Integrating Semantic World Modeling, 3D-Simulation, Virtual Reality and Remote Sensing Techniques for a new Class of Interactive GIS-based Simulation Systems

Jürgen Roßmann, Michael Schluse, Martin Hoppen, Ralf Waspe
Institute of Man Machine Interaction (MMI)
RWTH Aachen University, Germany
{rossmann, schluse, waspe, hoppen}@mmi.rwth-aachen.de

***Abstract* — Integrating well known GIS functionalities, object-oriented modeling, 3D simulation, Virtual Reality, space robotics and remote sensing methods with new semantic world modeling techniques, from the point of view of an industrial automation and 3D simulation expert, leads to a new approach to GIS.**

GIS; 3D-Simulation; Virtual Reality; Semantic World Modeling; Remote Sensing

I. INTRODUCTION

We present a new interdisciplinary approach to geographic information systems. The integration of well known GIS functionalities, object-oriented data modeling, 3D real-time simulation, Virtual Reality techniques, space robotics and remote sensing methods with new semantic world modeling techniques, from the point of view of an industrial automation and 3D simulation expert, leads to a new approach to GIS. Such GIS-based simulation systems present complex and large GIS data sets in an interactively analyzable way and provide the basis for a new class of GIS-based simulation applications in a wide variety of different areas.

Several projects[13][14][15] have already combined simulation systems with GIS but do not incorporate a general simulation system or Virtual Reality. Thus they are only suitable for limited fields of application.

The addition of GIS, remote sensing and semantic world modeling functionalities to a 3D simulation system results in an integrated 3D-GIS simulation system, combining the features of GIS and a 3D robotics simulation system originally developed for space and industrial robotics, as well as Virtual Reality applications. This new system is based on novel distributed computing techniques for the processing, visualization and simulation of large data sets. It provides a flexible real-time 3D visualization engine, that scales from low end ruggedized portable computers to high end stereo multi-screen projection systems to present the geographic and simulation data in a clear, vivid and immersive way to the user. Augmented by so called visualization and interaction metaphors originally developed for the commanding and supervision of space robots, geographic data can now be easily understood and interactively analyzed. It turned out that this approach is an ideal basis for intuitive and interactive decision support systems.

Due to the fact that the system is developed as a 3D real-time simulation system it offers various integrated simulation algorithms such as kinematics, rigid body physics, particles, soil or fire. In addition to this, real world interfaces provide real-time interaction means like 3D joysticks, data gloves, driver seats or motion platforms. These simulation and interaction methods are now the basis for the development of new interactive GIS-based real-time simulation applications.

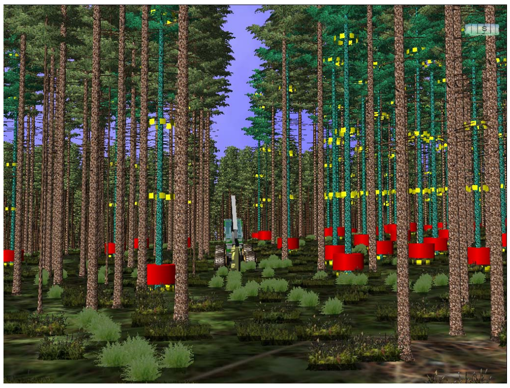

Figure 1. A first example for simulation based 4D-GIS applications: A forest machine working in a 3D model generated using standard remote sensing algorithms to delineate the single trees and analyzed using standard GIS techniques (for example “Which trees should I fell?”).

Our idea of a GIS-based simulation system is already used in various fields of applications. One major application is the “Virtual Forest”™[1][2], a research and development project that provides new means for forest inventory and the application of automation techniques to forest industry. Other applications can be found in city and urban simulation, onboard information systems, training simulators and sensor systems.

In this paper we will outline the basic ideas, results and benefits of this approach, summarize the key visualization and simulation features which are the basis for interactive GIS-based simulation and introduce the major applications realized so far.

