Use of a Virtual Twin for Dynamic Storage Space Monitoring in a Port Terminal

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Abstract: The paper describes research and development for dynamic 3D models and Virtual Reality (VR) applications in the context of port processes. The work described is carried out in the currently ongoing EU-funded project *PortForward*. The paper addresses the use of VR technologies in the context of industrial applications and describes how dynamic sensor data can be integrated into a 3D model of a Port. In addition to tracking data of moving assets, the sensor data mainly comprises 3D measurement data from LiDAR sensors. These sensors are installed in the port infrastructure to automatically record the current occupancy status of storage areas. The measurement data from the LiDAR sensors are dynamically integrated into the VR model in an abstracted form together process related meta-data to reflect the current process status in the port terminal. Based on that approach in the sense of a Virtual Twin, process flows and storage space management can be optimized. The use of VR technologies is crucial in this context in order to depict the complex spatial and dynamic process situation in an intuitive way.

1 INTRODUCTION

Digitization and Industry 4.0 are buzzwords that pose new challenges for companies and infrastructure operators. The ability to process and store digital data and to make decisions on the basis of digital data is becoming an elementary component of companies to ensure their competitiveness. This is all the more important in logistics, which operates at the hubs of the economy.

In the course of digitization, ports are faced with the challenge of intuitively and perceptibly mapping a wide variety of data and information on widely distributed infrastructures, superstructures, operating resources as well as freight and stored goods in an integrated form. The PortForward project (2018-2021), which is funded by the EU Commission within the framework of Horizon 2020 and its specific program Port of the Future, addresses these points and challenges with regard to the digitization of port infrastructure. The Fraunhofer IFF leads the project and works with twelve European partners to develop solutions and technologies for small and medium-sized ports in Europe.

In the PortForward project, the IFF relies primarily on its long-standing cooperation with the Port of Magdeburg, which is the biggest inland port in central Germany with an annual handling volume of about four million tons. Here, preliminary projects have already produced virtual models of the port area for strategic infrastructure planning. Against this background, the Fraunhofer IFF is developing a so-called Virtual Twin (Adler and Masik, 2020) of the Magdeburg inland port as part of PortForward in order to integrate real-time information and interaction possibilities into the virtual model.

A central use case in the project focussing on the consistent use of 3D data is the so-called Dynamic Storage Space Monitoring. For this purpose, an approach is being developed that links the spatial model of a port terminal with the dynamic movements of logistics objects and the changing space occupancy states. These are automatically and cyclically recorded by LiDAR sensors integrated into the port infrastructure. Thus real-time information about the occupancy status of dedicated storage areas and the shapes of stored objects will be available in the Virtual Twin model to enable efficient yard management for a multi-purpose use terminal.

Section 2 of the paper describes the Virtual Twin of the port that is used as a basis for the use case. Based on a static 3D model initially developed, it is briefly described how information from sensor sources are integrated to generate a dynamic 3D model.

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Section 3 gives an overview on the specific requirements in the use case in a multi-purpose use terminal and describes the overall approach for the development of the Dynamic Storage Space Monitoring.

In section 4 the approach for 3D data capture based on LiDAR sensors is described. The paper closes with a short summary and outlook in section 5.

2 VIRTUAL TWIN OF THE PORT

2.1 Objectives and Vision

The Virtual Twin approach is based on the concept of the Digital Twin, which was first introduced in 2010 (Shafto et al., 2010). With the advent of new and powerful Virtual Reality (VR) technologies, the focus of this concept is also shifting to the virtual and interactive representations of Digital Twin solutions (see Schroeder et al., 2016).

The Fraunhofer IFF creates Virtual Twin solutions by integrating different system models. For example, Höpfner et al. describe the combination of a spatial model with an energy model in a VR application for strategic decision making in industrial parks (Hoepfner et al., 2017). For the application in the port environment, the focus is on the combination of the spatial model with a logistics model of the port to enable tactical and operational decision support for the management of port processes. To allow operational support, real-time information from the physical port environment need to be integrated into the 3D model – thus, making it a dynamic 3D model. This dynamic Virtual Twin is also used for other use cases along the Dynamic Storage Space Monitoring within the project PortForward.

