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Visualization Support for Design of Manufacturing Systems and Prototypes – Lessons Learned from Two Case Studies

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Abstract

This paper presents two case studies in which a framework for classifying the needed Level of Detail, Level of Accuracy and Level of Recognizability for 3D-scanns are used to 1) support installation of a robotic system for cleaning of fish processing lines and 2) support a retrofitting engineering project. Both cases are set in the Norwegian Aquaculture Industry. In Case 1, effort is done to develop a robotic cleaning solution for fish processing plants, due to a need to rationalize and automate the process. The chances of errors in the manual cleaning process is large. 3D-scanning is successfully used to create a solid model of processing equipment which in turn is used to create a cleaning path for the robot. In Case 2, the point cloud from 3D-scanning is used to check a planned layout of a retrofit project against the actual processing plant. Typically, such retrofit projects take more time and costs more money than initially planned because of unforeseen rework is necessary. This often is a result from poor or missing documentation of the existing processing plant. During the project, several errors were discovered in the planned installation due to missing or wrong information about the existing plant.

Both cases show that point clouds from 3D-scans greatly enhances communication, can aid in getting rid of design errors in the planning phase and can help shortening installation and commissioning times. 3D-scans are also beneficial when developing robotic simulations in complex environments. The framework helps in classifying the needed amount of work for 3D-scanning projects based on what the needed output is, thus potentially mitigating unnecessary resources being spent on either the scanning itself or post-processing of scan-data.

Keywords: 3D-scanning; point cloud; retrofit; simulation; robotic cleaning

1. Introduction

This paper presents two case studies in which 3D-scanning is used to improve processes in the Norwegian Aquaculture Industry.

A challenge when modernizing and rationalizing fish processing plants (FPPs) is the layout and complexity of the plants. 3D-layouts are now the industry standard, but earlier, FPPs were often designed using 2D-layouts. Creating up-to-date layouts of current FPPs is a labor-intensive job with traditional tools, which often result in inaccuracies [1]. Unforeseen complications, often resulting from the inaccuracies mentioned, during installation or lack of accurate data during design phases can result in changes that are not captured in as-built layout documentation. To make matters harder, each plant has its own unique design with regards to layout, size and height, and they are often modified extensively through several years of operation, normally without capturing documentation of the changes in overall plant layouts. This creates a gap in the spatial data available

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for most FPPs which results in a high risk of wrong input during planning phases of retrofit projects. A large part of the problem will also be the information that is not captured during planning but needed later during the design phase of a project.

FPPs are often situated far from the offices of the equipment providers, and the FPP may be a fishing vessel which in extreme cases only docks once each year. Faulty or missing plant layouts causes costly errors when doing retrofit.

The high throughput of fish in current FPPs are challenging for installation and commissioning of complex equipment/retrofit. Most plants run two processing shifts, 5 days a week throughout most of the year. This makes the allotted time window for installation and commissioning very short. Violation of the allotted installation time due to errors during planning costs a lot of money, with fish prices in excess of 5 USD per kg [2]. In addition, doing such retrofitting into existing FPPs are accompanied by increased risk of bacterial contamination [3–5] and the threat increases with installation time.

This creates a need for an efficient method to capture the complex layout and infrastructure which exists in processing plants whilst enabling an engineer to check measurements in the post-planning phase. 3D-scanning of processing facilities is foreseen to be a good approach to solve these trials.

Another challenge to develop more efficient processing plants is to automate more of the processes on the plant. Automating more of the processing has been a research effort over several years [6–9]. One such opportunity is automated cleaning of the processing facilities. It is tough manual labor, consisting of repetitive tasks in an environment which is unpleasant due to spray fog and chemicals, often at undesirable working hours. Errors occur during the manual cleaning process, making it unstable. Cleaning must be done each day due to food safety [10,11], and failure to do so could lead to bacterial outbreaks which could be harmful for humans [12]. Foodborne diseases are also costly [13] with $1.4 trillion per year in costs related to foodborne illness worldwide, e.g. cleaning is important from both a "safe-to-eat" and an economic standpoint.

A novel robotic cleaning solution is proposed to solve the challenges [14,15], whilst adhering to hygienic design principles [16] to avoid introduction of bacterial risk. It consists of a customized robot manipulator, a custom-built rail to carry the manipulator in the processing plant and a design which allows customization of the solution to different processing plants. It also has a custom control system [17], which is based on 3D-simulation of the manipulator and rail to create cleaning paths. This 3D-simulation requires 3D-data of the equipment which is to be cleaned in order to program the manipulator. Because of the already mentioned complexity and challenges of the processing plants, a method of capturing the layout in high accuracy is needed. This level of accuracy is not possible to obtain through traditional methods due to time and cost constraints.

