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Concept for the comparison of intralogistics designs with real factory layout using augmented reality, SLAM and marker-based tracking

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Abstract

In the automotive industry, the intralogistics planning faces the problem of matching the planning data with the current conditions in the assembly hall. The large variety of parts leads to a constantly changing production. Based on this, we establish an approach for the comparison using augmented reality (AR) and simultaneous localization and mapping (SLAM). The use of SLAM enables the consistent application of AR in an assembly hall. Based on this, the objective of this article is to visualize 3D objects from the corresponding CAD planning tool in the real factory and thus the comparison of the intralogistics design with the real factory is possible due to AR. Nevertheless, there was a lack of practical implementations in intralogistics and therefore the concept is evaluated by two prototypical solutions. The first one is implemented on an iPhone 7 using SLAM. The second prototype is developed on a HoloLens 2 and is based on a hybrid tracking solution, SLAM and marker tracking.

Keywords: Augmented Reality, Intralogistics Planning, SLAM Tracking, Hybrid Tracking

1. Introduction

The automotive industry faces a variety of challenges that have an impact on the intralogistics of the final assembly. Here, the intralogistics, as the core of the supply chain, is particularly noteworthy [1]. Intralogistics can be classified into the operational logistics and intralogistics planning. To guarantee a seamless intralogistics process, it must be ensured that there is a comparison between the intralogistics design and the current conditions in the assembly hall. The large variety of parts and the high turnover rate lead to constantly changing production and re-planning in intralogistics. It is to mention that many minor short-term changes in the assembly hall are implemented without notifying the logistics-planning department. This leads to incorrect planning and thus to faulty processes in the intralogistics.

Therefore, on the one hand it is important to have an innovative tool to support the intralogistics planning. In this case, we identified Augmented Reality (AR) as a potential tool [2]. On the other hand, the comparison of intralogistics designs with real factory layout is indispensable. Based on this, the objective of this article is to visualize created 3D objects from the corresponding intralogistics design in the real factory layout using AR. To achieve the objective, we establish a conceptual approach for the comparison of the intralogistics design and the real factory using AR and simultaneous localization and mapping (SLAM). SLAM, as a tracking method is considered as the future of indoor tracking in the scientific literature and is more and more in common [3]. As a basis for the concept, we illustrate beneficial properties of using SLAM for AR based on a literature analysis. This is followed by a demonstration of the concept and by an implementation of two prototypes for the evaluation. Prototype 1 is implemented on an iPhone 7 using SLAM and prototype 2 is developed on a HoloLens 2 with a hybrid tracking solution. At the end, there is an outlook for further steps of the concept and prototypes.

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2. General guidelines

2.1. Intralogistics planning

Intralogistics, or internal logistics, covers the internal material flows as well as all logistics stations and resources, such as load carriers. Further, the intralogistics comprises everything from goods receipt to goods issue and functions as an interface to procurement and distribution logistics [4, 5]. The complex processes and the resulting performance of intralogistics determine the achievements of the contiguous areas along the supply chain [6].

The intralogistics can be divided into the intralogistics planning and the operational intralogistics. Intralogistics planning includes various tasks, such as load carrier planning, material flow planning with process and layout planning, input factor planning and operational planning. For example, the objective of the material flow planning is to design a logistics-compatible factory [4, 4, 7]. The operational intralogistics with its functions transportation, order picking and warehousing enables a consistent intralogistics process [1, 8].

External circumstances, various model series and derivatives as well as the requirement of special equipment can lead to an increase in complexity in the automotive industry and leads to new challenges for the industry, especially for the intralogistics [7]. Further, a large variety of parts causes a high turnover rate with countless variants [4, 5]. At the same time, increasingly shorter product life cycles and model upgrading lead to adjustments and re-planning in intralogistics [8].

2.2. Augmented reality

Augmented reality (AR) can be explained by reference to the reality- virtuality continuum. The continuum, limited by the extremes reality and virtuality, contains all possible combinations of the real and virtual world. In a virtual world, the user immerses in a completely reconstructed world and the user is not able to interact with the real world. AR, on the other hand, is closer to the extreme reality and is augmented with virtual elements [9]. The understanding of AR is based on the work of Azuma. AR is defined as the enhancement of the real world with digital content. In addition, the understanding is based on the three criteria of Azuma, namely the interaction in real time, the combination of reality and virtuality, and the registration in a three-dimensional space [10].

