Internal Version (Early Draft)

A Concept of Effective Landmark Depiction in Geovirtual 3D Environments by View-Dependent Deformation

Tassilo Glander, Matthias Trapp, Jürgen Döllner

Hasso Plattner-Institute at the University of Potsdam

{tassilo.glander, matthias.trapp, doellner}@hpi.uni-potsdam.de

Abstract: Landmarks represent elements of geovirtual 3D environments with outstanding importance for user orientation. Especially, they facilitate navigation and exploration within virtual 3D city models. This paper presents a novel concept for the real-time depiction of landmarks that effectively emphasizes these 3D objects by improving their visibility with respect to their surrounding areas and the current 3D viewing settings. The concept is based on scaling landmark geometry according to an importance function while simultaneously adjusting the corresponding surrounding region. The amplification of landmarks takes into account the current camera parameters. To reduce visual artifacts caused by this multi-scale presentation, e.g., geometry intersections, the surrounding objects of each landmark are adapted according to a deformation field that encodes the displacement and scaling transformations. An individual weight coefficient can be defined that denotes the landmark's importance. To render a collection of weighted landmarks within a virtual 3D city model, the technique accumulates their associated, weighted deformation fields in a view-dependent way. Our concept provides a flexible solution for the importance-driven enhancement of objects within interactive geovirtual 3D environments and aims at improving the perceptual and cognitive quality of their display. In particular, the concept can be applied to systems and applications that use abstracted, generalized virtual 3D city models such as in the fields of car and pedestrian navigation, disaster management, and spatial data mining.

Keywords: Visualization, Smart Environments and Landmarks, Navigation Systems

1. Introduction

Traveling in the real world depends on structures and objects standing out, e.g., regarding their height, color, structure or usage. These objects or structures are landmarks, used by the human brain to create a mental map and remember the right way (Ware 2000).

Emerging interactive 3D geovirtual environments, e.g., virtual city models, can be used to provide more than just a photorealistic depiction of reality: they give users a high degree of freedom for exploring complex geospatial and georeferenced information. In consequence, using standard projections, these 3D environments have the problem of occluding distant objects by near objects, which is different to classical 2D maps or top-down views. For effectively providing a location based service as in a handheld navigational system, the user must be able to be aware of important landmark objects, even if they are occluded or may be too small in reality.

In classical 2D maps, the problem is solved by displaying landmarks differently to reflect their importance. Depending on the current scale, they can be depicted larger than their neighborhood (Hake et al. 2002, Imhof 1972), they can be highlighted by different colors or drawing styles, and exposed by clearing their immediate surrounding.

