Transdisciplinarity and the Future of Engineering
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An Approach for the Incremental Update of a Digital Twin of a Process Plant

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Abstract. Process plants have a long life cycle which often has started prior to the digital era. Most recently, the concept of digital twin provides significant support for process optimization and reducing the erroneous impact of human factors. The twinning of the existing plants or a portion of is necessary based on automated and accurate object acquisition by scanning. Automatic shape segmentation based on machine learning from unstructured (e.g. point cloud) data is a core step of the digital twinning process for industrial facilities. Once this twin has been generated, a frequent, mostly incremental update is necessary due to modifications during the maintenance and modernisation. The exploration of the pipeline semantics presents a further research step to keep coherence of 3D model with the pipeline and instrumentation diagram. In this paper, the entire approach is described based on a use case of a biogas plant in an industrial collaboration. Transdisciplinary aspects of this approach are further explored.

Keywords. Digital Twin, Process Plant, Object Recognition, Human Factors, Simulation, Transdisciplinary Engineering

Introduction

Plant operators must document the construction and operating conditions of their plants (as built/as maintained) for various reasons. This starts with the legal obligations to provide evidence. Up-to-date plant documentation is a pre-requisite for reconstructing the causes of malfunctions and minimizing risks for operating personnel. So far this documentation is still done manually and paper-based, which is easier in the first step however increases difficulties with regards to audits. While the operating status of the plant can be reconstructed relatively easily via the process control system, the construction status is often poorly documented. Already during the construction of a plant deviations to the planning status occur. These deviations are usually only incompletely updated in the documentation. Further, due to time constraints, plants are not planned down to the last pipe or are built before the planning has been completed [1].

Also with regards to maintenance this incomplete documentation leads to more difficulties. Planning and executing maintenance activities are done on basis of piping and instrumentation diagrams (P&ID). It describes in a schematical way the layout of the plant from a process engineering point of view. Solitary components such as equipments, instruments etc. are provided. However, with regards to piping, it only provides a

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simplified representation. The connection between two instruments for example are represented by lines. In reality such a line can consist of various components such as pipes, elbows, flanges, etc. In addition, a P&ID diagram does not provide any spatial information based on P&ID, the maintenance technician thus cannot tell where which equipment such as a pump is located or where which pipes run [2]. Two pipes that branch out to the left and right of a pump according to the diagram can run parallel in the real system. In practice, this can lead to a scaffold being erected and dismantled again for a maintenance step, although it is needed at the same place for the next step [3].

For a biogas plant or food production facility that normally cascades from top to bottom, the lack of spatial dimension in the P&ID may be manageable. With increase of complexity this changes. Prominent examples are plants in the chemical industry. They consist of hundreds of meters and can be spread over several buildings and floors. In such cases maintenance technicians spent significant time in orientation by walking through the plant to find the component of interest. Besides the amount of time spent for orientation caused by limited planning, operators also try to reduce the presence of workers in the plants for safety reasons. Additionally, such maintenance workers are often employed by sub-contractors and are not familiar with a specific plant. This increases risks and is contradicting the operators objective.

Another challenge with regards to documentation appears when the ownership changes. The lifecycles of plants are very long and owner may change over time. As stated above, the documentation usually is not updated according to changes e.g by maintenance activities. A transfer of documented knowledge from one owner to another one is inevitably incomplete. In many cases the know how is stored as expert knowledge in the heads of the operating and maintenance personnel. It is lost when the personnel retire or are replaced by employees from outside companies who are not familiar with the operation of a specific plant. In order to compensate this lack of knowlegde transfer, operators demand for a better provision of visual orientation for their technicians. Personnel can better orientate in the plant and is enabled to carry out work more efficient.

During the last decades also in process industry the complexity increased due to new developments and automation technology. In consequence, also experienced employees are challenged with maintaining their overview. All this demands for a sufficient representation of expert knowledge in a visual manner. That also can be understood by maintenance technicians who, as service providers, are not sufficiently familiar with the plant or additionally language barriers can be overcome. Today's young technicians in particular expect information to be in digital form and to have it available from anywhere [3].

Plants are also constantly being redesigned and rebuilt to increase their productivity or to be able to produce other products [4]. When optimizing existing plants, planners start with a status that may be procedurally consistent with P&ID, but does not reflect actual building and space conditions. Today, in case of modernization design, firms spend a considerable amount of time and effort to match the P&ID with the spatial conditions before they can begin the actual design of the new plant components. Accurate documentation of the current construction status is also required for the recommissioning of the modernized plant, and in many cases the clients and also the regulatory authorities now expect 3D documentation. This gap must be closed by setting up a digital twin of the plant.