The implementation of AR requires different concept steps [11, 12]. An important one is tracking, which enables the recognition and the traceability of the digital objects. By an exact calculation of the given conditions and fixed markers or algorithms the determination of the movement speed, acceleration or deceleration of the digital objects are possible [13]. There are different kinds of tracking methods like non-optical tracking, optical tracking, object-based tracking or SLAM [11, 12]. The SLAM algorithm generates a simultaneous map and thus an autonomous localization. The exact position relative to the orientation points is determined by identifying artificial or natural orientation points. Through mapping, the position of the orientation points is defined. By the continuous calculation of the location and the individual position resulting measurement errors are reduced and localization becomes more and more accurate [12, 14]. The combination of position and orientation resulting from the tracking system includes all 6DOF and is called pose [11]. The rendering, i. e., the illustration of the AR objects, follows the tracking. In order to enable AR, different types of displays can be used as output units [11, 13].

2.3. Literature review of augmented reality and SLAM

Within the scientific literature, the terms AR and SLAM are mentioned increasingly. For a more detailed consideration, we have conducted a comprehensive literature research. The database IEEE contains approx. 181 results and Science Direct approx. 492 results (from 2003 to 2019) for the keywords AR and SLAM. A detailed investigation resulted in 88 publications dealing with the combination of AR and SLAM. Especially noteworthy is that the number of publications has increased over time, which is illustrated in Fig. 1.

High varieties of scientific publications mention the beneficial properties of using SLAM as a tracking method for AR. In 2003, the authors Davison et al. already investigated a practical application in the field of SLAM for the localization of wearable robots. They pointed out that SLAM technology can be used in many other areas for the localization, such as for real-time AR [15]. Martin et al. 2014 indicate that the application of SLAM as a tracking method becomes ubiquitous. At the same time, there is an increase in powerful smartphones enabling mobile AR applications. However, the authors recommend decoupling the mapping and the localization process to save computational power for the usage. The proposed method was successfully implemented on different smartphones to demonstrate its efficiency [16].

Munoz-montoya et al. 2019 apply the SLAM-based approach for an experiment with an AR app. The experiment involves an evaluation of spatial short-term memory with 55 participants. Next to that, the authors refer to the fact that SLAM becomes increasingly more common as an indoor localization method. A more detailed literature analysis reveals that SLAM provides a higher position accuracy for AR. Furthermore, they underline beneficial properties of SLAM-based AR applications. Firstly, this tracking method enables a comprehensive, seamless indoor application. Secondly, the method is wireless and therefore the user is able to apply the application at any place. Further, there is no need of additional elements for the tracking in the environment. Moreover, there is meanwhile powerful hardware and software to create AR apps using SLAM for mobile devices [17].

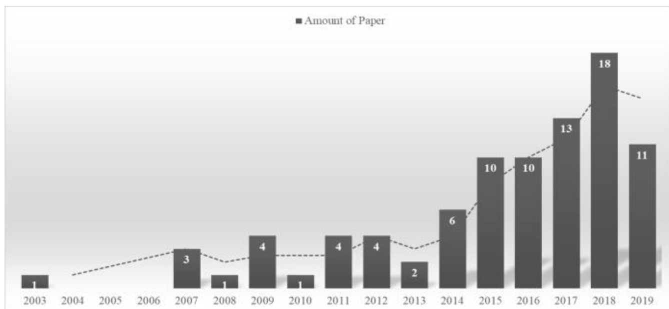

Fig. 1: Amount of scientific literature from 2003 to 2019

According to the beneficial properties of using SLAM as a tracking method, there are also many publications in various areas. For example, Yeh et al. 2018 implemented an indoor AR-system using Project Tango. The system is divided into two parts: mapping and relocation. The mapping includes the design of a 3D environment. In the second step, the generated data is reused for the relocation of mobile devices and therefore the actual position of the user is determined. The 3D point cloud can be converted into a raster map. After that, the system can estimate the navigation path and guides the user to the position of the AR content [18].

Another example is the work of Clemens et al. 2015. They investigated a technique for an extensive localization and global tracking of mobile devices in large urban areas. To generate a 3D SLAM map in the world coordinate system, the authors combined the resulting 6DOF-Pose with information from a city map model [19].

