AN INTEGRATED QUALITY MANAGEMENT SYSTEM FOR PIPING FABRICATION USING 3D LASER SCANNING AND PHOTOGRAMMETRY

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ABSTRACT

Addressing deficiencies and defects that occur during construction projects is costly and time consuming. The manual quality assurance programs currently used in the industry have certain limitations, including human error and lack of consistency. Hence, there is a need for integrated electronic models that employ new technologies and methods. This research introduces an integrated construction quality control system that has the potential to improve quality management processes in the construction field for piping construction, which is a complex process often requiring rework. The proposed integrated system relies on data collected from construction sites using photogrammetry and laser scanning, which is then used to compare actual work performed to that designed. The proposed system aims to improve the promptness and accuracy of quality assurance processes, in particular dimension measurements, by avoiding human error and integrating defect detection and quality management. The use of this system has highlighted some of the limitations during data fusion and acquisition process, which are highlighted in this paper. These aspects must be considered to increase the reliability of the acquired information.

KEYWORDS

Quality Assurance, Construction Management, Laser Scanning, Photogrammetry, Piping Module

INTRODUCTION

Traditional approaches to construction Quality Assurance (QA) are inadequate and there is great promise for the construction process's quality improvement (Rounds & Chi, 1985; Arditi & Gunaydin, 1997). Currently, several problems exist in developing a Quality Assurance (QA) system for piping production for mega construction projects. The construction projects are characterized by their one-off nature and hence the inherent lack of standardization (Rowlinson & Walker, 1995). The extreme changes to the details of the design of products over project lifecycle are also very common. These problems may cause delays in completion of the project and may trigger claims by the owner and other parties of the project (Gopal & Alfred, 1998). Moreover, the QA processes mostly rely on paper forms and manual human operations. The main objective of this research is to improve the current practice of QA for the industrial piping by developing an automated system, thus minimizing the errors and increasing the accuracy and consistency of the overall QA model. Within this main objective, this research evaluates the feasibly of the use of the existing state-of-the-art technologies to provide an efficient, accurate, and reliable pipe spool measurement system.

The scope of the research presented in this paper was limited to quality control of pre-fabricated pipe spools. The application of prefabrication techniques has brought a profound change in the development of the construction industry worldwide. Prefabrication can be defined as "a manufacturing process, generally taking place at a specialized facility, in which various materials are joined to form a component part of a final installation" (Tatum, 1987). Benefits include improved quality, improved design, reduced project time and less reliance on site labour. These benefits come with an increase in costs for some projects, but could be minimized as the construction industry becomes more familiar with the technology (Yeung, 2002). Any component that is manufactured offsite and is not a complete system can be considered to be prefabricated.

Quality Assurance system refers to how owners and contractors use systematic quantitative and qualitative measurements to provide adequate confidence that a product, process, or service will conform to contract requirements (Eschemuller & Lambeck, 2008; Burati et al. 1992). Adequate quality levels in construction processes have long been an issue to achieve on time and on budget in a highly complex environment (Battikha M. G., 2003). The QA process continues until the construction of the entire project has been completed (Chung, 1999). Most design related quality assurance processes are controlled by a set of QA procedure standards. Using these standards within the quality assurance procedures is the responsibility of designer and the construction management team (Arditi & Gunaydin, 1997; Barrett, 2000). The proposed system considers all aspects of QA to improve current quality management practice for piping processes.

This paper is organized into three sections. The first section provides a brief discussion of the current QA practice in construction industry. The proposes system is then introduced and the results of the study are presented.

CURRENT QA PRACTICE

Current quality assurance processes are slow and prone to human errors. Very few processes take advantage of the advances in technology. Typical quality assurance procedures for piping production used in North American construction companies usually include the following elements: drawing design calculations and specification, examination and inspection program, audits, non-destructive examination, stamping name plates, shop and field repairs and alteration, records retention, authorized inspection agency, material control, nonconforming items and heat treatment inspection, pressure testing, and calibration of measurement and test equipment.

The project manager controls the specifications provided which are compared against the appropriate code for drawing design calculations. For the examination and inspection program, the superintendent or assigned supervisor is responsible for ensuring that the incoming, in process, and final examinations and testing are performed in accordance with the approved inspection and test plan or Piping System Quality Plan (PSQP) requirements. These requirements usually contain long checklists that need to be followed. Examinations of welds are also conducted in accordance with Quality Control Program (QCP) laid out by the company.

