INTERNATIONAL DESIGN CONFERENCE – DESIGN 2020
https://doi.org/10.1017/dsd.2020.22

SYSTEM BASED COMPONENT IDENTIFICATION USING COORDINATE DETERMINATION IN MIXED REALITY

S. G. Kunnen ✉, D. Adamenko, R. Pluhnau and A. Nagarajah

University of Duisburg-Essen, Germany
✉ steffen.kunnen@uni-due.de

Abstract

The maintenance of an industrial plant is mainly based on analogue and manual methods and processes. In the future, the maintenance data of the real object should be determined digital and transferred to a PDM system in real time. This is made possible with a digital method of component identification. This publication presents a system-based component identification using Mixed Reality. Coordinates are determined by the terminal device and compared with a reference structure. After successful identification, maintenance data can be determined and automatically transferred to a PDM System.

Keywords: systems engineering (SE), product data management (PDM), mixed reality (MR), augmented reality (AR)

1. Introduction

New development trends in plant construction, such as shifting demand and production outside Europe towards developing countries, increasing competition from new-European participants and increasing demand for customer-specific solutions, demand the continuous further development and efficiency enhancement of European plant construction companies. The new priorities in plant construction and operations are standardization and modularization, adaptation to the lead markets around resource efficiency, energy and environmental technology with large global growth, introduction of smart factories and new business models. Aftersales and services are becoming particularly important in this context. In 2016, the service sector contributed almost 19 % to the revenue of mechanical engineering companies and has grown by 6% since 1991. This illustrates the trend that in the future the service phase will play an important role for the company, which must be executed as quickly and efficiently as possible (VDMA, 2017). The digital transformation of the manufacturing industry towards “Industry 4.0” is also changing plant operation. The new possibilities in digitization and automation offer great potential for improving the productivity of plants, but also for accelerating and simplifying existing maintenance processes. In addition, more and more data are generated and collected during the life cycle of large-scale plants - a resource that will become increasingly valuable in the future if it is meaningfully collected, combined and evaluated. The digitally processed and provided data can increase the learning effect in future inspections and at the same time reduce the amount of paper waste (VDMA, 2019).
Due to constant development and implementation of new functions as well as highly varying customer requirements, industrial plants are becoming more and more complex (Adamenko et al., 2017). This results in a higher number of different components, whose clear identification is a major challenge.

Technologies such as QR codes, RFID or Bluetooth chipsets and, in rare cases, geometry matching are suitable for uniquely identifying these components. The aim of these technologies is the unique identification of a component within a large industrial plant.

1.1. Problem statement

The maintenance process of an industrial plant is a mainly manual and analogously documented process. The service team, which is responsible for carrying out the maintenance of a plant, performs a visual inspection for damage and wear during a service phase. The test results are documented by hand during the inspection. After the inspection and clarification, the documented results are transferred to a PDM system. The entire process from the inspection to the generation of a service order for repairs on a large industrial plant is very time-consuming and can be significantly increased in duration and volume by unexpected problems due to a bad data quality. For the plant operator, this leads to increased maintenance costs and a longer downtime of the plant. Better planning of maintenance could prevent this problem. This can be done by making the maintenance data of all previous inspections available so that damage patterns or repetitive problems can be identified. (Apel, 2018)
A critical point of the manual maintenance process is the assignment of datasets to the associated elements within the product data management. The previously mentioned technologies, such as QR codes, RFID chips and geometry matching, make such assignments possible but have some weaknesses.
Locating methods based on signals, such as RFID chips, only work in the plant environment if these are already integrated in the components and are not attached externally. Due to the very high number of different elements, upgrading is very cost-intensive and time-consuming (L-Mobile, 2019). In addition, there may be interference between the individual elements, as these are very often very close to each other. In addition, only individual elements and not surfaces can be determined. Due to the possibility of heavy contamination of the components, the QR codes can no longer be readable and the signals of the chipsets can be disturbed. In industrial plants where liquids or chemicals are transported, e.g. cooling towers of power plants, thick layers of limescale can form which lead to the fact that the components can no longer be recognized optically and thus make geometry adjustment impossible. An identification possibility is therefore necessary which can be applied independently of optical recognition methods and signals.

