Post-processing of Laser Scanning Point Clouds for the As-built Modeling of Petrochemical Installations

Aymen TRIGUI, Tunisia

Key words: As-built 3D Modeling, Laser scanning, Petrochemical Installations.

SUMMARY

The cost of a single lost production day of a petrochemical installation can easily run into millions. Such losses can be avoided through preventive maintenance and the ability to quickly react in case of disturbance or damage. Both measures require accurate and precise documentation of the installation site condition. Even if petrochemical installations are well documented when built, rapidly, i.e. through extensions and repairs, the correspondence between the documents and the site condition is no longer existent. Especially for old plants, often no reliable documentation is at the disposal of the plant operator. This makes the survey of the whole plant inevitable. But because of the very high complexity of petrochemical installations, the task of surveying them is a challenge that is hardly to be mastered with classical surveying instruments such as theodolites or total stations. In the last decade the Laser Scanning technique emerged in the surveying community and brought solutions for several applications among which the process, power and piping installation survey. Laser Scanning offers the possibility to acquire in a few days site work, a very dense point cloud of the surveyed installation containing billions of points with millimeter precision without neglecting any visible detail. During the post-processing of the collected data, the surveyor is assisted with computer aided modeling tools to retrieve from the point cloud a geometrically correct 3D model of the installation. But while most of the Laser Scanning post-processing software concentrate on the geometrical aspect like shape estimation and primitive extraction, the installation operator is very interested in an “intelligent 3D Model” containing a correct topology and semantic. Such an intelligent 3D Model can be automatically converted into isometric or orthographic plans which are essential for the installation maintenance. This paper is a general overview of the state-of-the-art and future directions of the post-processing of laser scanning point clouds for the as-built modeling of petrochemical installations.

Post-processing of Laser Scanning point clouds for the as-built modeling of Petrochemical Installations

Aymen TRIGUI, Tunisia

1. INTRODUCTION

Laser scanning delivers as a first output point clouds containing a huge amount of geometrical and intensity data with a high density of details. Although this primary product represents the raw data of laser scanning and contains the complete information of the scans, the end-user is only interested in a small part of this data with a higher level representation such as models that are suitable for incorporation in his workflow.

To reach this final product, the laser scanning data must go through a post-processing pipeline going from registration and segmentation to shape extraction through object recognition and complete modeling to finally a so-called intelligent as-built 3D model.

While great effort has been made in the last decade in reaching a high level of automation in the registration, segmentation, and shape extraction more effort is needed in automating the 3D and intelligent 3D modeling of an industrial scene like petrochemical plants.

This paper gives an overview of the available techniques and future directions in automating or assisting the manual post-processing of laser scanning data applied to the 3D modeling of petrochemical installations.

2. LASER SCANNING FOR THE AS-BUILT MODELING OF PETROCHEMICAL INSTALLATIONS

Petrochemical installations are extremely complex facilities facing the installation operator with a lot of challenges like safety issues, maintenance, need for optimization and so on.

In fact, safety is a very important matter, especially for installations where extremely inflammable and/or toxic products are being processed. Moreover, to be profitable, the processing pipeline of such installations must be optimized. Unpredictable downtimes caused by failure or insufficient planning of revamping or maintenance activities can quickly generate costs running into millions.

Thus, correct, complete and up-to-date plans and models representing the site condition of the installation are essential tools required by the installation operators to guarantee high level of safety, optimal operating and the possibility to easily perform extensions and revamping actions.

Unfortunately such models are not always available for the installation operators despite the fact that an as built plan is always delivered by the contractor of each new built installation. In fact, through improperly documented extensions, revamping etc. quickly the available plans no longer correspond to the real site condition and a survey of the installation becomes necessary.

Figure 1: Two images of petrochemical plants showing the complexity of such installations.

Laser scanning is the most suitable technique for acquiring the required data to generate the as-built model of a petrochemical plant. The surveying of a petrochemical installation in the last decades could only be performed with theodolites or tapes because these were the only available instruments that could meet the accuracy required for such surveying tasks. These classical techniques are contact techniques requiring the surveyor to be at the immediate proximity of the objects to be measured. Unfortunately, petrochemical installations are not built in a manner that a human being can reach every single corner of it.

