

## TRUE REALISTIC 3D MODELS OF BUILDINGS IN URBAN AREAS

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**KEY WORDS:** 3D, Buildings, Visualisation, Photogrammetry, VRM

### ABSTRACT:

Developing realistic 3D models of cities provides designers, planners, the public, and the others with imagery closely coupled with the human expertise. This paper continues on the results of an earlier innovation in the field of texture creation for the construction of Virtually Realistic Model (VRM) of buildings in urban areas. Using a CCD camera mounted on a theodolite the system takes the images of building facades; and using a number of automated/semi-automated tools converts them into textures. The textures will then be applied to the CAD models of buildings obtained from aerial photographs. Having reviewed the components of the system, the paper reports on the development of a new On-Demand Measuring Tool (ODMT). The results show that, using such system can greatly improve the speed of realistic modelling of buildings in urban areas.

### 1. INTRODUCTION

The Visually Realistic Model (VRM) of a city is a digital 3D representation of existing objects within a town that contains all the information necessary to view and recognise each object from all sides. Such three dimensional realistic representation provides designers, planners, the public, and the others with imagery closely coupled with the human experience and, hence, is of great interest (e.g. Day, 1994; and Gruber and Karner, 1996; Brenner and Haala, 1998; El-Hakim *et al.*, 1998).

VRMs can be considered as being either geometric or photo-realistic. A geometric model shows the spatial location and the topology of objects, purely based on their geometric shapes. However, a geometric model can be greatly enhanced with textures, exploited from real images, to form a photo-realistic representation (e.g. Figure 1).



Figure 1: Virtual Los Angeles (Jepson and Friedman, 2003)

Using real textures, in contrast, increases the reality and usability of a model for a number of reasons:

- *Improved realism and ease of access:* incorporating real textures not only increases the realism of the model but also enables the viewing of details, which are absent from the geometric model. Objects can instantly be recognised and accessed as required.
- *Improved interpretability:* when models are enhanced using real textures, the relationship between objects can easily be perceived. This not only includes features on

the facades of buildings such as doors and windows, but also the surrounding buildings and features like telephone boxes, etc.

- *Making instant measurements:* a geometric model rendered with real textures can be used as a base to perform measurements on objects that may not even be included in the geometric model. The accuracy of the measurements, however, depends on the accuracy of the geometric model and the way the measurements are carried out.

Commonly VRMs are created using simple geometric models rendered with textures obtained from images. Depending on the type of the camera used, the texture images may show a panoramic or perspective view of objects, which need to be compensated for through a rectification process. For this, at least four control points have to be measured in order to orient and scale the image. If more than one image is used to cover the face, all of them have to be processed in a similar manner and be mosaiced to form a single texture. Looking at the literature, can be realised that there exist no fully automatic texture processing technique. Attempts so far have mainly concentrated on the automatic acquisition of the images. The modelling process is highly dependent on human interaction and, thus, improvement in this area is extremely desirable.

Depending on the angle from which a building is visualised, aerial or terrestrial images may be utilised as the source of textures. Aerial photographs cover details of roofs, while terrestrial images show building facades. From a practical point of view, textures are required mostly for the facades of buildings that show, from a pedestrian view level, the way buildings look in reality.

Having high vertical perspectives, aerial images are either not or rarely suitable for the extraction of textures for vertical sides of buildings. Therefore, the photo-realism of building facades can usually be achieved only if terrestrial images are acquired and mapped to their corresponding building faces (Brenner and Haala, 1998).

This paper presents a system for creating textures of building façades, based on the use of images acquired and indexed in a special manner. The details of the system and its components

were fully explored in a previous paper (Varshosaz *et al*, 2000) and are only briefly reviewed here.

Along with the indexed images, a geometric model is used to define, extract, rectify, and mosaic the image portions which form the texture of a given building face. In the following section, the method utilised to acquire and index images is described. Then, having explained the way the textures are created, the paper continues by reporting on the development of an On-Demand Measuring Tool (ODMT).