1.2. Objective of the research activities

The aim of this paper is to present a solution that can capture all the information required for maintenance clearly and digitally and to manage it throughout the plant lifecycle. Component identification must be independent of outgoing signals from components, such as RFID chips, and independent of optical geometry adjustment, since contamination impairs this adjustment. Even in the case of contamination or defects in the components, the position within the system remains unchanged. The determination of a coordinate point is thus possible independent of time. There is still the problem of of how to determine a coordinate within an installation and then assign it to a specific element.
Thus, a virtual model of the plant can be created at any time, which represents the current status. In order to represent the digital twin, a system structure will be developed that allows objects and the coordinate point to be compared by setting appropriate parameters. The coordinates are determined by a corresponding device using extended reality technologies. A calculation algorithm compares the coordinate point with the parameters of the system structure and determines which plant element belongs to the specific coordinate point. An ID for that specific element gets generated, which is compared to a PDM system, so that the generated maintenance data can be uniquely assigned. The determined data should then be visualized and made available to the user. A system-based approach is shown how data can be captured, assigned and subsequently made available again in the real environment using extended reality technologies.

2. Digital twin

2.1. Definition

A digital twin (DT) is a digital representation of a material or immaterial object from the real world. Digital twins enable a comprehensive exchange of data. However, there is more to it than pure data

https://doi.org/10.1017/dsd.2020.22 Published online by Cambridge University Press

and they contain models, simulations and algorithms that describe their counterparts from the real world and their properties and behaviour.

2.2. Digital twin for plant maintenance

Digital twins have great potential for the maintenance phase of systems. Possible fields are the identification of the location of specific components, condition monitoring, predictive maintenance and risk management (Kunnen et al., 2019b). The digital twin of an industrial plant is developed for a specific task. Since industrial plants are very complex and both, application areas and products, are varied, a multitude of potential application areas is possible. For this reason, the developed digital twin must offer the possibility of subsequent expansion and adaptation. Consequently, digital twin can be modelled in a PDM system and is therefore suitable for industrial plant engineering. The PDM system stores the collected process data and at the same time reflects the structure of the plant. It can be extended and supplemented as required by continuous adaptation of the plant. Furthermore, this form of digital twin enables the implementation of process data through almost all possibilities of determination.

3. Data acquisition and provision

3.1. Extended reality

The various realities enable the user to detach himself from the restriction of his perception of reality and, as in the case of virtual reality (VR), to "immerse" himself in completely computer-generated worlds or to experience an enrichment respectively superimposition of the real environment with additional information and interactive digital content through augmented reality (AR).
The term Virtual Reality (VR) is defined as a real-time computer-generated environment in which the user can "immerse" himself. The goal of VR is to achieve the highest possible degree of immersion, up to a point where the virtual environment corresponds to the real environment in all multisensory aspects (Dörner et al., 2014; Spath, 2017).
Augmented reality offers the contrast to complete isolation from the environment. In AR, the real world is superimposed with a computer-generated image or its virtual content. Thus, the perception of the real world is extended (augmented) by the virtual contents. The user has the possibility to interact with the real world as well as with the virtual world and can manipulate the virtual contents. (Spath, 2017)
Figure 1 illustrates the demarcation between the individual realities, which are summarized under the generic term of Extended Reality (XR). An area is defined between the two extremes of reality and virtual reality. This area is the Mixed Reality Continuum, in which real and virtual contents are combined. The state of the augmented reality depends on the number of triggered multi-sensors up to a point where the user perceives the virtual content as virtual reality (Milgram et al., 1995).

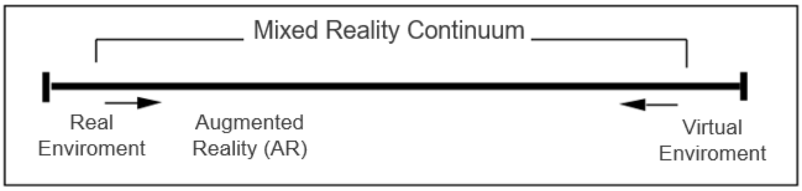

Figure 1. Extended reality overview (adapted from Milgram et al., 1995)

One possibility for mapping the Mixed Reality Continuum is the Microsoft HoloLens. This is a self-sufficient computer that makes it possible to display virtual objects and data in a real environment. Furthermore, an interaction with the virtual environment is possible by movements of the user. The HoloLens is a so-called Head-Mounted Display (HMD). In contrast to the commercially available VR devices, it is possible to see the real world through the transparent display. The HoloLens offers interaction via the gestures as well as the possibility of voice control. At present, however, this is only possible in the English language. A combination of gesture and voice control allows the user simple operations in mixed reality. (Collins et al., 2017)
Every extended reality has a preferred field of application. The application cases also illustrate the weak points of these methods. In the VR, the user can have the information provided displayed

https://doi.org/10.1017/dsd.2020.22 Published online by Cambridge University Press

regardless of location, so that intercontinental data provision and information procurement are possible. As a result, for the maintenance of a plant it is no longer necessary for a responsible person to be able to decide without having seen the problems on site. Due to the contradictory nature of reality, MR/AR is particularly suitable for direct use in the respective problem area. During the plant inspection, a maintenance team can access relevant information in real time and also record information and data like photos or voice recordings. This information can later be processed and visualized in the VR environment. (Kunnen et al., 2019a)

