AN INTEGRATED 3D GIS DATA EXTRACTION AND APPLICATIONS BASED ON HIGH RESOLUTION IMAGERY TECHNOLOGY

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ABSTRACT

GIS has been widely used for environment and geospatial related applications. Due to high resolution remote sensing images and aerial photos could be acquired periodically, more and more stereoscopic images might be used for fast three dimensional (3D) GIS data extraction. This will result in more detail GIS datasets applications for relevant decision making.

Actually, high resolution GIS datasets are still lack of in supporting large scale applications such as at national or states levels. This situation is similar even in small countries such as Kuwait, where only the middle scale resolution GIS database established. However, GIS users are urgent to use and integrate high resolution geospatial datasets and 3D information for their applications. This will push GIS data providers and researchers to have rapid methods in paralleling the market requirements.

An integrated Comprehensive Multilevel Method (CMD) 3D GIS modeling method is used in this paper for the support of high resolution GIS applications. A region of more than 500 km² is selected in Kuwait city for the test of the method. The selected terrain characteristics include ocean, desert, and residential land which are covered by 62 aerial stereophotos. As the result, a stereo model is established based on the high accuracy photogrammetric interior orientation elements, exterior orientation elements, limited ground control points (GCPs), manual and automatic selected tie points, and bundle block aerial triangulation methods. A high resolution (0.38 m) mosaicked orthoimage database is created as the GIS background data by the controlling of the stereo model. More detail road and 3D objects such as buildings information were extracted for the project application analysis. Two 3D and Virtual Reality (VR) GIS models were established. QuickBird high resolution image in the selected place is used for updating the changed terrain features.

Clearly, the integrated digital photogrammetry stereo modeling and the high resolution imagery application technologies are useful for the fast extracting and updating of GIS datasets. The integration of high resolution remote sensing images, aerial stereophotos, and existed GIS datasets with CMD method will provide GIS users more reality applications for special demands. The dynamic high resolution GIS database may also be promptly used for multi aims spatial-temporal analysis with the integration of the existed moderate scale GIS geodatabase.

INTRODUCTION

Aerial stereo photos and high resolution remote sensing images have a strong application trend in GIS world. The plentiful geometry information included in the images is an unlimited resource for geospatial research and application (Zhou G.Q., Albertz J., Gwinner K.,1999). Those include extracting buildings three dimensional (3D) features and digital terrain/elevation model (DTM/DEM) for the 3D and virtual reality (VR) GIS modeling (Zhao Yongping etc., 2000). The implicated 3D information would be strong quantitative geometry data which supports precisely decision makings related to environmental issues such as emergency management and others (Kwan M-P, Lee J., 2005).

No matter how important the potential 3D GIS datasets could help us dealing with environment issues, high resolution GIS datasets and 3D information are still lack at national or states levels. This situation is similar even in small countries such as Kuwait, where only the middle scale resolution GIS database is widely used in civil
applications (Dirk Hermsmeyer etc., 2005). Clearly, more detail GIS datasets should be created in order to use accuracy geometry information for geospatial analysis. According to the development trends of aerial photogrammetry and remote sensing technologies, the challenge of how to quickly extract massive information from aerial photos and high resolution images for large scale 3D GIS establishment is one of the key issues for 3D GIS research (Zhou G.Q., Albertz J., Gwinner K., 1999).

The authors introduced a Comprehensive Multilevel Method (CMD) 3D GIS modeling method for the support of high resolution GIS applications. The research region covered by 62 aerial stereo photos around Kuwait city is selected for the CMD test. The selected land is more than 500 km². It contains the most typical Kuwait terrestrial areas such as ocean, desert, and residential characteristics. By the data process and information integration, a stereo model is established based on the high accuracy photogrammetric interior orientation elements, exterior orientation elements, limited ground control points (GCPs), manual and automatic selected tie points, and bundle block aerial triangulation adjustment. A high resolution (0.38 m) mosaicicked orthoimage database is created for the using as GIS background data. QuickBird High resolution image in the selected place is used for updating the changed ground features. More detail roads, landmarks, networks, and buildings 3D information are extracted for the 3D GIS modeling test. As the result, the high resolution layers can be quickly extracted for spatial-temporal analysis at multi levels with the integration of existed moderate scale GIS geodatabase.

