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# IMPROVING DISASTER RESILIENCE OF POWER DISTRIBUTION NETWORK USING PHOTOGRAMMETRY TECHNOLOGY

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**Abstract:** The resilience approach continuously investigates the competence of a system to anticipate and absorb threats. The vast and vital infrastructures are highly vulnerable to various natural disasters while the threats of adversarial natural disasters are rapidly growing. For instance, the frequency of extreme, wind-related events (e.g. hurricanes, tornados, and storms) have increased over the last twenty years. Electric power distribution system, as a critical infrastructure, is extremely liable to wind-related disasters. This study introduces a methodology to facilitate the preparation and mitigation action in order to improve resilience in electric power distribution system. Developing and implementing such a methodology in the power distribution infrastructure sector can result in tremendous productivity improvements and, operation cost and schedule savings. The main contribution of this research to the body of knowledge is developing a methodology to increase the resilience of electric power distribution networks. The proposed model has a potential to radically increase accuracy and rapidity of the assessment of resilience of this critical infrastructure by utilizing the state-of-the-art technology: photogrammetry. The proposed methodology also has a potential to mitigate existing vulnerabilities of the power distribution infrastructure by precise monitoring the health of the power distribution facilities.

## 1 INTRODUCTION

The construction sector is not fast when it comes to adopting and utilizing technological solutions. However, the impacts of new technologies on construction industry have been evolutionary over the past recent years. Using new technologies have been provided a high potential for significant developments which have already apparent in other sectors (Safa et al. 2015a). These developments have direct technological impacts on the construction project performance and critical changes in the manner of governing and accomplishing a construction business (Son et al. 2015; Safa et al. 2013; Shokri et al. 2011). The aim of this study is to explore a proposed framework to improve health monitoring process result in increasing the resilience of electric power distribution networks using a state-of-the-art technology: photogrammetry. Health monitoring of infrastructure and design automation began in the early 1980's at places like Stanford (Levitt, Paulson, and Tatum) and CMU (Maher, Hendrickson, Fenves, Garrett, et al) with the NSF-funded HIRISE project and related research projects. Recent works by Haas, Kim, and Golparvar-Fard represent current activity in this area. Commercial applications are also beginning to emerge for automated site layout design, and applications for interference checking have been available for several years already. However, a few major constructors in North America are producing 3D isometric solid model assembly drawings for infrastructure projects. In this area, Building Information Modeling (BIM) is a term that has become so widely used. One key purpose of these information modeling and data standards is to improve interoperability and thus improve infrastructure maintenance and operation.

One of the critical inputs to BIM is the result of sensing process. Sensing applications and modes are almost too numerous to cover here, but a brief summary photogrammetry technology is presented here. 3D environment, using photogrammetry has been used in construction as per researchers' evaluation within educational or industrial settings (Goodrum et al. 2010). Photogrammetry as recent advances in generating 3D model creates an opportunity to explore the technological feasibility of frequently gathering complete and accurate 3D information of any facilities and infrastructure (as-built data). Photogrammetry has been suggested and validated inspecting the settling displacements of existing facilities and for measuring the geometric dimensions of as-built construction products through efficient dimension takeoffs (Ghahremani et al. 2015; Safa et al. 2015b; Kavulya et al. 2011; Dai and Lu 2010; Zhu and Brilakis 2010).

Electric power distribution networks were studied in this study as a critical infrastructure. The significance of resilient electric power distribution networks continues to grow in the modern societies. The vast and vital infrastructure, however, is highly vulnerable to various natural disasters while the threat of adversarial natural disasters is rapidly growing. For instance, the estimated loss caused by wind-related damages in the U.S. ranges $20 to $55 billion per year (Campbell, 2012; Panteli et al., 2015). This clearly shows the critical impact of timely preventive maintenance and repairing how important on the resilience of the indispensable infrastructure. In order to account for the vast deployment of power distribution network infrastructure, the resulting approach needs to allow one to assess current conditions and make necessary follow-up actions as quickly as possible while ensuring accuracy. Therefore, the proposed framework aims to radically increase accuracy and rapidity of the assessment of resilience of the infrastructure by utilizing the state-of-the-art technologies. The Resilience Approach continuously investigates the capability of a system to anticipate and absorb threats. It accomplishes this by establishing precautionary measures to reduce anticipated adverse consequences, as well protocol for expedient response and recovery of normal system operation (Eren Tokgoz and Gheorghe, 2014). Unfortunately, efficient forecasting and preparation for all possible vulnerabilities in order to protect individuals, communities, and society against disasters is often unfeasible. However, adequately developing a strategic plan for the management of the factors of resilience such as preparation, response, recovery, and mitigation can reduce the adverse consequences (Eren Tokgoz and Gheorghe, 2013).