3.2. Data gathering in mixed reality

There are various approaches to position determination and orientation in industry. The basis, however, is always a reference system which serves for the apparent and perspective positioning of the virtual environment in the real environment. Furthermore, a spatial model can be created from the determined coordinate points of the surface, which is superimposed with the reality and allows a position determination with subsequent data assignment. In order to determine the position and orientation of objects in closed spaces, procedures are necessary that use different signals which are either generated for this purpose or which are already available. The most important methods are satellite technology, inertial position determination using sensor data, optical position determination using markers and hybrid systems which use combinations of these technologies.

Gaze is the primary way to fix a point in Mixed Reality and therefore to determine a coordinate in three-dimensional space. By overlaying a reference coordinate system with the real world, the position of the observer and the viewing direction can be determined at any time. From these two factors the so-called Gaze vector is formed. A distinction is made between Head-Gaze and Eye-Gaze. If the used device has a built-in eye-tracker, the Gaze vector can be determined simply by the viewing direction of the eyes. The HoloLens 1 does not offer this method, so that the Head-Gaze vector must be used, which determines the viewing direction from the head position of the observer. As soon as the viewer fixates on an object, the distance to this object as well as the size is determined. At approximately two meters, objects with a size of 5-10 cm can still be recognized. Especially in large power plants, most of the maintained components are significantly larger. Furthermore, they are arranged in a pattern with a sufficiently large space between them so that the neighbouring object cannot disturb the Gaze vector of the HoloLens. (cre8ivepark, 2019)

As soon as the viewer has fixated an object, its coordinate point is determined. This point is compared with a coordinate field within the system structure so that a system component is determined. Each system component is assigned an ID that is uniquely referenced to a PDM element. All subsequently determined data records can thus be assigned without errors.

The Software Development Kit (SDK) for the Microsoft HoloLens already offers the possibility to integrate the Gaze vector into a HoloLens application.

The comparison with a coordinate field was chosen because the inaccuracy of the Gaze vector allows a large tolerance of the determined coordinate point. These tolerances can be compensated by a coordinate field for an element.

3.3. Cross structural system architectures requirements

One of the major prerequisites for such maintenance process is a data model that enables continuous data transmission. The digital twin of the system enables continuous data availability. In order to be able to realize a virtual image of a plant for maintenance as a digital twin, it is necessary to incorporate all available information into the data model. In addition to environmental conditions and sensor data, this also includes data such as operating settings, inspection and maintenance information. This data must be transmitted continuously to the twin in order to always represent an actual image.

In addition, a digital twin must be adaptable, i.e. if something changes in the object itself or in the ambient conditions or operating conditions, these changes must be adaptable in the digital twin without great effort or even automatically through complete parameterization.

In addition to physical models, artificial intelligence and machine learning technologies are also used for the digital twin. The artificial intelligence (AI) can be used to identify patterns in the data and to draw conclusions about possible faults or anomalies. These different physical and analytical models

https://doi.org/10.1017/dsd.2020.22 Published online by Cambridge University Press

must be linked together and exchange data in order to create an actual image. The collected data must be stored, managed and converted into a format that can be used for algorithms or simulations. A wide variety of data, such as data from sensors, simulations and maintenance information, must be combined in order to make the most accurate predictions possible.

In order to realize a digital twin at all, technologies and a sufficient infrastructure are essential to create models and simulations, but also to collect data and enable communication and interaction between the digital twin and the physical object. Cross-structure system models offer the possibility of connecting information within a given context. In the case of component recognition within a plant, the structure must be connected to the parameters or coordinates so that assignment is possible. (Kunnen et al., 2018)

In addition to the requirements that must be met for a digital twin to create a value, the security of the digital twin also plays an important role. Since the digital twin has all the current and historical data and models of the object, it must be protected from unwanted manipulation. Different profiles must also be set up for different user groups, so that a specific employee only receives the necessary information they need.