RESEARCH AREA SELECTION

Kuwait is a small country. The total area is 17,820 km² and about 85% of it is terrestrial environment. It is connected with Saudi Arabia from south (length of the border is 222 km), Iraq from north (length of the border is 240 km), and Arabian Gulf from east (coastline is 499 km) (Figure 1). Most of Kuwait land is desert and the arable land is 0.3%. The landscape of Kuwait is nearly flat. The highest point in the country is about 306 m. Most of the residential areas are distributed along the coastline and close to Kuwait city.

Kuwait has established multi-scales GIS databases which are used for government routine works and environmental researches, such as the Soil Survey GIS datasets (Grealish, etc. 2005), Kuwait Environmental Information System (KEIS phase I and KEIS Phase II) (Abdul Nabi Al-Ghadhan, 1997), Kuwait Basic GIS Datasets that used in Kuwait Institute for Scientific Research (KISR). The existed databases are plentiful GIS resources for related applications. Anyway, the existed two dimensional GIS databases were designed based on the lower scale maps. They are weak to be used for precision decision making.

Recently, Kuwait has had tremendous changes which are led by the city planning and road reconstruction. Many new buildings have been established and the highways reconstruction is also started. At the same time, Kuwait e-Government strategy has demonstrated fast development by the support of government and IT technologies. This supplies an active development stage for GIS, photogrammetry, and remote sensing technologies in supporting government decision making.
In the late of 2003, the high resolution aerial stereo photos which cover Kuwait terrestrial environment were taken by the cooperation of Kuwait Municipality and SwedeSurvey. The photogrammetry scale is 25,000. At the same time, different agencies such as KISR have launched several new projects related to environmental research which use high resolution remote sensing images, such as QuickBird and IKONOS. All the high resolution images information provides us a possible opportunity to develop a new 3D and VR GIS system for geospatial applications.

In accordance with Kuwait plentiful terrestrial characteristics, a research region which contains ocean, desert, and residential areas is selected for the experiment of 3D and VR GIS modeling with high resolution images. It represents typical terrestrial environment of Kuwait. The covered area is more than 500 km² (Figure 2).

**STEREO MODEL ESTABLISHMENT**

Stereo modeling with the existed aerial stereo photos is the first step for the constructing of a 3D GIS. This procedure should be processed by digital photogrammetry technology.

By analyzing the collected digital aerial stereo photos, the 62 aerial photos are distributed in 6 strips. All the east and north aerial photos are connected with Arabian Gulf. Some of the photos include more than 50% water area (Figure 3). The mixing of large water area with sand and buildings causes too much white noise in those aerial photos. This would influence the automatic tie points creation for images match in digital photogrammetry modeling. Another situation is that much desert land existed in the south and west of the region. Although some camping tents or temporal houses existed in the photogrammetry area, the temporal objects are impossible to be used for ground control points (GCP) collection to improve the accuracy in digital stereo modeling. This means non-standard procedures should be designed in order to deal with the mixed landscape.

Kuwait has no high resolution GIS system. The GCPs collection could not be acquired from current GIS features. Therefore Global Positioning System (GPS) receiver is used to deal with this issue. In order to avoid the weakness of the aerial triangulation network which may be resulted from the limited GCPs, more than 200 tie points were selected by manual method in initial. The well designed high accuracy tie points plus the collected 35 GCPs in the research area ensured a strong aerial triangulation network construction (Figure 2).

The interior orientation parameters (such as camera parameters and fiducial marks information) and part of exterior orientation information (such as photogrammetry exposure center's coordinates) were supplied by Kuwait Municipality. Digital photogrammetry workstation installed with Leica Photogrammetry Suite was used for the data process and model establishment. By the efficient design and data quality control, all the interior
orientation accuracy is less than 0.34 pixel and the Root Mean Square Error (RMSE) of the block aerial triangulation result is 3.77. It is a high accuracy stereo model for 3D features extraction and orthoimage creation.