In a previous work, the approach of generation of the digital twin of a brownfield process plant based on automatic object recognition by machine learning was presented [5]. The next step in the evolution of digital twin provides the possibility of a continuous update of a digital twin under aforementioned changing operating conditions, well-harmonized with the updated P&ID [6]. It is a concept that requires a transdisciplinary approach for its creation, implementation, and use. Even when applied in the manufacturing domain predominantly, business knowledge as well as human behavior knowledge are needed, next to the technical knowledge [7]. Without collaboration between people from these different disciplines, the digital twin concept cannot fully be exploited [8].

The outline of the paper is as follows. In section 1, the background of the generation of a digital twin is introduced. In section 2, the process definition for generation of digital twin in a process plant is explained, followed by automatic identification of pipe systems in section 3. Discussion of the results and challenges that still exist in the process domain is presented in section 4. The paper ends with a brief conclusion and outlook.

1. Background

The digital twin is the virtual surrogate of a real existing plant. It can include different information and have different users, depending on whether it is to support development, planning, assembly, production or service. The challenge for plant designers and operators is to build this digital twin with reasonable time and cost and keep it up-to-date during the entire life cycle [9].

Due to incomplete 3D documentation, building digital twins in plant engineering is more difficult than in other industries. Typically, plants are first captured in 3D using laser scanners. Depending on the resolution of the scanners and the size of the plant, this creates point clouds with enormous amounts of data that are almost impossible to handle in today's systems. The point clouds represent the surface of a plant and serve the designers as a kind of template or reference. On this basis, the manually remodelling of equipment (tanks, pumps, etc.), pipelines and fittings is carried out by using a common authoring system. However, this is very time-consuming and cost-intensive, which also is the reason why today only very few digital twins cover actual spatial information. This complete description of the plant is missing for various works. Planning maintenance activities is a typical example. The maintenance engineers have do do their planning based on the P&ID, without any spatial information. This leads to unprecise planning, because significant time is spent on searching for the correct component in the real plant. This inaccuray today is compensated by additional effort and increased costs.

Up to now, there is or was no technical solution that enables an automatic linking of the P&ID with the spatial information of the current construction status of plants and thus lifts the P&ID into the third dimension [10]. The prerequisite for this is, first, an automatic object recognition system that is capable of recognizing objects such as pipelines or fittings on the basis of a fraction of the scanned points and determining their position in space [11]. This goal was achieved in the previous research [5] and the object classes can be recognized reliably by using methods of artificial intelligence (machine learning, ML) [12]. Secondly, it must be possible to enrich the recognized objects with the corresponding information in the P&ID with as little effort as possible [13]. If required, these "intelligent" objects can then be converted into editable CAD models, e.g. in order to plan modifications to the plant [16]. Finally, the singular objects have to be connected in a pipeline system by using the pipeline semantics.

2. Process definition

Actuality is a key requirement for the digital twin with regards to legal verification. However, plants undergo numerous changes over their life cycle, and while these changes are tracked in the P&ID if they are relevant to the process, they are usually not reflected in the geometric information of the construction documents. This is also due to the fact that many plant engineers do not provide these documents in electronic form or as 3D model to the operators. Since plants undergo several geometrical changes throughout their lifetimes, is is not enough to set up the digital twin only once [15]. It has to be maintained over the entire plant life cycle in order to be able to use it during operation for planning maintenance measures or preventive failure analyses [16].

A digital twin covering spatial information offers the possibility of moving virtually through the plant and simulating, for example, the evacuation of employees in the event of an incident. Operating technicians can be trained on malfunctions so that they know right away where to turn offvalves are located, for example. Maintenance measures can also be prepared virtually on the 3D model. Inspection points can be spatially localized in advance and the use of auxiliary equipment, such as scaffolding, can be taken into account. The digital twin offers the possibility of mapping the expert knowledge of operating and maintenance personnel who are gradually retiring due to age. This makes it the central source of knowledge for training the next generation. [16].

