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An Open Standard-based Terrain Tile Production Chain for Geo-referenced Simulation

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Abstract : The needs for digital models of real environment such as 3D terrain or cyber city model are increasing. Most of applications related with modeling and simulation require virtual environment constructed from geospatial information of real world in order to guarantee reliability and accuracy of the simulation. The most fundamental data for building virtual environment, terrain elevation and orthogonal imagery is acquired from optical sensor of satellite or airplane. Providing interoperable and reusable digital model is important to promote practical application of high-resolution satellite imagery.

This paper presents the new research regarding representation of geospatial information, especially for 3D shape and appearance of virtual terrain, and describe framework for constructing real-time 3D model of large terrain based on high-resolution satellite imagery. It provides infrastructure of 3D simulation with geographical context. Web architecture, XML language and open protocols to build a standard based 3D terrain are presented. Details of standard-based approach for providing infrastructure of real-time 3D simulation using high-resolution satellite imagery are also presented. This work would facilitate interchange and interoperability across diverse systems and be usable by governments, industry scientists and general public.

Key Words : interactive simulation, interoperability, X3D Earth, application infrastructure, standard.

1. Introduction

High-resolution EO (Electro-optical) images are being supplied widely, which were restrictively used for the purpose of military sector and/or intelligence community, according to the development and spread of satellite payloads capable of taking sub-meter class resolution images. Nonetheless, the use of high-resolution satellite imagery is limited to the primary demands such as GIS (Geographical Information Systems) and environmental, agricultural and oceanographic monitoring applications in civilian sector. It is due to the lack of infrastructure for utilization of the imagery. Contrastively, the need for virtual environments is increasing by the growth of economy in cyber world including computer game and metaverse. The virtual environment required in the simulation of transportation, agriculture, forestry, hydrology, environment and military research and its application, however, must be built from real object

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data, geospatial information such as satellite imagery. Therefore, the real-time 3D simulation infrastructure that can provide base platform of simulation in these verbose areas is required to promote utilization of high-resolution satellite imagery.

This paper describes a terrain tile production chain that has been developed to provide an infrastructure of building virtual terrain model for real-time 3D simulation based on high-resolution satellite imagery. Moreover, standards for geospatial data representation and interchange are evaluated, and also an open standard-based framework is proposed and validated through experiments. Since an open infrastructure is not dependent on commercial technology at all, its solution benefits the public by establishing the foundation for vigorous use of geospatial information in various areas including public sector.

Section 2 explains related work about simulation tools utilizing geospatial information and demonstrates limitation of the existing tools and the direction of the approach. Section 3 evaluates technical requirements for the infrastructure described in following sections and compares candidates of standards as possible solution of the requirements. Section 4 proposes an approach to represent geospatial information using open standard and content production framework. Section 5 discusses geospatial components of X3D standard (Web3D, 2008) to represent geo-referenced 3D object with simulation capability. Section 6 describes the issues occurring from implementation of proposed approach and its solution. Section 7 presents several experiments and sufficiency of the proposed approach from the requirements mentioned at section 3. Section 8 discusses results and directions for improvement.

2. Related work

Satellite imagery is one of representative data type among the various kind of geospatial information. 3D geospatial data and satellite images are widely and pervasively used due to outstanding improvement of geo-browsing applications (Butler, 2006; Nature, 2006). The digital earth (Gore, 1998) advocated ten years ago has progressed. Grossner defined vision of the digital earth comparing to the Google Earth and the digital earth (Grossner and Clarke, 2007). Google Earth, Microsoft Virtual Earth, NASA World Wind and ESRI ArcGIS Explorer are well known geobrowsers. Besides, there are a number of 3D virtual earth applications providing satellite imagery display, like Geosoft Dapple, Lunar Software EarthBrowser, Skyline TerraExplorer, GeoFusion GeoPlayer, Poly9 FreeEarth, *et al.* Google Earth (Ertac, 2008) and ArcGIS Explorer let the user add data layers to the original map and imagery. ArcGIS Explorer allows user analysis with simple task (Lund and Macklin, 2007; Kienberger and Tiede, 2008). Geo-referenced output from other applications may be overlaid on the Earth surface or at elevation of some geobrowsers. Integration, and fusion of data from multiple sources are, however, hardly possible within the applications itself (Grossner and Clarke, 2007). Although NASA World Wind provides advanced system architecture through open source code base of its SDK for Java programming language, it still does not provide simulation functionality and requires Java developers to embed World Wind in their own applications, i.e. they need their own simulation capability. Consequently, we need real-time 3D simulation infrastructure for the practical applications utilizing satellite imagery.