Visual aids, such as CAD and point clouds may be of help in such cases [18,19]. Off-line programming of robots (simulation) has also been proven useful in shortening commissioning times [20–22] and discover design errors [23], because a lot of the initial errors are discovered and fixed already in the virtual stage.

This paper will utilize a newly developed framework [24] to determine requirements of Virtual Factory Layouts (VFLs) for the two cases. VFLs must be modeled in just enough detail to fit their purpose, and this paper will apply the framework to explore the two different needs of details for two different purposes. Specifically, this work will investigate if the framework is suitable for a 3D-simulation application and planning of a retrofit installation.

2. Method

Level of Detail (LoD), Level of Accuracy (LoA) and Level of Recognizability (LoR) from Eriksson et al. [24] is used to define properties and quality, and by combining features or levels from these classification areas, clarity should be provided of what the 3D-scan shall deliver as output. In the same work, the authors classify three purposes of having a VFL: Knowledge transfer, Layout management and Simulation, which are covered by the three levels. Each of the levels can also be divided in several sub-areas. LoD describes what a virtual object can be used for and features included are: As-is, Moveable objects, Measurable footprint, Measurable 2D distances, Measurable 3D-distances, Object kinematics, Order of stations, Material flow. Regardless of the use of a VFL, a defined accuracy is needed, and LoA options consists of: Very coarse, Coarse, Medium, Fine, Very fine. For a VFL to fulfil its purpose, the receiver must understand what the VFL illustrates, and a LoR-level must be decided on. LoR includes features such as: Object name/no, 2D-area, 3D-block, Color, Shapes and features highly significant for object, Shapes and features significant for specific objects.

The cases will have two different applications of the 3D-data captured from 3D-scanning and will thus have different requirements for output.

2.1. Case 1 – 3D-simulation

A prototype of the cleaning robot discussed in Introduction was built. A test room was built to enable close to full-scale testing of the custom robot. Due to the multidisciplinary aspect of the problem studied, a full system prototype was built. Virtual tools is not suitable to test all the facets, although analytical prototypes in virtual tools were used on parts of the system [25]. Due to the mentioned challenges related to spatial data, the test room was scanned to mimic a retrofit installation of the robotic cleaning system.

The VFL requirement in this case is Simulation, but cleaning processes need less accuracy than traditional robotic simulation processes, such as robotic welding.

2.1.1. 3D-scanning of the test area

The test area is approximately 5x8 meters and is seen in Fig. 1. It consists of typical fish processing equipment, a frame to suspend the custom robot system in and the custom robot system itself. It is scanned using a Faro X130 HD scanner, with a total of 6 scans. 4 scans would have been enough, but to ensure sufficient accuracy and detail needed, two extra scans were made.

2.1.2. Post-work with the scan data

The scans were imported into Autodesk Recap to be combined into one large point cloud. This point cloud was exported into 3D Systems' Geomagic Design X as a .E57-file where it was further processed to a mesh. This was further developed on inside Geomagic Design X to build solid models which can be exported into any CAD-software platform. The hybrid model of mesh and solid can be seen in Fig. 2. The solid models were exported as .STEP-files and imported in Visual Components to serve as both a placement reference for the robot base, and a geometry to link the cleaning (robot) path to, see Fig. 3.

2.1.3. Use – 3D-simulations

The model was used as a reference model for the simulation program when generating a robot cleaning path using Visual Components. A picture of the simulation environment is shown in Fig. 3 in chapter 3.1.

Fig. 1. Picture of test room with equipment.

2.2. Case 2 – Retrofit

A running retrofit project of new equipment and layout change into an existing processing plant serves as a full-scale prototype case for installing the robotic cleaning system. The requirement in this case is Layout Management. From the LoA, a medium to fine accuracy is needed. The machines must be recognizable, and, in some cases, the new equipment will be fitted to existing machines, making it necessary to have a fine accuracy. Also, from LoA, 3D-blocks are needed, and for specific objects, shapes and features are significant (e.g. where new equipment will interface with existing). The planned new layout is modeled based on existing 2D floor plan data.

2.2.1. 3D-scanning of the test area

The tested area is approximately 1800m^2, and is filled with existing processing equipment, machines and other installations such as pipes and HVAC-components. The same laser scanner as in Case 1 was used, but it took 12 scans to cover the area. The scans were done without color to save time, and with less accuracy, detail and coverage compared to Case 1.

