SEMI-AUTOMATIC 3D FLIGHT SIMULATOR SCENARIOS RECONSTRUCTION FROM GEOREFERENCED AERIAL PHOTOS AND TERRESTRIAL MAPS

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Abstract

In this paper we present a completely new technique to extract 3D models from digital aerial images, by combining them with topographical maps of the site. An efficient C++ application has been developed, in order to generate 3D VRML models by exploiting both image data from on board digital camera and a database of topographical maps covering very large amounts of sites. Obviously, GPS data sets are required in order to match images with topographical maps.

The described system works as follow. Aerial images are taken during traditional airplane or UAV (Unmanned Aerial Vehicle) flight. DEM data are used to generate a 3D terrain model. Then, all images are referred on the 3D terrain model and glued onto it. By matching topographical maps with aerial images an automatic recognition algorithm extracts civil and industrial buildings contours and creates 3D textured models of them.

1 Introduction

Nowadays most of high level flight simulators exploit scenarios developed over Digital Elevation Model data (terrain databases coming from satellites) and high resolution textures. To increase the realism, also building modeling have been added to some image generators, in order to supply a tri-dimensional feeling to the operator, if a stereo vision is provided.

But the amount of manual work to perform a complete building modeling (normally only buildings around airports) is absolutely significant and passes through many problems, like building dimensions extraction and correct texture positioning. Furthermore some research activities have been started in many countries in order to reconstruct building combining both aerial photos and SAR spanning.

High fidelity 3D representations of real geographical sites are required for an increasingly amount of applications, not only for flight simulators, but also for industrial applications, i.e. telecommunication antennas lay-outs development. This is due to the need of having realistic models of mountains and hills, buildings and trees, in order to make virtual navigation of scenarios more realistic, and also to give people involved in large scale projects development a more realistic awareness of available spaces. Nowadays flight simulator are based on very simple visuals, which offer limited realism. Several efforts have been taking place in order to better visual quality especially in low altitude flight, a step forward this improvement is done by performing automatic building reconstruction.

At V-Lab (University of Bologna - Forlì) (http://v-lab.ingfo.unibo.it) applications which require this kind of 3D models are developed. They range from large scale terrain visualization for training, to flight simulators. This laboratory is based on IRR Immersive Reconfigurable Room, a VR system based on a PC graphic cluster. High performance graphic boards permit active stereoscopic vision, in order to better user’s visual feedback.

In the following we describe how ground images taken by an onboard camera and digital elevation maps can be combined with an automatic recognition algorithm in order to obtain advanced 3d models of the terrain and buildings.

2 State-of-the-art

A virtual scenery is realized through the generation in three-dimensional environment of geometric elements, constituted by polygonal surfaces. They assume the form of the real elements that we need to reproduce; on their surfaces are applied the corresponding images digitized by the real environment. In the following images an example of realization of a three-dimensional virtual building is shown.

Fig. 1. Real photo.

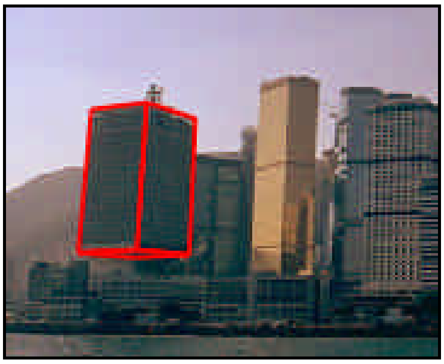


Fig. 2. Building geometry reconstructed.

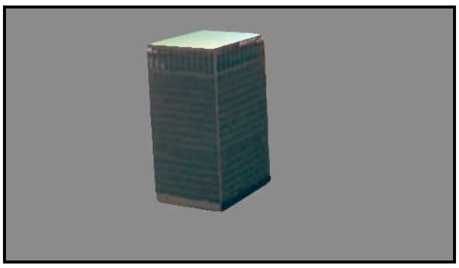


Fig. 3. Virtual 3D (file Wrml).