Another disadvantage of the classical techniques is that they measure only single points or isolated distance information. In the case of a petrochemical plant and due to the huge amount of objects to be surveyed such as pipes, valves, cylinders and so on, this would be a very exhausting and time consuming task. Moreover, to be able to build from all these single measurements the required model, the surveyor has to draw sketches explaining the meaning of each measured point and each measured distance. This makes the surveying task even more time consuming and error-prone.

In the last decade, laser scanning emerged in the surveying community. This technique enables measuring millions of points within minutes, with adjustable resolution reaching the millimeter and enabling thus to acquire all relevant details of the installation. The use of this technique reduces dramatically the field work time. The following figure is an intensity image of a test scan with the FARO Photon 120 scanner performed in the refinery of STIR in Bizerte in Tunisia.

Figure 2: Intensity image of one scan performed in the STIR Refinery of Bizerte in Tunisia

3. REGISTRATION

Laser scanning enables only to acquire 3D points on the surface of visible objects. Due to the complexity of petrochemical installations, each object such as a pipe, a valve or a vessel considered from a single position, makes invisible the objects and details behind it. This is called occlusion.

To be able to acquire all relevant details of an installation, several scans from different positions have to be performed. These different scans have to be connected to each other, so that the 3D points of all scans can be transformed to a single coordinate system.

The test scans in the STIR refinery of Bizerte in Tunisia, were performed in order to acquire a point cloud of a small unit having a surface of approx. 24 square meters (3m by 8m). To avoid the occlusion problem and to be able to acquire all relevant details of the considered area, two additional scans had to be performed.

The next issue is the registration of the different scans. N. Pfeifer and J. Boehm (2008) divided the registration approaches methods into 3 types

- Marker-based approaches, requiring the use of markers in the scene (see figure 3)
- Sensor-based approaches, requiring additional sensors on the scanner like GPS and compass to directly determine the position and orientation of the scanner.
- Data-driven approaches, which use the only the raw data of yielded by the scanner

namely the point cloud and the intensity image to register scans.

Most modern laser scanning data post-processing tools are able to recognize normalized markers like white spheres or predefined patterns in the intensity image using the correlation technique. The recognized markers are then validated through the geometrical information to yield 3D tie points for the registration of scans. With a robust estimation it is then possible with enough recognized markers to determine the 3 translation and 3 rotation parameters necessary for the 3D transformation to register each scan.

The next section explains some techniques of the further post-processing of the registered point cloud towards an intelligent 3D model.

4. SHAPE EXTRACTION

The registration of the different scans yields a point cloud that is in a unified coordinate system. Besides the normalized marker extraction from the intensity image explained above, some post-processing solutions give the possibility to extract semi automatically geometrical primitives like cylinders, spheres or planes.

This step is very relevant for petrochemical plants because pipe runs are mainly composed of cylinders and tori. Even vessels have commonly cylinder shapes.

Here there are 2 approaches implemented in the available post-processing tools:

- The first approach is the automatically segmentation of the point cloud and the subsequent testing of the resulting segments for fitting to some geometrical primitive. The result of such process is often not satisfying. It still necessitate that the user performs some a posteriori selection and editing of the recognized geometrical primitives.
- The second approach requires the user to select a set of points in the point cloud and specify the corresponding type of primitive then the program has only to compute the estimation of the position and scale of the primitive using the selected points set. This supposes the user to be able to isolate set of points belonging to some geometrical primitive to feed them in the position and scale estimation process

Both approaches are very user dependant. The post-processing tools have to simplify the user tasks by offering some clipping also called cropping feature. Such a feature enables the user to master the huge amount of 3D points contained in a point cloud even by using common 2D displays and 2D selection techniques like window or free line selection.

For better visualization of the point cloud together with the so far extracted objects and shapes, it is also suitable to give the user the possibility to adjust either the density or the transparency of the point cloud.

5. 3D MODELS VS. INTELLIGENT 3D MODELS

As shown in the last section, most of the laser scanning post-processing tools offer the possibility to semi-automatically estimate the position of primitive shapes.

In the case of petrochemical plant modeling, these Primitive shapes can be combined to describe more complex objects like pumps or valves. This could be helpful to build a realistic 3D model of a petrochemical installation.