3. Requirements and solution

Following technical requirements are derived for the real-time 3D simulation infrastructure. While there are many geospatial data formats currently, this comparative research focuses on a selected number of widely used standards (ESRI, 2003). This research attempts to find the single best fit standard for both of real-time simulation and geospatial information with primary requirements:

- Geospatial support (including spatial reference frames and earth geoids)
- Interoperability
- Open architecture
- Real-time 3D
- Interactive simulation

Secondary requirements include:

- Metadata
- CAD layer
- User interaction and scripting
- Extensibility
- Advanced 3D graphics support

In order to find best fit solution for the requirements defined, a comparative study of existing standards for representation and interchange of geospatial information was conducted. Table 1 shows the comparative result among selected standards, GML (OGC, 2007), CityGML (Kolbe *et al.*, 2005; OGC, 2008b), KML (OGC, 2008a), X3D (Daly and Brutzman, 2007), SEDRIS (SEDRIS, 2007), SDTS (USGS, 2007), and DXF (Autodesk, 2008). The websites and papers cited in this research were used as informative references. Taking the stated primary requirements into consideration, X3D provides the competitive features with royalty-free open standards file format and run-time architecture to represent and communicate 3D scenes and objects using XML.

Crews (2008) conducted comparative study of open 3D graphics standards among open standards, free to use standard formats that are preferably based on XML, among over 42 3D graphics file format through defining requirements for publishing 3D models. Taking the stated objectives for each 3D format into consideration with satisfaction of his study requirements, X3D provides the most comprehensive solution with reasonably sized memory and file storage. His study requirements are equivalent to the stated secondary requirements and somewhat extensive especially for 3D graphics capability.

X3D is a well known standard that is currently gaining more traction with recent collaboration with

Table 1. Comparison table of open standard for geospatial data representation and interchange (Yoo *et al.*, 2008)

	GML/CityGML	KML	X3D	SEDRIS	SDTS	DXF
Geospatial Component	Feature	Feature	Geospatial Component	Environmental Data	Profile	Geodata object
Standards Organization	ISO, OGC	ISO, Google, OGC	ISO, Web3D.org	ISO, SEDRIS.org	USGS	Autodesk
Interoperability	Yes	Yes	Yes	Yes	Weak	Weak
Simulation	N/A	Limited, simple task	Interactive profile	Yes	N/A	N/A
Real-Time 3D	Weak	Yes	Yes	Limited	Limited	Limited
Multimedia	N/A	Limited	Yes	N/A	N/A	N/A
Run-time Architecture	Limited	Google Earth, geobrowsers	Multiple implementation	Limited	N/A	N/A
Advanced 3D	N/A	N/A	Shader support	N/A	N/A	N/A

Open Geospatial Consortium and Collada.org of the Khronos Group. From these two comparative researches conducted about two dominant information standards, geospatial standards and 3D graphics standards, X3D provides best fit solution for the requirement defined.

4. Terrain tile production chain

Contents authoring of high fidelity virtual environment for real-time simulation application has been laborious but essential process for reliable and trustworthy result of the simulation. In order to reduce troublesome and painful repetition of geodata processing and automate most time consuming process of generating the virtual terrain, an open standard-based content production framework - terrain tile production chain - is proposed. Reusability for the reproduction of virtual terrain due to frequent update and variety of application is mostly taken into consideration in design of the framework. Furthermore the interoperability of the terrain model guaranteed in the proposed framework owes its origin to the X3D standard. The series of the chain generate multi-resolution terrain model in X3D standard format from geospatial information including hi-resolution satellite imagery for the real-time interactive visualization while simulation applications are running. Overall framework of the terrain tile production chain is shown in Fig. 1 and the details are available from the online publication (Yoo, 2007) as well. The proposed framework has been validated successfully by two times of class term projects conducted by the graduate students of the Naval Postgraduate School to generate X3D scene of several locales of their own geographical interest.