Previous work on building reconstruction problem shows that the problem should be divided into two steps: building detection and building reconstruction. In the first step the problem is to recognize the area, region of interest, where the building lies; in the second, the problem is the determination of geometrical properties of buildings, essential for the reconstruction. The inputs used to carry on this analysis are: digital images, High-quality Digital Surface Models (DSM), 2D GIS information. All this types of input need specific algorithms for their elaboration. There are some limits: the greatest reside in the performances that the actual tools allow, particularly extended and detailed scenarios require extremely elevated performances in comparison to those allowed by the actual commercial PC, so there is a great research on simplification the scenery representation. The complexity of the scenery is proportional to the number of polygons and texture that compose it. Moreover the texture is crucial for the final result, but it is influenced by many environmental factors: lightness, position of the sun, whether, position of mobile objects. Moreover there are many difficulties to make data acquisition that can be automatic or semi-automatic: the first is done by hands and is slow but reliable, the second is faster but the results are not always correct. A lot of work has been done to extract buildings models from photogrammetrics approaches, such as aerial images [4][12][9]. Attempting to reconstruct buildings from high-resolution satellite stereo imagery we can find Fraser, Baltsavias and Gruen [8]. Alternatively, airborne laser scanning (LIDAR) data is a reliable source of information for the surface reconstruction and the creation of high quality DSMs. Weidner and Forntner [22], Maas and Vosselman [16] founded the reconstruction on DSMs or laser altimetry data. Best results are reached when photogrammetric and laser sources are mixed. Haala [11] uses DSMs with colour aerial images, Vosselman and Suveg [17] combines GIS maps with laser data and images. Many systems have been developed so far: system for quality improvement ad systems for simplification. The use of microtexture is tied to the necessity to realize a better visual quality when a portion of scenery is very near to the point of observation. Such textures appear in closer visualizations, and they have the purpose to increase the graphic detail of the polygonal surfaces. Mip Mapping (Mip = multum in parvo) imposes the realization of a certain number of texture (three) related to the same part of scenery, each derived from the reduction of 1/4 of resolution from the previous one (system of pyramid reduction). This allows to improve the quality of the scenery in the parts most distant from the point of observation, where the presence of a texture in low resolution doesn't produce the effect of distorsion of the image related to the interpretation of the color to assign to the pixels with raised resolution. Systems for the simplification are based on remeshing, to decrease the number of polygons at great distances in the virtual environment, and L.O.D.: different versions of the same element with decreasing level of detail are stored and represented.

There are a number of commercial applications that permit, by manually defining on them three dimensional shapes' corners, to build 3D textured models. In other words these kind of applications are able to build 3D shapes and to apply on their faces the right portions of the texture. Human labor required to perform this kind of task is so time wasting that many research activities have been conduced in the field of automatic reconstruction of both 3D buildings and terrains. Anyway building reconstruction in most cases is done by manually modeling buildings with CAD-like applications. In those cases a great precision could be reached; such high level of detail is not required for flight simulator applications, where one meter error in building position is tolerated.

3 System outline

The following flow-chart describes how the program works. Five input data are required: topographical map 1:25.000, DEM file, orthonormal aerial image, positioning data, template image. The software application processes these items and gives out a 3D textured model.

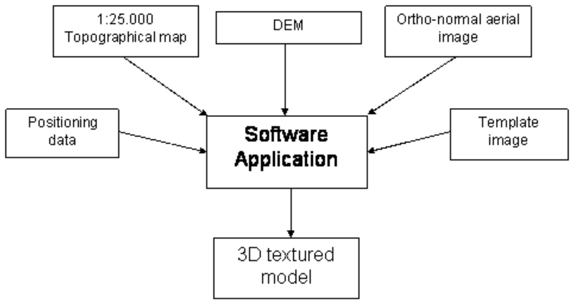


Fig. 4. Software application I/O.