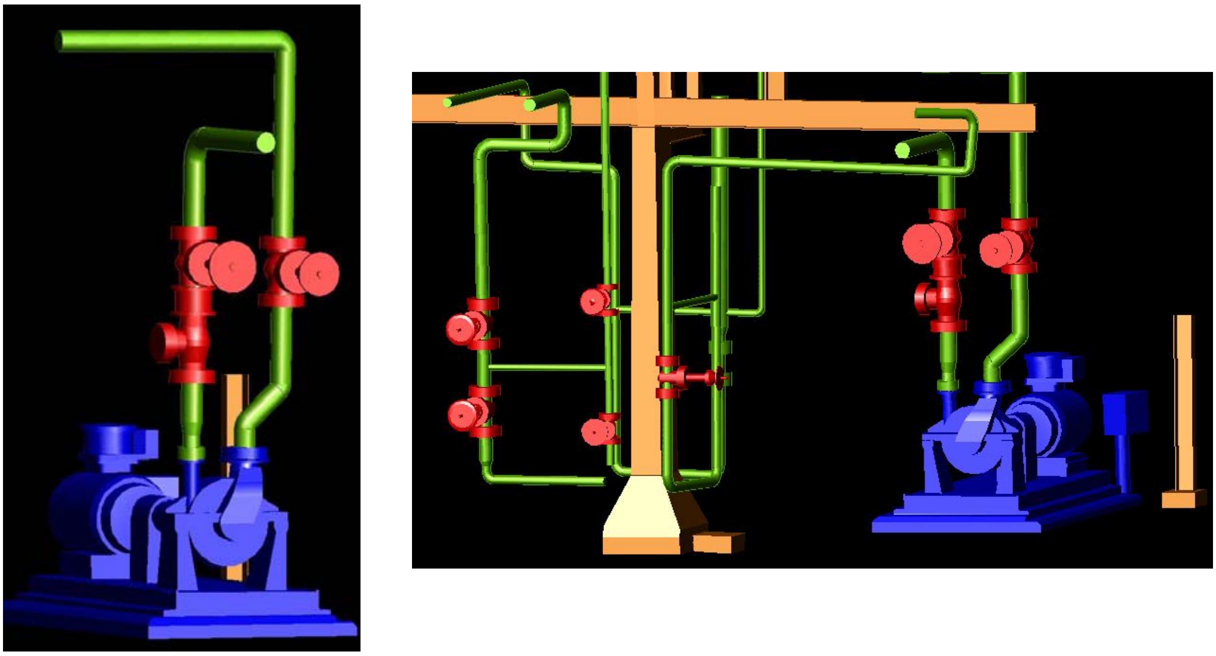

Figure 3: 3D Model of some digitized parts of the test scans performed in the STIR refinery of Bizerte

The model shown in the figure above is only composed of geometrical solid bodies which do not have any semantic or topology attributes and could only be used for visualization or very basic analysis like clash detection. Both applications could even be done with the raw point cloud, so the added value of such geometrical modeling of a petrochemical installation is still not satisfying. In fact a cylinder in such a model does not have any attribute showing if it is a pipe, a vessel or a pillar. Its relationships with the neighboring geometrical objects are not specified so pipe runs cannot be considered as a whole structure because of the lack of a higher level of abstraction than the geometrical primitives with their positions and orientations.
For the case of petrochemical installations, the plant operator is interested in the incorporation and use of the 3D model in the installation management system i.e. for

- providing Process control data
- enabling exhaustive Asset inventories (i.e. bill of materials)
- Inspection management (generation of orthometric drawings etc.)
- providing a database useful for the work order system
- enhancing Construction and project management

This could only be achieved with a so-called intelligent 3D model containing besides of the geometrical information, semantic and topological information about the 3D model on the base of field specific knowledge.

6. TOOLS AND TECHNIQUES AVAILABLE FOR THE GENERATION OF INTELLIGENT 3D MODELS

To be able to generate intelligent 3D models that could be incorporated in the plant management processes, the used modeling tools should offer apart of the ability to deal with

the geometrical aspect of laser scanning data, the possibilities of designing the intelligent 3D model. In the designing phase the stress is on the field specific knowledge that covers all relevant aspects of the designed installation like norms, topology, semantics, layers and so on. In fact petrochemical plants are very normalized installations. Every diameter of a pipe run, every type of pump or vessel is specified in a part catalogue.
So based on the shape extraction ability described above, the tool estimates the position, diameter and orientation of a cylinders to describe straight pipe segments. The intelligent modeling tools subsequently perform a matching of the cylinders to a specific type of pipe in the used norm of the installation. This procedure creates an attributed object pipe that describes the geometrical and the semantical aspect of the pipe. Such an object has interfaces for interconnection with objects like elbows, reducers, instruments or other pipes.
Here the intelligent modeling tools use some sequence rules or constraints of piping segments to enhance the productivity of the asset modeling and validate the resulting 3D Model. Some of these constraints are listed below:

- A pipe run cannot have variable diameters unless it is intercepted with a so called reducer or another type of instrumentation.
- A valve does not change the orientation and diameter of a pipe.