## 2. TEXTURE CREATION PROCESS

### 2.1 Acquiring and Indexing Images for Texture Creation

The aim of image acquisition is to provide digital input for the production of textures. A proper image acquisition system should be flexible and allow simultaneous recording of both geometry and texture. It has to cope with various lighting conditions and be able to produce satisfactory images for the production of continuous textures. The system used in this project, is one developed as a part of a project called HAZMAP (Chapman *et al*, 1994).

The main goal of HAZMAP was to minimise human intervention during the image acquisition in hazardous environments. Image acquisition is performed using a Charge Coupled Device (CCD) camera mounted on the telescope of a theodolite, linked to a computer server. At each station a set of image tiles that cover a virtual field of view of 360 ° horizontally and 90 ° vertically are taken. In a process called “indexing”, the horizontal and vertical angles corresponding to the centre of each image are also recorded.

Indexing is an important feature of the system. In other words, in order to localise the coordinate system of each images, usually a number of control points are pre-marked in the image capture area. However, here, as the images are related to each other through their recorded vertical and horizontal angles, localisation is done only once for each station, not each image. The result is a grate reduction in the localisation time and the number of control points needed. As a result of indexing, the relative angular location of images with respect to each other is known. Therefore, by knowing only the exterior orientation of image capture stations, the relative orientation of images at all camera positions can be determined.

Once the images are captured a “reference” file is created. For each image it has an entry line which includes the image ID and its dimensions, name of the file containing camera calibration information (so called “camera file”), the station ID at which the images was taken, angular theodolite readings, and the computer location at which the image is saved.

The reference file, along with the file containing exterior orientation of imaging stations, the camera file, and the images themselves forms a Texture Image Database (TID) which provides all information required to define the image sections corresponding to each part of the texture.

### 2.2 Texture Formation

In general, texture processing involves the geometric and radiometric modelling of images. Geometric modelling refers to the rectification and mosaicing of images in order to obtain

textures of appropriate shape and dimensions. Radiometric enhancement deals with the quality of the resulting texture making sure it is homogenised and is of sufficient quality for the application of interest. This project deals only with the geometric aspects of texture processing. In order to improve the state-of-the-art, an Automatic Texture Processing Tool (ATPT) is presented which works based on the information provided by TID. It is aimed to make the texture creation more economical, simple, and fast.

Given the corners of a building face, the ATPT searches the TID images, via the reference file, and automatically extracts, rectifies, and mosaics the image portions covering the face. The output is the texture of the given face. The textures are processed for all building faces individually. Figure 2 shows the procedure.

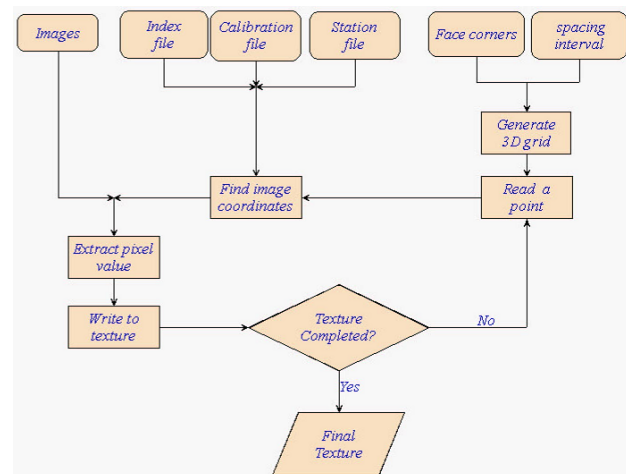


Figure 2: Flowchart of texture processing

Based on a given ground spacing interval a 3D grid is defined for the given building face. The dimensions of this grid will also define points on the texture. The basic goal of ATPT is to define the pixel values associated to the grid points, which are processed one at a time.