2.2.2. Post-work with the scan data

The 12 scans were imported into Autodesk Recap and merged into one larger point cloud. The scans were not processed any further in Autodesk Recap. The resulting point cloud is shown in Fig. 4, and it was overlaid the planned CAD-layout and aligned using the pre-existing columns in the factory, visualized in Fig. 5.

2.2.3. Use – Design review

The hybrid model was used for reviewing the proposed layout and evaluating the fit between the existing building infrastructure and equipment and the new proposed layout of equipment.

3. Results

In both cases, the 3D-scans provided visual aid which helped communication. We saw that even though the cases were different, the same method could be used. Two different levels of VFLs are developed for two different use cases with different levels of requirements. The framework presented in Eriksson et al. [24] can be used to establish the necessary requirements for using point clouds.

3.1. Case 1 – 3D-simulation

The solid model obtained from the 3D-scan was used to create new robotic cleaning paths, reducing the needed iterations to create a complete cleaning program with higher accuracy than achieved before. Solids were also used to check for collisions between the robot and existing equipment, which in earlier run throughs of the testing had happened due to the inequalities between the virtual and the physical prototype.

In relation to the framework, the following features were important from the three different classification areas:

Table 1. Features related to a VFL for simulation.

Level of Development	Level of Accuracy	Level of Recognizability
As-is	Fine	Color
Measurable 3D- and 2D-distances		Shapes and features highly significant for object and specific objects
Measurable footprint		

Surfaces are created based on the mesh of the point cloud. The solids are created by typical CAD-software operations.

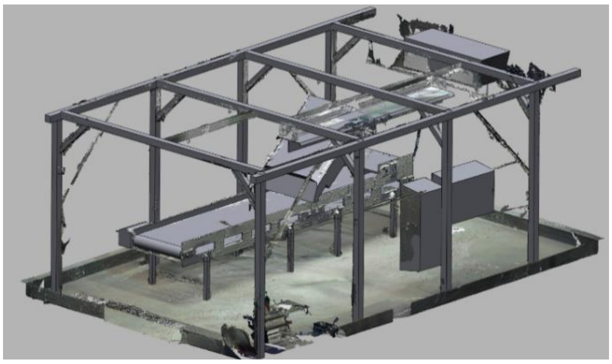

Fig. 2. Hybrid model of point cloud and solid models.

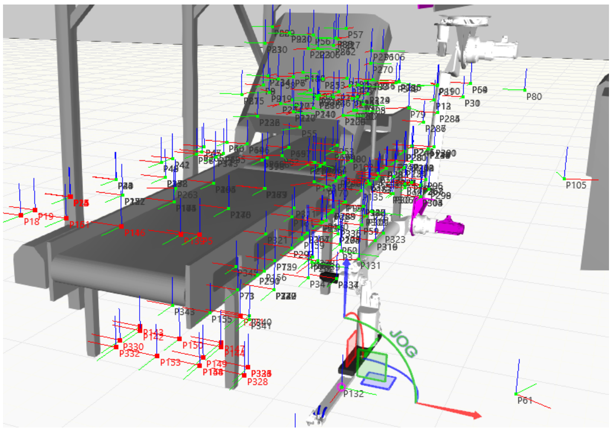

Fig. 3. Solid model from 3D-scan used in 3D-simulation software.

The points in Fig. 3 are displaying the x-, y-, and z-coordinates and rotation against the x-, y- and z-axis for the Tool Center Point of the robot manipulator.

3.2. Case 2 – Retrofit

The point cloud was used for a design review of a planned retrofit installation. In relation to the framework, the following features were important from the three different classification areas:

Table 2. Features related to a VFL for retrofit (layout management)

Level of Development	Level of Accuracy	Level of Recognizability
As-is	Coarse	3D block
Measurable 3D- and 2D-distances		Shapes and features highly significant for object and specific objects
Measurable footprint		

The point cloud aided in communication and knowledge transfer in the project, and the hybrid model with both the planned new layout and the point cloud of the existing processing facility showed several occurrences where the planned new layout interfered with existing infrastructure or layout. The list is exhaustive, and not all of them are presented in this paper, but a brief overview of some important issues is presented for illustrative purposes.

Fig. 5. Comparing fit with existing 3D building model with point cloud.

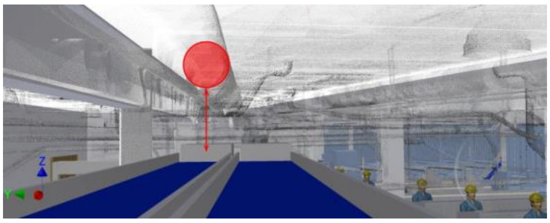

Fig. 6. HVAC-interference.