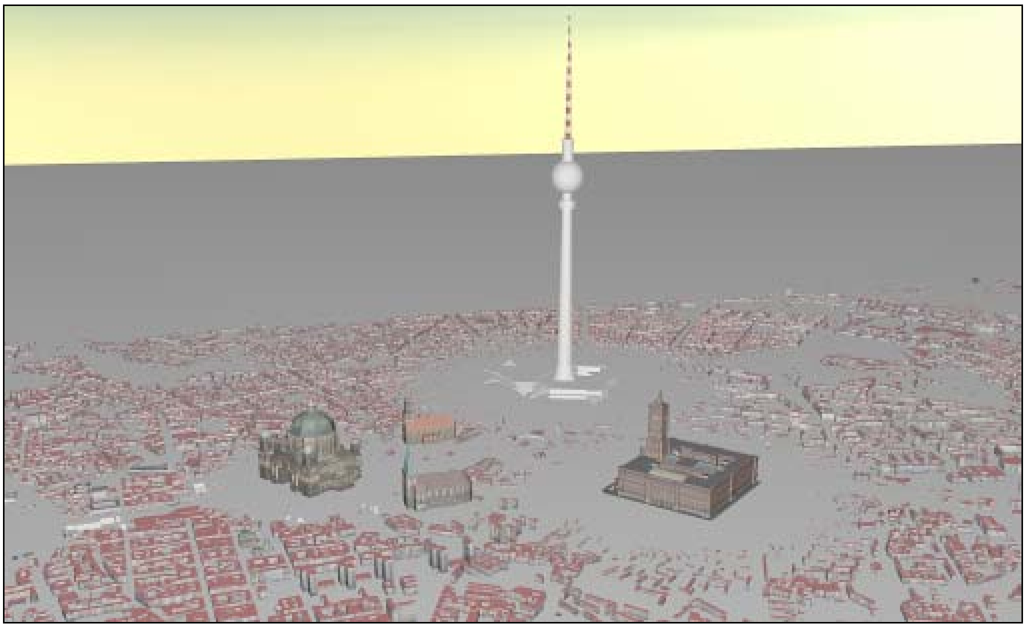

Fig. 1: Enhancement of multiple landmarks in a virtual 3D city model.

In our paper, we provide a first concept of a landmark visualization technique that resolves the problem of occluded or too small landmarks (Fig. 1). The deformation is performed dynamically in real-time and considers landmark objects that displace both each other and their surrounding buildings.

The remainder of the paper is structured as follows: In Section 2, existing approaches in the fields of cartography, visualization and computer graphics are summarized that are closely related to our method. In Section 3, we present an outline of our concept by introducing the particular working phases. Section 4 discusses necessary preprocessing tasks for city model data in detail. Section 5 introduces the used deformation model while Section 6 briefly commits some rendering aspects. Section 7 demonstrates and discusses results of our work and describes current limitations. Section 8 concludes this paper and gives suggestions for future work.

2. Related Work

2.1 Landmarks in Maps and Virtual Environments

The management of landmark objects in maps and map-like visualizations is an ongoing major challenge for effectively providing Location Based Services (LBS) (Cartwright 2005, Steck et al 2000). Generally, many accentuation techniques have been developed like symbols, annotations, and hybrid perspectives (Lee et al. 2001), which are difficult to transfer to 3D geovirtual environments.

Vinson (1999) presented design guidelines for design and placement of landmarks in virtual environments to ease navigation. They comprise among others:

- Landmarks should be visible at all times, especially at all navigable scales.
- They should be distinguishable from their environment.
- Concrete objects should be preferred over abstract ones for landmarks.

In previous works, we integrated information lenses showing photographs connected with landmark objects in 3D city models (Trapp 2007). Elias et al. (2006) analyzed different graphical representations of landmark buildings ranging from photorealistic to more abstract icons to plain text. They introduced a design matrix to help choosing the appropriate representation for different categories of buildings (e.g., commercial buildings, visually outstanding buildings). Lee et al. (2001) suggested depicting landmark buildings by placing photographs in the scene, which have been took from a similar perspective.

A halo technique was suggested in (Baudisch 2003) to indicate the location of off-screen objects. A lot of research has been done towards the automatic detection of landmarks (Elias et al. 2004 , Galler 2002, Raubal et al. 2002) and their relevance (Reichenbacher 2005).

2.2 Focus & Context Visualization

Focus & Context Visualization is a principle of information visualization. It displays the most important data at the focal point at full size and detail, as well as the area around the focal point (the context) to help make sense of how the important information relates to the entire data structure. Displaying information in a context that makes it easier for users to understand is the central task in information visualization. Information visualization is an attempt to display structural relationships and context that would be more difficult to detect by individual retrieval requests (Mackinlay 1993).

Focus & Context Visualization in virtual 3D environments has been well researched during the past years (Schumann et al. 2006, Baar 2005, Fuchs 2004). There is a multitude of approaches for virtual 3D terrain lenses: view dependent non-linear visualization techniques (Leung et al.1994, Carpendale et al. 1996). These approaches distort the mesh vertices so that the impression of magnification occurs. One can find also texture based approaches like cartographic and thematic texture lenses (Döllner 2001). Many researchers have addressed the screen real-estate problem. One solution, the so-called detail-in-context technique, integrates detail with contextual information. Keahey (1998) describes a general formulation of the "detail-in-context" problem, which is a central issue of fundamental importance to a wide variety of nonlinear magnification systems.