There are also geometrical constraints that are used to simplify the modeling process such as:

- An elbow changes only the orientation of a pipe run by predefined angles that are multiples of 45 degrees.
- When two pipes are joined with an elbow, they have also to be coplanar.

For more complex objects like valves pumps, handrails or even Tee branches, most tools rely on the user to specify approximately the position and orientation of the object with the help of the underlying point cloud and the constraints resulting from the used norms and topology of the pipe run. This results in a lower accuracy in the position and orientation estimation of the model components but enables a higher productivity of the as-built asset generation especially in very complex areas where less long straight pipes are available.

7. FUTURE DIRECTIONS TOWARDS AUTOMATING OF INTELLIGENT MODEL GENERATION

The research efforts are aiming to achieve more automation in the generation of 3D and intelligent 3D Models in order to reduce to the utmost the intervention of the user. Rabbani, T. (2006) describes the state of the art achieved till now in the field of automatic recognition and modeling of industrial installations. Nevertheless the approaches are still not using the full potential of the normalized environment and field specific constraints of petrochemical installations. This norms and constraints represent a knowledge database that could assist the modeling algorithms to achieve complete and valid intelligent 3D model. After objects have correctly been recognized a high level of abstraction has to be achieved to enable the modeling algorithms to use the field specific knowledge database as a formal grammar see Becker S. (2010) presents some approach in this direction even though in another application. The most difficult challenge for automatic 3D modeling of petrochemical plants would rather remain the correct shape estimation and recognition of complex instrumentations like pumps, vessels, valves and so on. Here also some help could be obtained from the field specific knowledge database and the norms of the derived formal grammar rules.

8. CONCLUSION

This paper described the state of the art techniques for the post-processing of laser scanning point clouds in order to achieve as-built 3D Models of petrochemical plants. The importance of an intelligent 3D Model to the installation operators was explained. Different approaches and techniques available in modeling tools for assisting the user in the modeling procedure have been described. One of the key features used by these tools is the use of field specific knowledge about the assets to be modeled like norms and geometrical and sequential constraints of components. Unfortunately these modeling procedures still requires extensive user interaction. Therefore more research effort is needed to automate the modeling process by enabling the so far available modeling algorithms to take profit of the field specific knowledge.

REFERENCES

[1] Becker S. [2011] Automatische Ableitung und Anwendung von Regeln für die Rekonstruktion von Fassaden aus heterogenen Sensordaten, München 2011.
[2] Pfeifer N. and Boehm J. [2008] : Early Stages of LiDAR Data Processing, in: Advances in Photogrammetry, Remote Sensing and Spatial Information Sciences: 2008 ISPRS Congress Book, Li, Z.; Chen, J. & Baltsavias, E. (ed.), ISPRS Book Series, CRC Press, 2008, 7, 169-184, 2008.
[3] Rabbani T. [2006] Automatic Reconstruction of Industrial Installations Using Point Clouds and Images, Publications on Geodesy 62, Delft, 2006.

ACKNOWLEDGMENT

Special thanks to FARO Europe and especially to Mr. Khaled El Nabbout for providing the laser scanner for the test scanning in the refinery of STIR in Bizerte, Tunisia.

BIOGRAPHICAL NOTES

Mr. Aymen Trigui has received his Dipl.-Ing and Dipl.-Inf degrees from the University of Stuttgart in Germany, where he is now a Ph.D. candidate in the Institute of Photogrammetry. He is also the head of the surveying office “SETOF” in Tunisia. His main research interests are in the automatic as-built modeling of petrochemical plants.

CONTACTS

Dipl.-Ing. Dipl.-Inf Aymen Trigui
Société d’Etudes Topographiques et Foncières (SETOF)
1 rue Jean Jacques Rousseau
Tunis, TUNISIA
Tel. +216 71 906 502
Fax + 216 71 909 008
Email: setof@setof.net
Web site: http://www.setof.net