Facility management of gas turbine power plants using 3D laser scanning

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ABSTRACT
Industrial projects are extremely complex in terms of designing, engineering, construction, operation and maintenance. These projects involve extremely specialized activities during operation and maintenance phases. Optimizing the operation and maintenance phases for mega-industrial complexes such costs as power plants, petrochemicals, pharmaceuticals, and oil refineries increases the potential cost saving and maximizes the net profit. Plant maintenance comprises thousands of tasks, hundreds of workers, huge amount of equipment and material highly dependent on plant size. This research proposes a procedure for facility management using 3D laser scanning technologies in gas turbine power plants. High Density Point Cloud (HDPC) is obtained from 3D laser scanning of the power plant to facilitate the process of maintenance. HDPC is converted to regions in Recap application and the Autodesk Revit add-in imports the point cloud to Autodesk Revit and populates all the required maintenance data. This research describes the developed Power Plant Operation and Maintenance Tool (PPOMT) platform and its components to synchronize the data of the power plant with the online workspace information. All equipment information, the type of maintenance and the tasks to be carried out are defined for facility management purpose.

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Introduction

The most important implementation of the concept of Building Information Modeling (BIM) in the operation and maintenance phases is the documentation of the facility geometries and textures. BIM-based documentation allows better preservation and centralization of historical records and guidelines to facilitate the facility maintenance and repair. As-is BIM concept is implemented for the analysis of the facilities performance including structural analysis, accessibility diagnosis and energy performance. In addition, BIM-based facility performance analysis is used to improve and study the facility
performance. Also, for the existing facilities, BIM models are beneficial to various facility management functionalities because of the ability of the superior of the 3D visualization and organized facility data. The operation and maintenance of the facility elements have been improved with the BIM-based processes. The BIM concept enables efficient localization of the facility elements and real-time access to the related data, thus reducing the time and cost of maintenance phase. This research presents the methodology objectives to provide the answers to the research questions. It presents the required steps for the power plant 3D laser scanning, dataset collection, obtaining a high-resolution set of 3D models, classification of 3D point cloud using deep learning and creation of an online platform to synchronize plant information.

Facility Management (FM) for the most part is troublesome and confusing work. Usually, the facility team use paper or data sheet to record the facilities maintenance tasks. Nonetheless, it is difficult for facility staff to utilize the conventional 2D CAD-based data delineation in the facilities maintenance. Additionally, the data of the same facilities maintenance need to repeat the record and cause burden for facility staff. On the other hand, the BIM approach is connected and created for overseeing and maintaining the facilities in the review as 3D information models. With the combination of the BIM model, the facilities maintenance-related data, the facility stakeholders may enhance the productivity of maintenance and administration work of the facilities [1]. FM has grown in the real-estate industry and development. To maximize profit, the organizations have to comprehend that they educate customers in dealing with their facilities and properties. Nonetheless, following and overseeing facility adequately are to a great degree troublesome attributable to the different facilities.

Present-day production lines, plants and assembling lines cannot be considered without various imaging frameworks for observing and controlling their mechanical procedures. These assignments must be robotized since the maximal dependability accomplished by people in the evaluation of items through dull perception crests at 80% [2]. Accordingly, mechanized visual examination frameworks have been generally utilized since the late 1980s [3]. From that point forward, machine vision-based examination and quality control in industry have developed strongly [4], and also handle control, parts distinguishing proof and mechanical direction and control [5]. Starting late, estimation, review and quality control in industry have benefitted from 3D strategies for imaging and portrayal [6]. The advancement of machine vision contraptions at diminished expenses and also their scaling down and joining in modern procedures have animated the usage of 3D imaging frameworks in industry [7]. 3D data acquisition systems are conventionally requested into contact and noncontact methods. Contact or tactile devices must touch the surface of a protest with a mechanical sensor,
for instance, Coordinate Measuring Machines (CMM), rolls or computerized arms using mechanical tests. On the other hand, noncontact devices depend on attractive, optical or acoustic principles to gain 3D data from an object. Noncontact techniques are ordinarily separated into idle and dynamic [8]. Previous methods, which use common or encompassing light to illuminate the scene, incorporate strategies, for instance, stereo vision and photogrammetry, among others. Instances of dynamic 3D imaging techniques incorporate laser scanning, interferometry, time of flight, photometric stereo and shape from shadows. A momentous number of 3D imaging strategies have been made and shown to be proper for use in a wide arrangement of industrial procedures [8]. 3D laser scanning has been applied in different industrial applications [9], heritage buildings [10,11] and facility management [12].

