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Västlänken - Façade Crack Detection

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Façade Recording Technique:

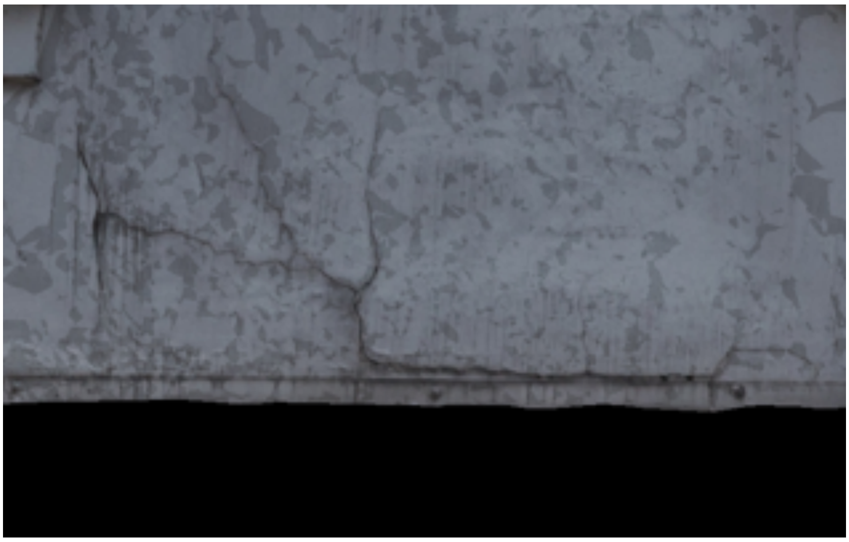
We will record high resolution panoramas of every facade using the most recent technologically advanced photography equipment. An automated panorama head will ensure full photographic coverage of the façades. We can choose the camera body and lens choice for a particular situation to ensure the highest resolution coverage of all façades.

A scale and Z-axis reference (accurate to 0.33 degrees) will be included in every panorama. Where present, we can locate this reference over existing control points cemented in the street. In addition, a control point network will be surveyed using existing survey points throughout the area of interest. These control points can be identified in the panoramas for geo-referencing. The camera station positions will also be geo-tagged for additional control.

Results:

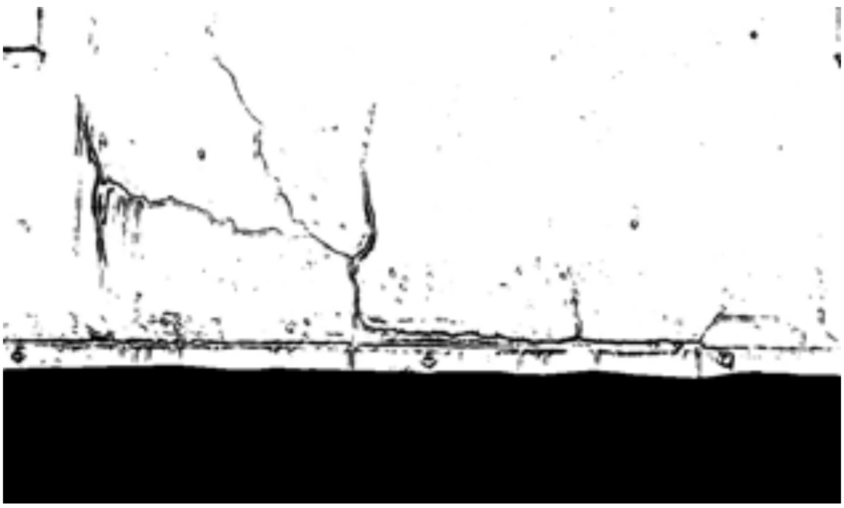
360 Panorama tour: The resulting panoramas can be built into an interactive tour of the area of interest. Each recording epoch will have its own interactive tour, where one can switch between viewpoints as well as move forwards and backwards in time. Anyone involved in the project, including property owners and building managers, can go through the tour and search for cracks. One a crack has been flagged for monitoring, a photogrammetric model can be built of the same position from two or more different recording epochs.

Photogrammetric model: The individual photos that comprise a panorama can be taken into photogrammetry software to build a 3D, color model. Entire façades can be modeled, or specific areas where cracks have been identified can be built separately. The resulting point clouds can be brought into mapping software to trace the cracks and compare deviation between older and newer models. The outlines of the cracks can be easily identified using the photorealistic texture achieved by photogrammetry, and the crack width, height and morphology can be measured and compared between models. Using image filtering techniques commonly used for crack identification in civil engineering, theocracy can be identified and monitored more clearly on the 3D model. In this way, human error can be reduced by increasing the contrast and visibility of cracks.