Recently, resilience has been placed in the docket as researchers attempt to observe and conclude based on disasters such as the 9/11 attack and natural disasters such as Hurricane Katrina and Sandy. The focus of this research has been to develop optimized strategies of response and recovery when these unfortunate circumstances arise. Academic studies and government reports alike point to resilience as an essential part of establishing national security platforms for policy (Carlson et al., 2012). A recent study shows any type of disaster, incurred by man or nature, can greatly affect our societies economically and physically (Arghandeh et al., 2016). Electric power systems are one of the most vital of the Critical Infrastructures (CIs), primarily because any other CIs are deeply dependent on electricity for operation and management. Based on the Executive Office of the U.S. President report in 2013, severe weather is responsible for about 87% of all power outages in the U.S. (EOot, 2013). In addition, the estimated loss resulting from wind-related outages in the U.S. ranges from $25 to $75 billion per year (Panteli and Mancarella, 2015).

As mentioned above, electric power systems are highly vulnerable to wind-related disasters. These systems can be categorized into three subsystems: generation, transmission, and distribution systems. Power generating plants and transmission phase subsystems are more robust in the face of extreme events because of the redundancy of design (i.e., safety factor). However, distribution systems are not as reliable during such events. Since, the frequency of extreme, wind-related events (i.e., hurricanes, tornados, and storms) have especially increased over the last 30 years. This study investigates the use of photogrammetry technology to provide an accurate data for improving resilience in electric power system operation from pre to post-disaster.

## 2 METHODOLOGY

Most of the poles (more than 80%) in North America are southern yellow pine. Although wood is one of the most variable materials used for structural purposes, wood poles have a long history of satisfactory performance in the electrical and communications industries (Dunn et al., 2004). The current practice of the inspection is utilizing a visual aboveground and belowground inspection process designed to determine the serviceability of poles to determine if a pole is serviceable, need an immediate action, or a reject. When inspection methods that do not utilize non-destructive testing (NDT) and new technologies are employed, determination of the fitness of a pole is a subjective decision made by a technician (human being). Given that all technician (inspectors) performance are not identical, the efficacy of in-place wood pole inspection is challenging (Daugherty, 1998). There are several types of inspection, each with a various level of accuracy and cost (Reinprecht and Šupina, 2015). As mentioned, a visual inspection should be considered the first step to inspecting poles but has the lowest accuracy. Through this method, only obvious data can be collected. Although this method is the most comment methodology for electrical pole inspection, this method is not recommended for detecting decay (Pierson and Blanc, 2016). Another common method is sound and bore which involves striking a pole with a hammer from ground-line to as high as the inspector can reach and detecting voids by the hollow sound. This methodology can provide some decay at a stage before the ground-line section is severely damaged. In some cases, excavation can use as another inspection methodology. If the sound and bore inspection and excavation are combined the effectiveness of inspection would be greatly increased. In general, excavation reveals the most susceptible section of the pole for inspection (Pierson and Blanc, 2016).

Taking the above current inspection practice into consideration, the proposed methodology can improve the inspection process for electrical poles. The general methodology of this study include: (1) conduct a comprehensive review through the literature on all aspects of the power distribution network resilience; 3D imaging technologies, and resilient of critical infrastructures; (2) test photogrammetry and supporting technologies; measure and compare their technical capabilities for accurate and rapid automatic data acquisition; and create a methodology for collecting geometric information of components, such as electric poles and power lines, as well as 3D reconstruction; (3) collect, analyze, and synthesize data for routine health monitoring and post-disaster damage assessment; investigate the existing standards applied to determine health conditions; and create a methodology for processing image data to evaluate and determine health condition. Figure 1 shows the conceptual view of the components of the proposed framework.