The magic lens metaphor and Toolglasses™ have been introduced by Pier et al. (1993). They describe widgets as interface tools that can appear between an application and a traditional

Fig. 2: Comparison between a visualization using the standard projection (left) and an enhanced rendering of landmarks (right) obtained with our approach.

cursor. Visual filters bound to the widgets, known as magic lenses, can modify the visual appearance of application objects, enhance data of interest or suppress information in the region of interest, which is determined by the shape of the lens. An overview of 3D magic lenses and magic lights is given in (Äyräväinen 2003).

3. Concept Outline

While exploring a geovirtual 3D environment the user needs to identify distinct features, i.e., landmark buildings. Our concept enables this by scaling these important features to a sufficient size, that is, a size that allows the user to identify them properly on the screen (Fig. 2). The scaling depends on the current camera distance and therefore is dynamically adapted when the user explores the environment.

Our concept can be associated with the visualization pipeline (Ware 2000), see Fig. 3. The input data is a city model. It has to be augmented by the creator of the map with landmark weights during the data gathering stage (**tagging**). The tagged city model serves as input for the next stage (**preprocessing**), where in an automatic process both city model geometry and deformation data are derived that are required for the real-time deformation. At runtime, during the **rendering**, the deformation data is evaluated and the objects of the city model are deformed, creating subsequent images for the impression of interactive display. The user can explore and navigate the city model, leading to permanent updates of the deformation model and, hence, the scaling of the landmark objects.

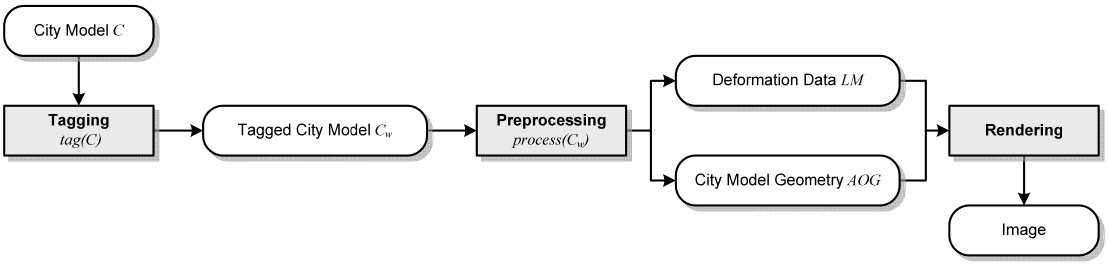

Fig. 3: Components and processing stages of our visualization concept.

4. Tagging and Preprocessing

During the tagging and preprocessing stage, the city model data is augmented and transformed prior to the rendering. While the tagging needs additional input provided for example by a human, the preprocessing is completely done automatically.

4.1 Tagging

During the tagging phase, weights are associated to a set of city model objects $C = \{c_1, ..., c_n\}$, by defining an importance function $w: C \rightarrow IR^+$. So the tagging can be expressed as a mapping:

$$tag(C) = C_w = \{(c_1, w(c_1)), \ldots, (c_n, w(c_n))\}$$

A common city model object is mapped to the weight 1, while landmark objects are usually mapped to higher weights.

Assuming the number of landmark objects to be small compared to the number of all city model objects, it seems appropriate to define a default weight of 1 for all buildings and only assign a higher weight to selected number of objects. Therefore, the importance function defines a partition into two sets of city objects: landmark objects and non-landmark objects.

At the moment, the weights for important objects have to be defined manually; our technique does not derive them automatically. As the weights are assigned prior to the rendering, any data source like a web service (MacKenzie et al. 2006) or a data base query can be integrated easily, as long as it can be mapped to our weight. For a simple example, Google™ queries for the landmark object's names (e.g.: "Statue of Liberty") could be used to derive their importance based on the number of hits.

4.2 Geometric Preprocessing

During the preprocessing stage, the city objects are automatically analyzed and a number of vertex attributes are derived and stored. Hence, input data are the tagged buildings together with their associated weights C_w . These are processed in a loop as sketched in the pseudo code implementation (Listing 1).