The use of 3D models and corresponding VR user interfaces is seen as a central possibility to intuitively display complex processes and states in their spatial and partly also temporal context. In general, the intuitive grasp of complex information and knowledge transfer are seen as central advantages of employing VR and AR solutions (see Adler and Masik, 2020 and Reder, 2019). In addition, the consistent use of 3D models in different life cycle phases from planning to operational use in terms of Digital Engineering opens up significant efficiency potentials (Adler et al., 2015).

2.2 Development of the Basic Static Model

As a basis for the dynamic Virtual Twin a static 3D model of the Port of Magdeburg was generated using basic geo data (digital terrain model DGM02 and digital ortho photos DOP20) from the State Office for Surveying and Geoinformatics LVermGeo Saxony-Anhalt. The special requirements of the later model application made further processing of this model necessary. The resulting terrain geometry of the previously regular DGM02 was transferred into a volume and performance optimized irregular triangular network TIN (Triangulated Irregular Network). The terminal areas of the Port of Magdeburg were manually integrated on the basis of digital plans. Port infrastructure, such as quay walls and locks, were integrated into the terrain model using as-built plans of the Port of Magdeburg and on-site photographs. Selected LoD 02 buildings of special relevance were modeled with façade textures (see figure 1). The result was a virtual 3D terrain model of the Port of Magdeburg, which is suitable for interactive work in real time.

Figure 1: 3D Terrain model TIN geometries (top); 3D building models with LoD 2 (down-left); relevant buildings with façade textures (down-right).

In a final modelling step, cityscape-defining vegetation and secondary objects were manually integrated into the virtual model using a 3D object library. As shown in Figure 2, this also includes logistics-related objects such as handling equipment (e.g. cranes) or stored goods (e.g. ISO containers, machinery components).

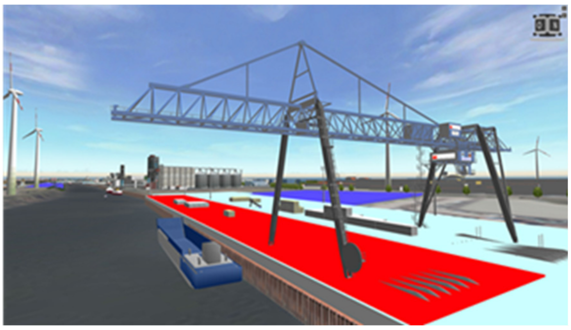


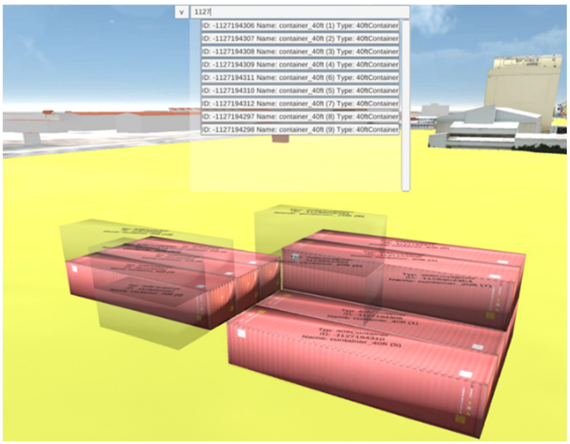
Figure 2: 3D model of the Hanse-Terminal with logistics objects and marking of areas with different storage purpose (right).

As also shown in Figure 2, individual sub-areas are differentiated as these offer different capabilities for handling and storage of goods (e.g. in terms of loads and storage capacity or regulations for storable types of goods). With such meta information assigned to storage areas, the model is currently already used operationally by the port for the administration of storage area permits.