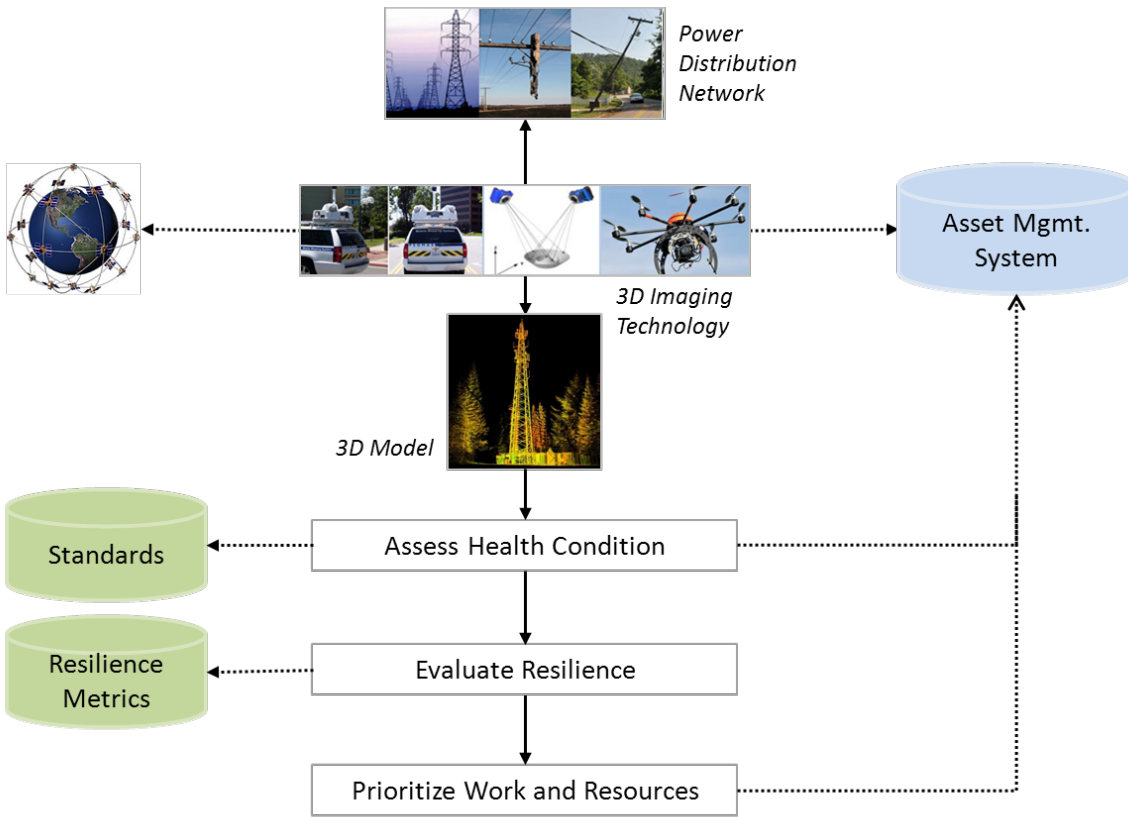


Figure 1: Conceptual view of the components of the proposed framework

The adopted research approach is to test and measure through well-designed experiments the effectiveness and efficiency of the proposed methodologies to improve routine maintenance operation as well as preparedness for and responsiveness to disasters while taking into consideration accuracy as well as time and cost performance. The proposed methodologies will be rigorously tested. The proposed project rationale incorporates the knowledge creation and transfer of the technological foundation of information generation, quality management, and use of the power distribution infrastructure. Maintaining power distribution grid in healthy and sound condition is indispensable. In particular, being able to assess the condition of its post-disaster in a fast and accurate manner is critical to the effective recovery of such a critical infrastructure. Broader Impacts of this project include accomplishing the research and educational objectives that will bring broader impacts on operation management of power distribution facilities. Although this paper only presents the first phase of a comprehensive research project, this development could benefit our society by promoting resilience and sustainability of the infrastructure. The scope of this phase is limited to measurement of the angle of the pole which is an important measurement criterion for maintenance of poles.