Based on the analysis, the following assumptions can be summarized. There is a high variety of literature dealing with SLAM. Optimization of the algorithm or technical solution are increasingly discussed, as in [20] or [21]. In addition, there are various prototypes concerning SLAM and AR in diverse sectors. This work focuses on AR in intralogistics planning, which is why we further considered practical examples using SLAM as a hybrid tracking method. In despite of beneficial properties, we did not identify any applications for intralogistics planning. There is a lack of applications, which apply SLAM as a seamless indoor tracking method for AR in large indoor areas, like–assembly halls in the automotive industry. Further, there are no known outcomes concerning SLAM´s performance in this dynamic environment. Nevertheless, we assume that SLAM is a beneficial tracking method for the intralogistics planning, which we consider closely in the following.

3. Description of the conceptual approach

3.1. Status quo and requirements

As already mentioned, the intralogistics in the automotive industry faces a number of challenges. The following assumptions are illustrated using the Mercedes-Benz AG as an example. Based on our practical experience, we assume that one of the major problems is the match of intralogistics design with the current conditions in the assembly hall. The large variety of parts and the high turnover rate lead to constantly changing production and re-planning in intralogistics. It is to mention that many minor short-term changes in the assembly hall are implemented without notifying the logistics-planning department. For example, there can be load carriers, which are located differently compared to the originally planned one, structural obstacles or other changes due to a running production. From this, it can be deduced that there is no comparison of the current conditions in the assembly hall and there are deviations of the planned data. The followed re-planning is based on the planned data but the status quo of the factory is not included. This leads to incorrect planning and thus to faulty intralogistics processes.

The problem of the missing match also affects the intralogistics planning. Intralogistics processes are digitally planned with a corresponding CAD planning tool. The logistics planner must directly inspect the assembly hall, because of the ongoing changes and adjustments. These are not digitally documented in the planning system. Measurements and corresponding notes of these changes are documented manually with paper and pen. Subsequently, the recorded changes are transferred into the planning system. Errors can occur due to the manual transmission. All in all, the planning process takes a considerable period of working hours and flexibility cannot be guaranteed [2].

In conclusion, it can be emphasized that there is the necessity to compare the real factory layout with the intralogistics designs. At the same time, it is important to have an innovative tool to support the intralogistics planning. In this case, we identified AR as a potential tool. Despite the beneficial properties of AR, there is lack of successful implementations in the intralogistics [2]. Therefore, the objective is to visualize created 3D objects from the corresponding CAD planning tool in the real factory layout using AR and SLAM. It is essential that the 3D objects be placed in the accurate position as previously determined in CAD. A high accuracy of AR is very important, otherwise incorrect planning or inefficient space distribution may occur [22]. As stated previously, the implementation of AR requires different steps, such as tracking. Since the intralogistics refers to an indoor assembly hall without indoor GPS, a continuous tracking method is essential.

3.2. The concept for the comparison of intralogistics designs with real factory layout

Based on the requirements, we establish a conceptual approach to compare the intralogistics design with the actual conditions in an assembly hall in the automotive industry using AR and SLAM. Fig. 2 illustrates the concept, which comprises three different elements. The concept describes the comparison of intralogistics designs with a real factory layout using AR and SLAM. On the left side, the intralogistics design incl. the CAD planning tool with the current planning status is located. At the beginning of the planning, this status is completely independent of the status quo of the real factory. On the right side, the status quo of the real factory with the constantly changing production is placed. In this context, AR is the link between the real and the virtual world, i.e. between the intralogistics design and the real factory layout. Further, the arrows point out the connection between the status quo of the intralogistics design and of the real factory. Within this connection, there are deviations, which we are eliminating with the following concept.

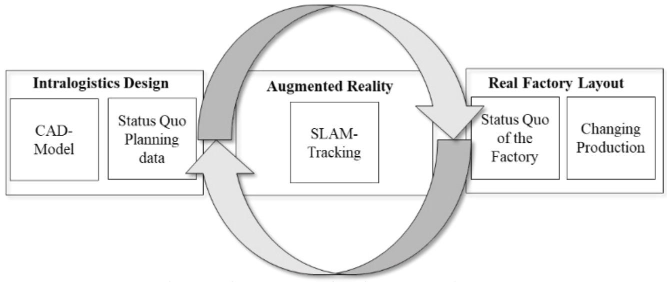

Fig. 2: The concept for the comparison

The benefit of the concept is the interface between the CAD planning tool and AR and thus the planning can be validated on-site. Furthermore, the status quo can be crosschecked with the planned data and discrepancies can be identified. The logistics planner can inspect the discrepancies on-site or verify the complete planning with AR. The user can digitally fade in the planned load carriers or shelves from the CAD planning tool along the assembly line and determine or manipulate the position. The final position can be simulated using AR and any obstacles and structural conditions are determined. Due to the use of SLAM, the user can digitally plan and check the data at any place in the assembly hall. As a result, the logistics planner can refer to this status for further planning.