To summarize the preprocessing stage: For each weighted city object c_i a unique object *id*, its geometry and axis-aligned bounding box *bb* are calculated. If the city object is a landmark object, a scaling function *s* is derived from the weight. The scaling function could be for example a linear or quadratic function of the distance of which the coefficients can be stored. The scaling function is introduced in Section 5.1.1 in more detail.

```
Input    C_w    //Weighted city objects
Output   LM     //Landmark objects
Output   AOG    //Attributed object geometries

process(C_w)
{
  ∀(c_i, w(c_i)) ∈ C_w
  {
      id ← id(c_i)
      bb ← boundingBox(c_i)
      if(w(c_i) > 1)
      {
         isLandmark(c_i) ← true
         s_{c_i} ← scalingFunction(c_i)
         LM ← LM ∪ (id, s_{c_i})
      } else {
         isLandmark(c_i) ← false
      }
    AOG ← AOG ∪ (generateGeometry(c_i), id, bb, isLandmark(c_i))
  }
}
```

Listing 1: Pseudo-code for the geometric processing of a city model.

5. Deformation Model

The deformation model describes how city model objects are displaced and scaled to achieve the desired landmark visualization. They are evaluated according to the deformation model, their bounding box, current position and weight during the rendering for each frame.

We rate landmark objects as more important than non-landmark objects, hence non-landmark objects can be scaled down or even omitted at all to achieve visibility of landmark objects. Thus, sacrificing completeness and accuracy of the depiction can be reasoned with the superior significance of landmark objects for navigation and is done similarly during cartographic generalization processes (Hake et al. 2002).

5.1 Landmark Deformation

The motivation of the landmark visualization is to achieve visibility of certain important objects in a 3D environment. To accomplish this, our technique scales these objects up if their appearance would be too small otherwise in the projected image. The scaling effect occurs only within a distance interval derived from the weight, defining a starting and ending distance $I = [d_{start}; d_{end}]$.

5.1.1 Landmark Scaling Function

For a deeper understanding of how we scale the landmark objects, two simple cases are looked at. Using the standard perspective projection (Akine-Möller and Haines 2002), an object with extent *x=1* is projected on the viewing plane to an extent *x'*. The projected size depends on the distance of the object to the projection plane, i.e., the camera distance, and an inverse proportionality can be observed. Simplified, the projected extent is $p_1(d) = 1/d$ where d corresponds to the camera distance. Fig. 4 shows the behavior of $p_1(d)$ (left) if the scaling is constantly 1 (right).

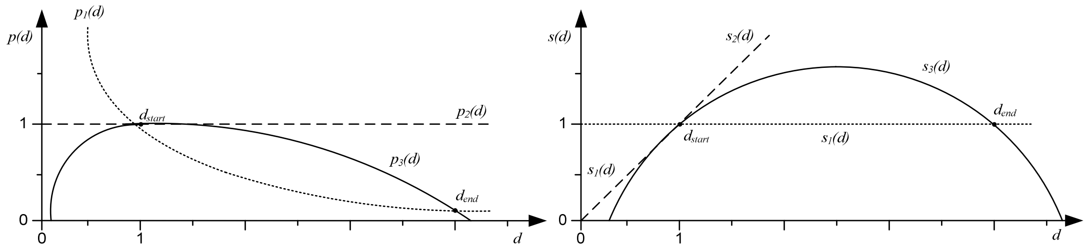

Fig. 4: Projected size of a landmark object (left) and the scale factor (right).

If an object should keep a constant projected size (stippled graph), its size (in the scene) would have to be scaled by the current distance before the projection: $p_2(d) = 1 \cdot d / d = 1$.
However, the effect shall be locally limited depending on the landmarks weight, e.g., a small church is only an important landmark in its neighborhood but not relative to the whole city. Therefore, when zooming out from a landmark object that has its projected size kept constant, eventually it has to loose this property and return to its usual shape to avoid "crowding" the scene.
For these two cases, the objects are scaled before the projection by a scaling function as depicted in Fig. 4 (right): $s_1(d) = 1$ and $s_2(d) = d$.
To accomplish a smooth return to the usual shape (i.e., scale = 1), we use a quadratic function $s_3'(d)$ that has a slope of one at a certain distance d_{start}, being the starting distance for the exaggeration of the landmark object. The exaggeration effect is limited to another distance d_{end}, where $s_3'(d)$ falls below 1. Fig. 4 shows an example of $s_3'(d)$ for $d_{start} = 1$, $d_{end} = 4$.