One of the most important use cases for operators the digital twin can support is plant modernization. Complete and up-to-date plant documentation is required for both planning rebuilds and for re-certifying the modernized plant. Engineers not only need the logical structure of the plants with equipment and fittings as well as the current piping, but also a 3D model in order to be able to fit the new components into the existing plant. To do this, plants today have to be extensively measured and remodeled, which can cost millions of euros depending on the size of a plant. A key requirement of plant operators is therefore that the digital twin can be built and maintained faster and more cost-effectively, especially with lower manual effort [17].

Due to the immense costs so far, plant operators have only had digital twins created in rare cases. In case of modernization, usually parts of a plant are kept and others are going to be replaced. Therefore the engineers need to ensure that the new areas fit to the kept and already existing ones. In order to reduce the costs to a necessary minimum and ensure that new and existing parts fit together only important areas are remodelled [18]. This way the connection point between new and legacy parts are defined.

If the effort required to create digital twins is drastically reduced, they can also be used for target/actual comparisons for new plants in the future. Plant operators will be able to track construction progress and, if necessary, demand rectification in the event of serious deviations. The prerequisite for this is, of course, that they request the 3D models from the plant engineers so that they can compare them with the 3D scan models [19].

3. Automatic identification of pipe systems

Two major challenges arise when creating a digital twin of existing plants, which can be automated using machine learning (ML) methods and object recognition. The prerequisite is that the ML has been trained appropriately beforehand [20]. On the one hand, the current state of the plant, which can differ significantly from the planning state, needs to be captured with all equipment, fittings and piping in 3D. On the other hand, the point cloud of the plant or the 3D models derived from it must be linked with additional information from the P&ID in order to be reliably able to identify the plant components and their function (Figure 1). It was addressed in collaboration of two companies.

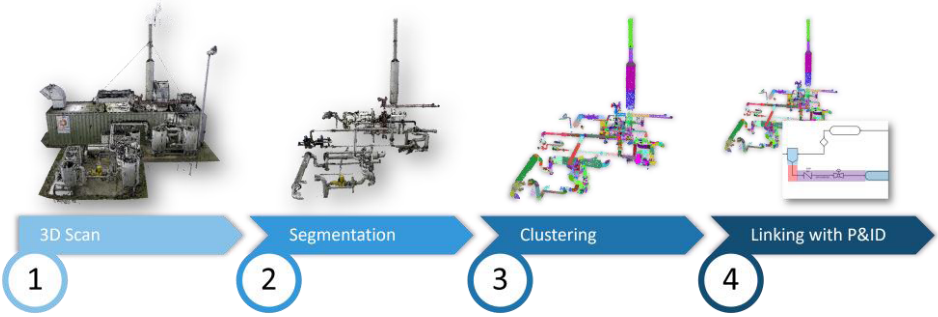


Figure 1. Identification of pipe systems.

The basis for the digital twin of an existing plant is a 3D scan with a high-performance scanner that generates a point cloud of the surfaces [21]. Instead of manually remodeling the plant by using a 3D CAD-system, which can cost hundreds of hours depending on the size of the plant, the point cloud is largely automatically converted into an intelligent 3D CAD model linked to the plant logic in a multi-stage process using the following method (Figure 2):

- First of all a 3D scan of the existing plant or parts of it (e.g. in case of an update) is needed. 3D scanners capture the surface of the plant and represent it as a point cloud. This way the current status of a plant is captured.
- The first process step covers the reduction of points to a necessary level for object recognition. This significantly reduces the amount of data and makes it manageable.
- In the next step, the point cloud is segmented according to functional aspects with the aid of object recognition, i.e. broken down into equipment, fittings, pipe sections and elbows. The ML processing the object recognition has to be trained appropriately beforehand. At the end of this process step each point is dedicated to a class/type of component such as pump, pipe etc. However, the objects and their position in space are not yet defined.
- During the clustering, the geometric properties such as radius, centerline and dimensions as well as their position in space are derived from the detected components. The points are clustered into a component, the geometric dimensions are determined and the position in space is detected. The result is a 3D model described by points.
- The linking of the previously recognized components with the P&ID is the last step. This expands the already recognized geometrical and positional information with the logical information from the P&ID. For this purpose, an algorithm was developed that compares the topology of fittings and pipes in the 3D model with the P&ID and searches for similar patterns. Once a piece of equipment has been correctly identified, the P&ID information of all other components in the pipe string can be automatically assigned.