The rest of this paper is organized as follows. Chapter II introduces robotic simulation techniques as an ideal basis for new GIS-based simulation systems, as proposed in this paper. Chapter III summarizes the basic GIS features integrated into the simulation system, combining robotic simulation techniques as well as state of the art GIS methods. Incorporating time as fourth dimension results in a 4D-GIS system as outlined in chapter IV. The basis of all simulation applications are 4D models of the environment, integrating the GIS as well as the 3D simulation part of the application. For this we developed new object oriented, semantic world modeling, as well as remote sensing methods as introduced in chapter V. State of the art methods for real-time visualization (chapter VI), 3D simulation (chapter VII) and intuitive interaction (chapter VIII) then allow for the realization of new GIS-based simulation applications. Some of them are outlined in chapter IX.

II. Robotic Simulation Techniques: An Ideal Basis for new GIS-Based Simulation Systems

The simulation system VEROSIM®, developed at the MMI in cooperation with industrial partners, was originally developed as a robot simulation and Virtual Reality system. It is the basis for the development of new Virtual Reality based man machine interaction methods, allows for a detailed planning of production lines in the field of automation technology and is the basis for a variety of driving simulators to name a few application areas tackled so far.

But after taking a look at GIS applications it turned out that the features originally developed for the application areas listed above are the ideal basis for one major aspect within the field of geographic information systems, too: **simulation**. Combining robotic simulation technology with GIS methods now adds dynamic aspects to up to now mainly static GIS worlds. GIS worlds can now be analyzed using standard 3D simulation techniques, which are used for factory or driving simulations so far. They use state of the art visualization techniques for an intuitive and interactive presentation and analysis of GIS worlds. In addition to this, modern GIS techniques are the basis for close to reality, interactive real-time simulation applications like driving simulators.

Therefore the combination of robotics simulation techniques with state of the art GIS methods results in a new class of applications: **GIS-based simulation applications**. For the applications worked on so far, GIS techniques are used to derive a 3D model of the environment, whereas robotic simulation techniques add the next dimension "time" resulting in **4D-GIS-applications**.

III. Providing Basic GIS-Features

When planning to add modern GIS-features for a wide variety of applications emphasis must be put on open interfaces and standard compliant behavior of the system. Thus an OGC compliant geometry representation, geometry operations (intersection, subtraction, …) and query infrastructure were implemented. This allows for a maximum possible compatibility to third-party applications. Also integrated are interfaces to vector and raster data sources such as ESRI© Shape-Files and databases, PostGIS database, WFS, WMS, WCS, CSW, SQL and proprietary tiled raster and image data formats. Most of these data sources are commonly used or even practically standardized. Other basic features of the system's GIS component are integrated tools to measure distances and areas, GPS-based localization, vector and image modeling as well as geo coordinate localization and transformation.

IV. 4D-GIS

Three dimensional data representation and visualization are common features of modern GIS. For this the system is able to store and process 3D GIS data and to visualize the data in interactive virtual environments. But our goal was to open the next, the fourth dimension and provide access to historic data and simulate the future state of the environment to be analyzed. That's why the system not only supports 3D but 4D data. The aspect of 4D is given by adding time as a fourth dimension to the spatial data representation.

For a historic view on data (Figure 2.) different representation techniques are integrated. On the one hand object oriented data models can contain multiple "data layers" describing objects such as trees in different periods of time. On the other hand property changes in objects (e.g. "tree felled") can be stored in and queried from databases supporting historic object states. For this all stored "objects" and their attributes (the "data") as well as the visualization itself are equipped with time stamps. By comparing the stored time stamps with the user defined visualization date the adequate objects and their attributes can easily be queried from the database.

Figure 2. Example for the historic view on data: forest before and shortly after a storm damage

In the other temporal direction – the future – estimations of future states are supported by several simulation techniques. The system supports real-time-simulations (e.g. of timber harvesters, see Figure 13.), discrete event simulation (e.g. logging simulation supported by HOLZERNTE[4], see Figure 1.) or state predictions (e.g. forest growth simulation using SILVA[5])

V. World Modelling

The integration of GIS and robotic simulation techniques requires new methods to describe the simulated environment. Therefore an important aspect of the system are its modeling concepts.

A. *Object Oriented Modeling*

The basis of all applications are object oriented world models. In contrast to a purely geometrical or table based representation of entities, the object oriented model features a one-on-one modeling of real world objects. This approach inherited from robotic simulation models allows the intuitive processing and simulation of objects, rather than abstract data sets. The object oriented model furthermore provides mechanisms for interaction with the objects.