We derive d_{start} and d_{end} from the single weight parameter $w(c_i)$ defined while tagging the city model objects like this:

$$d_{start} = 1000, \; d_{end} = 1000 \cdot 2^{w(c_i)} \; .$$

As they only depend on the previously defined weight of the landmark, the function $s_3'(d) = ad^2 + bd + c$ can be precomputed using the distance interval and its coefficients a, b, c are then stored for each landmark object.
As we do not want the scale to go below 1, the actual scaling function is clamped to be greater than 1:

$$s_3(d) = \begin{cases} s_3'(d) & N < d < F \\ 1 & else \end{cases}$$

5.1.2 Landmark Displacement Using a Simple Spring Model

Scaling landmark objects up means that surrounding objects like other landmark objects have to be displaced to avoid self intersection artifacts. Fig. 5 shows the intersection of the landmarks' extents, when enlarged.

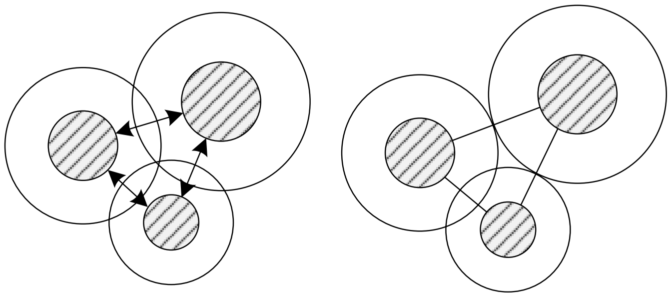

Fig. 5: Spring model for mutual landmark displacement. It shows original landmark positions before (left) and after (right) the application the model spring.

Solutions for this problem have been researched in simulated annealing (Kirkpatrick et al. 1983, Ware et al. 2003), spring mass models (Bobrich 1996), and least squares adjustment (Sester 2000). We resolve the problem by applying a naive spring model without mass, where overlapping objects create a small repelling force that shifts the objects apart. This model is applied iteratively until no shifting takes place anymore or a maximum of iterations is reached. In spite of its simplicity, the model yields acceptable results.

5.1.3 Displacement of Non-Landmark Buildings

While the spring model as described above can be computed sufficiently fast for a small number of objects, it is not suitable for the entirety of city objects. In addition, this is not necessary since common city objects usually will be too small to reason a high computational effort for their correct individual positioning. Instead, we apply a radial distortion to all non-landmark objects in the environment of the landmark object as an application of the distortion lenses presented by Carpendale et al. (2004). Their lenses work with a drop-off function defining how features in the vicinity of the lens are displaced and scaled.

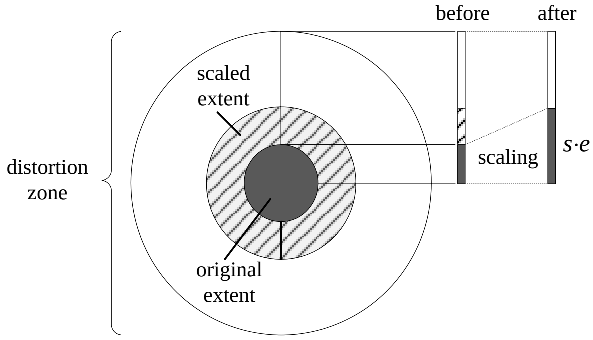

Fig. 6: Illustration comparing original and scaled extent of a single landmark.