4. System-based component identification

4.1. Concept for data determination and assignment

The concept for data collection and allocation is shown in Figure 2 and is based on a central system model in SysML. In this case, the SysML model serves as an interface between the HoloLens application and the PDM system. The Gaze vector is used to determine three coordinate points in a space using the HoloLens camera system. The identification of a component can be done in two different forms. Parameters stored in the model can be retrieved so that a grid box, defined by a tolerance field, is placed over the inspection elements. If the determined point is within this box, the component can be clearly identified. The coordinate point is thus determined at the collision point of the viewing direction of the observer with the real object. The second possibility is to compare the coordinate points with the model.

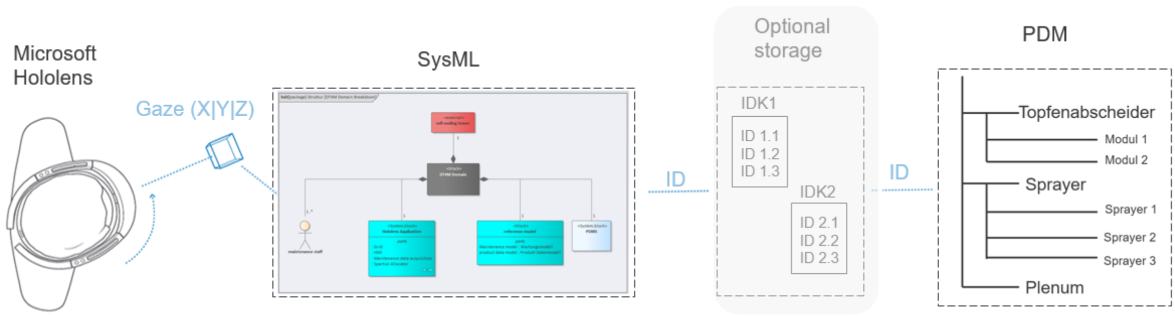

Figure 2. Concept for data transfer between HoloLens and PDM system

However, both methods require that the parameters are previously and clearly assigned to a component. Due to the accuracy, only larger elements or assemblies can be identified at this time. An example is the machinery of a cell cooling tower, which consists of a fan, a motor and a gearbox. Thus, the three main components can be determined via parameterization, smaller elements or components of the assemblies cannot be identified at this stage. Both methods have their advantages and disadvantages. The comparison of coordinate and model is much faster, but the user does not get any visual support during the inspection. If, for example, only a part of the component is visible, the application of visually displayed objects is recommended, so that the identification can be carried out more easily and clearly. The determined coordinates or objects are then assigned to the corresponding components of the product structure using the Spatial Allocator. This adjustment can be done by comparing the coordinates with the parameterized system model or with a stored list with the required information. The application then checks whether an ID is already stored for the component, or if this ID must be created for the component. This ID is optionally stored in a memory. The optional memory is necessary because the maintenance method must also work without a network connection to the PDM system. The assignment of an ID is described below in section 4.2.

https://doi.org/10.1017/dsd.2020.22 Published online by Cambridge University Press

After the ID has been determined, an object is created on the local HoloLens memory in which the generated maintenance data is stored. If there is a direct connection to the PDM system, the maintenance data can be transferred directly to the PDM elements. The maintenance data can be documented in the form of images, voice or text recordings and checklists. If these have been determined offline, the PDM system queries for all stored IDs as soon as a network connection is available. If these IDs already exist, a new maintenance status for an existing PDM element is created for the object. If no corresponding ID exists, the PDM element is created again so that future maintenance documents can be appended to it. It should be emphasized that the data transfer from the real to the virtual environment is not one-sided. The bidirectional interface allows the data to be retrieved and models or drawings to be built to visualize the data. SysML offers the possibility to connect a 3D visualization tool so that the data can also be transferred to 3D models. If maintenance of the components is carried out after the inspection, damage mapping can thus be created in advance and made available to the user. Furthermore, it is possible to highlight defective components in the HoloLens with different colors. This is possible by displaying a virtual object, for example a small red cross, at the coordinate point of the defective element. The maintenance staff thus gets a quick overview of the elements to be maintained.
The inspection procedure can best be described by a simple example.
During an inspection interval, the contracted company must check the sprayers of a cooling tower for a failure. These elements are arranged at regular intervals within the cooling tower. The inspector inspects the individual elements one by one. If a damage was visually detected, it must be documented. For this purpose, the inspector looks at the component through the HoloLens and confirms on the user interface that there is a damage regarding that specific element. Then a damage class is determined by the inspector and, if necessary, additional voice or image recordings are made. The inspector ends the damage recording and can inspect the next elements.
All necessary comparisons and assignments are carried out in the background without the inspector having to enter the system environment. If a network connection is available, the inspection results are automatically transferred to the PDM system. The HoloLens Application consists of four parts:

