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EYE IN THE SKY: SUB-INCH AERIAL IMAGING OF BRIDGE DECKS

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Sub-inch aerial imaging using small format aerial photography has been found to be an ideal technique for rapid deployment of bridge scan missions. Using an under-belly photography technique, aerial imaging can generate geo-referenced, high-resolution images for quantifying bridge deck problems. The eye in the sky approach, with the ability to scan the entire bridge surface in a single flyby, is seen as an excellent supplement to bridge visual inspection and may be superior to conventional truck-mount or vehicle-mount deck imaging technologies. Conventional truck-mount technique only sees a very portion of the bridge deck, hence, requires using sampling approach to quantify damages on a bridge deck. Using full bridge deck image, aerial photography can establish much more realistic damage scenarios. However, aerial imaging poses different issues that are not encountered by ground-based techniques including shadows from trees, power lines and vehicles, visual obstructions from vehicles-on-bridge, and image resolution-induced uncertainties, etc. Different image processing tools such as image extraction, shadow removals and crack detection, therefore, have to be integrated into the damage quantification workflow. The tool development can be either post geo-referencing or pre-GIS operation. Post geo-referencing operation can rely on built-in GIS functions, however, it is limited in image processing capabilities. Pre-GIS operation, however, resulted in relative quantities that may create numerical distortions. Some preliminary results are presented in this paper.

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ABSTRACT: Sub-inch aerial imaging using small format aerial photography has been found to be an ideal technique for rapid deployment of bridge scan missions. Using an photographic technique with cameras mounted under the fuselage, aerial imaging can generate geo-referenced, high-resolution images for quantifying bridge deck problems. The eye in the sky approach, with the ability to scan the entire bridge surface in a single pass, is seen as an excellent supplement to visual inspection of bridges and is at least as useful, safer and more convenient than conventional truck-mount or vehicle-mount deck imaging applications. Conventional truck-mount technique only sees a portion of the bridge deck. This requires using a sampling approach to quantify damages on a bridge deck. By providing a full bridge deck image, aerial photography can establish higher resolution damage scenarios. However, aerial imaging poses different issues that are not encountered by ground-based techniques including shadows from trees, power lines and vehicles, visual obstructions from vehicles-on-bridge, and image resolution-induced uncertainties, etc. Different image processing tools such as image extraction, shadow removals and crack detection, therefore, have to be integrated into the damage quantification workflow. The image clarification process can be either post geo-referencing or pre-GIS operation. Post geo-referencing operation can rely on built-in GIS functions. However, it is limited in image processing capabilities. Pre-GIS operation, however, resulted in relative quantities that may create numerical distortions.

1 INTRODUCTION

Physical scanning of bridge deck surfaces can be challenging - consider their sizes and physical locations; however, bridge deck scans can help quantify deck distress conditions and provide documentation for temporal tracing of deterioration progress. Conventional truck-mount systems include laser scanner (LiDAR) or video recording are unable to completely capture the entirety of the bridge deck without several passes - air-borne techniques appear to be the most logical for bridge scans. The Eye-in-the-Sky approach coupled with sufficiently high resolution imageries can be a rapid and frequent solution to bridge scans without interruptions to traffic flows. However, conventional air-borne techniques are difficult to establish the resolution requirements for bridge deck monitoring such as crack detections (usually in sub-inch width or smaller).

In this paper, the SI-SFAP (Spatially Integrated - Small Format Aerial Photography), which is a high resolution aerial imaging technique that creatively integrates onboard GPS, vertical shots and GIS software into a measurement technique that provides geo-

referenced bridge deck images, is introduced. The low-cost aerial photography is ideal for rapid deployment of bridge scan missions, especially when the bridges are close together. SI-SFAP technique, with the ability to scan the entire bridge surface in a single flyby, provides excellent supplement to bridge visual inspections for pre-field visit assessment.

However, the Eye-in-the-Sky imaging is highly challenging consider the vast amount of obstacles that potentially may obscure viewpoints including shadows from trees, power lines and vehicles and signs or luminaire structures, that add challenges to the image processing for damage evaluation. There are also the issues of image resolution-induced uncertainties, which can be a function of the pilot skills and the flying conditions.