As shown in the above diagram, our application makes use of DEMs: Digital Elevation Models are data files that contain the elevation of the terrain over a specified area, usually at a fixed grid interval over the surface of the earth. The intervals between each of the grid points will always be referenced to some geographical coordinate system. This is usually either latitude-longitude or UTM (Universal Transverse Mercator) coordinate systems. The closer together the grid points are located, the more detailed the information will be in the file. The details of the peaks and valleys in the terrain will be better modeled with a small grid spacing than when the grid intervals are very large. Elevations other than at the specific grid point locations are not contained in the file. As a result peak points and valley points not coincident with the grid will not be recorded in the file. The DEM file also does not contain civil information such as roads or buildings, it is not a scanned image of the paper map (graphic). It is not a bitmap. The DEM does not contain elevation contours, only the specific elevation values at specific grid point locations.

For the purpose of this work, a custom hardware system is needed. We based our work on sets of digital images captured by a digital camera boarded on a aircraft, as shown in the picture above. GPS data are required in order to match images to geographical position; the camera is mounted on a special bracket which fixes view direction, so that by combining aircraft position and orientation with camera view direction, it is possible to get the geographical position of the center of each image. The software application described in the present work has been developed by exploiting IPL (Intel Image Processing Library) and TGS Open Inventor, a OpenGL based graphic SDK.

Although a digital camera have been used, it is possible to use also a video camera: the resolution would be worst, but the number of frames higher.

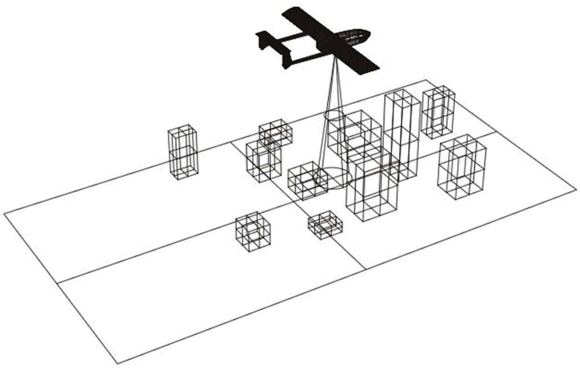


Fig. 5. Hardware Setup.

Acquired data are stored in an indexed set organized as in the below table.

TIME	GPS			PICTURE ID
	LAT.	LONG.	ALT	
0	44°15'45"	12°07'13"	100	0
1	44°15'46"	12°07'13"	101	1
2	44°15'46"	12°07'14"	100	2
..	..	..	..	..
…	…	…	…	…

The described system works as follow. Aerial images are taken during traditional airplane or UAV (Unmanned Aerial Vehicle) flight. DEM data are used to generate a 3D terrain model. Then, all images are referred on the 3D terrain model and glued onto it. By matching topographical maps with aerial images, as described in the next section, an automatic recognition algorithm extracts civil and industrial buildings contours and creates 3D textured models of them. In other words, once the contours are defined, it's possible to crop away from the original aerial image, the portions of that corresponding to the building roofs. The 3D model is obtained by modeling 3D objects made of face sets. Roof textures are applied at the top of each building, while lateral faces are filled with a user definable color; if lateral views are also available, it's possible to glue them to buildings sides, as shown in figure 9. The height of the buildings may be determined by a laser telemeter, which permits to easily pick two points, at the base and at the top of the building, so evaluating height by mathematical operations. Currently we are working on the possibility to make also this operation completely automatic, by mounting the laser telemeter directly on the aircraft, and by acquiring data automatically.

2 The reconstruction algorithm

In this paragraph we will describe the reconstruction algorithm that is divided in two parts: civil buildings reconstruction and industrial building reconstruction.

Topographical images are processed by IPL image processing functions, in order to isolate the contour of areas representing civil buildings. Pattern recognition techniques are used in the second part, since in topographical maps this kind of building is represented by a pattern.