## 3 CASE STUDY: BEAUMONT POWER NETWORK

Beaumont is located on the Gulf of Mexico. This city is in a prime position to be hit both by hurricanes and flood. The strong winds and storms routinely cause devastating damage to communities throughout in this area. The power poles are vulnerable to these natural disasters. Hence, the coastal are such as Beaumont will be subjected to more severe exposure and would require special protection and a shorter service life. In this study, the condition of series electrical poles of the two major transit roads of Beaumont, TX were selected: (1) S M L King Jr Pkwy and (2) Highway 69 (Figure 2).

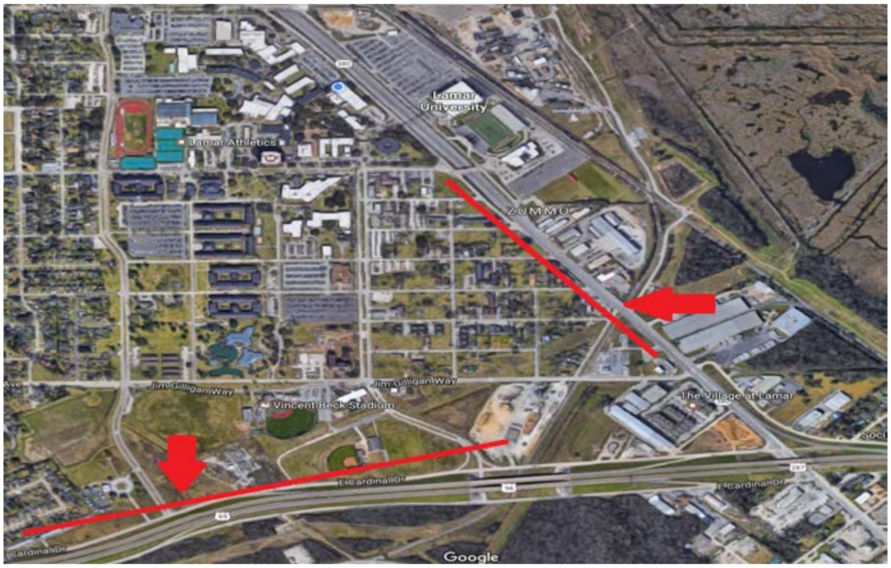


Figure 2: Aerial view of S M L King Jr Pkwy and Highway 69 in Beaumont, TX

In order to maintain poles structural integrity, minor repairs will be required over its service life. The service life of these poles is the period of years over which it will continue to serve without excessive maintenance. The critical technical aspects of maintenance of these poles are ensuring that: (1) there are adequate clearances between the conductors and the ground and the various phase conductors and circuits; (2) the mechanical load forces do not exceed the strength of poles. The loads on a pole consist of three mutually perpendicular systems: (a) vertical load; (b) transverse load; (c) Longitudinal load. The vertical load includes the weight of conductors, earth wires, cross arms and pole mounted plant. The transverse load is caused by the wind on conductor and structure (Horizon Power Corporation, 2012). However, in this phase of this research project, only the angle of the pole is considered as an important measurement criterion for maintenance of poles. This angle is defined by how the pole is located to offset the resultant force which tends to pull the pole to the vertical position. To measuring this angle, the photogrammetry technology and an associated software (PhotoModeler) were used (Figure 4). Accurate and efficient monitoring of these angles of electrical poles after/before/during disaster rescue operations are important factors which support disaster response operations and have applications in health monitoring system (Golparvar-Fard, 2011).

Figure 3: Sample of scanned point cloud of power facilities using PhotoModeler

As mentioned, this research project demonstrates the industrial modeling and measurement capabilities of photogrammetry. Results were viewed and measured in PhotoModeler. The project coordinate data was studied in PhotoModeler's point table and then exported to CAD for measurement. The developed process includes the flows between different parts is illustrated in Figure 4.