The issues and challenges are discussed in this paper and several recommendations on how different image processing techniques can be integrated into the damage quantification workflow, are proposed. The image processing can either be post geo-referencing or before GIS operation.

2 SI-SFAP

Contrast to conventional mapping-grade aerial photographies, which are generally taken at high altitudes (i.e. 5,000 ft and above), the SI-SFAP technique involve low-flying (around 1,000 ft altitute) at a controled airspeed (typically around 150 mph). Because of flying low, onboard small-format DSLR (Digital Single Lens Reflex) camera with pre-calibrated shutter speeds, can capture extremely high resolution images in the sub-inch range. Since these photos are from a lower altitude, the orthogonal rectification of the imagery was not performed. Also using the full frame sensors (35 mm lense size) with high electrostatic recharge rates allowing rapid firing (4-5 frames per second) at maximum pixel sensor utilization. The use of extremely high shutter speeds help avoid the need for Forward Motion Compensation (FMC). Figure 1 shows the camera set up including the camera in a) a mount and b) the belly of an airplane. The camera is docked in the underside of the aircraft for unrestricted viewing (Rice 2010).

a) On a Mount b) In Airplane Belly

Figure 1 Camera For SI-SFAP

The SI-SFAP technology is dependent on the actual flight height and the photo quality. The following factors have impacts on the photo quality including: shadows from surrounding objects and lighting, material surface roughness, traffic and possible lens smudging from airplane vibrations. Figure 2 shows an aerial image comparing to Google Earth® image and crack analysis using aerial photography method effectively identified cracks larger than 0.5 inch (shown as white markings).

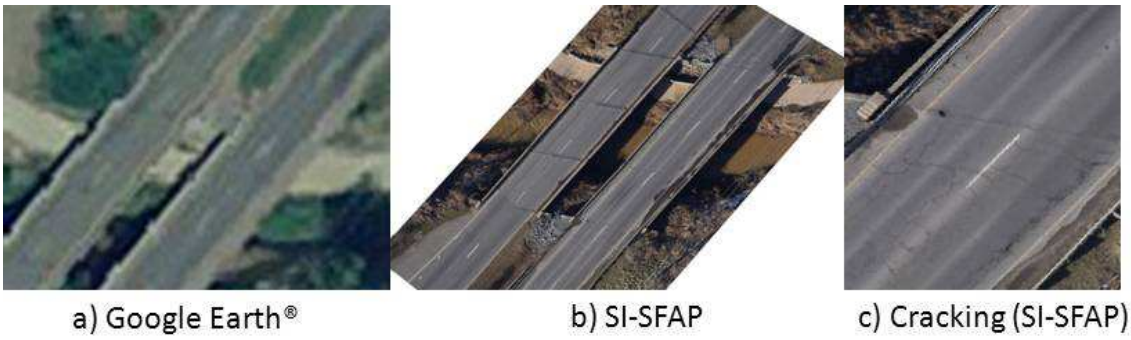

Figure 2. Aerial imaging at different scales and resolutions: a) Google Earth b) SI-SFAP and 3) Cracking (SI-SFAP)

The Photo Mission Trip (PMT) planning is a critical part of the success and the economy of the technique: Flight planning should consider the required photo resolution including camera setup; routing to the mission bridges including minimal flight time with considerations of the approach and exit from each bridge target; and finally, the time and weather conditions. The resolution of the digital images, which is defined as the ratio of the actual physical dimension to the physical length of the object in photo. Parameters such as focal length, and flight height, can be determined beforehand. Appropriate flight planning can also help establish the obstructions within the photos, for example, avoid rush hour shootings or evening shootings so that prolonged tree

Figure 3. Heavily Shadowed Bridge Deck (SI-SFAP)

shadows will not cover over the bridge. Figure 3 shows the same two bridges in Figure 2 but with heavy tree covers and shadowing.