2.1 Civil building reconstruction

Topographical maps are available in a variety of scale formats; we chose for our application 1:25.000 scale maps, as we considered this the best compromise between the need of having a good resolution for buildings' contours but at the same time a quite large represented area.

Figure 6 shows an example of these maps, in which it's possible to see buildings contours.

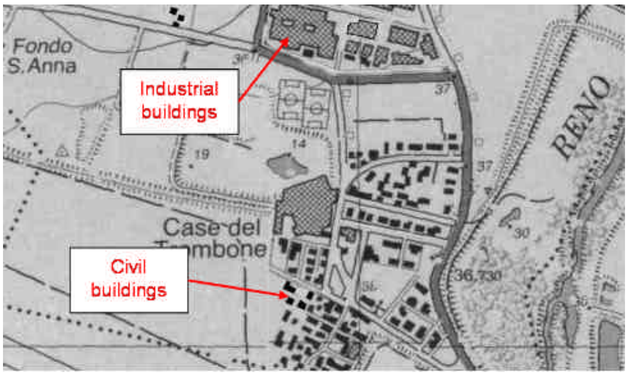


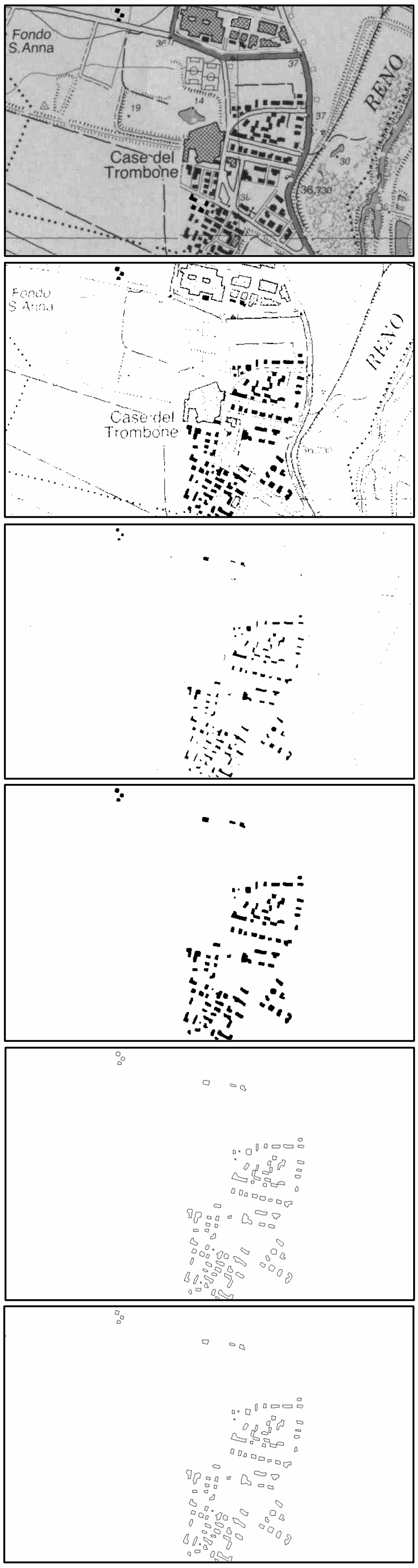
Fig. 6. Topographical map.

First of all a matching procedure is required, in order to correctly refer digital image to the topographical map. To do this, two points on the image have to be referred to the corresponding ones to the map. At this point the program computes how the map has to be moved and rotated.

Two different kinds of buildings are considered in this work, civil buildings and industrial buildings. While civil buildings are represented by a almost black filled area, industrial ones have a conventional pattern, so a bitmap template image with the pattern is required in order to find industrial buildings contours.

All civil buildings are represented in the topographic map as almost dark filled areas (fig. 7a), so the first image processing operation is a threshold, at a very low value (76). With this operation all the pixels that were almost dark become dark (fig. 7b) and a great part of pixels that were not due to civil buildings are truncated. The remaining pixels due to streets and industrial buildings contours are eliminated by an "erosion" step (fig. 7c). Erosion is a function that sets each output pixel to the minimum of the corresponding input pixel and its eight neighbors. Next step consists on a "dilation" (fig. 7d), that sets each output pixels to the maximum of the corresponding pixel and its eight neighbors.