- Human-Machine-Interface (HMI)
- Maintenance data acquisition
- Spatial allocator
- Grid or coordinate system

The HMI serves as an interface between the viewer and the software. The user interface should be as simple as possible so that it can be used intuitively. A template with a stored workflow provides a step-by-step guide for the user, so that a consistent performance of maintenance can be enabled. The optional storage corresponds to the storage of the end device and is connected to the app. Thus, the maintenance data can be saved locally and transferred to the PDM system as soon as a network connection is available. The intermediate storage step is intended as an emergency solution for systems in which no network is available for political or data security reasons or for technical reasons, due to shielding or interference signals.
The third part of the HoloLens App is the Spatial Allocator. This includes the calculation algorithm for comparing the coordinates with the product data model. The last part describes the grid, which is necessary for the determination of IDs. Coupled to the grid are the nodes of the grid on which the individual components lie. Six parameters are required to determine the coordinates within the grid. Three of these parameters describe the position of the observer.
The other three parameters can be used to determine the offset vector of the observer's position to a predefined reference point within the system. The reference point within the system can be defined in advance at the best possible location. This location must fulfil the following criteria:

- Fast access in case of loss of signal or connection to the anchor point of the coordinate system
- As centrally located as possible to minimize the chance of signal loss.

Figure 3 shows the SysML domain model of the HoloLens application. The four described parts of the HoloLens Application are modelled as a composition. This means that the HoloLens application can only work if all four parts are integrated.

https://doi.org/10.1017/dsd.2020.22 Published online by Cambridge University Press

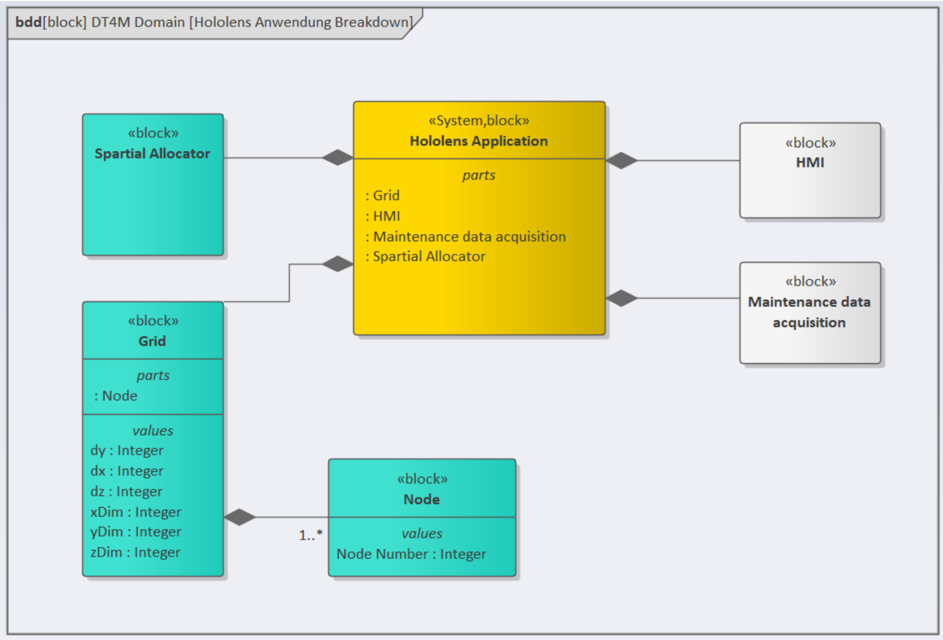

Figure 3. Domain model for the HoloLens maintenance method for industrial plants

When identifying components within the plant, a differentiation is made between elements that are either parameterizable (shown in blue in Figure 4), meaning that they occur in large numbers and regularly, or elements that occur in very small numbers (green in Figure 4).