3D FEATURES EXTRACTION AND VISUALIZATION

The geometry information existed in the stereo model is unlimited. Therefore the 3D features extraction is a time consuming procedure and could not be finished one day (Gruen, A. 1998). In order to quickly acquire the 3D information from the model, all the potential features extracted from the model should be defined based on variety application requirements. In the research region, two areas were selected for the detailed 3D and VR GIS establishment. One was KISR main campus and the other was Shark Mall-a popular shopping center in Kuwait. The 3D features extraction was controlled by the stereo model. Stereo glassed and stereo screen were used for the virtual reality environment display and observation. ArcGIS 3D interface was used for the visualization of the 3D information.

In KISR main campus, the extracted features were used for the experiment of 3D and VR GIS establishment. By the analysis of the landscape, man made objects, and KISR campus management requirements, the 3D buildings, roads, parking lots, fire hydrants, network manholes, network lines, light rods, and the DTM features were extracted for the establishment of a typical 3D and VR GIS. The extracted datasets were integrated to the existed ArcGIS.
Geodatabase to update the lower accuracy geometry information. Figure 5 is the example of the 3D buildings information in KISR. The features' areas, peripherals, heights, and the buildings footprint heights were recorded in the geodatabase for further application. Figure 6 is the simple 2D representation of the related 3D features extracted from the model. With the comparison of Figure 5 and Figure 6, we could find the high resolution 2D information is still with the limitation for the better understanding of the environment. It is hard to know the 3D world from Figure 6 directly.

Shark Mall is selected for the experiment of fast VR GIS implementation based on the stereo model. The test would help the authors to conclude a method for the rapid establishing of a VR GIS. Figure 7 is the 2D image information where the buildings are composed of series pixels. Figure 8 is the corresponding 3D buildings of Shark Mall which were extracted from the stereo model and represented in 3D GIS environment. Compared with KISR 3D and VR GIS, Shark Mall is a simple VR GIS where only 3D buildings were extracted from the stereo model. Because of high resolution roads and other related information that can be visually recognized from the background image, the VR model is a successful example method for fast detailed 3D and VR GIS implementation. The existed lower resolution GIS layers were integrated with the model for further analysis based on the high resolution image and 3D information. Clearly the 3D buildings information in Figure 7 could help people to have better understanding of the three dimension reality environment.

**DESIGN AND INTEGRATION OF 3D AND VR GIS**

Although simple 3D features could be extracted from the stereo model and represented by ArcGIS, more complex 3D structures are still difficult to be extracted and represented by the existed commercial ArcGIS package. In order to establish a VR GIS, the complex 3D objects acquired from the stereo model are needed to do further designing. Especially for complex 3D buildings, both the structure design and the texture information of the buildings faces should be considered.

Figure 5 is the simple 3D buildings which were extracted from the 3D stereo mode and represented by ArcGIS. The 3D features have the advantage in comparing with the 2D representation in Figure 6. Anyway, some complex buildings structure can not be depicted with the simple 3D model and this will influence precisely environment decision making. The missed buildings faced texture information will decrease the potential application of the 3D objects on virtual planning and decision making. For example, it is impossible to know whether a new building established with beautiful faced decoration could match the whole environment characteristics from the simple 3D model.

Figure 9 is the improved 3D features of Figure 5. All the 3D objects have been texturized. Some complex 3D structures have been further designed. By the designing of the data format conversion and 3D objects combination,
the 3D information was integrated with our existed geodatabase. The variety virtual reality 3D features stored in the geodatabase could be directly displayed in the same 3D environment such as ArcScene and ArgGlobe.

Figure 10 is the enlarged 3D objects displayed in the VR GIS. The upper left building is the new constructed Water and Agriculture research laboratory in KISR. It includes different 3D structures such as crater cone shape in the front, convex triangular and concave polyhedral shape on the roof, overpass in the front, and other concaved faces. Even the main structure of the building is a terraced shape. The lower left 3D object is the gate of KISR main campus. The light rods information attached in the 3D object was also represented in the VR GIS environment.

Obviously, this is another interested 3D and VR GIS model. By the integration of the 3D structure, faced textures, redesigned objects, and other 3D features, the GIS system could supply stronger visualized information for decision analysis. KISR main building (upper right in Figure 10) is a relative low complex, so the Water and Agriculture building could not be designed higher than the main one. The faced color and decoration materials should be designed to match the environment. The other 3D objects such as the main gate and the light rods should also be furnished to adapt the main building dominated environment. Actually, the analysis result based on the VR GIS model is exactly the same as the established new building.