Above: *Crack from panorama built as 3D mesh with texture*

Below: *Same crack with filtered binary texture*



Resolution and Accuracy:

We can adapt the resolution for any requirement by simply changing the camera and lens combination. Our goal will be a **minimum resolution of 1mm** and **maximum resolution of 0.5mm** (ground pixel size, or ground sample size). **The planimetric accuracy** is simply a fraction of the ground pixel size; our highest possible accuracy is 1/10th of a pixel: (in this case) a range between **0.1mm** and **0.05mm** respectively. Depth accuracy is calculated by accounting for the base to distance ratio ([distance between camera stations] x [distance from camera station to facade]) in addition to the planimetric accuracy. So if we have a camera station every 5m, and the distance from each camera station to the façade is 5m, our **depth accuracy** will range between **0.17mm** and **0.09mm** respectively.

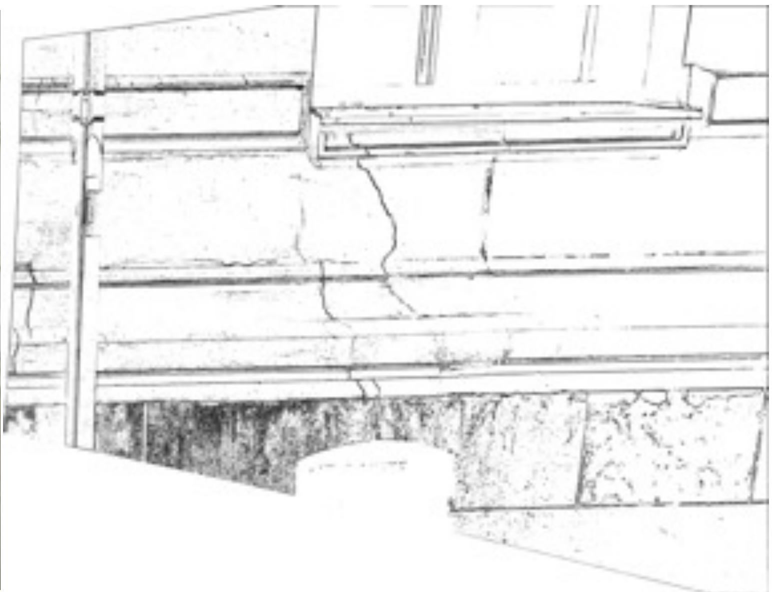
Crack monitoring:

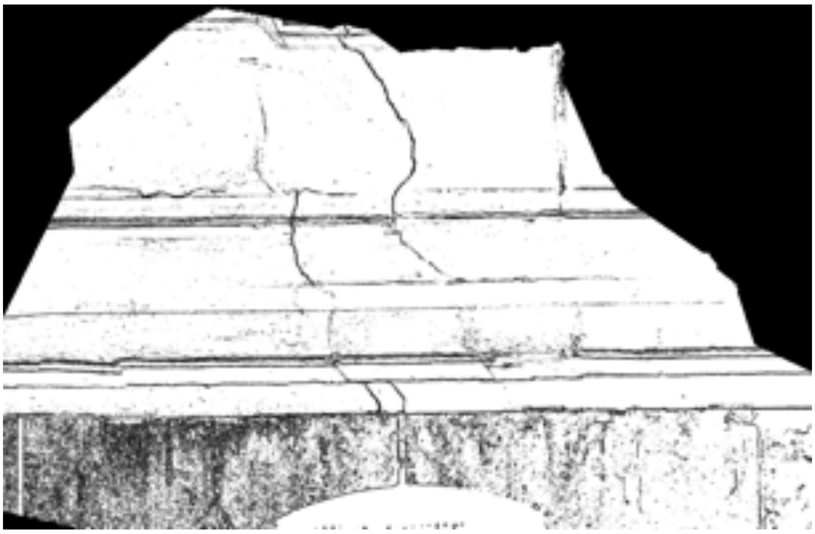
Any cracks that have been flagged for monitoring will be built in 3D using photogrammetry. Our technique allows the measurement of displacements on either side of the crack in three dimensions rather than in two (just shearing with traditional crack gauges). Detailed photographic texture intrinsic to photogrammetric models allow accurate recording of cracks.

We can integrate and improve upon recent experimental image-based crack detection and monitoring techniques (Zhang et al. 2014; Martins et al. 2013) because we can export distortion-free images from the photogrammetrically-corrected photos. These techniques use filters to smooth, detect edges and then binarize the images to black and white to allow easier crack detection and profiling. We can then apply these edited images as texture to our 3D models to accurately outline the cracks, so when we overlay future 3D models of the same crack, we can both visually and mathematically identify deviation very easily.