Assuming a high percentage of recognized singular components recognized and linked to the P&ID, it is possible to generate CAD models of existing pipe systems and compose them to the entire plants. Of course, the not recognized components must be added manually. Apart from that, plant designers work with simplified CAD geometries anyway. The nominal diameter and outer diameter of a pipeline are not described geometrically, but are defined by the pipe class in the P&ID. Many fittings are also represented in graphically simplified form in order to reduce the volume of data, because they can occur tens of thousands of times in a large plant. In this respect, the use of CAD in plant engineering differs significantly from mechanical engineering.

The approach presented here provides the users the "extended 3D P&ID" which can be simultaneously used for both plant and mechanical engineering with the possibility to switch to another domain at any time. It fulfills not only the regulatory rules but also supports an integrated design environment. At the same time, it is shown that such complex tasks can be successfully carried out within the framework of a collaboration.

It is worth to figure out that in case of any error, the user has the adapted point cloud or cluster (steps 2 & 3 in Figure 1) of the missing components and can easily incrementally add the missing information e.g. centerlines as shown in Figure 3.

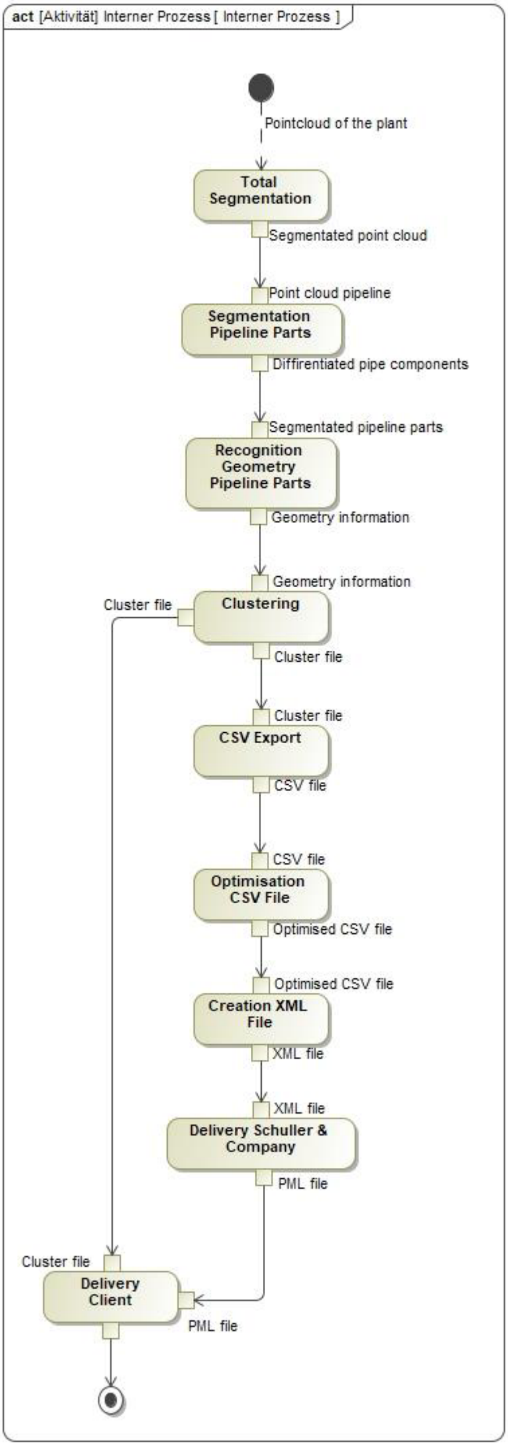


Figure 2. Process of identification of the pipeline system.

Finally, the complete resulting information about a pipeline system or a segment of is collected in a XML file which can be easily imported and interpreted in a user specific CAD system for plant engineering (e.g. AVEVA Unified Engineering or similar) as depicted in Figure 4. The sematic and structural consistency of the imported dataset can be approved in real-time with standard functions to ensure its usability in subsequent process steps [22]. Likewise, every model error and inconsistency leads to loss of time and additional costs.

