Post Facto Registration Tools for Urban Modelling

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Abstract
Urban modelling applications require high-precision geometric models both for graphical rendering and for engineering purposes. While geometric models, photographic images and laser-scanned point clouds are ideally co-registered to national coordinate grids at the time of acquisition, the quantity and diversity of data sources means that registration must often be performed post facto. Moreover, the sheer size of urban point clouds prevents automated conversion and registration of the entire data set at once. We describe an interactive tool that manages the workflow for converting urban-scale point clouds to grid-registered geometric models. Our "user in the loop" approach lets us leverage natural human understanding of the data to bypass issues of scale.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Digitizing and scanning

1. Introduction

Urban modelling tools are used by scientists, engineers and urban planners to study pollution, noise, traffic flow, and tunnel and bridge development. These tools are also used for computer graphics applications to visualize cityscapes [HO03].

Given aerial and terrestrial laser range scanners and advanced photogrammetry, automated collection of urban data can potentially replace manual surveying or painstaking construction of building models [BH07].

Data sources use disparate coordinate systems. This necessitates *georeferencing* all the data into a common geodetic coordinate system. Traditional surveying techniques control errors by working outwards from known survey locations. More recent work uses an initial aerial laser range scan as the framework for georeferencing [SB05].

This task is impeded by the increasing volume of urban aerial laser range data, especially when heavily redundant flight plans are chosen to maximize façade acquisition quality. Thus, georeferencing requires effective tools to locate the relevant aerial data for registration and for the subsequent incorporation of geometric models into an overall urban model.

The ideal solution would release humans from the burden of data processing. However, the sheer size of the datasets makes fully automated approaches difficult to realize. Thus, effective tools for working with huge datasets require consideration of the associated human workflow.

1.1. Contributions

The overall purpose of this research is the design and implementation of tools for simplifying the task of georeferencing huge data sets. This is achieved through the following individual contributions:

1. A set of tools for locating and excerpting subsets of the primary georeferenced aerial range scan,
2. A novel method of initial manual registration between range scans optimized for building scans, and
3. The proposal and demonstration of a workflow integrating these tools.

2. Related Work

Irrespective of the capture method used (e.g., laser scanner, digital camera, manual survey), a comprehensive representation of a typical building requires multiple recordings taken from several vantage points. Ultimately, all recordings must be merged into a common frame of reference, a process referred to as *registration*. The two main approaches are sensor-driven and data-driven registration. Data driven registration is necessary because Aerial Laser Scan (ALS) data - georeferenced using sensors such as differential GPS and inertial measurement units - is often incomplete due to blind

spots in the sampling where structures shadow each other. Efforts to complement ALS data with terrestrial scans have involved terrestrial laser scanners (TLS) on trucks driven along the streets while recording façades [FZ03], and photogrammetric approaches using digital cameras, optionally combined with terrestrial laser scanners [BH07].

Where many geometric features are distinguishable, data-driven registration can be extremely accurate [MGPG04]. However, it often relies upon an iterative refinement step, that in turn requires the datasets to be roughly aligned in order to converge. A commonly used iterative refinement method is the Iterative Closest Point (ICP) [BM92, RL01]. The rough initial guess is often done manually. Schuhmacher and Böhm [SB05] show that accurate results can be obtained when combining ALS and TLS for urban environments.

Existing tools for working with range scans typically assume a single type of laser range data - terrestrial, aerial or artefactual. TLS software packages are built with the assumption that scans can be registered by high-quality survey measurements or by the use of special targets placed. However, neither scenario applies to post facto registration of TLS data to ALS data. ALS software packages commonly assume that ALS data is 2.5D (height-field), making it difficult to register with 3D TLS data. High resolution laser scanners are also used to produce highly detailed geometric models of artefacts such as Michelangelo's David [LPC*00], for which custom registration software (Scanalyze [Sca07]) was written.

Gelfand et al. [GMGP05] propose a fully automatic alignment technique for the purpose of initializing an ICP. They demonstrate their approach on scans of artefacts, which contain unique features of high curvature, but not in an urban context.