In addition, this concept considers SLAM as a tracking method for AR, which enables the comparison. Next to that, the application of SLAM provides a major contribution in the field of intralogistics. Firstly, due to the missing indoor-GPS, SLAM enables a seamless indoor AR application. Because of the wireless characteristics, it is possible to use AR in the whole factory and on different devices. In addition, SLAM provides a very high tracking range, which is required according to the dimension of the factory. All these features offer the required flexibility and adaptability of innovative intralogistics concepts and support the intralogistics planner. Further, the literature indicates that SLAM provides a higher position accuracy for AR. Within this approach, 3D objects from CAD shall be placed exactly at the intended location and thus the accuracy of AR is indispensable. Otherwise, there will be planning errors. This is accompanied by the required interface of AR and CAD planning tool. This delivers a suitable tool to compare the intralogistics design with the real factory.

The implementation of the concept requires several steps, which are illustrated in Fig. 3. The first step is to create a feature map of the real factory using SLAM (1). This map is synchronized and aligned with the CAD layout of the real factory (2). Through this step, the positions of objects in the CAD layout, such as shelves, are transferred to a position in the feature map. Finally, this one is used to localize AR devices (3). Thus, the planned objects from the CAD planning tool can be displayed at the intended location in the real factory.

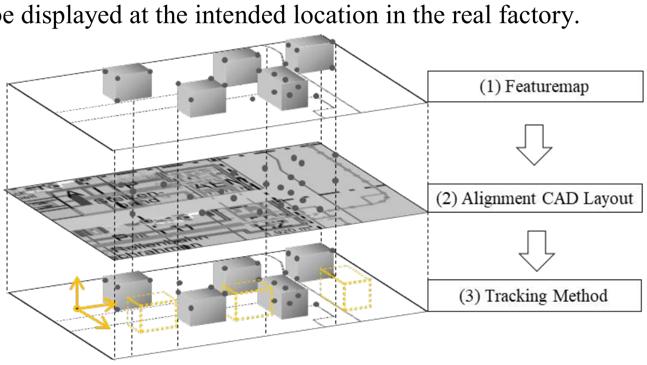

Fig. 3: Implementation steps of the concept

4. Prototype

4.1. Implementation of the prototypes within the Mercedes-Benz AG

In order to investigate the concept more closely, prototypes need to be developed and then evaluated with regard to the achievement of the objective. On the present market, there are different types of devices to enable AR. The literature indicates that there are meanwhile powerful mobile devices to create AR using SLAM. Based on that, we created two prototypes. Prototype 1 is implemented on an iPhone 7 and prototype 2 on a HoloLens 2. The HoloLens 2 is used because of the multi camera system and the depth sensor [14]. The creation of these prototypes is based on Fig. 3, which are described in more detail in the following. For the implementation, certain technical requirements shall be considered. Similar to the works of Martin et al. 2014 [16]; Mur-Artal and Tardos 2017 [14] as well as Yeh et al. 2018 [18], we also separate the mapping and the localization in order to have enough computable power for the application. Another aspect is the need of having access to the map after its creation at any time (analog Fig. 3). To enable a true to position and true to scale visualization of objects with AR, an important requirement is to localize the AR device in 6DOF and in relation to the real factory.

The first prototype comprises SLAM tracking on iOS devices and is generated with the SDK Placenote. Placenote combined with ARCore is used because of the Spatial Capture App functionalities to record the map and of the separate storage in the Placenote cloud. Fig. 4 illustrates the construction of the prototype 1. The first step is to generate the map. Therefore, we use the separate Spatial Capture App from Placenote. In this case, a camera records a previously defined section of the factory. This feature map consists of different feature points as well as different planes and is stored in the Placenote cloud. Each map is assigned a MapID, which can be used to access the map. Afterwards, the feature map will be imported and visualized in the game engine Unity, which supports the required Placenote functionalities. We chose Unity, because Placenote is not compatible with Unreal Engine. The PlaceMesh script is added to the Unity project, which is part of the SDK Placenote. This script contains input fields for the Placenote API-Key as well the MapID [23]. The next step is the transmission of the 3D objects from the CAD planning tool. It is important to ensure that the objects are aligned correctly, e.g. at columns. Finally, the app is created in XCode. While using the application, an initial recognition of the underlying feature map in the reality is done. After recognizing the previously recorded environment, the 3D objects, like shelves and load carriers, are faded in the defined position.