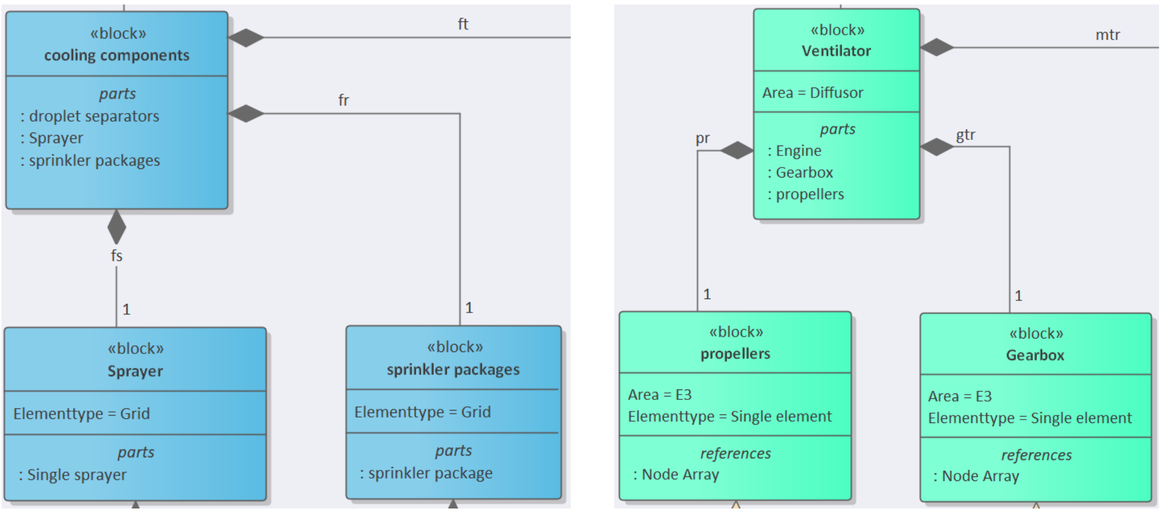

Figure 4. Extract of the element types of the product data model

The parameterizable components can be divided into single and area elements. Figure 4 shows two excerpts from the product structure of a cell cooling tower. The cooling components block contains three further components, sprayer, sprinkler packages and droplet separator. The figure shows examples of the sub-element sprayer and sprinkler packages. Both component types can be illustrated using the grid, whereby the sprayer is a single element and the trickle pack is an area element.

Single elements are located on a node and have a fixed coordinate. After comparing the coordinates of the HoloLens with the product structure, inaccuracies are corrected by assigning them to the nearest coordinate or node in the reference structure or list. Area elements are defined by at least four node or coordinate points. This number of points depends on the shape of the determined area.

The green blocks of the system model describe elements that occur only once in the product structure and are therefore defined using the element type Single Element. The comparison with a grid is not necessary, which means that these can be defined uniquely by the position in the room.

https://doi.org/10.1017/dsd.2020.22 Published online by Cambridge University Press

The digital twin of the plant consists of the parameterized system structure in SysML and product structure as well as the data in the PDM system. All relevant and required product data, such as geometry and dimensions, can be derived from the SysML structure. If components or the structure change, this can be adapted quickly and without major complications and represents a virtual representation of the plant at any time. The PDM system adopts the structure of the SysML model and the process data, in this case maintenance data, is saved in it. SysML enables the creation of a universal parameterized system structure. Thus, a generally valid template for a cell cooling tower can be created, from which the individual variants can be derived. Via an input mask, the most important parameters for parameterization can be entered and made available to the model. Thus, the individual models for a specific cooling tower can be built up quickly and easily. Through the interface to the PDM system, this model can be transformed into a structure, so that a separate article is created for each component included. These aspects are among the most important functions that justify the use of a SysML model.
The combination of both instances forms the virtual model of the plant from product and process data, so that the current maintenance status of the plant can always be displayed. This forms the digital twin for maintenance applications. The digital twin can be extended to implement engineering processes such as change management and condition monitoring.