This is done in order to restore original buildings dimensions. After this, the automatic procedure finds the contours of civil buildings (fig. 7e). These contours are then



a
b
c
d
e
f

Fig. 7. Civil buildings contours recognition.

approximated by closed polylines, whose number of vertex is proportional to the required level of detail (fig. 7f). The contours so obtained will be used to crop from the aerial image the civil buildings roofs images.

2.2 Industrial building recognition method

For industrial buildings a template image is used, as seen above, in order to extract their contours by matching it with the topographical map. This procedure is different from the one used for civil buildings because in this case we have to look for a particular texture in the map, and not a dark filled area.

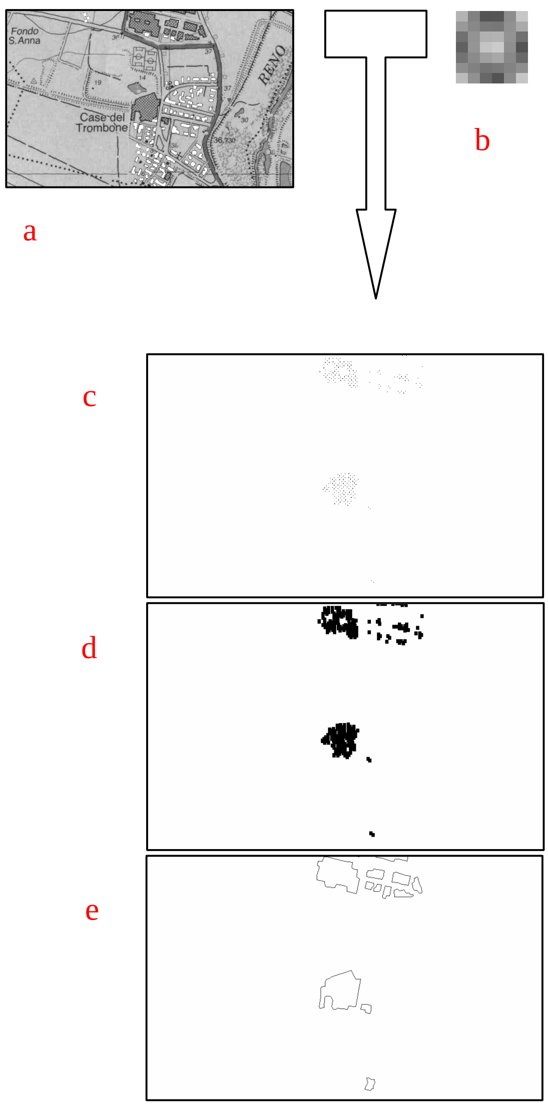


Fig. 8. Industrial buildings contours recognition.

Figure 8 describes the steps of this algorithm. After both topographical map and template image have been thresholded, the latter is matched to the topographical map; this matching is performed in two nested for-cycles in order to examine every pixel. Figure 8c shows pixels that were positive to matching test, while in figure 8d are shown in dark image areas all rectangles positive to matching test. Now the program knows that in those points there are industrial buildings. In the following step the system performs a threshold operation at a higher value, after that the contours of the resulting image are extracted. Areas corresponding to industrial buildings present non uniform black color but they have white holes. With an iterative cycle all interior holes are darkened, till the findContours routine finds no more interior contours. Now the resulting image is formed by black areas corresponding to the industrial buildings, but also by other spot, determined by other non-building objects. In a final step only dark zones that are made by a number of pixels ranging between two fixed limit are maintained, so that all those are buildings. In order to distinguish civil buildings from industrial ones, the result of matching procedure is used. Finally contours are extracted and approximated with polygons (fig. 8e).