This research proposes a procedure for facility management using 3D laser scanning technologies in gas turbine power plants. Identification of the data requirements contains facility components, level of detail and non-geometric items. For the plant components that need to be modeled, the required level of details of each element has been identified. The level of detail term describes the degree to which the facility component is detailed and specified. The stationary and rotating elements of power plants are subjected to degradation throughout the normal turbine operation. The gas turbine’s lifespan is influenced by multiple factors, and the way these factors affect that plant’s equipment lifespan has been well understood for the maintenance planning. The most significant factors that affect the lifetime of the gas turbine include starting cycle, power setting, type of fuel and steam level or water injection. These significant factors influence the lifespan of the plant critical components and impact the interval of the plant maintenance.

**Gas turbine-based power plants**

Gas turbine-based power plants are generally used for land electric power generation. The maintenance and planning of these plants have a strong impact on the profitability. For modern heavy-duty gas turbines, performance requirements demand hot gas path components for extreme operating conditions. These crucial elements, as a result, have a limited lifetime. In addition, the gas turbine represents an aging system during its operation that experiences continuous degradation. The continuous degradation represents in operation performance along with an increased risk of enforced outage. Operating conditions of gas turbine-based power plants determine the degradation rates and aging processes of their elements and consequently affect the plant unit’s performance and reliability. Appropriate maintenance has been scheduled to prevent the plant unit from additional degradation and then to restore its reliability and performance.
Gas turbine-based power plants are chosen compared to the huge power stations such as coal fired and nuclear stations. The construction time of the gas turbine-based power plants is quicker, and their capital investment is lower. Based on the changing of the electric power demand and its market price, these power plants deliver the appropriate flexibility during the operation for the power generation adjustment. The power plants of the combined cycle are favored for their low emission levels. The gas turbines high efficiency and demand have increased substantially in recent years for these reasons. The main reason for the rapid growth of these power plants is the combined cycle plant. The combined cycle plants combine the steam turbine and the gas turbine for electric power generation. Gas turbine-based power plants are designed for a service life of over 30 years [13]. Maintenance practices have a strong influence on the unit engine restoration and performance. The degree of the unit restoration depends heavily on the degree of the maintenance activities. Hoeft et al. [14] indicated the maintenance practices that are utilized for performance restoration include combustion inspection, hot gas path inspection, online water wash, offline water wash, steam cleaning, hand scouring abrasive cleaning and hot gas path parts replacement. Furthermore, applications of the new technologies are an option for reliability restoration and performance. The advanced technology components are frequently designed to enhance the performance of the unit and the reliability of its components [15].

**Research methodology**

The framework research methodology consists of consequence phases. The first phase in the developed framework is to identify the information requirement as shown in Figure 1. The second phase is the determination of the required scan data quality. The third phase involves the acquisition of the scanned data. This research adopts the laser scanning technologies in the

![Figure 1. Proposed framework methodology.](image-url)
power plant projects during operation and maintenance phases. Two main motivations informed the implementation of this approach. First, an increasing prominence of the critical review of the literature for primary research. Secondly, the aforementioned literature reveals that there are still gaps in the field of research in relation to data requirements for the implementation of 3D laser scanning during operation and maintenance phase of the power plants.