4.2. Calculation of an ID

The determination of an ID can be done in two different options, the direct coordinate adjustment or the adjustment according to vector grid mapping. Both methods are based on the determination of coordinates using the Gaze vector but differ in the processing of the determined points.
For direct coordinate comparison, a reference list is required in which a fixed coordinate is defined for each element of the product structure. This method is particularly suitable for parameterizable elements such as sprayers or droplet separators. Area elements can be defined, as already mentioned, by a delimitation of several coordinates. The coordinate alignment method has the advantage that no additional element is necessary for the identification of a component other than the list. The interface or the interrogation algorithm can be easily modelled and universally transferred to other plant types and variants. Furthermore, no additional limitation in planes is necessary, as the coordinates are determined from the previously defined origin of the plant. A major weakness of this method is the resource consumption for large amounts of data. The larger the product structure and the associated reference list, the longer the query takes until the ID can be determined using a coordinate. The reference list must be of a very high quality, since a coordinate must be defined in advance for each element type, because these cannot be subsequently transferred to the system during the inspection.
The adjustment using a vector grid is based on the method shown in Figure 5. Two parameters (xDim & yDim) describe the mesh in a two-dimensional space. The additional zDim parameter allows the extension to a three-dimensional space. The parameters dx and dy describe the distance between the individual nodes in X and Y direction. The selected mesh must be so fine-grained that each element is located on a node. The coordinate alignment automatically selects the nearest node to determine the ID. An advantage of this method is that the grid can be created during the plant inspection. In the first step of calibration, the origin is selected and then the coordinate of at least three parameterizable elements is determined.

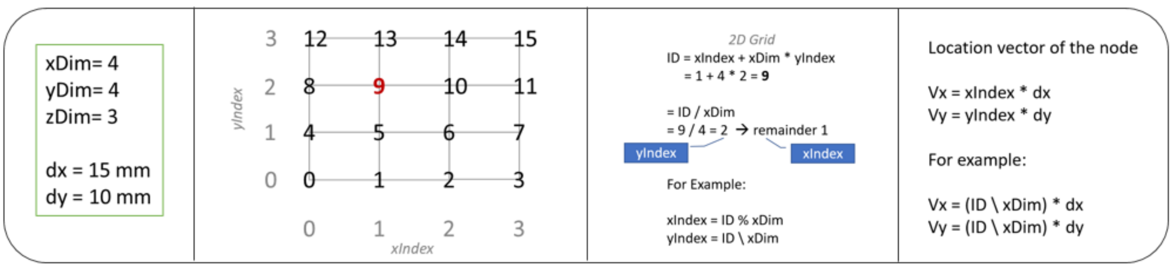

Figure 5. Vector-Grid mapping adapted from (Grasemann, 2014)

This is sufficient to map the network overlaid with the structure. Since the calculation algorithm can be performed using two simple formulas, the required resources are very low. Furthermore, a very simple calculation back and forth between the coordinate point and the ID is possible. If the ID is transferred to the PDM system, the associated coordinate of the element can be determined in a subsequent maintenance order based on the ID. It is therefore no longer necessary to save both information separately and to have them available. A disadvantage, however, is that an extra element and an additional interface are required. The grid must be adapted to the respective elements in a two-dimensional plane. If a 3D grid is created in advance for the entire system, it must be ensured that the objects within the system that cannot be parameterized also have a node within the grid. Furthermore, the delimitation of area elements is only possible via the predefined nodes, which can lead to inaccuracies in the image, depending on the resolution of the grid.

4.3. Benefits and pain-points of a mixed reality supported maintenance

A Mixed Reality supported maintenance of an industrial plant has many advantages for the responsible personnel. The determined data is captured digitally so that no manual post-processing is necessary. In this way, the source of errors in the transfer of analogue to digital data records can be avoided. Furthermore, no additional manual assignment of the data to the corresponding elements is necessary, as this step is performed automatically by the HoloLens application with connection to the PDM system. The developed system-based digital twin of the plant can be extended to other application areas at any time by connecting additional software systems. This enables a query of the current maintenance status of the system with all relevant information at any time. These information records can be visualized to see, for example, damage patterns of defective or faulty components. From the point of view of the maintenance personnel, the greatest advantage is that all information is now determined on a single device and the hands remain free. In critical situations, personnel are not forced to switch between devices. Furthermore, the HoloLens can be connected to a safety helmet, which is mandatory during the maintenance of a system. Therefore, maintenance personnel have no safety restrictions.

Despite the many advantages, this method also has some pain points. The dependency to a technical device is very high, so that the maintenance documentation cannot be carried out in case of a fault of the device and the person involved must go back to the analogous documentation. The same problem occurs with the battery capacities of the Mixed Reality devices. The battery is not replaceable and has an operating time of 2-3 hours under full load. For one working day, 2-3 devices are necessary with the HoloLens 1. However, cooling towers in particular are often contaminated, so that the break times can be used for charging or changing the units.

5. Conclusion and outlook

In summary, it can be said that a digital twin in combination with Mixed Reality supported component identification offers many advantages for the maintenance personnel of a plant. By connecting the Microsoft HoloLens to a digital twin, components can be identified during the inspection of a plant using the coordinates. Once the components have been identified, an ID is defined and, in the next step, all relevant data of the maintenance process is determined in the form of images, voice recordings, checklists or textual descriptions. This data is transferred to a PDM system with the assistance of the ID and stored. The combination of product and process data represents the digital twin. The product data is presented as a system model in the modelling language SysML. This system model includes a parameterized structure of the plant.

