send by backend processes to the smart watch and notify the user via alarm, vibration etc. about the current situation. But the smart watch

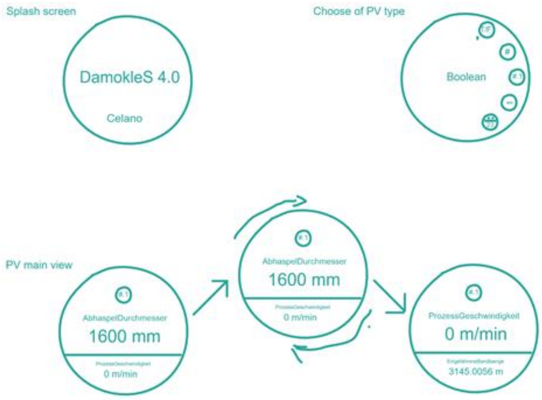

Figure 6: Mockup smart watch UI

can also be used for providing information about the current state and condition of machines and production processes. This information is stored in the form of process values in the backend processes of the celCAP-framework. To display this information on the smart watch in an intuitive manner a new smart watch UI was developed. Furthermore, a new

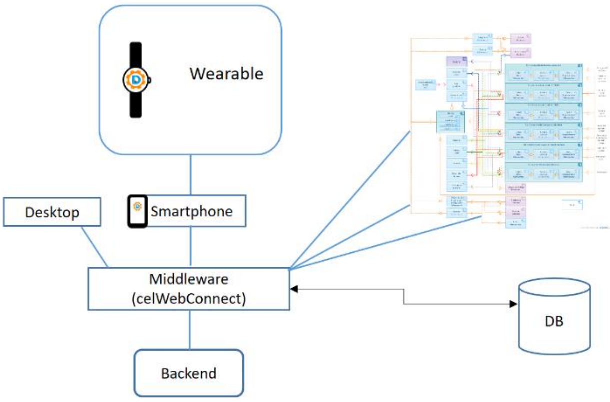

Figure 7: Communication between smart watch and context model

communication library was integrated to handle the data-exchange between the smart watch the associated smartphone and the middleware including the context model. With this concept process information can be prefiltered depending on the current situations, e.g. current furnace temperatures, lifetime hours of machine parts etc.

"Second Screen"
In this concept the smart phone or tablet acts as a "second screen" for desktop applications. Operators in control centres or at the shop floor can use these devices as a remote to control the desktop UI like

mouse navigation, keyboard, selections etc. or the devices can be used to augment the desktop UI to show more content related to the current situation, display notifications or to zoom into a more detailed process view. The coupling is done by barcodes displayed on the desktop screen and scanned with the smart phone.

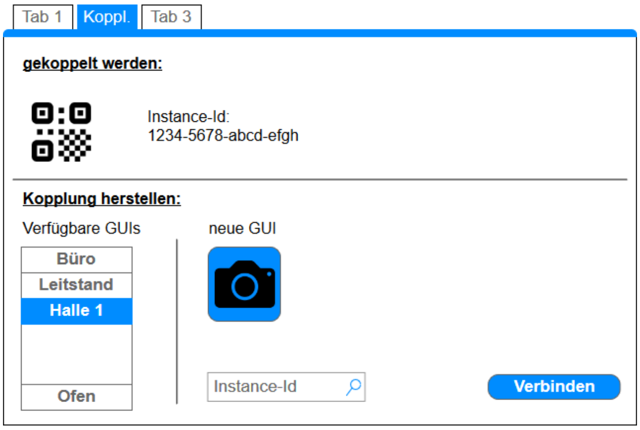

Figure 8: Example "Second Screen"

Evaluation

An experiment was designed in which test users were confronted with a noisy and windy hall scenario with dimmed lights that should resemble a typical environment in heavy industry surroundings. Users either tested the arrow navigation condition or the line navigation condition and were asked to follow the instructions displayed in the HoloLens. Each of them walked a course with different stations (all the same) where they had to fulfill specific tasks. During the experiment they were captured by several cameras in order to compare camera-based and HoloLens based tracking data. Also, their heart rate was captured. Before checking in, they filled in a questionnaire asking for their prior experience with and attitude towards AR/VR technology, demographic data etc. and were briefed regarding recordings made and data collected in the experiment. After the experiment they were asked to provide answers on motion sickness, acceptance and a variety of user experience aspects (e.g. understanding, usage intention, ease of use) during the navigation and at the stations. The trials are still running. Altogether, 50 tests users (25 for each condition) will complete the course. A triangulation of different data sources, e.g. camera data compared to Beacon data and HoloLens navigation data, heart rate data and self-report measures from the questionnaire will give deep insights into how acceptable and useful the system is for users and with regard to what kind of tasks and allow the deduction of a variety of recommendations.

Conclusion

In this paper, the software approach for a context-based system using mobile and smart devices to supports employees in the steel industry is introduced. Based on scenarios focusing on safety, production, maintenance and warehouse management, concepts were developed and evaluated. In addition to the more technical perspective, this also includes the development of new applications and UI concepts for mobile and smart devices, methods for localization and contextualization, psychological aspects like user experience or acceptance of new concepts. The use of smart glasses was evaluated in an experiment simulating different situations from the scenarios in steel production environments. As a next step, this evaluation has to be done with the new concepts for smart watches and for a combination of both, smart glasses and smart watches.

Acknowledgments

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