3D Imaging

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3D spatial representation of the real world has always been one of the main objectives of mapping. However, most of the time 2D or 2.5D representations are being used to represent the 3D world. For example, in topographic maps the elevation is represented by 2D contours and in GIS the elevation is represented as a feature attribute. The 2/2.5D representations require additional cognitive effort and computations to allow for straightforward visualization and 3D calculations related to the physical size and shape of an object. Recently geometric and photo-realistic accurate three dimensional (3D) models of landscape scenes and objects have been gaining significant attention. These "realistic representations" are becoming vital to better modelling, analysis and scene understanding. 3D models serve as replicas of the real world and can be used for urban applications, digital terrain modelling, facilities management, telecommunications, transportation, infrastructure engineering, reverse engineering, decision-support, emergency services, tourism, architecture and preservation of cultural artefacts, integration of GIS and CAD and generation of augmented reality environments. The main stages of 3D modelling are: a) data acquisition, b) 3D object reconstruction, c) 3D virtual model generation by photorealistic texture rendering, d) analytical computations and e) interactive visualization of the virtual model and results on a computer or via web-mapping.

3D imaging can be defined as the 3D visual representation of the imaged scene and objects using passive and active sensors. 3D imaging techniques can be direct or indirect. Direct techniques refer the use of active sensors to directly measure the X,Y,Z coordinates of the object shape; indirect refers to use of passive sensors and the determination of the object shape through some process. A camera is a passive sensor as it records the electromagnetic radiation reflected from an object, while Light Detection and Ranging (LiDAR) is an active sensor as it transmits its own energy and receives its backscattered signal. The following are some examples of 3D imaging systems and techniques.

3D imaging using cameras

Single view cameras capture 2D images of the 3D space. The third dimension of space can be recovered photogrammetrically using two or more camera views of the scene, either simultaneously (stereoscopic coverage and stereo-viewing) or by using a single moving camera capturing multiple overlapping views (photogrammetric triangulation and structure from motion). In both cases, dense sets of corresponding points are measured across the images using image matching techniques. The rays determined by the perspective centre of the cameras and the 2D image coordinates of the points can be intersected in space to provide the 3D locations of the image points of the scene (or object) using a photogrammetric bundle adjustment solution. These 3D photogrammetrically derived point clouds can be texture mapped based on the image pixel values, forming a point–based photorealistic 3D shape representation. Furthermore, a surface triangular mesh (TIN) can be generated from the 3D point cloud, followed by the mapping of the image textures to the mesh triangles, thus resulting in a photorealistic surface-based 3D surface representation.

A low cost stereo-metric mobile mapping system has been developed at York University (Figure 1). Its stereo-viewing

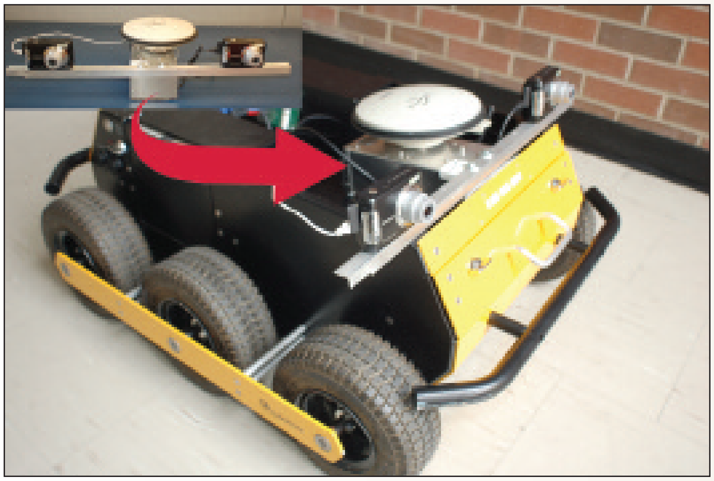

Figure 1: The mobile stereo-mapping systems onboard the Husky A200 UGV

mapping sensors are two Canon A480 digital cameras. The system uses onboard navigation sensors to determine the position and attitude of the stereo imaging sensors. 3D mapping coordinates are determined using photogrammetric solutions modified for direct georeferencing.

An example of 3D imaging using the structure from motion approach with still images taken from a mobile platform is illustrated in Figure 2. While the sparse point cloud does not reveal any object shapes, in the denser point cloud we are able to distinguish the trees, pavement surface and the sidewalk curb.