The area shown in Fig. 6 above, contains several building infrastructure elements like HVAC (heating, ventilation and air-conditioning) and roof drainage piping as well as cable trays. The double conveyor (in blue) was initially planned

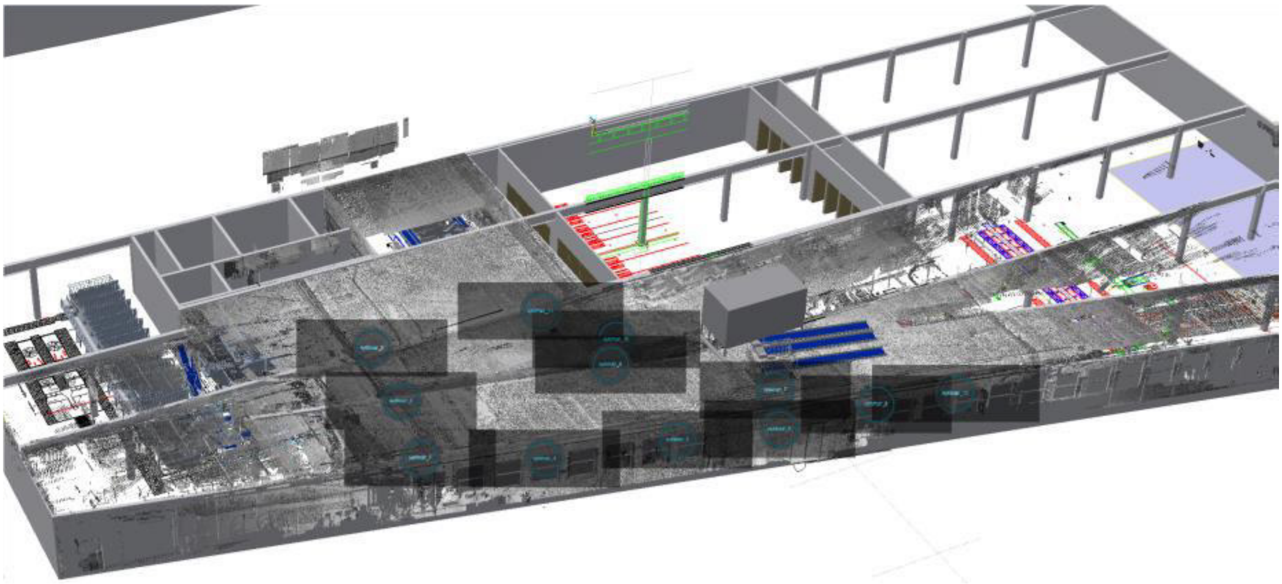

Fig. 4. 3D scan overlaid planned layout.

flush with the underside of the ceiling beam (to the left above the z-axis shown on the picture). A HVAC-pipe marked in red was in the way. After identifying the amount of changes required to the building infrastructure systems in this area to achieve this, it was decided to lower the conveyor line instead. These changes were not discovered from the initial 2D- and 3D-layouts used for planning.

Fig. 7. Walkway-issues.

In Fig. 7 above, a conveyor was situated in the red area. A walkway passes under this now, but the new conveyor (in blue) will be an obstacle for this walkway, and a new walkway must be planned.

In Fig. 8 a conveyor and tank are seen placed into the existing building structure. According to the building model and floorplan drawings, the conveyor and tank clears the obstructions but as illustrated in the figure, the placement and dimension of the wall is incorrect. The red-dotted line shows the needed new placement of the conveyor. The red circle indicates interference between a tank and an existing building column. During installation this equipment would be one of the first things to be installed due to the size of it. The consequence of modifying the installation to clear the obstructions would require the entire interconnected installation to be changed as well, potentially causing huge delay (the interference itself and additional modifications) if not identified before entering the installation phase of the project.

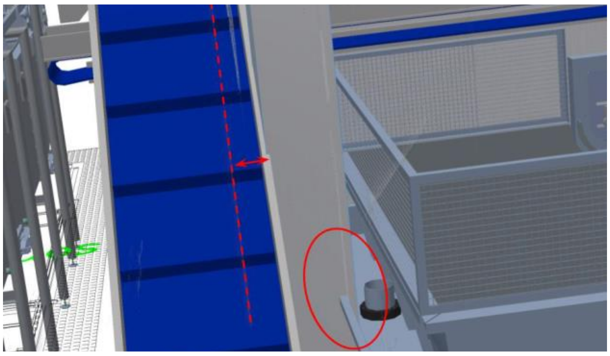

Fig. 8. Interference with infrastructure.