As we want to limit the distortion effect locally, we define a distortion zone twice the size of the scaled landmark's extent. Fig. 6 illustrates how the environment of the landmark is compressed and offset to fit in the distortion zone. The translation function shifting elements at distance *x* from the landmark center within the distortion zone is defined:

$$t_{nonLM}(x) = s \cdot e + (x - e) \cdot \frac{s}{2s - 1}$$

with *s* being the landmark's scaling and *e* its half extent. Just offsetting the neighbouring buildings would create self-intersections; therefore we also define a scaling function that shrinks buildings within the distortion zone. Objects near the landmark are small and get linearly bigger until they reach their original size:

$$s_{nonLM}(x) = \frac{x}{2s \cdot e} \quad \text{with } 0 \le x \le 2s \cdot e$$

Thus the lens effect integrates smoothly in the city model while it exposes the landmark object. Fig. 7 shows landmark buildings in growing distance to the camera.

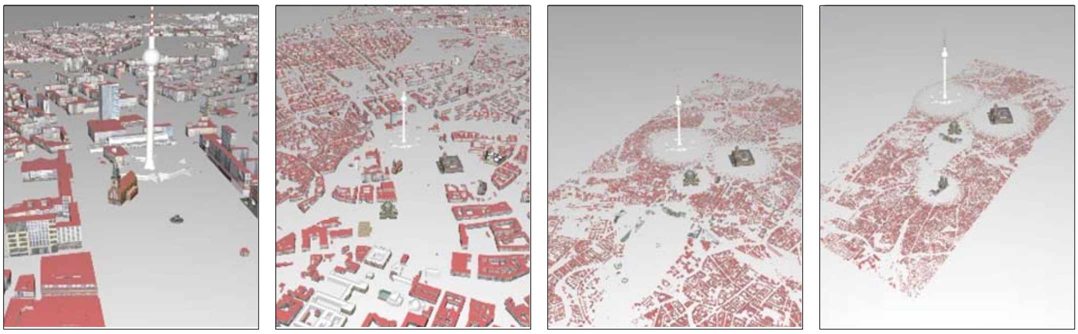

Fig. 7: Behavior of landmark enhancement with increasing distance to the camera.

6. Rendering Technique

The implementation of the underlying rendering technique relies on the scenegraph-based high-level rendering framework VRS (Döllner 1995). It requires programmable graphics hardware as available on today's consumer graphics hardware.

The rendering process per frame is divided into two passes: a pre-traversal pass and a rendering pass. Both passes must be evaluated per frame, since the deformation parameters depend on the current camera settings which can be changed in an interactive system:

1. **Pre-Traversal Pass:** The first pass traverses the scene graph and collects all attribute nodes that represent landmarks. This set can be optional culled against the current view-frustum (Akine-Möller and Haines 2002) to reduce the further calculation complexity. Now, the deformation model described in Section 5 determines the deformation parameters. After this, the deformation parameters will be encoded in global shader constants (Kessenich 2006) for the subsequent rendering pass.

2. **Rendering Pass:** During this pass a vertex shader program (Kessenich 2006) is activated that deforms every vertex of the building geometry according to the global shader constants. Additional vertex attributes such as object identity (*id*) and the buildings bounding box (*bb*), which were set during the preprocessing of the scene-geometry (see Section 4.2), enable the distinction between landmark and non-landmark geometry. The shader program then scales and displaces the landmark geometry or applies the deformation parameters to clear space for the landmarks.

This approach is efficient in terms of rendering complexity because the complete scene geometry is rendered only once per frame. Thus, the rendering performance is limited only by the number of landmarks and the number of vertices of the city model geometry.

Fig. 8: Comparison between standard (left) and enhanced rendering (right) in a view perspective close to the ground.

7. Results

Fig. 2 and 8 compare our approach with a standard rendering of the same viewpoint. The enhancement clearly improves the perceptual and cognitive quality of the landmark display. Consequently it facilitates the task of finding landmarks that have an impact on navigation and exploration of virtual 3D city models. This concept enables also an overview of the main landmarks that can be compared to detail-in-context applications in the field of focus & context visualization.

The choice of an adequate scaling function emerged to be important for the interactive application of this concept. The recurrence of a landmark to its original size on close and far distances is necessary to enable a smooth integration into standard 3D navigation techniques (Buchholz 2005). Further, it seems to be useful to research the impact of shape-preserving (uniform) deformation vs. per-vertex (non-uniform) deformation to the viewer’s perception. To ease the preparation of special visualizations using this technique, the parameter settings for the scaling functions should stay modifiable on run time.