To form the texture of a face, the ground coordinates each grid point, are passed to ATPT that uses the camera calibration, localisation, and reference data to find the images, which cover the face of interest. For each point the reference file is searched and an image with most orthogonal view over the point is selected. The coordinates of the point on this image are then computed using an extended form of the collinearity equations (see Varshosaz, 1999). An image interpolation is finally carried out to estimate the pixel value of the point. The estimated value is then written to a new image, which is in fact the texture of the face. Figure 3 provides an example.

## 3. ON-DEMAND MEASURING TOOL

Once formed, a VRM not only permits objects to be viewed from various positions and directions but also allows for 3D measurements of features, included in the textures, to be made. Examples of such measurements are the distance between two points, the height of a building, and the 3D coordinates of a given point. Essentially, the accuracy of such measurements is directly related to the accuracy of the geometric model. In other words, the coordinates of a point measured on a texture feature

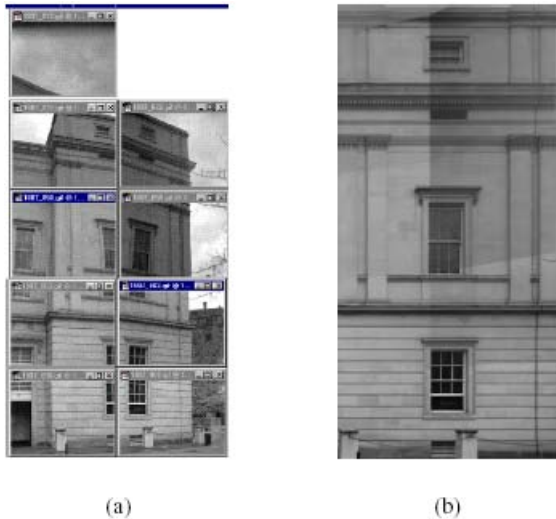


Figure 3: Individual images and the corresponding texture

are actually measured on the geometric plane underlying the texture.

A point picked up for the measurement may be directly included in the geometric model (e.g. a building corner) or be close to one of its planes (e.g. a point on a building wall). In such situations, the accuracy of the measured point is equal or close to that of geometric model and can be accepted if the accuracy of the underlying point is acceptable. However, if the point is not directly used in the model, its accuracy depends on its location relative to the measured points. For instance, Figure 4 shows a texture that includes parts of a tree. Any point measured on the tree is actually measured on the wall plane initially used to process the texture. Therefore, the accuracy of a tree point depends on how far the tree is from the wall. This situation is illustrated in Figure 5.

As already mentioned, to create the texture of a face a 3D grid is fitted to the face and an image value is defined for each grid point. The value refers to the grey level of the nearest point to the camera on the ray joining the camera centre to the grid point (i.e. P). Consequently, when a point like A is measured, the coordinates of point P are obtained instead. The larger the distance AP, the less accurate the coordinates of point A. This means, the difference between the real and the measured coordinates of a point can even be several metres.

A solution to this problem is proposed here which can achieve highest possible accuracy for the coordinates of a point regardless of whether or not it is included in the geometric model. The so-called On-Demand Measuring Tool (ODMT) employs a method, which involves obtaining initial values for the coordinates of the point, an automatic link to the full resolution images, and interactive measurement of the point coordinates.

The general structure of ODMT is shown in Figure 6 and its components are the geometric model, TID, and a standard photogrammetric measuring tool. A point is measured by first defining its location on the texture interactively. The result is 3D coordinates of the point, the accuracy of which is limited, as discussed above. The coordinates of the point are used to search the image database in order to locate the full resolution images that see the point from at least two different stations. First, a few stations that cover the point from a suitable perspective are



Figure 4: Texture that includes a view of a tree.