High accuracy image information and precisely GCPs were used in the modeling of KISRGIS. Therefore the 3D and VR information can be used as a container to integrate any geospatial information. KISR network manholes and the lines distribution management system is a good application example. All the manholes positions were directly collected from the stereo model and the connections between them were designed by the support of network group of KISR. The 3D system could even be directly used for engineering planning such as manholes reconstruction and the new network lines designing. This makes any geospatial related planning and management more convenient and easier.

**MULTISCALE 3D AND VR GIS IMPLEMENTATION**

3D and VR GIS is an interested application trend in GIS world. The precisely three dimensional geodata and more reality digital environment could be used for unlimited purposes such as city planning, disaster analysis, transportation routes designing, and routine works for government agencies and private companies (Dirk Herrnsmeyer etc., 2005). The plentiful georeferenced information could even be used for 3D modeling from national resources and environmental management level to single object. As a variety of multi-application demands and huge work is included in 3D information extraction, a comprehensive 3D and VR GIS modeling method should be well defined.

No doubt, 3D and VR GIS modeling and implementing should be planned in different levels. The authors defined a Comprehensive Multilevel Method (CMD) for the establishment of a 3D and VR GIS system based on Kuwait Administrative distribution (more detail of CMD method will be discussed in another paper). The multilevel 3D and VR GIS modeling method is divided into 5 levels which are national, regional, local, objective, and internal. According to the CMD method, a 3D and VR GIS can be implemented rapidly by different groups with the control of the common stereo model.

Figure 11 includes snapshots acquired from the 3D and VR GIS model which were established by the CMD method. The red square in each image is an interested area which will be enlarged and illustrated in the following levels. Figure 11a is the snapshot acquired from the system at the scale of 1:500,000. The image information included in this level is mainly created from the lower resolution remote sensing images such as Landsat and Spot. It supplied the bird viewing of the state geographic information quickly. The lower resolution information may be used for the national level environmental analysis and planning.

Figure 11b is the snapshot of the interested area in Figure 11a acquired at the scale of 1:50,000. The image information included in this level could show the road and administrative blocks information. The main imagery resources should be integrated from both higher resolution remote sensing images and mosaicked aerial photos. It is a nice data source for regional related analysis and applications such as transportation management and disaster analysis.

Figure 11c is the snapshot of the interested area in Figure 11b acquired at the scale of 1:5,000. It is already a very high accuracy image that could be used for any local environmental related analysis such as city planning and
virtual campus travel. The 3D features at this level should be extracted from the common stereo model by stereoscopic observation. The image database should be created from orthorectified aerial orthophotos or other high resolution stereo image pairs. The burden work of 3D and VR GIS modeling at this level could be implemented by the cooperation with different teams and groups with the control of the established common stereo model. This would make the 3D and VR modeling efficiency to be enhanced dramatically.

Figure 11d is the snapshot of the interested area in Figure 11c acquired at the scale of 1:500. It is the Objective and the highest level for external 3D objects modeling. The information included in this level contains the 3D object's structure and more detail designed contents. All 3D objects facet texture information and the visualization result of the 3D and VR system will be mainly dominated by this level. The extraction of 3D features will be based on both stereo model and other additional survey technologies. The work at this level also should be finished by the cooperation with related teams and groups.

The fifth level of the VR GIS implementation will be based on both 3D GIS and internal survey technologies. It is the step that describes the internal structures of 3D objects by GIS technology. Variety information such as offices distribution, telephone lines, internet lines, and water and gas tubes etc. may be integrated at this level. Because of very detail GIS features and the related attributes included in this level, it can be only implemented by
the cooperation with related professional agencies or departments. Figure 12 is the comparison of the 3D building switched from external to internal. Figure 12b is the interior description of the first floor in Figure 12a. The offices, stairs, and the whole arrangement of the building are described in the model.

The 3D and VR GIS may also be implemented by using limited selected objects. This option could allure more small companies and agencies to establish the system with less expense for more interested applications such as virtual tour, advertising, and location based service. Figure 13 is the example of Shark Mall virtual tour demo which was implemented with the CMD method. Figure 13a includes only a part of selected Kuwait City 3D buildings and the high resolution background image information. When zooming in, more detail information of the Shark Mall could be displayed by the 3D and VR GIS model. Figure 13b is the enlarged information enclosed by the red rectangular in Figure 13a. By the support of the 3D model, all the facets and the detail information of the 3D building could be displayed.