Despite the limited physical resources such as main and graphics memory our concept is mainly limited by the following hardware dependant issues: With an increasing number of visible landmarks, the calculation cost of the deformation parameters on CPU side can stall the GPU. This did not occur in our tests, but is possible in theory. Furthermore, the encoding of the deformation parameters into an adequate assignment of constant registers can exceed the limitations of shader programs.

The presented concept shows some limitations and drawbacks. The used spring model to control the mutual landmarks displacement cannot guarantee a stable frame-to-frame coherence, i.e., jumps do occur. Furthermore, this model is not able to properly visualize a large number of landmarks having equal or similar weights. In addition, the current deformation model cannot fully avoid self-intersections for non-landmark buildings.

8. Conclusion & Future Work

We have presented a novel concept and technique for the real-time depiction of 3D landmarks. These 3D objects are emphasized by improving their visibility with respect to their surrounding areas and the current 3D viewing settings. The approach has proven to be applicable to complex geovirtual 3D environments such as virtual 3D city models. We have integrated our prototypical implementation into the real-time 3D geovisualization framework LandXplorer (http://www.3dgeo.de).

Our concept delivers an adequate solution for the landmark enhancement problem. Nevertheless, several features should be improved and further investigated. Despite handling only points of interests, our approach can be abstracted in a way that it can be applied to regions of interest (ROI). In addition, the research of other displacement models or alternative scaling function can be of interest. The usage of object-aligned bounding boxes as well as the consideration of the buildings perimeter could achieve a more precise displacement of the surrounding area.

Our approach can also be extended non-uniform displacement and scaling of terrain, line data such as streets or railway lines, as well as other surface objects such as geometric representations of land use data. Furthermore, a landmark could be enhanced by rotating it towards to camera, which enables a priority-based view on the landmark. The necessary information for this enhancement could also be processed during the tagging step.

Acknowledgment

This work has been funded by the German Federal Ministry of Education and Research (BMBF) as part of the InnoProfile research group "3D Geoinformation" (www.3dgi.de).

References

T. Akenine-Möller and E. Haines, "Real-Time Rendering", 2nd Ed., A K Peters, 2002.

S. Äyräväinen, "3D Magic Lenses, Magic Lights, and their application for immersive building services information visualization". Technical report, Helsinki, 2003

D. Baar, "Questions of Focus: Advances in Lens-based Visualizations for Intelligence Analysis", 2005

P. Baudisch and Ruth Rosenholtz, "Halo: a Technique for Visualizing Off-Screen Locations", Proceedings of the ACM SIGCHI conference on Human factors in computing systems, pp. 481-488, 2003

J.Bobrich, "Ein neuer Ansatz zur kartographischen Verdrängung auf der Grundlage eines mechanischen Federmodells", Ph.D. Thesis, Vol. C 455, Deutsche Geodätische Kommission, München, 1996

H. Buchholz, J. Bohnet, and J. Döllner, "Smart and Physically-Based Navigation in 3D Geovirtual Environments", IEEE Information Visualisation, London, 2005.

W. Cartwright, "Landmarks and the Perception of a Space in Web-Delivered 3D-worlds", Location Based Services and TeleCartography, Springer-Verlag, Berlin, Heidelberg, 2005

S. Carpendale, J. Light, E. Pattison, "Achieving Higher Magnification in Context", Proceedings of the 17th annual ACM symposium on User Interface software and technology, pp. 71-80, Santa Fe, 2004

Sheelagh, M.; Carpendale, T.; Cowperthwaite, D.J.; Fracchia, F.D., "Distortion Viewing Techniques for 3-dimensional Data", Information Visualization 1996

J. Döllner, H. Buchholz, M. Nienhaus and Florian Kirsch," Illustrative Visualization of 3D City Models ", Proceedings of Visualization and Data Analysis 2005, page 42-51, 2005

J. Döllner, „Raumbezogene Informationsvisualisierung mit dynamischen, interaktiven 3D-Karten", Kartographische Nachrichten, 2001.