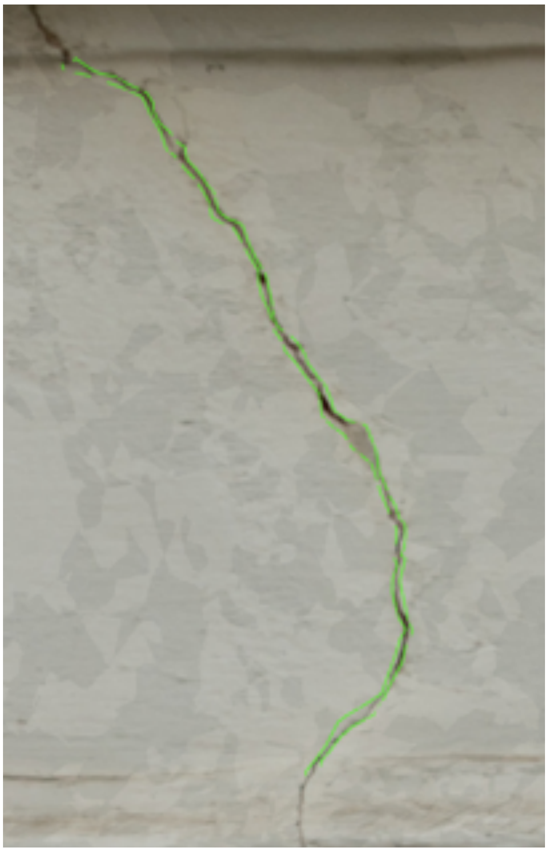
***A**) Unedited distortion and perspective corrected image*

***B)** Processed version of same image*





***C)** Processed image as texture on 3D photogrammetric model*



***D)** Polyline (in green) traced along crack edges on photorealistic texture*

Competition:

Visual inspection (manual individual measurements)

Traditional crack monitoring involves technicians walking around to visually search for cracks. This is an entirely subjective way of recording and monitoring cracks. After a crack has been identified, a technician can measure its width using either a graduated scale or a feeler gauge. A permanent crack gauge can be applied to the facade for monitoring change over time. However, a crack gauge can only map deviation in 2 dimensions at a single point of reference: how far has the crack widened, and has the crack sheared (separated more on one side or another of the gauge).

Our technique involves the creation of a photographic record over time. We are increasing transparency for all stakeholders (where building owners can look for cracks themselves) and attempting to reduce human error during the recording process. Using 3D models built from the photographic record, crack length, width and morphology can be tracked in three dimensions and recorded and exported to other software. The panoramas can also be used as documentation for liability reasons in case of future problems. The photos can always be re-built as photogrammetric models if a crack develops on a particular spot even 5 years after the project is complete.

Leica TS11 & TS15 KUMONOS

The Leica based total station - crack monitoring system is essentially the same as traditional hand recorded crack gauges, but used at a distance with a crack scale reticle superimposed in the viewfinder. It still relies on operator input to determine the crack width at a specific spot. This technique is only useful to monitor existing cracks, and can not be used to detect **when** a crack appeared or how the full façade is changing over time.

We can use the high-resolution panoramas to provide an **intuitive and transparent way of determining if a crack has appeared during the period of tunnelling**. The crack morphology -- its path and width -- mapped through photogrammetry will assist structural engineers in determining whether the crack was formed due to the subsidence trough from tunnelling activities.

LiDAR (laser scanning)

LiDAR scanning can be used in a similar manner to our technique, where a series of scan positions are used to build up a model of an entire area of interest. However, using LiDAR scans for crack detection and monitoring has a number of issues. First, the data size is immense.

Billions of points will be required to cover such a large area, and manipulating the data to search for cracks will require immense computing power to cope with the number of points. Second, the cameras built in to LiDAR scanners have low image quality and resolution, since they are used to apply texture to the points, so using the 360 degree panorama view from a LiDAR scanner will not allow as high-resolution recording as our technique. Third, the point spacing on current terrestrial LiDAR systems for this application is greater than our pixel-level resolution, so we will collect higher resolution data. While a LiDAR scanner's resolution is limited by distance, we can use a longer focal length at a greater distance but still achieve the same resolution as we would at a closer distance and a wider lens. As noted in a recent paper (Laefer et al. 2013), **the crack detection limit using LiDAR is limited to an absolute error of 1.16mm on crack widths between 1-3mm at an orthogonal (0 degrees) scan distance of 5m.**