The Quality Manager is responsible for ensuring that each element of this QCP is audited at least once a year. Noncompliant conditions are detected during the audit process and will be recorded on a Corrective & Preventive Action Report and handled in accordance with company's audit policy. Audits address the evaluation of manufactured pipe and fittings in inventory, inspection and recalibration of QA test equipment, QA inspection and reporting procedures, raw material sampling, testing, and processing of customer complaints. The Project Manager (PM), Production Engineering Manager (PEM), Quality Manager (QM), or the Site QA Manager (QAM)/Supervisor would be responsible to ensure that Non-Destructive Examination (NDE) requirements are identified on the drawings, inspection and test plans, PSQP's, or other referenced project documentation.

For shop and field repairs and alteration, the Quality Manager (QM) is responsible for assuring compliance with this Quality Control Manual for repairs, alterations and re-rating of Code items. The Quality Manager is responsible for preparing procedures for the work being performed and, in the case of fieldwork, shall supply the Authorized Inspector with those procedures.

Services and records are traceable to the provider and related project for welding and records retention. For welding, the superintendent shall be responsible to ensure that welding on Code items is performed in accordance with the approved WPS's (Weld Procedure Specifications). Tack welds, whether left in place or completely removed, shall be made by qualified welders using a qualified WPS that has been assigned for the material to be joined. Completed permanent welds are identified so as to be traceable to the welder who made the weld. For records retention, oversized records such as drawings or radiographic film shall be maintained in the applicable job file or in other organized systems such as drawing racks or film boxes. All QA records and the written reports on record should be traceable to the item and applicable project to which they apply.

The authorized inspection is the final QA phase that is taken, according to government standards, to ensure the safety of the project. The QM is responsible to communicate with the Authorized Inspection Agency and to accompany the authorized inspector when audits or reviews of the program are conducted. The project manager is responsible for ensuring the availability of all project related documents for the authorized inspector. The QA manager is responsible for informing the authorized inspector about any non-conformances that occur on site, whether or not they need to be repaired.

The current processes and technologies used by construction companies in North America today are the product of continuously advancing technologies. Advancements have carried on for a long time providing ample amount of confidence in the safety and quality of finished products. However, immature implementations of new technologies in QA processes have kept progress of the quality assurance programs slow. Continuing to adapt QA processes to new technologies while refining current implementations will ensure a more productive future. The following section explains the proposed process. Figure 1 summarizes the main components and processes of the current piping QA system.