For example each tree/building in a forest/city is modeled as an instance of the corresponding tree/building class while characteristics and connections are modeled as attributes and relations. The active parts of the simulated environments are modeled in the same way. A "car" class describes the geometry as well as the behavior of a car driving through the GIS world while interacting (e. g. colliding) with its instances, the trees or buildings.

B. *Semantic World Modelling*

Based on the aforementioned object oriented data model the system provides objects with a meaning, accordant with the real world. Geometrical and numerical attributes of objects are interpreted thus adding semantics to the data, which is especially important when describing the behavior of these objects in simulation applications.

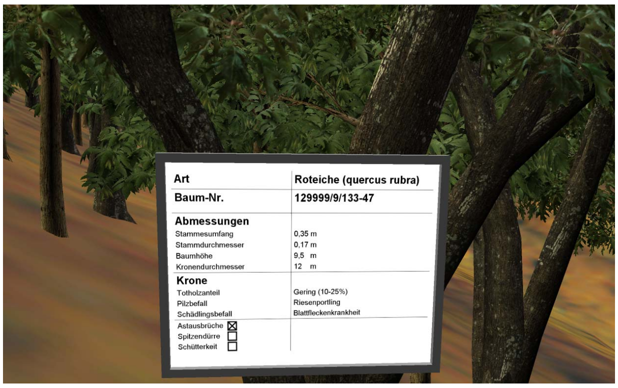

Figure 3. Example for semantic world modeling: the "virtual business card" of a tree

An example for this approach is depicted in Figure 3. where the properties of a tree object (geo position, type, height, diameter, …) are visualized in a virtual environment with the metaphor of a "virtual business card".

C. *Remote Sensing Algorithms*

To obtain such semantic world models from remotely sensed data remote sensing algorithms are necessary. Their task is to delineate instances (e. g. trees[3] or buildings) of previously defined classes and calculate their attributes (like diameter or height). The algorithms integrated so far in the simulation system focus on the modeling of forestry environments. We are able to delineate forest stands as well as single trees and calculate their key properties, like tree types, stand densities or tree diameters and heights. For this raster data, which comes as raw data from airborne or satellite based laser scanners or cameras, is used.

VI. REAL-TIME-VISUALIZATION

The key visualization features of the system derive from its origin as a Virtual Reality system. Based on modern OpenGL rendering techniques complex and large GIS data sets can be interactively navigated and analyzed. For this purpose the system implements data streaming techniques that allow for piecewise loading and unloading of geo data.

Figure 4. Example for the high-performance rendering system: a forest scenario

The high-performance engine also allows for photo-realistic rendering of real world models in real-time (see Figure 4.). In Figure 5. two examples for an intuitive visualization of complex data are shown. On the left side the content of our single tree database is depicted as trees in the virtual environment. This visualization is far more intuitive than the color-coded map underneath that shows the tree type information. On the right road navigation data is projected onto the 3D ground, giving a user an intuitive feel of the placement of the roads within the terrain.

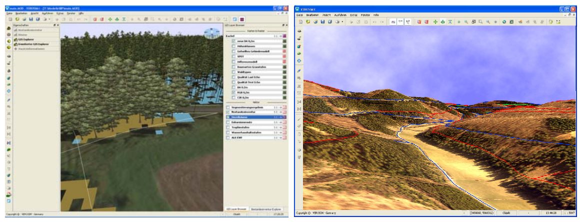

Figure 5. Example for the intuitive visualization of complex data: single tree and road data

A. *Scaleable Visualization Engine*

The scalability of the 3D visualization engine allows the system to be flexibly used in a wide area of applications. The engine scales from low-end ruggedized portable computers to high-end stereoscopic multi-screen projection systems. Thus the system can be (and already is) used as the basis for a portable forest information system or serve as the software platform for the institute's projection environment.

B. *Stereoscopic 3D Multi-Screen-Visualization*

Based on distributed software techniques the system provides high-performance simulation and visualization of 3D virtual environments on stereoscopic multi-screen projection systems.

Figure 6. Example for the stereoscopic 3D multi-screen-visualization

Using such techniques GIS data can be experienced in an immersive way. In Figure 6. (left) an example is depicted where the impact of a proposed urban development measure at the historic coal mine "Ewald" in the city of Recklinghausen is presented to a general public. On the right side of Figure 6. the results of a logging simulation are visualized in the VR environment.