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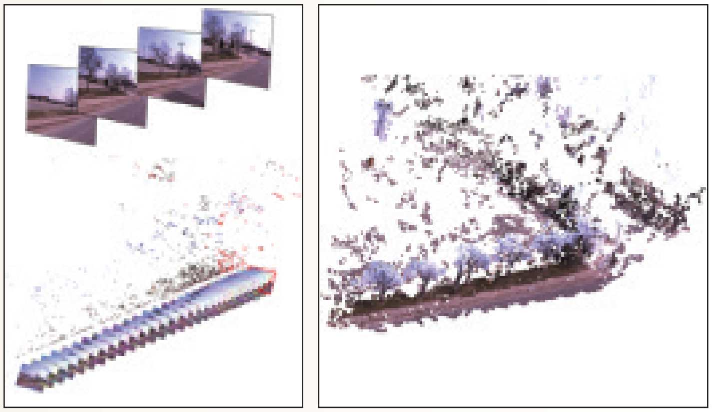

Figure 2: Structure from Motion. (Left) Sparse 3D point cloud; (Right) Denser 3D point cloud

3D imaging using LiDAR

Aerial, terrestrial, and mobile LiDAR systems use an active sensor - a laser scanner measuring range and direction - to collect patterns of dense 3D point clouds, forming a point-based 3D image of the shape of the scene. Dense point clouds are required to derive certain semantic information about the objects in a scene. The 3D point image can be texture mapped using, for example, the distance to object, the timestamp, or the height from the ground (Figure 3). A 2D image can be also generated using the

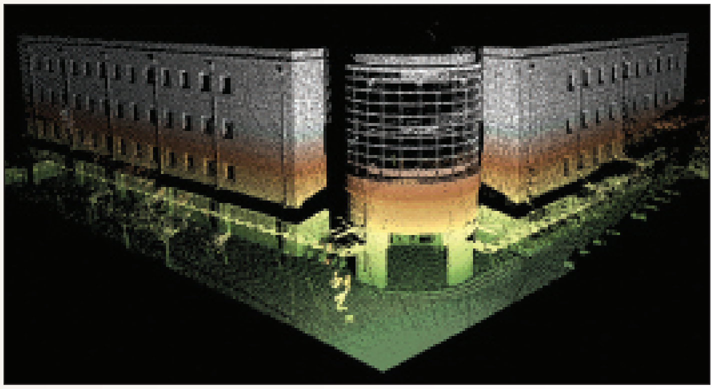

Figure 3: Colour-coded terrestrial LiDAR point cloud based on height *(credit: Langyue Wang, PhD candidate, York University)*

distance to object as its pixel values by interpolating the 3D points at a regular gridded pattern. The LiDAR scanning provides an additional image called intensity that represents the strength of the reflection of the signal from the target. The intensity image is spatially referenced to the coordinate

Figure 4: LiDAR digital surface model (DSM) (Left); LiDAR intensity georeferenced image (Right)

system used and can provide useful semantic information about the shape of the objects (Figure 4).

3D imaging using cameras and LiDAR

Digital imagery and high-density LiDAR point clouds data can be combined to generate geo-referenced photo-realistic 3D building models. An example is presented here illustrating the point cloud registration and geo-referencing, the building surface modelling and the building surface texture mapping. The point clouds were collected by the ILRIS-3D TLS laser scanner with an average point spacing of 1.5 centimetres. The imagery was captured with a Nikon D9 digital camera attached to the LiDAR system. Multiple scans, covering the building object from different viewpoints were co-registered using automatically determined tie points to create a digitized object with complete surface coverage (Figure 5). Distance images were generated from

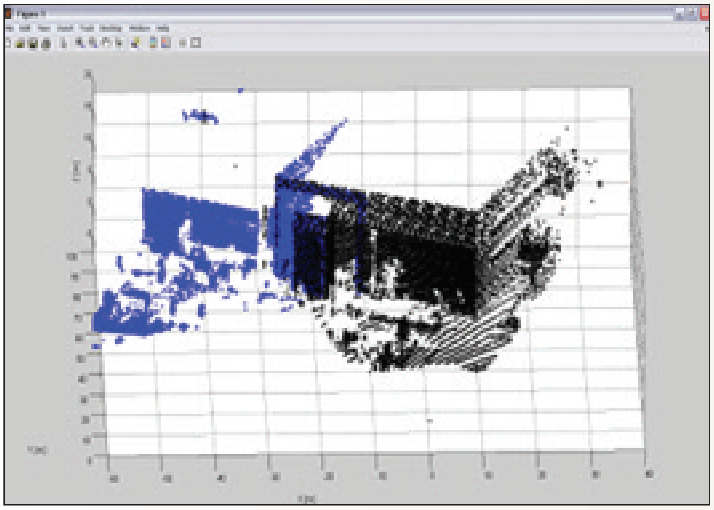

Figure 5: Registered point clouds

the 3D LiDAR point clouds, where each pixel is populated with a range-based intensity value (Figure 6).