The scanning factors including scanning locations, scanning instrument and the angular resolutions have been predefined before the scanning data acquisition. The scanning data coverage is influenced by the scanning device, the scanning locations and the angular resolutions. The required areas of the plant have been covered with the spatial resolution and required accuracy by the scan data. The scanning device contains the necessary instruments such as a camera to capture red, green and blue colors in order to capture other properties. In addition, the locations of scanning have enabled a sight line from the scanning device to the target required to capture these properties. The option to enable or disable a sensor by setting scanning parameters has been determined according to the system components priorities. Having more scanning locations with shorter distances, higher angular resolutions and lower incident angles satisfy the desired scanning data coverage, accuracy and spatial resolution. However, this scanning process causes more efforts, is time consuming and produces redundant scanning data. Site study has been conducted to find the near optimum scanning parameters with the minimum number of scans and also satisfying the required scanning data quality (see Figure 2). For a specific scanner position, the number of horizontal and vertical repetitions that determine the laser scanner positions is considered to be in the range 2–20 repetitions. The constraint of the maximum spacing is utilized to range between 4 and 6 mm, and 60° is the maximum used incidence angle. The scanning resolution is considered to be the final optimization parameter.

**Proposed platform**

Modeling industrial project components tends to be difficult, time consuming and laborious because of the lack of BIM knowledge of the industrial plant’s stakeholders and their complex structure. For the plant stakeholders, BIM modeling is very difficult and they may not fully participate in the implementation of the BIM processes. This problem has been solved in this research by developing a framework that synchronizes non-technical stakeholders’ day-to-day work with the BIM models. Additionally, the industrial plants have an extended usage time that regularly changes some of their features, such as the reused materials, repurposed structures and the design variations. Industrial plant stakeholders have different objectives from
general Architectural Engineering Construction (AEC) specialists, and these differences have to be reflected. An investigation of the industrial plant stakeholders’ requirements is essential with an understanding of the plant workflows, the current frameworks and the systems that they implement in the routine work. BIM for industrial plant contains different users who usually work in multiple geographic locations that makes the team collaboration a challenging task.

The proposed Power Plant Operation and Maintenance Tool (PPOMT) is developed with a simple and easy-to-use interface to simplify its use. The platform automates the exchange of data for both operation and maintenance teams and real-time access to the required information, thereby decreasing the time and cost of maintenance phase. The PPOMT responsive design allows its usage in mobile devices. The developed website workspace automatically synchronizes the information with the point cloud and consequently the technical users are able to review the input of non-technical
users. Accurate and efficient extraction of power plant information plays a significant role in the operation and maintenance of such facilities. The problem has been identified via experts’ interviews and the analysis of the industrial plant procedures and requirements that permit the definition of the research objectives. Then, the proposed framework design took place. The proposed framework is worked out using a case study that will be further detailed in the next section. The platform and its application have been evaluated and validated through the plant stakeholders and experts group. Interview with plant experts highlighted that, for end users, the platform has to be simple to use and friendly. The objectives have been identified to explore the requirements of the interface, the functionality and the database required to design the prototype of the proposed platform. The following stage is the design of the platform, and it has been presented with a simple and intuitive interface and workspace to facilitate the daily work as presented in Figure 3.

The proposed platform can be easily utilized by technical and non-technical stakeholders. Technical stakeholders implement the developed platform’s website as the secondary workstation where they can view and download the required files. The non-technical users use the platform as the main workspace to fill in the required documentary fields and view the desired reports. Different documentation levels have been created to sort, order and categorize the information on the platform database. These levels are related to the following items in Autodesk Revit

![Figure 3. Platform worksite interface.](image-url)
- Creation of the project file (see Figure 4).
- Definition of the Autodesk Revit families (see Figure 5).

Families are the main equipment, and their data fields are associated with the specific information about the equipment type. The platform searches for the plant equipment’s ID to synchronize with the work website and then each family belongs to a BIM category.

Figure 4. Creation of power plant point cloud to Autodesk Revit.
Autodesk Revit project parameters are synchronized with PPOMT website fields, and the Autodesk Revit family parameters are synchronized with the sector website. Finally, the parameters of the family in Autodesk Revit are synchronized with the singular element’s fields.