The terrain tile production chain for generating multi-resolution terrain tile is composed with following processes:

- Data survey and acquisition: Survey and access public and/or commercial geospatial database for acquisition of geospatial information. Heterogeneous data set from multiple sources is needed sometime due to the range of coverage and resolution provided by each service. Select and download data depending on the region of interest and resolution.
- Preprocessing and data enhancement: Convert projection, unit, spatial coordinate system and

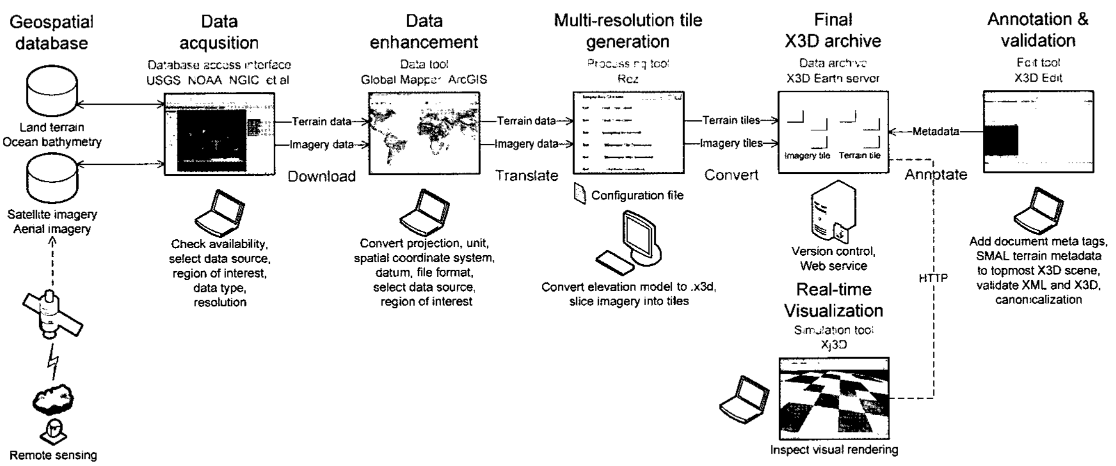

Fig. 1. X3D terrain tile production chain: the framework generating multi-resolution X3D terrain tile set from geospatial information (Yoo *et al.*, 2008).

datum for the consistency of data and processing tools. Merge multiple data from multiple data source in different data type. Select range of interest and crop. Translate file format to feed terrain tile processing tool.

- Multi-resolution tile generation: Define depth of LOD (level of detail) for multi-resolution terrain tile generation depending on the terrain and imagery data source and purpose of simulation. Slice and dice source terrain and imagery data into multi-resolution X3D terrain tile set using Rez and ImageSlicer. Elevation model is converted into X3D scene with texture imagery.
- Annotation and validation: Finalizing X3D scene with creating top level scene and adding metadata for geospatial context. Validate all tile set generated by the processing tools.
- Archiving and application: Check into X3D Earth server for the version control. Validate X3D scene with visual inspection using standard X3D browser that is capable to render geospatial components.

There are several issues that should be taken into account in each process. Especially maintaining consistency of geospatial context during the data processing through overall production chain is the most sensitive and consequent issues which should be managed concretely. It is discussed in section 6.

5. X3D geospatial component

In the terrain tile production chain, the X3D geospatial component is used for representing terrain model without loss of geospatial context. The X3D Earth working group of Web3D Consortium uses the Web architecture, XML languages, and open protocols to build a standards-based X3D Earth specification usable by governments, industry, scientists, academia, and the general public (Brutzman *et al.*, 2007). The geospatial component provides support for geographic and geospatial applications including the ability to embed geospatial coordinates in certain X3D nodes, to support high-precision geospatial modeling, and to handle large multi-resolution terrain databases. The terrain tile production chain uses following nodes for the representation of multi-resolution terrain tile:

- GeoCoordinate
- GeoElevationGrid
- GeoLOD
- GeoMetadata
- GeoOrigin

The details of each nodes of the geospatial component are described in the specification document (Web3D, 2008). For the performance of rendering in real-time simulation application the LOD is specified in the terrain tile of the production chain. The LOD structure of X3D tile is specified in following expression:

```
<GeoLOD
  child1Url='100g.x3d'
  child2Url='101g.x3d'
  child3Url='102g.x3d'
  child4Url='103g.x3d'>
<Group containerField='rootNode'>
  <Shape>
    <Appearance>
      <ImageTexture url="0g.png"/>
    </Appearance>
    <GeoElevationGrid
      geoGridOrigin="-90 -180 0"
      yScale='1.0'
      xDimension='21'
      xSpacing='18'
      zDimension='21'
      zSpacing='9'
      height="...">
    </GeoElevationGrid>
  </Shape>
</Group>
</GeoLOD>
```

Code 1. Concise example of X3D node expression in XML encoding for multi-resolution terrain tile

The X3D terrain tile set of LOD structure generated from the production chain is like Fig. 2. It shows conceptual architecture of terrain tile set and corresponding imagery tile set at arbitrary level of LOD scene.