The scientific literature indicates that using stereo and depth sensors for SLAM tracking provide better results [14]. For this,

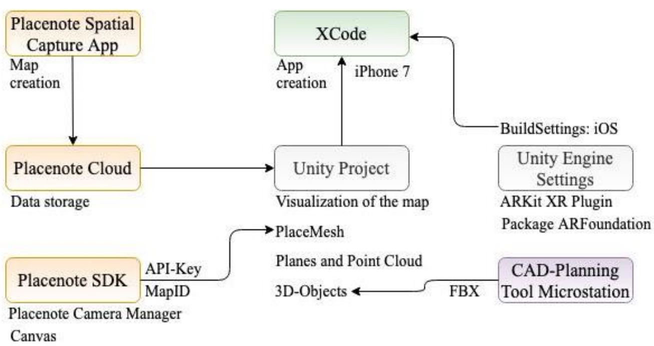

Fig. 4: Construction of prototype 1

we developed a second prototype on the HoloLens 2 and discussed the results of the prototypes afterwards. The tracking of the HoloLens 2 also captures the surrounding space and creates a feature map of the room based on a SLAM technology. In this context, the spatial mapping, also called 3D reconstruction, is important. With that a detailed representation of real-world objects in the surroundings of the HoloLens is possible [24]. Within this prototype, the requirement to access the created map at any time is not fulfilled. A solution for the missing access contains a marker tracking and thus a hybrid tracking. Nevertheless, the HoloLens 2 is applied because of the better performance of the existing sensors. In addition, the focus is still on a Slam-tracking to visualize 3D objects from the corresponding CAD planning tool in the real factory

This prototype was also created with Unity and the corresponding Mixed Reality Toolkit (MRTK). One of the major functions of the application is the spatial awareness function. This one is necessary to interpret the environment and to create the feature map based on the polygon mesh. The HoloLens constantly scans the area and reconstructs the environment in the 3D feature map. For the implementation of the marker tracking, the SDK Vuforia is used due its extended tracking function. Therefore, it is possible to integrate both tracking systems. In this case, we used Vuforia, because MRTK does not support the marker tracking and ARCore is not run on the HoloLens. After the prototype was implemented with the corresponding software in Unity, the concrete and current planning data of the CAD planning tool can be added to the project. At this point, it is also important to add a CAD layout model of the factory. Afterwards the application can be installed on the HoloLens 2, whereby the tracking operates as follows: First, the marker is detected and the marker tracking is initialized. The position and the rotation of the marker is analyzed to generate an estimate of the pose for the HoloLens. The SDK Vuforia transfers the pose of the marker in a spatial coordination system of the HoloLens. As soon as the marker is out of view, the tracking is continued with the HoloLens based on the spatial awareness. Due to the marker, 3D objects of the CAD planning tool can be faded in at the intended position. Fig. 5 illustrates the tracking process.

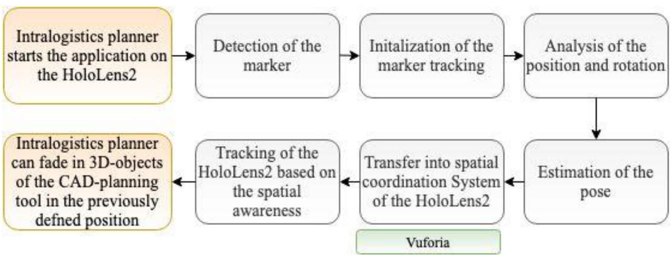

Fig.5: The tracking process while using the AR application

4.2. Evaluation

After an extensive evaluation and testing of prototype 1 on-site, we determined that this application could only be used for small working areas. Therefore, prototype 1 is not adequate to validate the concept, as an integrated solution for a large factory is required. The prototype 1 functioned for small working areas of about 4 m². An increase of the investigated area led to tracking inaccuracy. As soon as the size of the area is more than 8 m², the system could not recognize the area anymore and the objects could not be displayed at the defined position. One problem here could be the used devices, i.e. Smartphone, and the installed cameras and motion sensors.