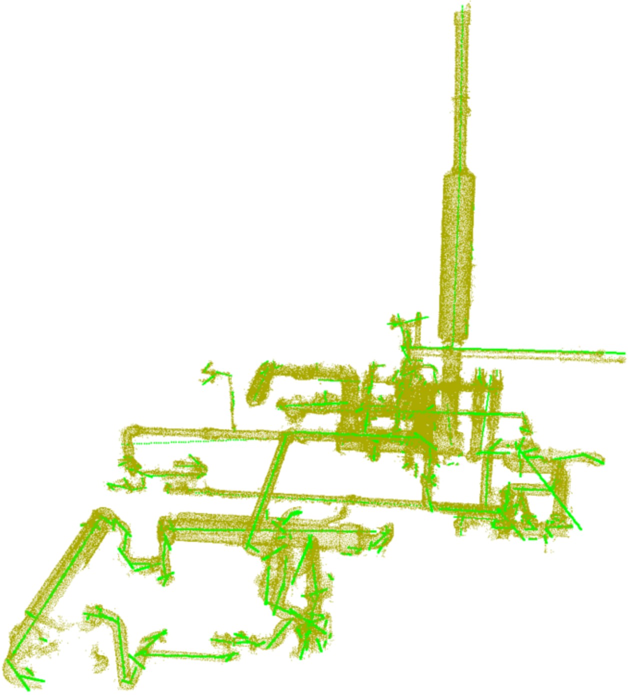
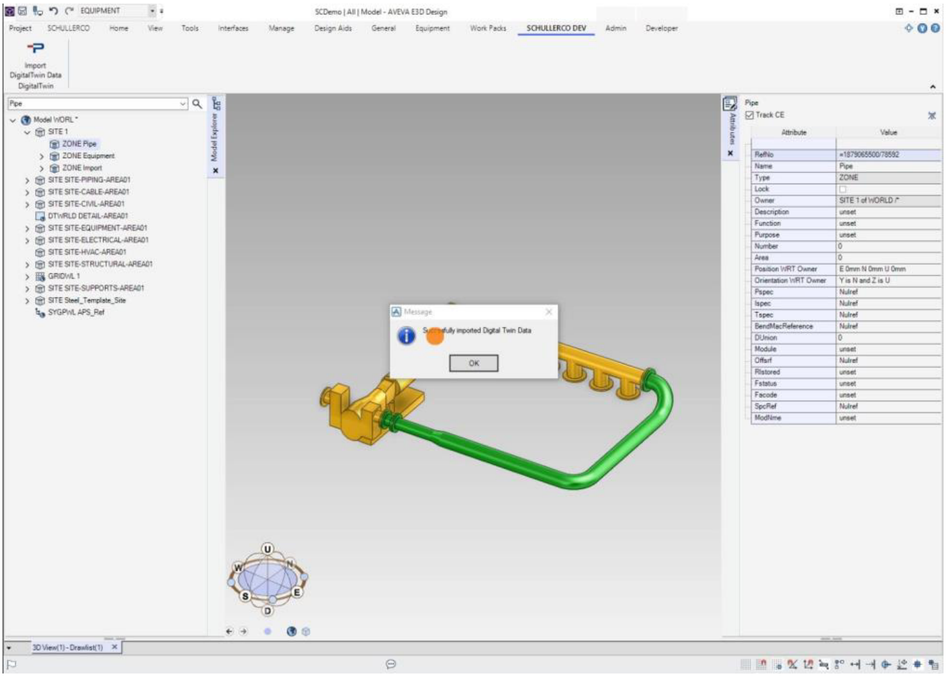


Figure 3. Results: the pipeline segments with the recognized centerlines.

4. Discussion from the transdisciplinary point of view

There are various potential use cases for the digital twin in plant engineering. The achievable benefits of automated creation of plant twins using the process described here are correspondingly diverse. The process can be used independently of the IT landscape of the respective plant designer or operator. The so called 3DigitalTwin solution is able to link P&IDs to the recognized 3D objects and then convert these objects into CAD models. Through conversion, the models can be provided in the needed native format to the users. They are therefore not forced to use specific tools in order to tap into the solution's potential benefits [23]. The migration from one to the next CAD systems runs correspondingly easily.

As estimated during this collaboration, for modernization projects and rebuilds, the automated creation of the digital twin can reduce the time spent manually remodeling existing plants significantly, estimated by up to 80 percent. Engineering offices in plant construction can therefore start designing the new plant components much earlier and improve incrementally. The costs are reduced accordingly, which makes the generation of the digital twin economically affordable for a larger number of plant operators for the first time. Moreover, an automated process based on exact position data from scans is more accurate and reliable than the manual one. User errors are reduced to a minimum and easy to identify.