6. Consistency management in geospatial context

Along the series of processing chain of the terrain tile production, there are a number of conversions and translations of projection type, unit, spatial coordinate system, datum, and file format in preprocessing and tile generation process. The consistency of geospatial context during the data processing through overall production chain must be managed. The possible error and correlation of geospatial context that should be considered in the terrain tile production chain are as follows:

- Consistency between terrain data and imagery data: Coverage, projection, spatial coordinate system, datum and unit of each data is usually different. These must be matched through the data enhancement process of the production chain.
- Consistency between feeding data and parsing scheme of tile generation tool: The Rez tool have to parse feeding data correctly with understanding of geodata format.
- Conformance of X3D output from tile generation tool: Output X3D tile set of the Rez tool should satisfy conformance of X3D Earth specification.
- Conformance of X3D browser enabled with geospatial component: Since it is very early stage of implementing geospatial component of X3D Earth specification, the conformance of X3D browser implementation also must be considered.
- Consistency of adjacent tiles in the same and different level of LOD: Location of GeoGridOrigin and direction of GeoElevationGrid field values in tile set at arbitrary level must be correlated with adjacent tiles of the same and different LOD tile set. A case of same tile set is shown in Fig. 2.
- Consistency between naming convention of LOD tiles and its contents: The naming convention of terrain tile and imagery tile must be correlated. Naming convention and direction of order for contents of each tile should be considered.
- GeoOrigin in an X3D scene and each tile: The GeoOrigin is supposed to provide high precision of geospatial location in run-time architecture. But X3D Earth specification is not handling multiple GeoOrigin for the present. The X3D terrain tile set should be validated for single GeoOrigin.

Rez tool (Thorne, 2007b), an open source tools for translating gridded data to different formats, is

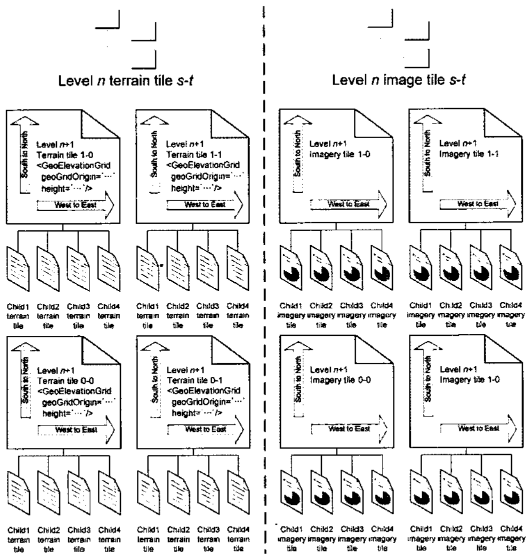

Fig. 2. Consistency of geo-referenced information of terrain tile set and corresponding imagery tile set at arbitrary level of detail in X3D multi-resolution terrain tiles.

modified and improved for the terrain tile production chain. The consistency of geospatial context and support for X3D geospatial component are improved. Most improvements are related with X3D Earth specification. Former GeoVRML output filter is modified to satisfy X3D Earth conformance and validation from 3 tiers (X3D scene generator, X3D contents and X3D browser) is conducted simultaneously for the stated consistency of geospatial context.

7. Experimental results

With the proposed terrain tile production chain, several experiments are conducted for validation of the framework. The most basic experiment is the generation of multi-resolution X3D tile from high-resolution satellite imagery and elevation grid. LANSAT7 satellite image and USGS high-resolution orthoimage are used for the experiment. The highest resolution of orthoimage is 0.3m per a grid of pixel. Fig. 3 shows different LOD levels of generated X3D tile set. It is composed with 20 LOD levels with binary tree structure. Smooth transition between LODs depending on the distance from terrain surface to the viewpoint, real-time 3D examine and navigation, geo-referenced viewpoint handling with geographic coordinate and performance of X3D run-time architecture were validated with this experiments. Furthermore interactive animation capability of 3D object was tested with adding 3D cargo ship model in an X3D terrain tile set. In this experiment, all 3D objects are geo-referenced with GeoLocation node providing the ability to geo-reference any standard X3D model as shown in Fig. 4. Also track information of cargo ship was overlaid on the terrain tile with GeoTransform which node allow for the translation and orientation of geometry built using GeoCoordinate nodes within the local world coordinate system. Finally the simulation capability of X3D terrain tile, generated with the proposed