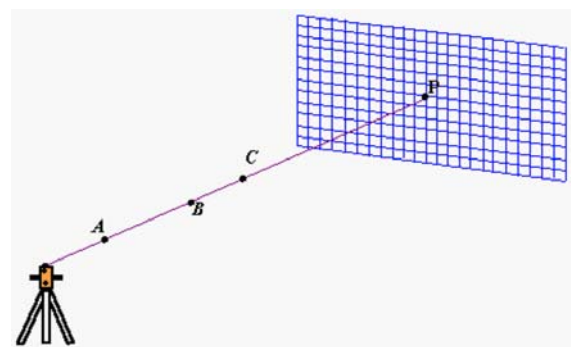


Figure 5: Projection of multiple points onto the same texture point.

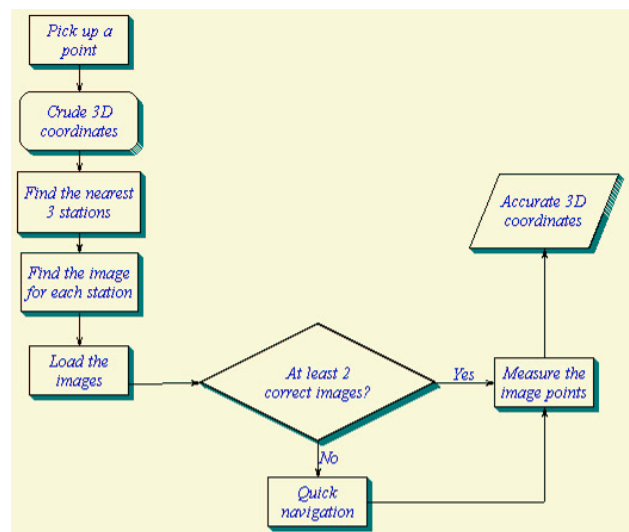


Figure 6: General structure of ODMT.

defined. Then, at each station the images are searched to define one that includes the point.

The images are loaded into a standard photogrammetric system where the accurate coordinates of the point are interactively measured. In this method, points can be measured accurately while there is no need to increase the resolution of textures or the accuracy of the geometric model. Defining stations in ODMT is slightly different from ATPT. In the latter, the stations relevant to a face are all identified by the user and

stored in a station file before textures are processed. The stations are ranked based on their horizontal view angles to the point and a best station is then selected. However, the points are measured on demand and in real time. Therefore, the station file has to contain all stations used to produce all the textures in the VRM. Consequently, there is a good chance that if stations are ranked based on their horizontal angles; the wrong station will be chosen. This problem is illustrated in Figure 7.

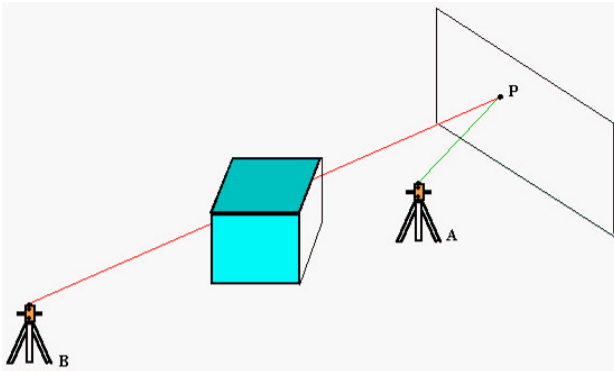


Figure 7: Possible failure of station selection.

As can be seen, although station B has a more orthogonal view to point P, it does not see it; hence station A is selected. In order to cope with such situations, the stations are chosen based on their distances to the given point, and the two stations with the smallest distances are selected. To avoid situations where the point is occluded, or the angle of the station to the point is not suitable for making 3D measurements, one or two extra stations may be selected. This ensures that at least two of the stations have a good angle to the point so the coordinates of the point are measured accurately.