Accurate tracking over the bridge is accomplished through strong piloting and use of onboard GPS unit. However, the WAAS-enabled portable GPS is only accurate to 10 feet and has a delayed update period; hence, a remote miniature video camera w/ cockpit viewing screen can be installed to facilitate visual acquisition of the bridge underneath. Both crew members must remain vigilant during the bridge overflights to ensure adequate scanning for other aircraft is accomplished. Additional measures of

safety are available from the ATC (Air Traffic Controller) when operating in Class B, C, and D airspace and when "VFR Flight Advisories" are requested by the pilot.

3 BRIDGE DECK MONITORING AND DAMAGE QUANTIFICATION

Bridge Inspector's Reference Manual (FHWA, 2002) defines bridge deck as the "component of a bridge to which the live load is directly applied." In this paper, only concrete decks, with or without wear surfaces, will be discussed. Critical elements to look for on a bridge deck include the deck surface conditions and the deck joint behaviors. Unlike highway pavements, currently, there is no bridge deck condition index defined. Loosely follow the Pavement Condition Index (PCI) system (Shahin 1994, Rice 2010), Chen et al. (2010) suggested a bridge surface condition index (BSCI) which defines deck crack severity based on crack length and density. SI-SFAP provides ideal mapping of crack on bridge decks, hence, can provide reasonable BSCI values on a perfectly illuminated, obstruction-free deck surface. However, BSCI does not consider special damage scenarios including punching shear, corner cracking, spalling, potholes, expansion movement data, and other damages in the bridge.

Another important feature of SI-SFAP method is the potential of quantifying bridge relative movements by measuring expansion joint openings. Current inspection reporting does not require exact joint movement measurements. Hence, no documentation of bridge superstructure movements has been included in the national bridge inventory database. However, using periodic, high-resolution aerial photography such as the SI-SFAP, it is possible to establish a temporal record of bridge joint movements. Figure 4 shows a transformation of a damaged joint over a one year period. By detecting the expansion joint distances, an inspector can visually see bridge span horizontal movements at a specific period. With further analysis of temporal data, i.e. more aerial photos taken of one bridge across a period of months or even years, the actual movement of a particular bridge can be observed and actions can be proposed to address the situation at hand. It is noted that vertical movements were not studied due to suggestions that state that horizontal movements seem much more critical to structural damage than vertical movements (Moulton et al. 1985). Bridges experiencing noticeably larger horizontal movements, greater than 2 inches and 1.5 inches for abutments, should be flagged for possible immediate inspections.

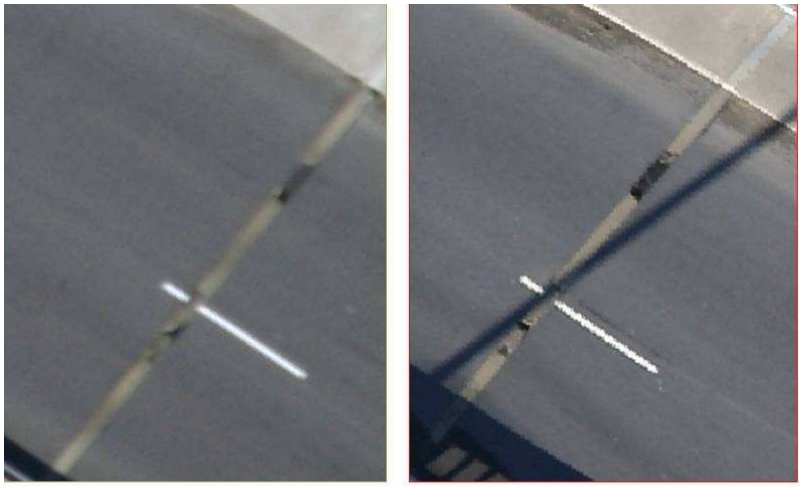

Figure 4. Joint damage progression: a) 2009 shot and b) 2010 shot

4 IMAGE PROCESSING CHALLENGES

Aerial bridge deck photos are much noisier than truck-mount camera shots for two reasons: 1) more artifacts (lighting, shadows) that cause noises and 2) obstructions such as trees and cars cannot be avoided. It is important to identify noise from the photos – however, this is not easy.