C. *Visualization metaphors*

A key advantage of our system is the use of 3D visualization metaphors to interactively analyze and easily understand geographic data and simulation results.

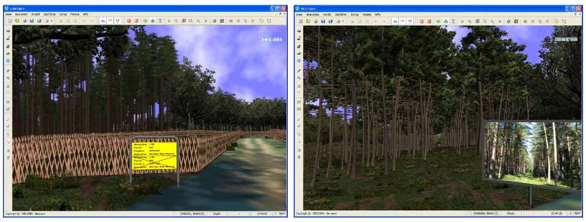

Figure 7. Examples for visualization metaphors in virtual environments: a fence, a sign and TV-View-Into-Reality

In Figure 7. several examples of such visualization metaphors are shown. On the left side a GIS layer of vector data that describes property borders is visualized using the fence metaphor. The sign metaphor gives additional information about the owner. On the right side the visualization metaphor TV-View-Into-Reality maps a real world video into the virtual world at real-time – an example for multi-media integration into the GIS world.

VII. Real-Time-Simulation

The combined system integrates a variety of real-time simulation features that originally were developed for robotic simulations. Now these key simulation features can be used for new GIS-based simulation applications. A selection of these features relevant for GIS applications is shown in the following sub-chapters.

A. *Kinematics and Rigid Body Simulation*

The usage of kinematics – developed for robotic simulations and the Digital Factory – opens up new possibilities for GIS-based simulations, by providing objects with the ability to be moved within the model. Figure 8. shows an example for the simulation of a ship canal lift, which allows for realistic shipping traffic analysis in a GIS-based virtual environment.

The flexible capabilities of the integrated kinematic simulation system are also shown by our implementation of the Virtual Human[9] that uses an anthropomorphic kinematic chain to provide a high degree of realism (see Figure 11.).

Rigid body simulations[12] take into account the dynamic aspects of the modeled objects and provide a basis for fields of applications that require physical correct behavior such as machine operator trainings. Embedding such simulations in GIS-based environments allows for more realistic scenarios, for example by realizing an operator training within a city model.

Figure 8. Example for GIS-based kinematics: simulation of a ship canal lift

B. *Particles and Soil Simulation*

Using particle simulation a wide range of natural effects such as fire, dust or water can be simulated. For example a water simulation integrated into a GIS-environment that provides a digital terrain model can be used to analyze flood scenarios and test dike facilities. An example for fire simulation can be seen in chapter IX.C.1).

Soil simulation – a technique similar to particle simulation – forms the basis for the analysis of interactions with the ground[10]. It can be used to simulate the sand on a virtual construction site or, on a wider scale, for the modification of landscapes as in surface mining.

VIII. Interaction

Interaction with large GIS models is supported by various methods that emerge from the integration of GIS components into Virtual Reality and simulation systems.

A. *Real-Time Interaction means*

For the navigation and interaction with data presented in a 2D GIS standard mouse and keyboard hardware are sufficient. To explore large and complex GIS models in a 3D virtual reality environment other real-time interaction means offer a way for intuitive navigation and interaction with the modeled world. Such means can be 3D joysticks or 3D mice or even personal tracking systems like data gloves that increase the degree of freedom and immersion.

B. Real world interfaces

Its support for different real world interfaces enables the system to be applied in even more fields of application. Genuine hardware parts such as a driver seat of a timber harvester (see Figure 9.) allow realistic training scenarios in GIS-based forest models. By basing the seat on a motion platform the degree of immersion of the operator can be increased.

When using the system for GIS-based navigation the integration of interfaces to GPS, crane sensors and orientation sensors build into timber harvesters or the build-in Visual GPS (see section IX.D) make an efficient positioning, localization and orientation determination possible.

Figure 9. Simulation of a timber harvester controlled using a driver seat

IX. APPLICATIONS

Our integrated GIS simulation system is already used in different application areas. Summarizing its features it builds an ideal basis for intuitive and interactive visualization, planning and decision support systems for various GIS-based simulation applications.