Once the stations are selected, their images are searched and the best image covering the point of interest is selected at each station. The process of image selection is exactly the same as that used in the design of ATPT. The selected images are loaded into a standard photogrammetric measuring tool where the measurements are made. For the purpose of this project, the HAZMAP Browser (HB) is used. Developed as part of the HAZMAP project, HB uses the localisation and the camera calibration information to compute the coordinates of the point. For this, the image coordinates of the point are measured, and the its coordinates are computed through a 3D intersection. It should be noted that in some situations a loaded image may not see the point to be measured. An example of such is shown in Figure 8.

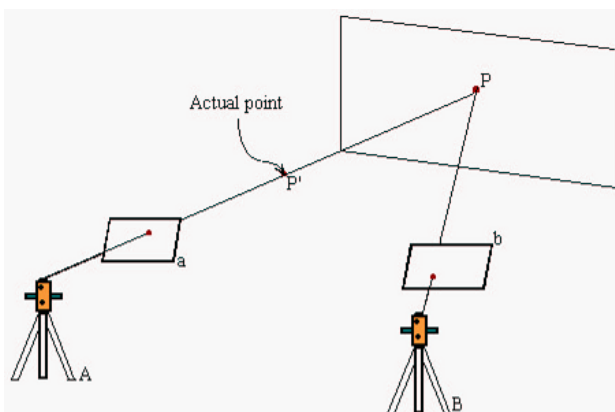


Figure 8: Possible failure of image selection program.

In this example point P' has been projected to the texture plane via images taken at station A. Therefore when the coordinates of P (the projection of P') are used to find the corresponding image at station A, the same image as that used to produce the texture of P is identified (i.e. image a). However, for station B a different image may be defined which covers P but not necessarily P'. In such cases, a small navigation between the images from B is required to locate the image seeing point P'.

As the original full resolution images are used in the process of ODMT, the accuracy of the measured coordinates is at the maximum. Using the original images, however, means that all images used to process the textures have to be accompanied with the VRM. In other words, any VRM user who intends to make accurate measurements should also purchase all full resolution images. As a result, using ODMT in such a way can be impractical. To overcome this problem, the images need to be stored on a remote host and the 3D measurements to be made locally. The measuring tool, hence, needs to be capable of using images over the Internet, or else only the selected images have to be downloaded and stored on a local machine. Fortunately, HB allows the use of remote images for making 3D measurements.

### 3.1 Examples

In this Section, a few examples are presented to illustrate the usefulness of ODMT in practice. Figure 9 shows snapshots of a texture point picked up by the user and the corresponding images loaded in the HB. To test the system, the coordinates of a number of texture points were measured. These coordinates were passed to ODMT in order to accurately define the real coordinates of the points.

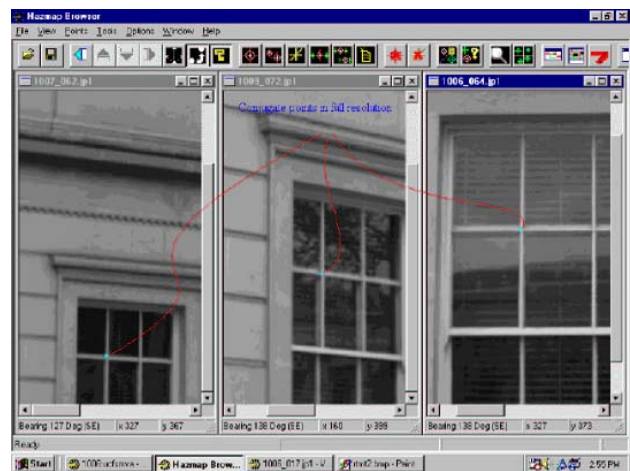


Figure 9: ODMT in action.

The points were of three types:

- Exact (E): these are the points used directly in the formation of the geometric model (e.g. roof corners).
- Crude (C): these points either belong to or are near one of the building points included in the geometric model (e.g. points on the wall, or on sills of relatively flat windows)
- Bad (B): a bad point is measured on features that are not part of a building (e.g. points on a ramp wall).