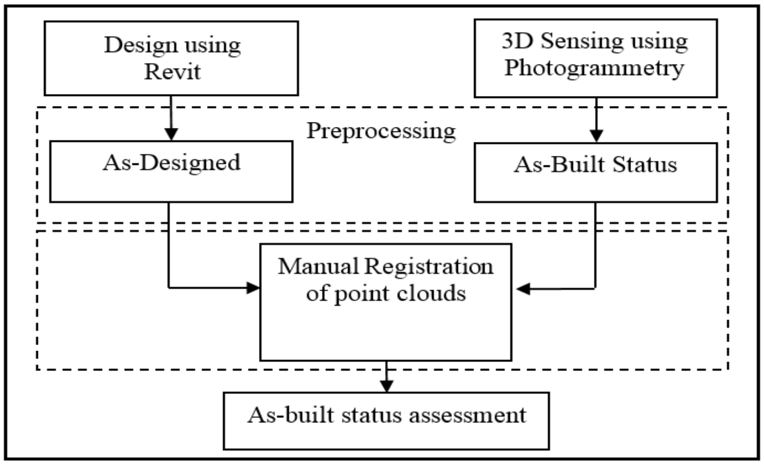


Figure 4: Proposed model for quality measurement

The photogrammetry generally can be summarized as follows (Tang et al., 2009; Safa et al., 2013): (1) common features are selected in more than three images; (2) the orientations and positions of the camera is calculated; and (3) the locations of intersecting feature points enable the reconstruction of 3D information. Hence, the first step in the process is the field experiment and retrieve useable photos of the object to use in the analysis. Multiple pictures should be taken of each pole to be used for analysis in the project. Lighting and shadows must be taken into consideration for the model to be removed correctly and accurate. The correct position and angles of the camera are important in terms of accuracy which involves a rough approximation stage. Once images of the poles have been captured for analysis one must next use PhotoModeler software to generate the model. The imported photos must be aligned to the highest degree of accuracy which will, in turn, give the image more reference points to use in generating the image. To have the absolute measurement of real poles a reference scale is needed. This issue is handled through measuring one or more scales and adding that to the photogrammetric project. Aligning the photos is providing reference points. As soon as aligned, the reference points will be shown in the workspace. Then, set the boundaries of the specific pole that is modeled this feature crop any excess image(s). Next, a raw image of the structure, dense cloud, should be made by using reference points. This process helps the workspace to be quite recognizable and as close to the pole photographed in the earlier processes. Then one must build the texture for a pole, this ultimately clean the image up and make it look sharp and realistic, therefore; producing the final image of the object (Figure 5).

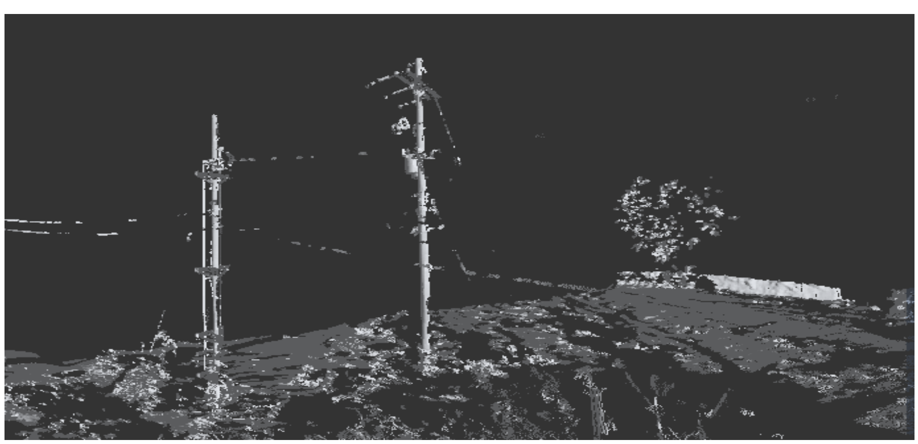

Figure 5: Scanned point cloud

The next phase is aligning the as-built point cloud model with the as-planned model (in this phase: only right angle). The transformation between these two Cartesian coordinate systems then needs to be found. The results of these study show that photogrammetry can be used to create accurate line drawings, DEMs, and orthophotos. Although the aforementioned process appears relatively straightforward, completing this with hundreds of photos and millions of points is very challenging to do efficiently and with high accuracy (Figure 6).

Figure 6: Sample of the manual registration, Galloway Building-Lamar University

While, several undesirable objects are scanned; they should be removed manually in point cloud processing software, PhotoModeler. Nonetheless, a fully automated registration that includes noise removal has been developed and presented by (Kim et al. 2013; Nahangi et al., 2013) as the results of the various research project. It should be noted that the proposed process is semi-automated as the noise removal is being performed manually. This process was performed for several electrical poles. Sample results for 22 poles from two different transit roads are shown in Table 1.