3. Workflow

Our proposed workflow is shown in Figure 1. Given a large ALS data set and TLS data that the user wishes to georeference, a building (or any region) in an aerial image generated from the aerial scan points is selected (Figure 2). The corresponding points are then used as a reference in registration with the TLS data. To rapidly align the two data sets, the user selects two corresponding planes (e.g. the same wall in both data sets) that are then used to compute an estimate of the final rigid body transformation. Thus, ensuring that the iterative refinement (ICP) will converge. Surface reconstruction can benefit from data such as existing CAD drawings, so this step is delayed until such information becomes available through spatial database queries. Ideally, the reconstructed mesh would then be fed back into the spatial database for future reference.

4. Implementation

Scanalyze was chosen as the package to extend, because it contains implementations of recent research papers on registration techniques [RL01] and is open source.
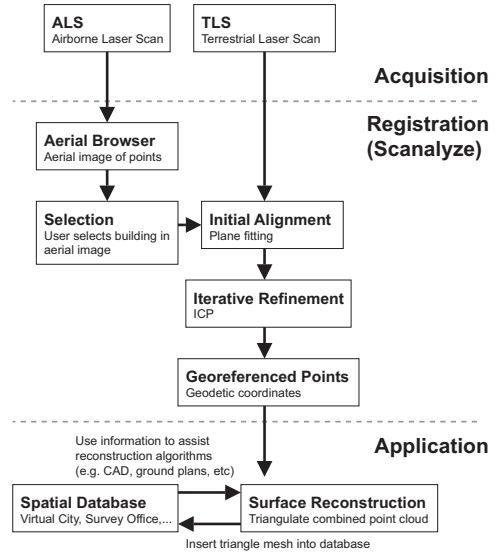

Figure 1: *Our proposed workflow.*

4.1. Aerial browsing and Selection

City-scale reconstruction projects based on ALS measurements at state-of-the-art accuracy now manipulate in the order of one billion points. For the purpose of registering a local terrestrial scan to the ALS data, the obvious thing to do is to only load the relevant portion of it.

The task of determining which part of the ALS dataset a new local scan belongs to cannot be carried out purely on the basis of measured information. Therefore the operator must provide the necessary meta-data, ultimately in this case the spatial bounds of the local scan expressed in the coordinate system of the existing data.

We take a map-reading approach to the problem, presenting the user with an aerial image of the area covered by the entire dataset. The building or block of interest is then selected with a polyline tool.

4.2. Oriented plane alignment tool

Performing a rough manual alignment of two point clouds using typical interaction techniques can be painstaking. The user must conduct a trial and error process, constantly changing viewpoints until the match holds from all angles. Corrections made in one particular viewpoint may partially invalidate those from a previous viewpoint.

Another option is to let the operator pick three corresponding points in each cloud, in order to allow for a rigid body transformation to be computed. However, picking corresponding points is error prone and tedious. When the goal is to register thousands of structures, as would be the case

Figure 2: *Our tool for browsing large aerial scan data sets. Top: the full context; Bottom: a zoomed in view for selecting a single building.*

for city-scale modelling, the above approaches become untenable. Our goal was to create a tool with only minimal operator involvement, while maintaining the accuracy levels required for the initial alignment. The proposed approach leverages the buildings' large, roughly planar surfaces and the user's natural understanding of their orientation.

4.2.1. Mode of operation

Figure 3 illustrates the setup of the two coordinate systems for which our plane fitting tool provides the initial rigid body transformation. The plane tool is operated as follows.

1. The user draws a line over a planar area of the first point cloud to define an initial direction.
2. The end-point of a second line, whose start-point is the end-point of the first one, is chosen to define a second direction orthogonal to the first one, using the user's understanding of orthogonal feature lines as seen from the current view.
3. The program generates the parallelogram spanned by the two lines, and fits a plane to the points that lie within its perimeter.
4. The two lines are then projected onto that plane using the

projection parameters of the current viewpoint, thereby producing two vectors in world coordinates.