2.3 Development of the Dynamic Model

To establish a dynamic real-time model, additional object information provided by heterogeneous software systems are necessary. Collecting these information via different special interfaces to the software systems are not effective. Therefore, an approach of using standard interface technologies and protocols, like RESTful API and MQTT was developed. In context to the Use Case of Dynamic Storage Space Monitoring, as described in section 3, an interface definition was developed that allows classified logistic objects (containers, storage goods etc.) and its meta-information to be defined and transferred. In order to map these additional information on objects in the 3D overall model, all classified objects need a unique identifier. In addition, an initial alignment of the coordinate systems between the model world and reality must be performed, e.g. to determine the reference point for positioning the objects.

There are different strategies to update the virtual model. On the one hand, the 3D model is able to pull new information periodically. But this is not always performant. On the other hand it is possible to trigger the virtual model when information are provided. The first prototype was implemented using an MQTT based publish-subscribe mechanism. With a central broker several input sources can be connected to the 3D model. The model itself fetches the relevant dynamic object data referring to the currently used features of the Virtual Twin (e.g. only fetch container related data).



ID: -1127194306 Name: container_40ft (1) Type: 40ftContainer
ID: -1127194307 Name: container_40ft (2) Type: 40ftContainer
ID: -1127194308 Name: container_40ft (3) Type: 40ftContainer
ID: -1127194309 Name: container_40ft (4) Type: 40ftContainer
ID: -1127194311 Name: container_40ft (6) Type: 40ftContainer
ID: -1127194310 Name: container_40ft (5) Type: 40ftContainer
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ID: -1127194297 Name: container_40ft (8) Type: 40ftContainer
ID: -1127194298 Name: container_40ft (9) Type: 40ftContainer

Figure 3: 3D model prototype with on-click annotations of container data and search function.

The project uses different visualization technologies to display the meta-information in the scene. For example, status information such as incoming logistics objects are coloured green. Other information such as cargo number, content, sensor data (temperature, humidity) etc. can be visualized as on-click annotation on the objects. The developed prototype of the dynamic 3D model also provides features for searching objects – e.g. container by container ID (figure 3).

The main advantage of using this dynamic real-time model is the compact, clear, object-based representation of meta-information from different software systems in one scene.

3 DYNAMIC STORAGE SPACE MONITORING

3.1 Use Case Requirements

In the Port of Magdeburg, individual port terminals are used for the handling and storage of a wide variety of goods (e.g. mixed use with palletised goods, containers, heavy goods, etc.). As a result, it is not possible to define fixed storage locations and mark them in the terminal area, as is done, for example, in pure container terminals with marking of storage aisles and locations. This of course results in a high complexity for documentation of storage locations and high efforts for the yard management.

To enable a more efficient yard management a use case was developed to implement and test a Dynamic Storage Space Monitoring. The requirements towards this use case were:

- to develop a technical approach to automatically capture the position of stored goods (without technical devices attached to the goods) and
- to integrate the good's information (meta data and actual storage location) into the 3D model of the Virtual Twin

Based on these requirements a technical approach was developed, is currently implemented and will be tested in a dedicated terminal of the port.

3.2 Approach of the Virtual Storage Location Grid and Data Capture

To make use of the Virtual Twin the approach for a Virtual Storage Location Grid was developed, based on the spatial model of the port. With a grid dimension of 2x2 meters, stored goods can be assigned to individual virtual storage locations. Thus occupied storage locations can be marked in the dynamic 3D model (see figure 4).

Figure 4: 3D model of the Hanse-Terminal with Virtual Storage Location Grid (occupied locations marked red).

This assignment requires the acquisition of information about the goods and their location during storage. In the project, this recording of meta data shall be carried out with mobile devices with an integrated GPS. For a dynamic storage space management, however, this GPS-based position acquisition is too imprecise, as there is always an offset between the mobile device used by personnel and the stored good itself.

In the focused Hanse-Terminal of the Port of Magdeburg, a camera infrastructure for research purposes already exists with which a so-called Virtual Bird Eye View (Borstell et al., 2012) can be generated. Based on differential image analyses, this allows to record the occupancy of the individual storage location grids. However, this camera based capturing is only giving 2D images and no 3D information to be integrated into the Virtual Twin.