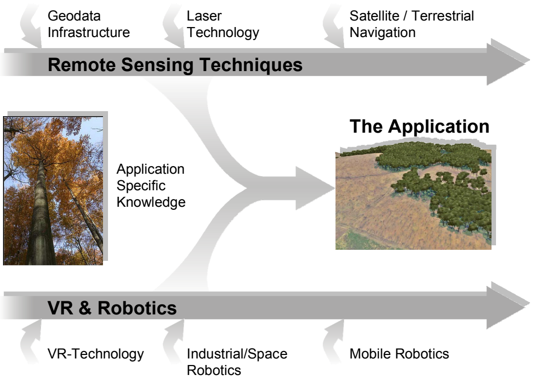

Figure 10. Combining remote sensing and VR as well as robotics technologies to set up new GIS applications

A. Virtual Forest

One major application of the system is the "Virtual Forest"™, a science project of the German federal state of North Rhine Westphalia supported by the European Union. The goal of this project is to provide new means for forest inventory serving as the basis for the development of new decision support systems and the application of state of the art industrial automation techniques to forest industry.

The project covers the acquisition, storage and processing of 240 million trees on the states total forest area of approx., 9,000 km². A visualization of the data of the "Virtual Forest" using Virtual Reality techniques allows an efficient analysis of the impact of thinning operations (see Figure 1.).

B. City and Urban simulation

In the field of city and urban simulation the integrated techniques for the development of interactive visualization, planning and decision support systems are used. Figure 11. shows an example for a crowd simulation[11] based on a city model. Analysis of such simulations allows authorities to optimize their city planning.

Figure 11. Crowd simulation in a virtual city environment

C. Training simulators

In the field of training simulators several examples of real life applications can be shown.

1) Firemen

The simulation of fire fighting scenarios (Figure 12.) combines forest or city models with particle based fire simulation to allow fire fighters the training of complex situations within models of the real world. Thus various mission types can be trained safely in the model of a real forest or a real city/building.

Figure 12. Example for a fire simulation in a forest environment

2) *Forest Machines*

The operation of forest machines is a complex activity. Thus an optimal training is of vital importance for the forest industry. Virtual training methods[6] lower the costs while GIS-based virtual environments allow for realistic scenarios. Figure 9. shows an example where an operator is trained on a timber harvester.

D. *Sensor Systems*

Combining the data of machine mounted sensor systems (laser scanners, crane and orientation sensors) with a single tree map we realized a GIS-based navigation system. This "Visual GPS"[7] matches tree groups found using sensor fusion techniques, with a global tree map obtained from remotely sensed data. This allows precise positioning, localization and orientation in forest environments. The retrieved data is used for additional applications such as the derivation of tree stem diameters[8]. The algorithms were developed using rapid prototyping within a simulated GIS-based forest environment (see Figure 13.).

Figure 13. A timber harvester navigates using the Visual GPS while measuring tree diameters at the same time

X. CONCLUSIONS

We have outlined the advantages of our approach of a GIS-based simulation system, that integrates semantic world modeling, 3D-simulation, virtual reality and remote sensing techniques by showing the various new interactive GIS-based real-time simulation applications. The system has proven itself to offer real-world solutions to real-world problems by the numerous applications already realized today, while even more applications can be thought of.

Plans for future work are further parallelization of the visualization and simulation algorithms and the support for autonomous multi-agent-systems to allow city simulations with various vehicles.

REFERENCES

[1] J. Rossmann, M. Schluse, and A. Bücken, "The virtual forest – Space- and Robotics technology for the efficient and environmentally compatible growth-planing and mobilization of wood resources," in FORMEC 08 - 41. Internationales Symposium, pp. 3-12, ISBN 978-3-9811335-2-3

[2] J. Roßmann, M. Schluse, A. Bücken, T. Jung, and P. Krahwinkler, "Der Virtuelle Wald in NRW," in AFZ - Der Wald, Nr. 18, 2007, pp. 966-971, ISSN 1430-2713.

[3] J. Roßmann, and A. Bücken, "Using 3D-Laser-Scanners and Image-Recognition for Volume-Based Single-Tree-Delineation and -Parameterization for 3D-GIS-Applications," in van Oesterom, Zlatanova, Penninga, Fendel (Eds): Proceedings of the 2nd International Workshop on 3D Geoinformation, Lecture Notes in Geoinformation and Cartography LNG&C, December 12-14, Delft, The Netherlands, pp. 131-146, ISBN 978-3-540-72134-5.