Clearly, with the development of IT technology, both the external and internal 3D and VR information could be managed with GIS technology. The required geospatial information which is used for e-Government and the related routine digital management may be rapidly implemented by CMD method.

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**Figure 12.** The information comparison of the Objective level and the Internal level.

**Figure 13.** Comparison of 3D and VR GIS display in different levels.
3D AND VR GIS UPDATE AND THE APPLICATION

Geographic information could not be stable by the development of city planning and residential areas renovation. This means 3D and VR GIS information should be updated periodically to match the changes of the corresponding geographic features. In traditional, the geographic information update is a time consuming and very expensive procedure. It needs several years or decades to finish the updating of a national basic map database in the middle scale such as from 1:250,000 to 1:50,000 by using the national survey and mapping crews. Therefore, much unavoidable errors are existed in most of geographic based data analysis and applications because the outdated geodatabase or maps were used. By the support of the established high resolution stereo model and 3D and VR GIS system, the speed of geospatial information updating will be enhanced. This would help basic data providers to supply more accuracy georeferenced information for environment and location based decision making. Furthermore, the updating of objects based information could be implemented with less cost.

Figure 14 is the example that shows the comparison of the land use change from the late of 2003 to the late of 2005 in KISR main campus. Figure 14a is the aerial photo taken in the late of 2003. This area has some changes in the last two years. In order to compare and update the changed area, the corresponding new QuickBird image is acquired and integrated to the system. As the high resolution image database of KISR has been established with the aerial photos of 2003 in this project, the geometry information becomes precise and has the ability to be used as a control field for the georectification of the QuickBird image. Consequently, the changed areas could be found and automatically extracted and calculated by the support of GIS technology.

When comparing Figure 14a and 14b, 5 changed places will be found in the selected area in the last 2 years. Those include the older buildings removed (place 1 and place 2), the new buildings set up (place 2, and place 4), the parking lot renovated (place 5), and the vegetation destroyed (place 3). In the 3D GIS model, the changed 3D objects were easily removed from the geodatabase and the new 3D objects were refreshed by very limited survey support. Figure 5 includes the updated 3D buildings information. Evidently, all the changes could be monitored by the 3D model and the changed information could be updated easily. This method could be used to decrease the huge burden on updating maps existed in related departments such as land and house management.

By using CMD method, the 3D GIS system can be established in a reasonable period. Besides the application on local land use changes analysis, it can also be used to monitor and estimate engineering progress related to some typical projects such as filling or digging work. Figure 15 is the progress of the sea filling engineering project. Figure 15a is the selected area near KISR main campus depicted by the aerial photo in the late of 2003. Figure 15b is the corresponding engineering area depicted by the QuickBird image in the late of 2005.

![Figure 14](image-url)

**Figure 14.** The comparison of the changes in KISR main campus from 2003 to 2005.
Figure 15c is the overlay comparison of the changed area near KISR main campus from 2003 to 2005. Apparently, since the start of the sea filling engineering project, more than 2 times of KISR main campus land has been increased in the last two years. This realistic comparison would help the higher managers to have better understanding of the environment changes and to help them make proper developing strategies by the support of the updated and quantitative GIS information.

CONCLUSION

The integrated GIS data extraction idea introduced in this paper is a useful method for the fast establishment of 3D and VR GIS model based on high resolution imagery information. The CMD method could help us constructing a useful 3D GIS model from the national to internal level for multi-application aims. Anyway, the establishment of the huge and detailed 3D and VR GIS system could not be implemented in one day. The digital photogrammetry stereo modeling, GCPs surveying, 3D GIS features extracting and designing, remote sensing imagery processing,
and the 3D and VR GIS representing are all professional procedures which need to be planned systematically. Therefore, much works should be done in order to provide more realistic 3D visualization GIS models. Those include the improvement of computer hardware and software, efficient cooperation among teams, GIS standards making for the data quality control (Zhao Yongping, Al-Akroka Jamal, 2005), continued funding support, and the awareness development of user groups.

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