Planning Infrastructure Documentation with Aerial Laser Scanning

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Summary

Worldwide there are millions of bridges and overpasses that need documentation, inspection, and maintenance. Aerial laser scanning has the potential to assist in this process not only through the initial documentation stage but through the automated creation of three-dimensional, computational models and a further integration of that data with the surrounding environment. This paper outlines the difficulties related to effective vertical data capture for major infrastructure elements and recommends specific approaches towards a geometric optimization of this problem.

Keywords: Aerial laser scanning; surveys; remote sensing; urban studies; three-dimensional models; geographic information systems; bridges; highway overpasses.

1. Introduction

Cost-effective stewardship of America's nearly 600000 bridges and highway structures poses several key challenges with respect to safe and effective inspection, permanent documentation, computational modelling, and subsequent financial allocation. The stewardship problem is exacerbated by the absence of existing drawings for a large portion of these structures. For instance, in North Carolina, documentation exists for barely more than half of the State's more than 13000 bridges and overpasses [2]. With 90% of all passenger travel and movement of more than 50% of the nation's freight tonnage relying on these types of facilities [1], ensuring proper maintenance and upgrading is critical, but doing so without baseline information and in the absence of drawings is problematic, particularly within the context of budget limitations. In more densely populated portions of the world such as Asia and Europe, the situation is further complicated by surrounding facilities. In European cities, 20-25% of urban space is devoted to transport.

To date, decision-making relating to these types of structures has been done in a myriad of ways spanning from probabilistic-based inspection programs (e.g. to prioritization-based intervention models. Physical inspections themselves have been augmented by the installation of sensors and the application of remote sensing processes. Presently, the application of laser scanning [also known as light detection and ranging (LiDAR)] has been restricted to the terrestrial format, for two-dimensional (2D) feature identification as in the case of railway lines, or for the collection of terrain information. Terrestrial usage involves the dispatching of a crew (typically in the form of a subcontract) and a one-time generation of a three-dimensional (3D) computer aided design (CAD) model. Recent developments, however, in aerial laser scanning (ALS), with respect to increasing quality and quantity of data capture, raises the question about the potential applicability of such an approach to aid in infrastructure documentation. The generation of models (either CAD or finite element) from ALS holds great potential for Urban Planners and Civil Engineers working in such seemingly disparate applications from vibration prediction to disaster mitigation. ALS offers the prospect of the auto-generation of key portions of such models combined with the advantages of both speed and worker safety. This paper presents a discussion of the geometric impediments to

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ALS flight planning to maximize the vertical data capture needed for such 3D model generation for both the generation of drawings where none exist and for rapid post-disaster analysis. Like traditional surveying, with the use of ALS many factors remain unknown (e.g. foundation depth and condition, reinforcement details, material characteristics), but what will be shown is that with intelligent flight planning, it will only be a matter of time until the advent of unmanned aviation vehicles combined with improved hardware resolution of such imaging will be sufficient not only for 3D model extraction for bridges and possible for defect identification, as well for a fraction of the cost and for enhanced worker safety.

2. Results and Viability Assessment

At current Irish aviation restrictions of 500m minimum flying height, combined with the most recent generation of aerial LIDAR equipment available in 2006, a scan of a portion of Dublin Ireland's city centre was made. Using the new flight plan, when considering buildings, major architectural details and the general structural form were visible and available for extraction. The bridges faired less well, with specific architectural or structural elements more difficult to identify because of their relatively modest surface area and thinner features. As shown by the lower panels of these two figures, the data quality is insufficient for surface rendering and other further processing, but by comparing these results to what was obtained from a single pass, the advantages of the rethought flight plan are evident. Although these results may seem presently untenable, recent work by the authors in using this same ALS data set to generate FEM models completely automatically has shown a process, although far from perfection, that does converge without error and without any manual intervention. Finally, the cost of achieving the Dublin aerial LiDAR flyover was approximately \$9000/km^2 and was based on a total day-long capture of 6 km^2. Although perhaps financially out of reach for many communities, aerial LiDAR of bridges and overpasses holds the distinct advantage of being simultaneously useful to a wide range of end users for applications as broad as flood plain mapping to landslide identification to disaster management and coastal erosion. As such, cost-sharing incentives should be strong amongst various governmental agencies and organizations, thus substantially decreasing the cost of such data acquisition. Flight plans would have to be optimized for all potential end users.

3. Discussion

When considering both financial and technical issues, the current resolution limitations are readily apparent. However the potential of using LiDAR to document previously undocumented bridges and overpasses for the purpose of generating permanent documentation and possibly computational models seems almost within reach technically. This may even be possible for the rapid assessment of such structures in a post-disaster situation such as Hurricane Katrina. Although the underside of a bridge would not be captured, unless the ALS unit was mounted on a small, unmanned unit (something not accomplished to date), the future potential of the technique is clear in terms of advantages of speed and worker safety.

4. Summary

Future ALS equipment has the potential to return significant amounts of data related to the vertical details of bridges and related infrastructure in urban environments. The successful acquisition of such data is, however, highly dependent on an alternative consideration of flight plans, where high quality data exists within the traditional flight plan's data capture (namely in the flanks, instead of at nadir) and the application of a flight plan that is set diagonally to the main orientation of the structures of interest. Although both of these aspects are readily achievable within the current state of practice, both are counterintuitive, with respect to traditional practice that has to date focused on the capture of elements in the horizontal plane, as opposed to those in the vertical.