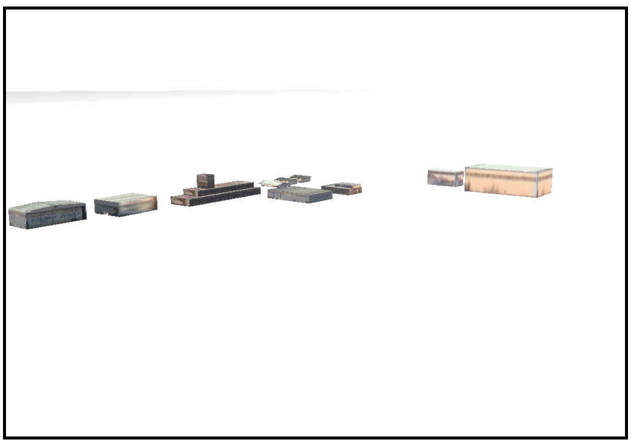


Fig. 9. Full textured reconstructed buildings.

4 Conclusions

The described software tool has been tested with several scenery configurations, different type of natural areas (airport neighborhood, mountains, hill, woods …) in order to improve the robustness and efficiency of the reconstruction method. In conclusion, the proposed method cannot be compared to other reconstruction systems from the point of view of precision. In fact the aim of the method is represented by giving a realistic and real-time-able 3D textured model to change a standard flight simulator visual device into a high-fidelity scenery projection.

So the goal has been completely matched, because, without any complex, time-wasting and high-costing data acquisition system (i.e. SAR), and simply automating manual activities and combining different data sources, a full and lean tri-dimensional scenery can be easily prepared. The precision is limited to 1.5 meters, but the pilot visual feedback is very appreciable: buildings are clearly visible and recognizable. At the moment lateral building textures are not available, but further pictures (taken during terrestrial inspections) can be easily attached to building model.

A optimized polygon representation and reduction has been also implemented in order to reduce the total number of building faces, but, at the same time, to make the model matching geometrically not only simply constructions, but also moderately complex buildings.

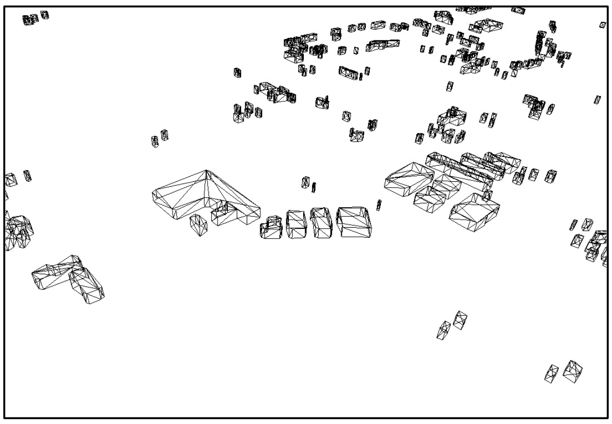


Fig. 10. Example of reconstructed geometry (wireframe)

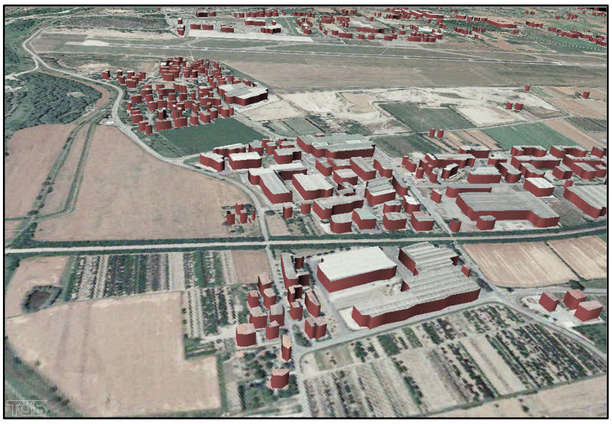


Fig. 11. Textures glued on the reconstructed buildings and terrain

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