Due to the better results using stereo and depth sensors, we generated the second prototype as a proof of concept. By implementing this prototype, an integrated AR solution and thus the comparison of design and the real factory area can be realized. For this, the application was evaluated on 120 m² in the factory (see Fig. 6). For a more detailed evaluation based on the specific intralogistics use case, the requirements of AR applications in industrial areas by Quandt et al were used [22]. The first point refers to the requirements during development and integration. The benefit of AR applications shall cover the additional expenses for development and installation. On the one hand, planning and transmission errors can be reduced by the application. An important argument is the interface to the CAD planning tool and thus the comparison to the real factory. Since, we could apply the prototype on a large indoor area, the required flexibility of an intralogistics planner is confirmed. A seamless AR indoor application is possible. On the other hand, there is the additional effort for creating the application in Unity, which takes about 30 minutes. In addition, there are the requirements during set-up, for example the set-up time. A critical aspect of the use case is the usage of the marker. This one has to be placed in advance, which increases the set-up effort. However, in comparison to conventional marker tracking, this prototype only needs one marker at the beginning and does not have to stay within the user's field of vision for robust tracking. The last point considers the requirements during operation, like the accuracy of presentation and real-time capability. The second prototype enabled a high accuracy of the 3D objects according to the marker. This ensures the planned intralogistics designs and subsequent processes as well as the required on-site planning. Further, it is possible to track the pose and to visualize the virtual objectives in real-time.

In summary, it can be affirmed that the planning process is simplified by the prototypes. The user is able to secure the planning with AR on-site by using the CAD layout based on the real conditions. The planned objectives are displayed in the previously defined position. Therefore, the depiction of the actual conditions in the assembly hall and the comparison of the real factory layout with the intralogistics designs is possible. Furthermore, it can be stated that for large indoor assembly halls, there is the requirement for a device with stereo and depth sensors. So far, a smartphone has not been sufficient for this application.

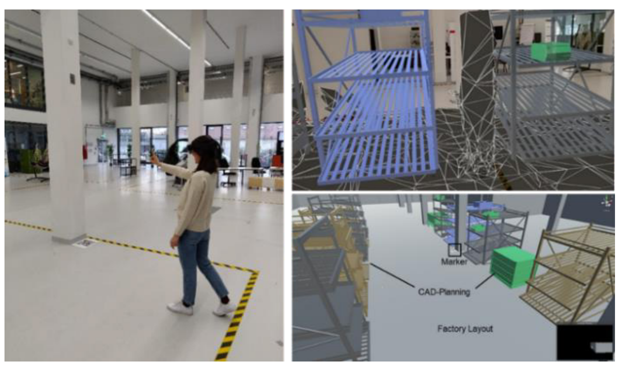

Fig. 6: Evaluation of the prototype 2 and construction in Unity with marker

5. Results and further implementations

Due to the increasing challenges of intralogistics in the automotive industry, we developed a concept that provides a comparison between the intralogistics design and the real factory. First, we demonstrated by a literature analysis that SLAM is a possible tracking method to enable continuous AR on large indoor areas. Nevertheless, there was a lack of practical implementations in intralogistics and therefore the demonstrated concept was evaluated using two prototypes. With that, it is possible to visualize the created 3D objects from the CAD planning tool in the real factory layout and thus the comparison of the intralogistics design and the real factory. The prototype 1, installed on an iPhone, functioned for small working areas of about 4 m². Due to the better results using a multi camera system and depth sensors, we generated the second prototype on a HoloLens 2 as a proof of concept. The application was evaluated on 120 m² in the factory. Despite the hybrid tracking solution, SLAM and marker-based, it was possible to confirm the concept. Through the prototype, the required flexibility of an intralogistics planner is confirmed and the planning process is simplified as well. Further, the prototypes enabled a high accuracy of the 3D objects. This is important to avoid additional planning errors and thus it ensures the planned intralogistics designs and subsequent processes.

In a next step, the prototypes shall be developed further and integrated better into intralogistics. For this, the usage of automated guided robots (AGR) enables a contiguous approach. By combining individual AGRs and their maps, a consistent 3D or also feature map of the assembly hall could be created. This generated feature map could be used for the localization of the mobile devices using AR. Furthermore, the generated feature maps offer several additional benefits. A current version of the real factory is always available and the logistics planner can refer to this status for future planning. In this feature map, all minor short-term changes are recorded resulting from a running production. Localizing the virtual objects can be insured due to the recognized features by the camera of a mobile device. These features can then be referred to the previously created map and therefore the device can be locally placed within the map. In addition, there is a need for further experiments with subjects to evaluate the prototypes more closely.

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