[4] J. Hradetzky, and W. Schöpfer, „Das Softwareprodukt HOLZERNTE. Eine Entscheidungshilfe für die Holzernte und die Holzvermarktung," in AFZ 56 (2001), 1100-1101

[5] H. Pretzsch, P. Biber, and J. Dursky, „The single tree-based stand simulator SILVA: construction, application and evaluation," Forest Ecology and Management 162 (2002) 3-21

[6] T. Jung, and J. Roßmann, "Realisierung von Simulatoren für Forstmaschinen für den Einsatz in der Maschinenführerausbildung mit einem universellen 3D-Simulationssystem," in Tagungsband der 10. IFF-Wissenschaftstage. 4. Fachtagung zu Virtual Reality, Magdeburg, June 27.-28., 2007, pp. 113 – 121, ISBN 978-3-8167-7383-2

[7] J. Roßmann, P. Krahwinkler, and A. Bücken, "Arbeitsmaschinen als autonome Roboter im Forst: Virtuelle Prototypen, Verfahren und Anwendungen," in 7. Paderborner Workshop Augmented & Virtual Reality in der Produktentstehung (HNI-Verlagsschriftenreihe "Rechnerintegrierte Produktion", Bd. 232), June 5.-6. 2008, Heinz Nixdorf MuseumsForum, Paderborn, pp. 323-333, ISBN 978-3-939350-51-4.

[8] J. Roßmann, M. Emde, C. Schlette, A. Bücken, M. Schluse, and P. Krahwinkler, "Data Fusion Based Multi-Sensor System for High Accuracy Forest Management," to be published at The International Conference on Multipurpose Forest Management, September 20 – 25, 2009, Niigata, Japan

[9] J. Roßmann, and C. Schlette, "Simulation und Animation humanoider Kinematiken in der Virtuellen Produktion – nicht nur für ergonomische Betrachtungen," in 6. Paderborner Workshop – Augmented & Virtual Reality in der Produktentstehung, Schriftenreihe des Heinz Nixdorf Instituts, Bd. 209, pp. 349-365, June 14. -15. 2007, Paderborn, ISBN 978-3-939350-28-6 und ISBN 3-939350-28-1.

[10] J. Roßmann, M. Schluse, T. Jung, and M. Rast, "Close to Reality Simulation of Bulk Solids Using a Kind of 3D Cellular Automation," submitted to The Computers and Information in Engineering Division Conference, ASME CIE 2009, August 30 - September 2, San Diego, CA, USA

[11] J. Roßmann, N. Hempe, and P. Tietjen, "A Flexible Model for Real-Time Crowd Simulation," submitted to The IEEE International Conference on Systems, Man, and Cybernetics (SMC2009), October 11-14, San Antonio, Texas, USA

[12] J. Roßmann, and T. Jung, "Dynamiksimulation für Virtuelle Welten: Erfahrungen, Anwendungen, Methoden," in Gausmeier, J. / Grafe, M. (Hrsg.): 7. Paderborner Workshop Augmented & Virtual Reality in der Produktentstehung (HNI-Verlagsschriftenreihe "Rechnerintegrierte Produktion", Bd. 232), June 5.-6. 2008, Heinz Nixdorf MuseumsForum, Paderborn, S. 61-76, ISBN 978-3-939350-51-4.

[13] P. Lindstrom, D. Koller, W. Ribarsky, L. F. Hodges, A. Op den Bosch, and N. Faust, "An Integrated Global GIS and Visual Simulation System," in Technical Report GIT-GVU-97-07, Georgia Inst. of Technology, Mar. 1997

[14] X. Wang, "Integrating GIS, simulation models, and visualization in traffic impact analysis," in Computers, Environment and Urban Systems, Volume 29, Issue 4, July 2005, pp. 471-496, ISSN 0198-9715

[15] L. Becker, L. Bernard, J. Döllner, S. Hammelbeck, K. Hinrichs, T. Krüger, B. Schmidt, and U. Streit, "Integration dynamischer Atmosphärenmodelle mit einem (3+1)-dimensionalen objektorientierten GIS-Kern," in 13. Internationales Symposium "Informatik für den Umweltschutz", pp. 429-442, 1999, ed. C. Rautenstrauch, M. Schenk, Publisher Metropolis