The photos are analyzed at a level where individual pixels can be seen and an outline of each object is carefully drawn. Figure 5 shows different features on a very noise bridge shot indicating shadows, cracks and joints. Figure 5 shows a critical representation of the challenges in aerial imaging: while it is easy to eyeball the damage scenarios, it is difficult to use computer to quantify the cracks, which may be partially hidden within shadows. Active removal of shadows would result in very little crack information left behind.

It should also be noted that surface roughness, discoloring and other surface conditions could cause the pixels to appear like cracks. Similar problem appears when using the color identification technique on both concrete and asphalt bridge surfaces.

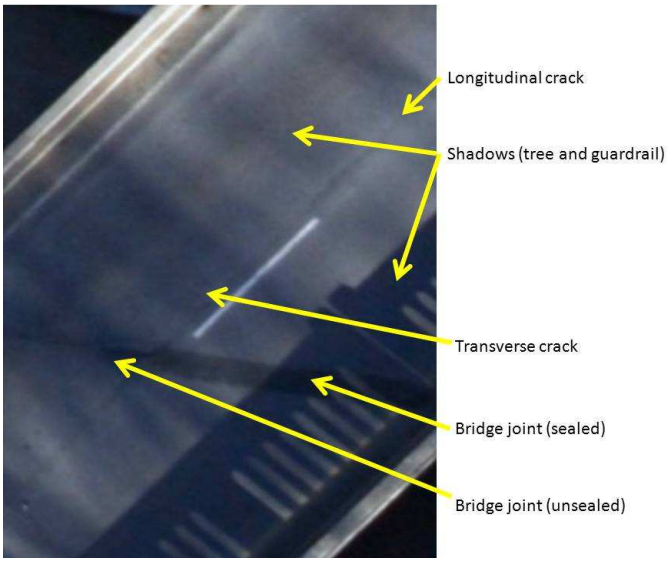

Figure 5. A very noisy image

On the other hand, indirectly some artifacts can help identify damages - while the view of the roadway surface is obscured by shadows, some larger objects may still be observed within the shadows such as holes in the surface and asphalt patches. By identifying the holes in the surface which are relatively easily observed, some cracks which radiate from the holes can be located. These kind of observations are heuristic and hard to quantify into computer procedures.

The specific challenges face possible image processing include the following:

- The shadows can be treated as regions without proper illumination which can hinder the pattern detection performance. They can also distort the crack patterns.
- Masking of vehicles may not be easy as the vehicles on the bridge might not have universal color or shape.
- A mask for trees is also difficult as they do not have specific shapes. Also the color of the leaves may change with season, makes it difficult to “procedurize” feature recognitions. Sometimes a tree branch with no leaves may appear as natural cracking.
- The reflectivity on bridge deck surface can vary the reflected color significantly throughout the course of a day – making it difficult to establish a single threshold level in image process.

5 POSSIBLE SOLUTIONS

The data manipulation performed on the aerial photos fell mainly into the categories of enhancement and classification (Gonzalez and Woods 2008). Enhancement, to improve the image for viewing and measurement, included the addition of outlines to objects and cracks present in the aerial photographs in order to make them more easily identifiable for evaluation. Once cracking and expansion joints were identified, assumptions can then be made about structural integrity. Other defects such as patching, scaling, spalling, delamination and exposed reinforcement and potholes can also be identified using aerial photography.

Since SI-SFAP is integrated with GIS software, there are two approach that can be used to enhance the bridge deck image analysis, which can be performed before or after integration to GIS software. Depending on the workflow, the image processing may be conducted by the data acquisition team (Flyers and consultants) or the bridge managers/engineers. The first approach is to preprocess the images by vectorizing the images and eliminate the artifacts, then geo-reference the images to GIS for physical quantification of damages. Figure 6 shows a processed single crack image: The 2D Haar Wavelet Transformation was applied to the images after removing the various obstructions. This process results in an image showing the major cracks. The color map also has an impact on the efficiency of inspection of the cracks. The choice between vertical and horizontal detail coefficient also plays an important role for the images. This approach is most appealing to engineers who are willing to investigate the cracking process and may perform their own image processing.