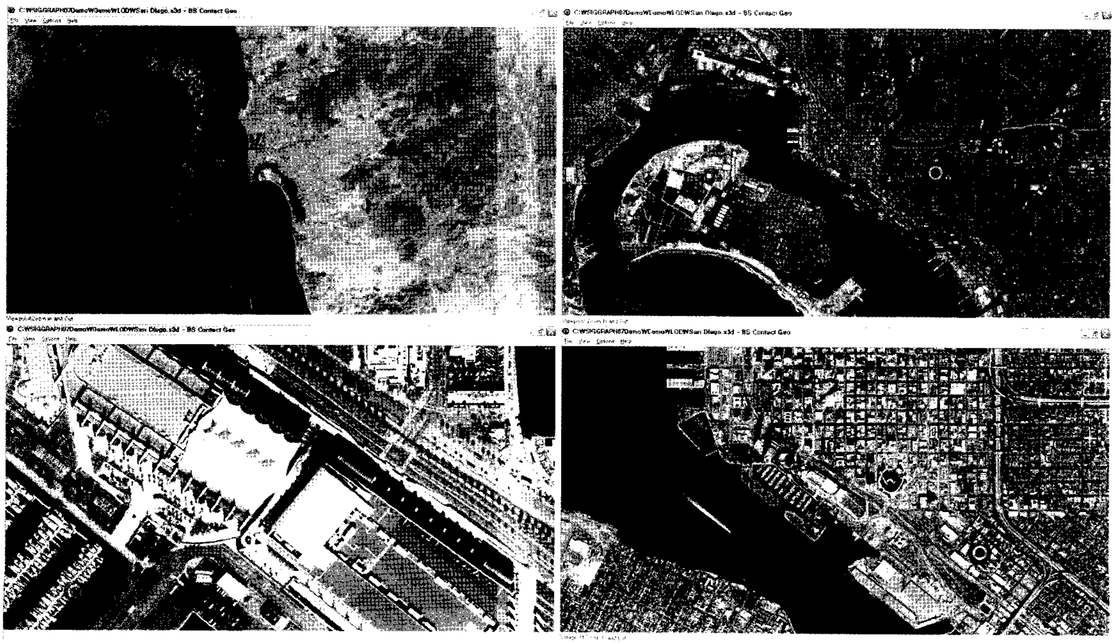

Fig. 3. Multi-resolution X3D terrain tile set of San Diego, California generated from the terrain tile production chain (Yoo et al., 2008).

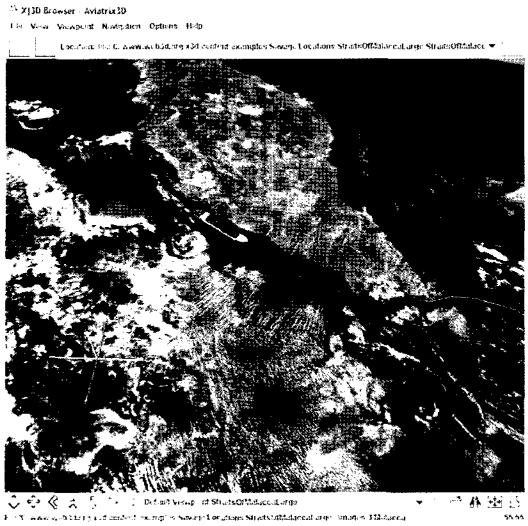

Fig. 4. X3D scene of Straits of Malacca with animating 3D object, a cargo ship.

terrain tile production chain, was successfully demonstrated with an experiment of coverage simulation of radio towers in Algeria as shown in Fig. 5. The terrain model used in second experiment is composed with 5 LOD levels of quad tree structure for multi-resolution terrain tiles of the Straits of Malacca. The Algeria scene is composed with 7 LOD levels of quad tree tile set.