J. Döllner, K. Hinrichs, "The Virtual Rendering System - A Toolkit for Object-Oriented 3D Rendering", EduGraphics - CompuGraphics Combined Proceedings, page 309--318 - 1995

B. Elias and C. Brenner, "Automatic Generation and Application of Landmarks in Navigation Data Sets", ,2004

B. Elias, V. Paelke and S. Kuhnt, “Kartographische Visualisierung von Landmarken” GEOVIS 2006, Potsdam, 2006

Fuchs, G.; Schumann, H., “Visualizing abstract data on maps”, IV 2004

I. Galler, „Identifikation von Landmarks in 3D-Stadtmodellen“, Master’s thesis, 2002.

G. Hake, D. Grünreich and L. Meng, “Kartographie”, Walter de Gruyter, Berlin, New York, 8. Ed., 2002

E. Imhof, „Thematische Kartographie. Lehrbuch der Allgemeinen Geographie“, Band 10, Hrsg.: E. Obst and J. Schmithüsen, Walter de Gruyter, Berlin, New York, 1972.

T. A. Keahey, “The Generalized Detail-In-Context Problem”,.Proceedings of the IEEE Symposium on Information Visualization, IEEE Visualization, October 1998.

J. Kessenich, “The OpenGL Shading Language Language Version: 1.20 Document Revision: 8”, 2006

S. Kirkpatrick, C. D. Gelatt Jr. and M. P. Vecchi, „Optimization by Simulated Annealing”, Science Vol. 220. no. 4598, pp. 671 – 680, 1983

Y.C. Lee, A. Kwong, L. Pun and A. Mack, “Multi-Media Map for Visual Navigation”, Journal of Geospatial Engineering, Hong Kong, 2001

Y.K. Leung, M.D. Apperley, “A Review and Taxonomy of Distortion-Oriented Presentation Techniques”, ACM Transactions on Computer-Human Interaction, 1994.

C. M. MacKenzie, K. Laskey, F. McCabe, P. F. Brown and R.Metz, editors. “Reference Model for Service Oriented Architectures”, Organization for the Advancement of Structured Information Standards (OASIS), August 2006

R. Mackinlay, “Information visualization using 3d interactive animation.” Communications of the ACM, 1993

K. Pier, W. Buxton T.D. DeRose, E. Bier, M.C. Stone. “Toolglass and magic lenses: The see-through interface”. In SIGGRAPH, pages 73–80. ACM Press, 1993

M. Raubal and S.Winter, “Enriching Wayfinding Instructions with Local Landmarks”, GIScience, Springer-Verlag, Berlin Heidelberg, 2002

T. Reichenbacher, “The concept of Relevance in Mobile Maps”, Location Based Services and TeleCartography, Springer-Verlag, Berlin, Heidelberg, 2005

H. Schumann, G. Fuchs, H. Griethe. „Definition allgemeiner Linsentechniken auf unterschiedlichen Stufen des Visualisierungsprozesses“, 2006.

M. Sester, “Generalization Based On Least Squares Adjustment”, Int. Archieves of Photogrammetry and Remote Sensing, Vol. 34, B4, Amsterdam 2000

S. D. Steck and H. A. Mallot, “The Role of Global and Local Landmarks in Virtual Environment Navigation”, Presence Vol. 9, No.1, MIT, 2000

M. Trapp, “Analysis and Exploration of Virtual 3D-Citymodels using 3D Information Lenses”, Diplomarbeit, Hasso-Plattner-Institute, University Potsdam, 2007

N. G. Vinson, “Design Guidelines for Landmarks to Support Navigation in Virtual Environments”, Proceedings of CHI ’99, ACM, 1999

C. Ware, “Information Visualization – Perception for Design”, Morgan Kaufmann, 2000

J. M. Ware, C.B. Jones, and N. Thomas, “Automated Map Generalization with Multiple Operators: a Simulated Annealing Approach”, Int. J. of Geographical Information Science, 2003