In order to obtain 3D information on the current occupancy of storage spaces for the Virtual Twin, the project is working on an expansion of the sensor infrastructure. Using LiDAR sensors installed in the Hanse-Terminal, real contours can be recorded and integrated into the 3D model of the port in an abstracted form. Figure 5 summarizes the concept of the Virtual Storage Location Grid and its status changes based on sensor data and provided meta data of stored freight.

The occupancy of individual grid locations shall be detected by LiDAR sensors and a referring processing of the sensor data. Based on the current occupancy, it is thus possible to check where a sufficiently large free storage area is available in the terminal for a new cargo to be stored. During storage, the identification of the freight and the metadata of the freight are to be entered on site via a mobile device (e.g. tablet computer).

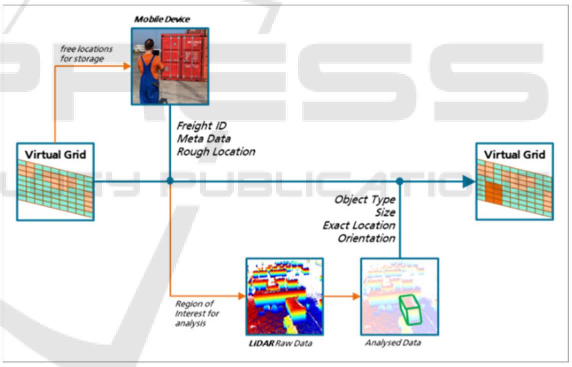

Figure 5: Concept for the Dynamic Storage Space Monitoring using a Virtual Grid.

In this way, the storage can be roughly localized via GPS. Once the storage has been confirmed, the data from the LiDAR system are be used to check whether there has been a corresponding change in the space allocation. Based on the size and position and orientation of the novel detected object the position of the stored freight can be corrected and the status of the correspondingly occupied grid areas is changed in the Virtual Storage Location Grid.

4 DATA CAPTURE IN BIGGER YARDS

4.1 Related Work

The central aspect described in this paper is the development of a novel approach for continuous recording of 3D information in a logistics specific environment using LiDAR sensors.

A classic approach of scanning 3D contours in port environments is the use of industrial line lasers (see Chun et al., 2004). Today there are also commercial solutions and applications available to automatically scan container stacks in automated or semi-automated terminals (e.g. LASE, 2021). They are creating the 3D information only in connection with the movement of cranes – thus other handling operations (e.g. freight handled by forklifts or reachstackers) are not directly captured. Newly stored freight is only scanned "by chance". For that reason such solutions are not suitable for the specific requirements of a multi-purpose terminal as described above.

Other fields of research and development are focussing on continuous scanning of storage yards with regard to the storage of bulk material (see Ou et al., 2012). But these approaches using videogrammetry and projector-contour scanning also rely on moveable sensor infrastructure.

Based on the specific experience with the Virtual Bird Eye View in the Hanse-Terminal of the Port of Magdeburg, the focus for a sensing solution was again laid on fixed sensor positions. For the purpose of the use cases described above, LiDAR sensors were identified as the most suitable sensor type to continuously generate 3D information of a wide area with no requirement of additional sensor movement.

4.2 Data Capture using LiDAR Sensors

Light Detection and Ranging (LiDAR) sensors belong to the group of time-of-flight sensors that determine distances by emitting light and measure distances by measuring the time of flight of light reflected from surfaces back to the sensor. Because the LiDAR sensor emits a laser beam in a previously known direction, it is possible to determine a 3D coordinate in space relative to the position of the sensor. Over time, this results in 3D point clouds that can be used to create spatial images and to detect and localize movements. LiDAR sensors are mainly used in the context of autonomous driving because they offer high reading ranges of >>100m and provide the 3D data comparatively quickly. First models are available on the market even in the low-cost range of <1,000€, which opens up new fields of application.