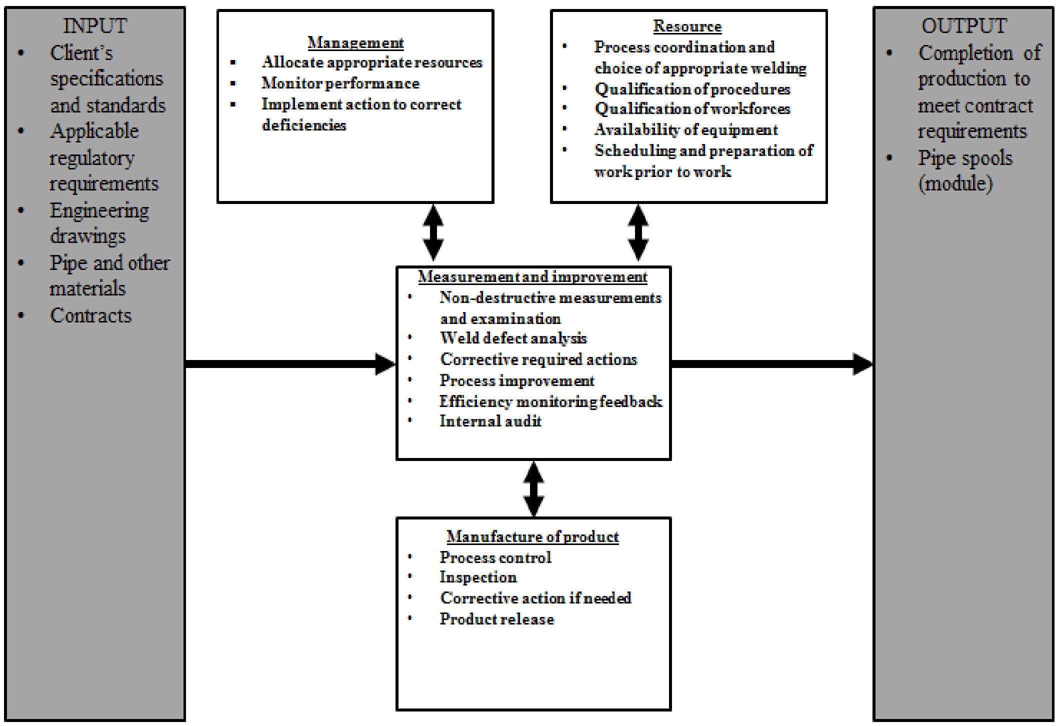

Figure 1 – Components of Current QA Processes

PROPOSED APPROACH

As mentioned in the previous section, the current QA system faces various challenges. The current system alongside with the proposed improvements are show in Figure 2. The area shown in the dotted-box shows the phase of QA that would be improved by applying the proposed system. As shown in this figure, the current QA approach requires extensive paper works. A controlled hard copy of QA principles and requirements and Engineering drawings should be available for the use of the authorized inspector in the shop and in the field. This system also needs QA teams for both shop fabrication and field construction of process piping. However, this research mostly focuses on shop fabrication. The QA team include skilled-technicians who are well trained and are responsible for several QA processes. In case of measurement process, the QA team should attend in shop to examine, measure and test of the characteristics of items to ensure they meet specified requirements. The QA manager/supervisor is responsible to ensure that all QA inspectors (technicians) perform quality verification activities in compliance with the applicable QA requirement standards.

Calibration of measurement and test equipment should be performed in accordance with the requirements and standards. Therefore, QA Inspectors should:

1. Only use calibrated measuring and test equipment.
2. Remove and segregate measuring and test equipment found to be out of calibration, attach an Out of Service tag, inform the QC Supervisor or Site QC Manager/Supervisor and identify the applicable measuring and test equipment is out of service in the database.
3. Handle equipment carefully, maintain, and store it in its container and/or in cabinets to maintain accuracy and protect it from damage and deterioration.

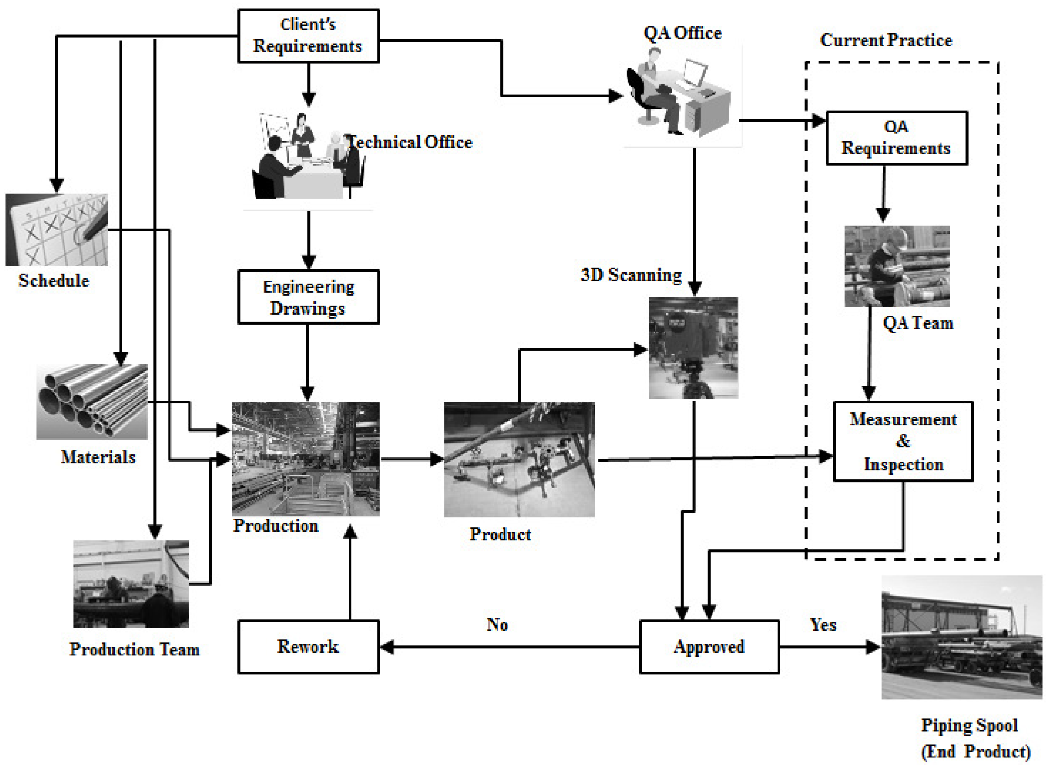

Figure 2 – Proposed Improvements to the Quality Control Process

The current approach is relatively time consuming in compared to the proposed system. The proposed QA system was developed to address these challenges, namely consistency, accuracy and human error. In order to test and check the feasibility of the system, a set of experiments were conducted. Several spools with different sizes, shapes and dimensions were tested in Quality Control area. This area was located at the end of production line where the QA preferred to install the system required-equipment.