5. Those are then used, along with the plane's normal vector, to generate an orthonormal basis. The projection on the plane of the corner point between the two user-defined lines is adjoined to the basis to form a reference frame.
6. Steps **1** to **5** are repeated over the corresponding area in the second point cloud to generate a second frame. The approach relies on the user to identify the corresponding area and the orientation of the lines that are consistent with those originally drawn on the first point cloud.
7. A rigid transformation that maps the second frame to the reference frame is computed. It can then be applied to the second point cloud to align it to the first.
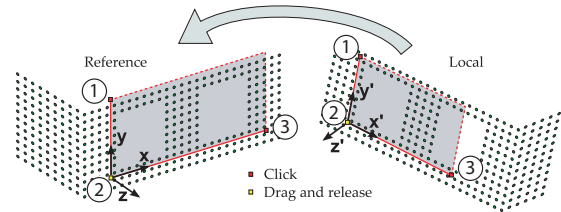

Figure 3: *Oriented plane alignment tool: the user draws two lines over both point clouds to be aligned. The tool computes the necessary transformation.*

The tool is intuitive to use because humans are good at drawing lines that are parallel to a feature. Ideally, the origins of the frames defined by the user would be actual corresponding points. However, this is not strictly needed, and neither is a perfect match of the orientations of the lines drawn. The rationale is that the alignment of the two fitted planes reduces the dimensionality of the problem from six degrees of freedom to three: a rotation with respect to the normal of the common plane and a translation within it.

4.2.2. Hidden point removal

In the context of proposing a visual interaction tool, there should be agreement between the automatically selected features and what the user judges visually relevant. In our case, this problem arises with overlapping point cloud regions (see Figure 4). While it only takes a few small changes of viewpoint for a human observer to get a sense of which points lie on which underlying plane in a point cloud, we have to make sure that this understanding is incorporated in the system. Katz et al.'s [KTB07] Hidden Point Removal operator was implemented in Scanalyze to ensure consistency.

5. Results

As an example of the workflow discussed in this paper, we show in Figure 5 the results of using our software to register terrestrial scans of a single building against a high density aerial laser scan of approximately 6 square kilometers of a city. In order to get good coverage of most of the building, we acquired terrestrial scans from seven different locations.
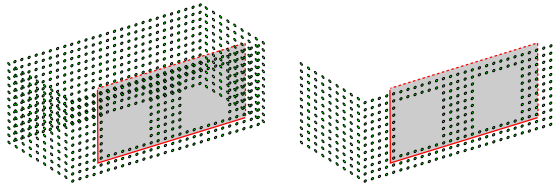
Figure 4: *Top: the user wishes to work with the points of the windowed façade, but the system will retain irrelevant points. Bottom: the discrepancy is eliminated through hidden point removal.*
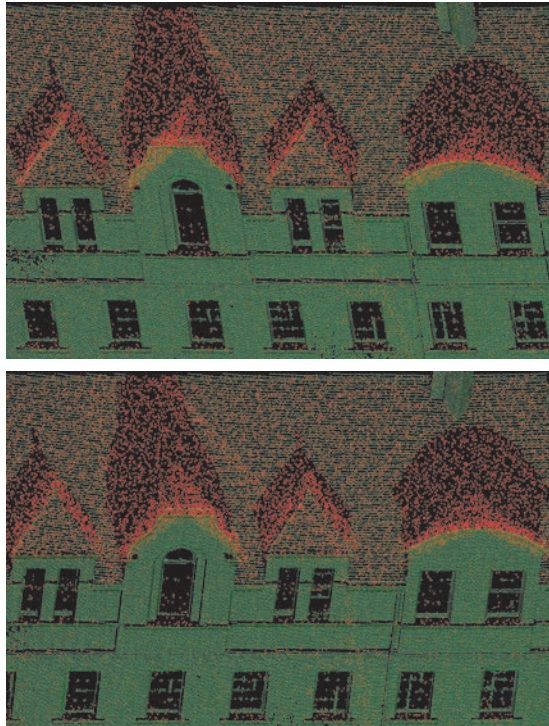

Figure 5: *Registration of terrestrial data in green with aerial data in red; two slightly different views.*

Using the method described in Section 4.2, we then used Scanalyze to co-register all seven scans. We then took the combined terrestrial scans and used the interface described in Section 4.1 to excerpt a suitable set of aerial scan points. The combined terrestrial scan was registered to the national grid coordinates used in the aerial scan. The result is shown in Figure 5.

6. Conclusions

We have established the workflow involved in generating urban models from multi-source point data, identified the missing tools required and developed tools to supplement existing software (Scanalyze) for this purpose. We demonstrated a tool for identifying the relevant area where data is to be fused within the whole geo-referenced dataset. Our tool exploits the presence of large planar regions present in urban regions.

7. Future Work

In addition to continuing to integrate our tools with Scanalyze, we intend to integrate them similarly with photogrammetric tools, and geometric modelling tools.

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