4. Discussion

Creating a solid model from a 3D-scan like in Case 1 required a lot of engineering hours despite the low complexity and small area due to the needed output of solid models. Intelligent and automated ways of reverse engineering of point clouds are emerging and will make this work easier in the future. Automatic generation of geometry based on point clouds has been a research topic for some time and still is [27,28]. Several software vendors are offering semi-automatic conversion from point clouds to solids through automated or semi-automated processes [26]. Such automated software was not utilized in this study. One should nevertheless be certain it is necessary before doing it due to the computational power required. In this case, only the equipment being cleaned was necessary to model in solids, and some time could have been saved.

Case 2 as presented in Fig. 6 illustrates a way 3D-scanning could provide additional value to processing facilities. The placement of lighting armatures seen in the upper right-hand corner are now captured, something that would not be surveyed by traditional methods. Since they now are known, the equipment provider was able to tell the processing facility that they needed to change the lighting armatures' location when the new processing line was put into the point cloud model. These sort of changes to infrastructure often happens during installation phase and have few or missing mechanisms to indicate necessity and as a result, the installation phase is often crowded of workers due to the high number of parallel "reactive" installation activities.

Grand-total for this case study, the total time estimated to be saved is estimated to be several weeks in rework, plus additional design optimizations were possible on the ground of a richer information basis. This amounts to a lot of money saved, both in man-hours and in additional parts needed (new parts, altered parts, discarding parts). The reduced time is also of importance and value for the FPPs, as such a time delay would impact their business significantly, due to the high throughput of the business discussed in Introduction.

Not all retrofit projects are suited for 3D-scanning. Some retrofit projects are so straight forward and low complexity, that it would be enough to use traditional measuring tape. Even though scanning time is not significantly high, the total added time of set up, scanning, post work of scan data adds more engineering hours than the traditional measuring tape. Some sort of threshold in complexity needs to be defined to make an informed decision of whether to do scanning of a planned retrofit project.

Nevertheless, 3D-scanning technology can help in retrofit projects by reducing the needed rework. It may even limit errors during new installations, as in some cases, the building infrastructure is not built as planned. These changes are often not discovered until processing equipment is being installed, and this also causes delays and rework. Building Information Models are often not containing the details of a facility as it was built [29]. 3D-scanning the new building infrastructure to validate its geometry may avoid errors. Discovering errors earlier in the process reduces the costs of those errors significantly. Informants from the Aquaculture industry in Norway estimated a 5x cost of errors during installation or production compared to discovering those errors in the sales phase of the project.

Some of the errors detected from the 3D-scan in case 2 may have been discovered regardless using only traditional methods, and as such it is hard to say exactly how much time is saved using 3D-scanning in this case. However, the use of a

3D-scanner does not add any significant time or cost during the planning phase, and as such it is seen as beneficial. Only two test cases are discussed in this paper. More testing of the framework is needed in the future.

5. Conclusion

Both cases benefited from 3D-spatial data derived from 3D-scans. 3D-scanning provides not only a visual aid but can also directly improve simulation, installation and commissioning processes. 3D-scanning also has a large potential in reducing uncertainty, rework and installation time for retrofit projects.

The proposed framework by Eriksson et al. [24] can be used to develop requirements in both cases and provide value of what output is needed. Developing clear understanding from all parties about what a point cloud/3D-scan will be used for will remove uncertainty for the surveyor and ensuring not spending more resources than necessary on any given 3D-scan data during reverse engineering stages. Understanding that in Case 2, knowledge transfer was the main aim, thus it was not needed to do solid modelling from the point cloud is such an important discovery. Discovering design errors during the planning of the retrofit was possible with only the point-cloud model as output. This saves time in developing the final output model. In contrast, more detail was needed in Case 1, and extra care was done to capture more details of the room by adding extra scans behind equipment, and it required further work on the output model. The features presented in the three different classification areas presented in the framework could be expanded and further refined in the future, maybe alongside a pre-project checklist to ensure the needed output is captured.

Both cases also reveal there is a potential for the technology to serve as a learning and cooperation facilitator for the larger cluster of involved stakeholders for aquaculture engineering projects. Through better identification of information, the aquaculture industry's ability as a whole can be improved in terms of meeting critical time windows in a harvesting schedule, or meeting go-live dates of newbuilds.

In the future, the framework may be expanded into a larger model of how to do 3D-scanning projects based on their use, and to further refine and develop which features are important in each of the three classification areas.

This work contributes to the application areas of the framework from Eriksson et al., and expands with suggestions of how to expand the framework.

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