Four laser scanner locations were identified in the corners of Quality Control room. Appropriate localization of scanners minimized the occlusion and covered as much sides of the spools as possible. Registration of separate scans were performed by finding the common points between separate point clouds. Detecting common features leads to transferring and merging the point clouds as one single and consolidated 3D model, which covers points from all sides and views. The area temperature was roughly around 15-20o C that would not influence the scanner results. FARO Laser scanner LS 840 HE was used to capture data in this study. This device measures the time for travelling a ray and calculates the distance by converting the time. This technology is well known as Time of Flight (ToF) and is used in most of available and affordable laser scanners. For merging captured data, the scanner software, FARO Scene, was used.

In this research a secondary quality control process was installed, using Photogrammetry, to analyse the feasibility and efficiency of both Photogrammetry and 3D Laser Scanning for this application. Theoretically, two images are sufficient to generate 3D point cloud using photogrammetry, but for achieving better results, four digital camera locations were identified in Quality Control room. The images taken were then analyzed using Photo Modeler software and 3D point clouds of pipe spools were generated.

The camera which is used in this research is Canon SX 40HS and the parameters are extracted by following the procedure indicated in the software. Figure 3 shows final point clouds generated by each method for one of the pipe spools. As seen in the Figure, the point cloud generated by laser scanner is denser and more continuous than the one generated by photogrammetry.

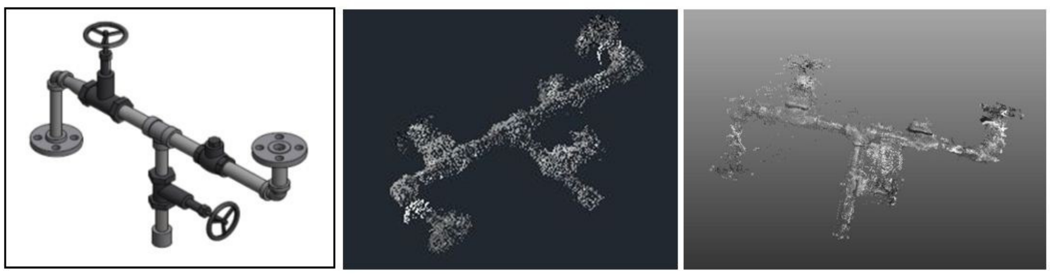

Figure 3 – (a) Original 3D CAD drawing (b) Point cloud generated by laser scanner (c) Point cloud generated by photogrammetry approach.

The proposed QA process was performed on several pipe spools and pre-processing steps were all done using the described method. Sample results for three pipe spools are shown in Table 1for both laser scan and photogrammetry data.

Table 1 – Comparing the resulted dimensions by each method, Dac: Accurate Dimension from original 3D drawing, DL: Dimension measured in the 3D point cloud from laser scanner, DP: Dimension measured from the 3D point cloud from photogrammetry (all dimensions are in mm)

Pipe Spool #	Dac (mm) Original Value	DL (mm) Laser Scan	Dp (mm) Photogrammetry	ΔL =Dac-DL	%ΔL	ΔP =Dac-DP	%ΔP
1	14	15	13	-1	-7.14%	1	7.69%
	374	378	379	-4	-1.07%	-5	-1.32%
	117	120	122	-3	-2.56%	-5	-4.10%
	38	38	38	0	0.00%	0	0.00%
	168	174	176	-6	-3.57%	-8	-4.55%
2	133	131	132	2	1.50%	1	0.76%
	1881	1879	1881	2	0.11%	0	0.00%
	214	216	218	-2	-0.93%	-4	-1.83%
	165	175	174	-10	-6.06%	-9	-5.17%
	89	90	93	-1	-1.12%	-4	-4.30%
3	38	43	44	-5	-13.2%	-6	-13.6%
	191	189	187	2	1.05%	4	2.14%
	23	23	22	0	0.00%	1	4.55%
	14	15	13	-1	-7.14%	1	7.69%

CONCLUSIONS

Piping accounts for a large portion of construction activities and has a significant impact on productivity. The current piping QA process has numerous limitations due to its inherent complexities and labour intensive QA processes. The aim of this study was to improve the QA current practice by developing new system and using new technologies: 3D laser scanning and photogrammetry. This system significantly increases the accuracy of measurements and reduces the number of work-hours of the QA personnel required, which is the primary benefit. It should be noted that the feasibility study for selecting QA area should be done prior to installing laser scanners and cameras. The implementation of the proposed system and the associated field study results indicate that the system will be a valuable tool for the piping QA and either Photogrammetry or 3D Laser scanning technologies would be suitable for this application.

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