Successfully imported Digital Twin Data

Pipe
☑ Track CE

Attribute	Value
RefNo	=1879065500/78592
Name	Pipe
Type	ZONE
Lock	☐
Owner	SITE 1 of WORLD /*
Description	unset
Function	unset
Purpose	unset
Number	0
Area	0
Position WRT Owner	E 0mm N 0mm U 0mm
Orientation WRT Owner	Y is N and Z is U
Pspec	Nulref
Ispec	Nulref
Tspec	Nulref
BendMacReference	Nulref
DUnion	0
Module	unset
Offsrf	Nulref
Rlstored	unset
Fstatus	unset
Facode	unset
SpcRef	Nulref
ModNme	unset

Figure 4. Results: import and generation of pipe system in AVEVA.

To be prepared for incidents, operators also have to conduct incident studies as part of the approval process. These are intended to reduce the risk of incidents and assess their impact. If an incident nevertheless occurs, the operator has the burden of proving that it has not breached his duty of care and that the incident is not the operator's fault. 3D models of the actual condition of the existing plant make this process more resilient and convincible. Modern operations centers are able to combine information from many different sources into a single graphical environment for enterprise visualization. With the support of virtual reality, the operator can provide an extended corresponding evidence nad initiate the appropriate countermeasures. This is of particular interest to those responsible, as they quickly have to face legal and personal consequences in the event of incidents.

However, the greatest benefit of the three-dimensional digital twin is being leveraged during operation. The connection of 3D models and P&IDs enables more efficient planning and preparation of maintenance measures, which not only saves additional personnel, which is often used to compensate for inaccuracies in planning. Most importantly, this approach provides a foundation for an event-triggered instead of routine-based maintenance. Better documentation drastically reduces the risk of wrong decisions and provides a good transparency for right decisions. This paves the way for a deeper automation of the entire operation.

Seeing the digital twin as the alternative being of the systems also yields provision of service modules, such as maintenance modules, that are not limited to just physical artifacts. Service module libraries should integrate tangible and intangible artifacts [24]. So 3DigitalTwin should be able to analyze a stream of surveillance cameras and inform about the module detection from different perspectives (maintenance, assembly, ... etc.). However, in order for multiple models to run together as a coherent structure, a careful integration is required [25].

5. Conclusions and outlook

A fast, precise and robust object recognition in a brownfield environment is a prerequisite for digital twin and thus subject of continuous research. The affordability of object reconstruction with semantic enrichment must be justified primarily in the cost-benefit ratio compared to manual remastering [5]. If object recognition is successful, as is the case here in an application from the biochemical industry, the reasoning is obvious. However, the disadvantages must be considered to prevent an unsuccessful use case (e.g. insufficient scans caused by a significant occlusion that cannot be compensated by additional information). Theoretically, in densely filled industrial spaces, data acquisition could be made impossible both by a lack of accessibility by the acquisition device and by poor recognition due to incomplete point clouds and occlusion [18]. Furthermore, as long as scanners need guidance by an operator, a human error in scanning can be expected at any time. Therefore, such obstacles can only be resolved by incremental scanning (e.g. by a highly flexible mobile device that can access each segment of a plant) [26].

The service concept for the so called 3DigitalTwin solves both challenges and thus enables digital twins to be created economically for various use cases in plant engineering for the first time. These include the modernization of existing plants, incident studies, the planning of maintenance measures, the virtual monitoring of plant operation and the training of operating and maintenance personnel. The use cases promise significant potential benefits, but also place different demands on the preparation and provision of the digital information. The vision of coherence between the real and the digital twin even in a brownfield environment is being implemented more and more.

Further ongoing developments in this approach are four-fold: At first, the improvement should go inline with the development of more powerful hardware to speed-up the acquisition of the objects in a plant, increase the flexibility and lower the costs. At second, apart of the improvement of the accuracy, the trend to real-time execution by a hand-held device will continue. The ”black-box” phenomenon of object recognition development and use must be addressed, too: supporting the integration of code and documentation generation as well as explicitly linking knowledge base structure and meaningful content with the recognition application elements and code [27]. The concept of a mobile recognition device powered by software products would be affordable, if a sufficient functionality can be provided. At third, the reduction of training period and expenses plays the crucial role in the costs of entire project e.g. by using external libraries [28] and an automated training. Finally, there are a few possibilities for a deeper integration with CAD and PLM systems to improve the overall system functionality and efficiency.

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