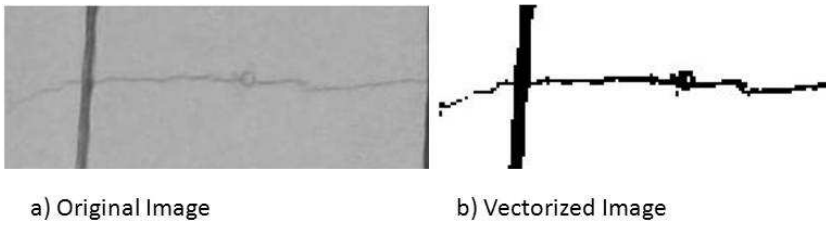

Figure 6. Original image and vectorized image of cracks and joint

The alternative approach is to upload images on GIS and use built-in image process modules for image processing. However, most GIS image processing capabilities are limited. Figure 7 shows a complete bridge image and the processed image indicating cracking patterns. This image is processed using Arc-GIS (ESRI 2006), where most of the cracks are manually annotated. This approach may be most appealing to consultants

Figure 7. Original image and image of cracks patterns

because it provides a visually clear product to the client. The client can then study the crack pattern to determine the rehabilitation planning for the bridge. In Figure 7 there are two bridges where one (lower) has more cracks than the other bridge (upper).

6. OBSERVATIONS

Being a low-cost alternative to Ortho-aerial imaging, SI-SFAP has several applications that has been identified (Chen et al. 2010):

- For project planning, high resolution aerial photography can be used to assess environmental impact potentials and used as quantitative tools for project estimations (Uddin 2002).
- Applications during project construction – frequent SI-SFAP flyovers would provide temporal recordings of construction processes allow project management teams to ensure site safety, optimize operation logistics, reduce traffic flow, minimize construction and environmental impacts, and ensure schedule compliance.
- Applications for asset condition assessment and inventory tracking – high resolution aerial photos can help identify defects and damage causes, hence are useful in establishing asset conditions and repair prioritization, which in return, can optimize rehabilitation design and fiscal planning. At times, SI-SFAP can also be deployed for emergency evaluation operations and planning.
- Applications during bridge operations – high-resolution imageries can be used to study impacts from surrounding activities near a bridge, including construction blasting and land developments.

Since high resolution aerial images have not been collected systematically, there have been limited documentations of structural implications of crack patterns. However, it is perceivable that most bridge deck cracking can be associated with performance or functionality issues, i.e. significant cracking would cause discomfort to travelers. Joint movements, as mentioned earlier, may be indications of overall superstructure integrities or substructure stabilities – more long-term studies such as Moulton et al. (1985) can help establish clear correlations between bridge movements and bridge creep or overall stabilities. Finally, shearing and spalling of decks are typically identifiable as radial cracking patterns and can be a critical indicator of insufficient reinforcement or significant delamination within the deck material.

There are other potential applications of bridge evaluation using SI-SFAP, such as detection of wingwall or foundation instability, sufficiency of channel width, and scour conditions, etc. It is suggested that further development of the Eye-in-the-Sky technologies can greatly enhance bridge condition monitoring.

7 CONCLUSIONS

In this paper, the Eye-in-the-Sky method of bridge deck scan by the means of high resolution (sub-inch) aerial photography (SI-SFAP) is introduced. The technique is ideal for rapid bridge assessment and provide a comprehensive view field of a bridge surface. However, the presence of obstructions and noises is much more challenging than conventional truck-mount scan techniques. This paper discussed the process of obtaining aerial images of bridge structures, evaluating those images for crack-like features that would should possible issues and evaluating images using GIS software.

While this technology may not replace current inspection processes, it can be used as an important structural tool for current inspection processes, in particular, the aerial images provide crack detection, bridge movements, and surrounding issues that are all effective in aiding the inspector rate the given bridge.

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