In the next steps, an application must be developed that compares the determined coordinates of the Gaze vector with the existing product structure so that a component is determined within the application. The decision whether the adjustment is carried out via a grid or a list adjustment is simulated using a fictitious example and then transferred to the real system. The collected possibilities are then combined in a maintenance method for plants, allowing future maintenance to be carried out digitally and quickly with the aid of mixed reality devices.

A future topic is the visualization of maintenance results. By connecting the PDM system with the system model, a new interface to a CAD or visualization tool can be developed. The defect

https://doi.org/10.1017/dsd.2020.22 Published online by Cambridge University Press

components requiring maintenance have a parameter that can be changed for the visualization. This parameter can be associated with a specific color through the interface in order to display the damage fields or damage areas in a two- or three-dimensional image or model. These images or models can then be passed on for evaluation or made available to personnel for support in future maintenance phases.

Acknowledgements

This work was supported by the German Federal Ministry for Economic Affairs and Energy within the Central Innovation Programme for SMEs.

References

Adamenko, D. et al. (2017), “Knowledge-based approach to classification in plant construction”, 15. Gemeinsames Kolloquium Konstruktionstechnik “Interdisziplinäre Produktentwicklung”, 15. KT-Kolloquium, 05.10.-06.10.2017, pp. 357-368.

Apel, H. (Ed.) (2018), *Instandhaltungs- und Servicemanagement: Systeme mit Industrie 4.0*, Hanser, Carl, München.

Collins, J., Regenbrecht, H. and Langlotz, T. (2017), “Visual Coherence in Mixed Reality: A Systematic Enquiry”, *Presence: Teleoperators and Virtual Environments*, Vol. 26 No. 1, pp. 16-41.

cre8ivepark (2019), “Mixed Reality - Gaze Targeting”, available at: https://docs.microsoft.com/de-de/windows/mixed-reality/gaze-targeting (accessed 28 October 2019).

Dörner, R., Broll, W. and Grimm, P. (2014), *Virtual und Augmented Reality (VR: Basics and Methods of Virtual and Augmented Reality)*, EXamen.press, Springer, Berlin.

Grasemann K. (2014), Druckverlustminimale Rohrleitungsführungen von Abdampfleitungen in Großkraftwerksanlagen: Minimum pressure loss in piping systems for exhaust steam lines in large power plants - Doctoral Thesis.

Kunnen, S., Adamenko, D. and Köhler, P. (2018), “Development and application of a cross-structural data model. 16. Gemeinsames Kolloquium Konstruktionstechnik am 11. und 12. Oktober 2018 in Bayreuth Tagungsband”, pp. 200-211.

Kunnen, S. et al. (2019a), Coupling of Mixed Reality and a digital twin for the maintenance process of an industrial plant.

Kunnen, S. et al. (2019b), “An Approach to Integrate Risk Management in Cross-structure SysML-models”, *Proceedings of the Design Society: International Conference on Engineering Design*, Vol. 1 No. 1, pp. 3571-3580.

L-Mobile Group (2019), “RFID-Transponder - RFID Finder”, available at: https://rfid-finder.com/rfid-auto-id-technologie/rfid-transponder/ (accessed 13 November 2019).

Milgram, P. et al. (1995), “Augmented reality: a class of displays on the reality-virtuality continuum”, In: Das, H. (Ed.), Monday 31 October 1994, SPIE, Boston, MA, pp. 282-292.

Spath, D. (2017), *New developments in corporate organization*, VDI-Buch, Springer Vieweg, Berlin, Heidelberg.

VDMA (2017), “Guide Fit for Service”, available at: https://www.vdma.org/documents/105628/878344/Fit_for_Service+Leitfaden.pdf/1d77a96a-a464-4ee4-98a1-a9d5763b565f (accessed 28 October 2019).

VDMA (2019), “Mechanical engineering – figures and charts 2019”, available at: https://www.vdma.org/documents/14969753/26250981/Maschinenbau+in+Zahl+und+Bild+2019.pdf/fe7cbf9d-3873-d927-4d98-c979dac2b5f0 (accessed 28 October 2019).

https://doi.org/10.1017/dsd.2020.22 Published online by Cambridge University Press