8. Discussion and future direction

The geospatial information is pervasively used in Web environment and this remarkable growth of geo-

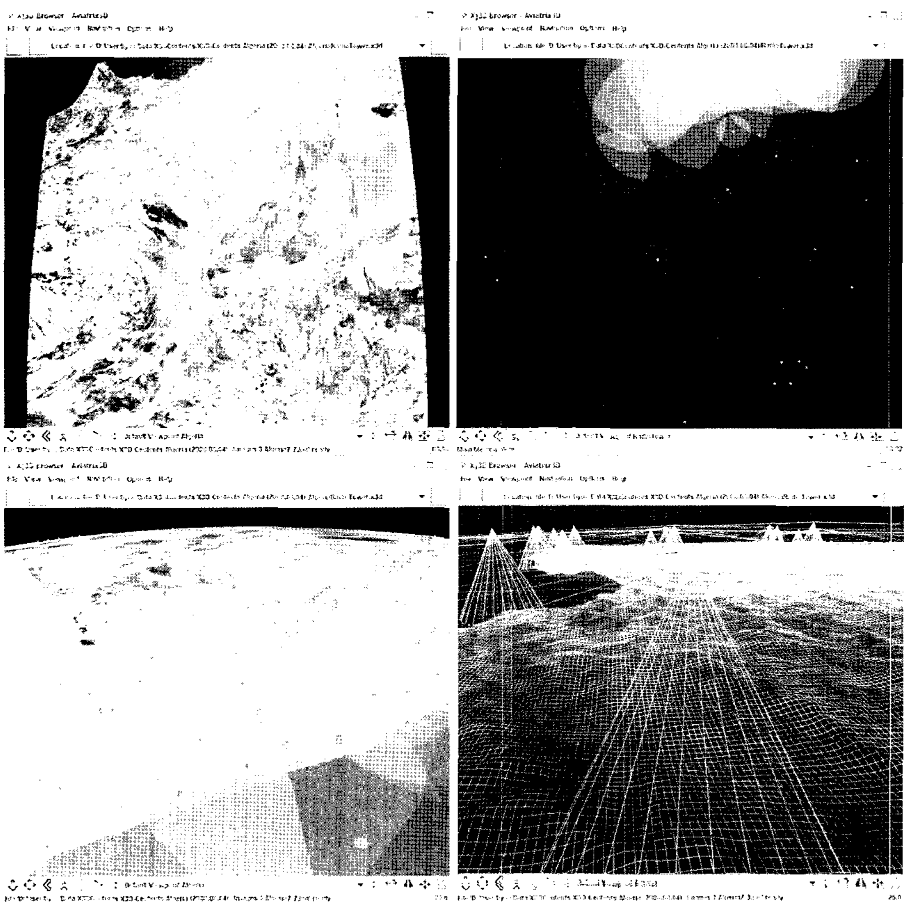

Fig. 5. An experiment of simulation capability using X3D scene of Algeria with coverage simulation of radio tower

web services is caused by the rich and free infrastructure and easy-to-use geospatial APIs for web development and mashup capability. It has made people who had been user of geo-web service turn into contributor or GIS user unconsciously without trained knowledge. In the same manner, we believe that the loyalty-free infrastructure for building interoperable, real-time 3D simulation environment of geospatial information will influence the growth of geo-referenced scientific simulation, education and analysis *et al.* In this paper we have proposed a foundation of real-time 3D simulation infrastructure using X3D geospatial component and validated the possibility with the experiments. The simulation capability of geobrowser can be improved with stated infrastructure.

A natural evolutionary path for the terrain tile production chain is to add flexible preprocessing tools in public domain instead of current commercial tools such as Global Mapper and ArcGIS. Another approach is to improve the processing tool for robust and scalable memory management of tile generation. Current version of Rez tool can handle up to about hundreds of million pixels in a single process. A third approach is to build a backdrop X3D model of planet Earth and Web service. It would be new spatial capabilities in various applications including Semantic Web and search-based application. KOMPSAT imagery would contribute to building the X3D Earth globe. There is an approach to improve precision of spatial systems using floating GeoOrigin (Thorne, 2007a).

9. Conclusion

We have shown that X3D terrain tile production from geospatial information can be routinely provided for various applications and performed evaluation of the existing geospatial information standards and 3D graphics standards. Moreover, we have demonstrated details of standard-based approach providing infrastructure of real-time 3D simulation using high-resolution satellite imagery. Proposed approach has facilitated interchange and interoperability across diverse systems.

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