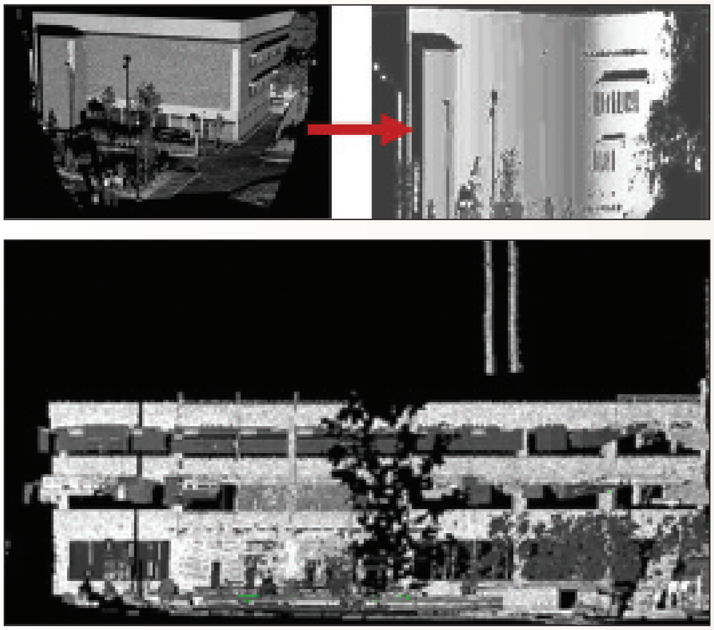

Figure 6: 2D range image of the point cloud

Upon generating the images of two overlapping point clouds, an image matching algorithm is applied to detect and match distinct features common to both images. Through georeferencing, the local coordinate system of the point cloud is transformed to a user specified geodetic coordinate system using known control points in the geodetic coordinate system. An automatic target recognition algorithm was implemented to identify these control points in the point cloud. Planar features of the building were automatically detected using a region algorithm and the 2D range image of the point clouds. The relative position and orientation of the camera coordinate system with respect to that of the laser scanner was determined through the co-registration of the image and LiDAR data. The red, green, blue (RGB) image textures were then mapped on the surface model through back projections using the collinearity equations. Figure 7 shows mapping the image to the point cloud.

Figure 7: RGB texture mapped point cloud

The 3D model of the Keele Campus of York University (Figure 8) is another example of 3D imaging using aerial digital imagery and LiDAR data together with terrestrial images of the campus buildings and vector planimetric data. The 3D model can be viewed using the Google Earth browser.

Figure 8: 3D building model of Keele Campus, York University

3D imaging using ToF cameras

Time-of-flight (ToF) is a new type of camera active sensor that, in addition to capturing a 2D intensity image of the scene, also provides a distance value at each pixel simultaneously. Therefore, these distance (range) measuring cameras can be used for the reconstruction of the 3D scape of a scene and for capturing the motion of an object. Some of these cameras are capable of video data rates, making them suitable for real-time 3D imaging. These range cameras are still of low resolution and have low measurement accuracy. They have a small field of view and they have limited range, most up to 10m, some up to 60m.

3D imaging technology is already having an impact on the ways we collect, visualise, model and analyse 3D spatial data. It will not be long before we see robotic 3D imaging and scanning total stations becoming common measuring instruments for 3D surveys.

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Calendar of Events

February 5 to 7, 2013

10th Annual ORCGA Damage Prevention Symposium
Niagara Falls, Ontario
www.orcga.com

February 11 to 13, 2013

International LiDAR Mapping Forum
Denver, Colorado
www.lidarmap.org/ILMF.aspx

February 27 to March 1, 2013

AOLS AGM
Together Towards Tomorrow
Toronto, Ontario
www.aols.org

May 6 to 10, 2013

FIG Working Week 2013
Abuja, Nigeria
www.fig.net/fig2013

June 5 to 7, 2013

CIG-ISPRS
Earth Observation for Global Changes Conference
Toronto, Ontario
http://eogc2013.blog.ryerson.ca

June 18 to 21, 2013

National Surveyors Conference and AGM
Niagara Falls, Ontario
www.acls-aatc.ca