The developed add-in imports the point cloud to Autodesk Revit and the users populate all the required maintenance data. The developed platform, shown in Figure 6, populates all the required maintenance data for each equipment types such as Equipment basic data, Equipment scheduled maintenance activities, safety requirements, material required, detailed steps of inspection activities and historical record for past maintenance.
The non-technical users who are not able to work with the BIM software will have access to add, edit and visualize multiple fields through the web portal. The developed platform database is able to address the synchronization of the information in realtime with the possibility of controlling the permits.

**Conclusion**

Industrial plant projects originate from oil and gas, mining, power and electricity, saline water conversion and oil sands sectors. As industrial plant projects involve extremely specialized maintenance activities, BIM is deemed to be a sufficient modeling system to handle these kinds of activities. Showing BIM visualization of the plant maintenance offers the opportunity for better training and avoids access problems. The power plant system is one of the most complex systems. Although there are no two power plant systems alike, some common fundamental characteristics of power plants include generation, transmission and distribution. This research provided a maintenance model using 3D laser scanning for linking equipment maintenance information within the power plants with the point cloud that is obtained from 3D laser scanning of the plant. The geometric modeling reproduces the original constructive process and it is time consuming and costly as all parameters need to be defined. Therefore, the developed framework utilizes the raw point cloud as an input and does not deal with the difficulties associated with modeling of the industrial projects.
Disclosure statement

No potential conflict of interest was reported by the author(s).

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References

1. Bosche F, Haas CT, Akinci B. Automated recognition of 3D CAD objects in site laser scans for project 3D status visualization and performance control. J Comput Civil Eng. 2009;23(6):311–318.
2. Newman TS, Jain AK. A survey of automated visual inspection. Comput Vision Image Understanding. 1995;61(2):231–262.
3. Malamas EN, Petakis EG, Zervakis M, et al. A survey on industrial vision systems, applications and tools. Image Vis Comput. 2003;21(2):171–188.
4. Golnabi H, Asadpour A. Design and application of industrial machine vision systems. Rob Comput Integr Manuf. 2007;23(6):630–637.
5. Blais F. Review of 20 years of range sensor development. J Electron Imaging. 2004;13(1):231–243.
6. Sansoni G, Trebeschi M, Docchio F. State-of-the-art and applications of 3D imaging sensors in industry, cultural heritage, medicine, and criminal investigation. Sensors. 2009;9(1):568–601.
7. Ahlers RJ, Lu J. Stereoscopic vision-an application oriented overview. In: Optics, Illumination, and Image Sensing for Machine Vision IV. Vol. 1194. Bellingham, WA, US: International Society for Optics and Photonics; 1989. p. 298–308.
8. Bi ZM, Wang L. Advances in 3D data acquisition and processing for industrial applications. Rob Comput Integr Manuf. 2010;26(5):403–413.
9. Marzouk M, Ahmed R. BIM-based facility management for water treatment plants using laser scanning. Water Pract Technol. 2019;14(2):325–330.
10. Marzouk M. Using 3D laser scanning to analyze heritage structures: the Case Study of Egyptian Palace. J Civil Eng Manage. 2020;26(1):53–65.
11. Metawie M, Marzouk M. Optimizing laser scanning positions in buildings exteriors: heritage building application. J Civil Eng Manage. 2020;26(3):304–314.
12. Gouda A, Marzouk M. 2019. Managing data of existing building facilities using 3D laser scanning. International Operation & Maintenance Conference in the Arab Countries (OMAINTEC 2019) Dubai, UAE.
13. Bohrenkämper G, Bals H, Wrede U, et al. Hot-gas-path life extension options for the V94.2 gas turbine. In: Turbo expo: power for land, sea, and air. Vol. 78569. New York, NY, US: American Society of Mechanical Engineers; May 2000. p. V003T02A003.
14. Hoeft RF, Janawitz J, Keck R. Heavy duty gas turbine operating and maintenance considerations. Atlanta, GA, US: General Electric Company, Gas Turbine Division; 1993.
15. Moritsuka H, Fujii T, Takahashi T. Development of a maintenance program for major gas turbine hot gas path parts. J Eng Gas Turbine Power. 2002;124(4):867–873.