Table 1 shows the difference between the measured coordinates. As can be seen, there is a very good consistency

Point	Type	$\Delta X(m)$	$\Delta Y(m)$	$\Delta Z(m)$	Comment
1	E	-0.005	0.013	0.034	Roof corner
2	E	0.055	-0.016	0.036	Roof corner
3	C	-0.168	-0.114	-0.036	Point on wall
4	C	0.030	-0.064	0.006	Window pane intersection
5	C	-0.205	-0.098	-0.022	Point on wall
6	C	-0.107	0.174	-0.003	Point on wall
7	C	-0.042	0.208	-0.089	Point on wall
8	C	0.00	0.052	-0.049	External window sill corner
9	B	-0.520	2.572	-0.027	Corner of ramp wall
10	B	-0.417	-2.475	0.17	Corner of ramp wall
11	B	-1.338	0.881	0.052	Concrete bollard corner
12	B	-0.335	-1.650	0.016	Corner of ramp wall
13	B	2.103	4.254	0.159	Corner of ramp wall

Table 1: The difference between the VRM and ODMT coordinates.

between the ODMT coordinates of points 1-2 and those measured on the texture. The small discrepancy between the coordinates is mainly due to the user's pointing precision. Although not as accurate as points 1 and 2, the texture and ODMT coordinates of points 3-9 still have a relatively good consistency. The larger disclosures of coordinates in this group are mainly due to the random errors inherent in the coordinates of the points defining corners of the texture planes and the small distance between the actual points and their projection on the corresponding texture plane.

As expected, the differences between the texture and the ODMT coordinates of the points in the third group are large. This is because they are measured on locations different from where they actually are (i.e. the geometric model). The distance between the real points and the corresponding geometric points has simply been ignored and a big discrepancy between the coordinates has resulted. The larger the distance, the bigger the discrepancy.

The reliability of the ODMT measurements can be recognised by comparing a few distances measured using ODMT and texture points with those obtained using an accurate measuring tape.

As shown in Table 2, unlike the distances measured using points measured on textures, which are only partially consistent with the actual values, all the ODMT distances are fairly close to the corresponding tape measurements. This means using ODMT can make a big improvement to the quality of the measurements especially when the point is a Bad one.

Dist.	Tape (m)	ODMT (m)	Real (m)	$\Delta$ ODMT (m)	$\Delta$ Real (m)
1	1.712	1.720	1.676	0.008	-0.036
2	17.890	17.878	17.956	-0.012	0.066
3	0.827	0.827	0.000	0.000	-0.827
4	7.550	7.536	11.655	-0.014	4.105

Table 2: Comparison between distances measured using ODMT

It should be noted that the accuracy of ODMT measurements depends mainly on the accuracy of camera calibration and localisation information. Therefore, inaccuracy in either of these could result in points with low accuracy. Consequently, if a VRM is to be used with the intention of making accurate measurements, it is suggested to perform the localisation and calibration tasks to the best possible degree of accuracy.

#### 4. CONCLUSIONS

This paper reviewed the components and architecture of an Automatic Texture Processing Tool (ATPT). The technique is simple, fast, and easy to use. This ensures no extensive training is required to learn how to operate the system. It was also shown that due to the way the CCD images are taken and processed, it is possible to make very accurate measurements on the texture-mapped models, regardless of the accuracy of the underlying geometric model and the resolution of textures.

In addition to the forgoing discussions, a look at occlusions problem is also critical. Occlusion by static or moving objects is problem in texture processing. The effect of occlusions can be reduced by having a good plan prior to data acquisition to gain an obstruction-free view of the buildings. A partial solution to remove occlusions is to apply computer graphic methods filling in the missing parts with artificial or image-based templates. Techniques like this, however, may result in unrealistic impression of objects in the model. Besides, even with imagery of similar information to that missing, different intensity, hue, etc. may result in discontinuities over the created texture. Techniques to overcome this problem are desired and need to be addressed in the future.

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