Table 1: Sample of results for 22 electrical poles

| Area | Pole # | $A_{ov}$ ° Original Value | $A_p$ ° Photogrammetry | $\Delta_L$ = $A_{ov}$- $A_p$ | Corrective Action $A_p$>25 | PM Priority 15>$A_p$>25 | PM 5>$A_p$>15 | Safe |
|---|---|---|---|---|---|---|---|---|
| S M L King Jr Pkwy | 1 | 90 | 73 | 17 | | × | | |
| | 2 | 90 | 69 | 21 | | × | | |
| | 3 | 90 | 77 | 13 | | | × | |
| | 4 | 90 | 64 | 26 | × | | | |
| | 5 | 90 | 79 | 11 | | | × | |
| | 6 | 90 | 73 | 17 | | × | | |
| | 7 | 90 | 86 | 4 | | | | × |
| | 8 | 90 | 73 | 17 | | × | | |
| | 9 | 90 | 78 | 12 | | | × | |
| | 10 | 90 | 76 | 14 | | | × | |
| | 11 | 90 | 83 | 7 | | | × | |
| Highway 69 | 1 | 90 | 88 | 2 | | | | × |
| | 2 | 90 | 86 | 4 | | | | × |
| | 3 | 90 | 85 | 5 | | | | × |
| | 4 | 90 | 87 | 3 | | | | × |
| | 5 | 90 | 73 | 17 | | × | | |
| | 6 | 90 | 78 | 12 | | | × | |
| | 7 | 90 | 81 | 9 | | | × | |
| | 8 | 90 | 72 | 18 | | × | | |
| | 9 | 90 | 78 | 12 | | | × | |
| | 10 | 90 | 75 | 15 | | × | | |
| | 11 | 90 | 82 | 8 | | | × | |

Table 1 shows four ranges: (1) Corrective Action, $A_p$>25; (2) PM Priority, 15>$A_p$>25; (3) PM, 5>$A_p$>15; and (4) safe. These ranges are accepted by local contractors and network owners in the area of southeast Texas. The results of these study show that one of the investigated electrical poles needs an immediate attention. In this study, input coordinates were recognized and accepted from other surveying methodologies, and outputs have potential to be geo-referenced. There are two key advantages of using the proposed system. First, the complete position and length of the electrical pole can be checked with its as-planned dimensions, through the use of the 3D model as apriori knowledge and therefore the reliability of the quality control process will be significantly improved. Second, the elimination human factor and associated errors in obtaining the dimensional measurements improve the precision and accuracy of the process (Nahangi et al. 2015). Given the several sources of error that exist for the current practice of inspection, including worker fatigue, eyesight errors, and other human related errors, the results obtained through the proposed approach are more accurate and reliable.

## 4 CONCLUSION

The proposed process rationale incorporates the knowledge creation and transfer of the technological foundation of information generation, quality management, and use of the power distribution infrastructure. Maintaining power distribution grid in healthy and sound condition is indispensable. In particular, being able to assess the condition of it post-disaster in a fast and accurate manner is critical to the effective recovery of such a critical infrastructure. This paper presents the first phase of the research project and (1) contributes new knowledge to the field of resilience and sustainability of power distribution grid infrastructure, and (2) provide valuable data to support respond preparation, recovery, and mitigation phases. This development will greatly benefit our society by promoting resilience and sustainability of the infrastructure. In other words, providing accurate data and enhancing the resilience of the power distribution facilities through pre-disaster and post-disaster assessment can greatly eliminate economic losses caused by disasters (e.g. wind-related disasters). The research approach was to test and measure through well-designed experiments the effectiveness and efficiency of the proposed methodologies to improve routine maintenance operation as well as preparedness for and responsiveness to disasters while taking into consideration accuracy as well as time and cost performance. The proposed methodologies were tested. The educational goal of this project was to further understanding and application of advanced technologies in the engineering, construction, and facility management field. The future phase of this project is to create an optimization algorithm for automatic prioritization of work and allocation of available resources for routine maintenance or repair work under prior-disaster situation and recovery and relief efforts under the post-disaster situation.

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