For the target application described above, the MID-40 model available from the company Livox offers a very good price-performance ratio. The performance parameters analysed by Ortiz Arteaga et al. show a very high accuracy of the sensor at ranges up to more than 200m (compare Ortiz et al., 2019). The special feature of the sensor is a non-repetitive scanning pattern, which allows a higher coverage of the Field of View (FOV) compared to line-based LiDAR sensors (Livox, 2021a), which is especially useful for the acquisition of 3D objects in port terminals over a longer integration time.

Given the possibilities to install such sensors on the light posts in the Hanse-Terminal and the required coverage of the dedicated storage area the MID-40 sensor will be complemented by another LiDAR model of Livox, offering a wider field of view (Livox, 2021b). Figure 6 shows exemplary test images taken with the MID-40 LiDAR sensor in the Hanse-Terminal of the Port of Magdeburg.

Figure 6: Test recordings with MID-40 LiDAR sensor – enriched with RGB data (left) and with height coding (right).

On the basis of the generated point clouds, standard shapes and sizes (e.g. for ISO containers or swap bodies) can be classified using AI methods. Fraunhofer IFF already developed AI based methodologies to classify objects based on dynamic point cloud data in other industrial contexts. For point cloud segmentation, object detection and tracking and object classification several AI methodologies are described in the literature (see Guo et al., 2020). For the use case several approaches can be evaluated now with the sensor installations completed.

Abstracted information of classified objects in the port environment will be directly integrated into the 3D model of the port. Freight and containers with shapes that cannot be directly classified are transferred using a bounding box. For the transfer of data on object type, size, position and orientation from the measuring system to the 3D model the

Machine2Machine communication protocol MQTT will be used as described above in section 2.3.

A simplified 3D model of the Hanse-Terminal is furthermore used for planning the LiDAR deployment. In particular, it can be used to check which viewing and detection ranges are available for the LiDAR sensors at different installation points and orientations. Currently the pilot installation of LiDAR sensors on the light posts in the Hanse-Terminal was finalised. With that installation, a defined storage area of approximately 2,000 m² is covered. The installations were planned in such a way that the storage area is detected from several sides to be able to detect the stored objects from as many sides as possible by matching the point clouds of the individual LiDARs.

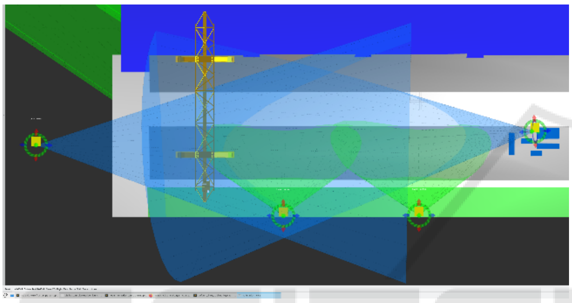

Figure 7: VR-based planning of sensor positions for the dedicated storage area.

The VR-based planning of LiDAR positions (figure 7) shows the potential for the consistent use of 3D models, since the 3D model data can be used both for planning purposes and later for the operational use of the sensor systems and corresponding evaluation of the 3D measurement data. Furthermore the high detail 3D model of the Virtual Twin can be used for a sensor simulation of the LiDAR sensors to derive synthetic 3D point clouds for virtual training of the AI methods for object classification. After the installation of the LiDAR sensors in the port environment it will be evaluated whether such virtual training can support the further development and implementation of the object classification.

5 SUMMARY AND OUTLOOK

The *PortForward* project has so far developed the technical concepts for several services, that can be integrated into Virtual Twin applications. One of these services is the Dynamic Storage Space Monitoring based on real-time 3D information. The use of the Virtual Storage Location Grid to document the space occupancy at the Hanse-Terminal, which is used for a wide variety of goods, can be used to tap into potential for optimizing the management of the storage areas. Furthermore, the use case shows the potential of the underlying VR technologies for the visualization and intuitive comprehension of complex spatial and process relationships.

In the further course of the project, the technical installations in the port will be carried out and the functions for transferring the scan data into the 3D model will be further developed and tested. On the basis of a robust recording of the storage situation and corresponding reproduction in the Virtual Twin, targeted applications can subsequently be developed which support the operative business, e.g. with regard to storage area management or optimised storage strategies.

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