VISGIS: Dynamic Situated Visualization for Geographic Information Systems

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***Abstract*—Situated Visualization techniques are visualization techniques that provide a presentation of information within its spatial context. Situated Visualization techniques have several advantages compared to traditional visualization techniques with the biggest advantage being providing the spatial relationship between data and the actual environment. However, Situated Visualization techniques are also subject to several challenges. In particular, Situated Visualization of data from geographic information systems (GIS) is exposed to a set of problems, such as limited visibility, legibility, information clutter and the limited understanding of spatial relationships.**

In this paper, we address the challenges of visibility, information clutter and understanding of spatial relationships with a set of dynamic Situated Visualization techniques that address the special needs of Situated Visualization of GIS data in particular for "street-view"-like perspectives as used for many navigation applications. The proposed techniques include dynamic annotation placement, dynamic label alignment and occlusion culling. We applied those techniques for two types of Situated Visualizations: Augmented Reality visualization and Indirect Augmented Reality using 360 Degree footage.

I. INTRODUCTION

The consistent growth of commercial and public domain geographic information systems (GIS) has made it now possible to access geospatial information about almost every densely populated region in the world. In particular, the biggest public domain database OpenStreetMap (OSM)[1] records continuously growing numbers of contributors and uploads[2].

OpenStreetMap represents physical features on the ground (e.g., roads, buildings and landmarks) using nodes, ways, relations and tags. Map viewers like the OpenStreetMap webviewer and virtual globe applications like Google Earth[3] allow users to explore geospatial information either in 2D or 3D space. This includes the visualization of outlines, annotation labels for buildings, streets, and other points of interest like images.

There is also an increasing interest in exploring geographic information within its spatial context [1]. *Situated Visualization* techniques [2], such as Augmented Reality (AR) visualizations address these needs. AR for instance allows users to access information on-site in its spatial context by overlaying digital data onto their view of the physical environment [3] for instance by using a mobile device or smart glasses. In recent years, a lot of research has been conducted investigating the visualization of GIS data in AR environments [1], [4]. However, there are still several open challenges for Situated Visualization of GIS data.

The main challenges arise from the fact that the GIS data is not optimized for first-person "street-view" (terrestrial) presentation such as required when inspecting data on-site. In contrast to virtual environments where users can easily change their positioning within the virtual world, in Situated Visualization environments users often explore the physical world from a fixed position and are interested in their surroundings. Often, they can only move to another position slowly by walking. Another challenge is that these databases often contain only 2.5D information about objects of interest instead of detailed models. This often leads to:

- Information clutter,
- Missing or wrong alignment of information,
- Limited visibility due to fixed placement.

In addition, Situated Visualization is often exposed to limited readability due to changing or uncontrollable environmental conditions [5], registration problems and data incompleteness [6].

In order to create optimized Situated Visualizations, it is important to have specialized visualization techniques that address those challenges. While there is already some research on view management and visualization techniques for virtual and augmented environments, there are only few techniques that address the specific problems that arise when visualizing GIS data in outdoor environments. For instance, a lot of work focuses on view management in smaller work spaces where objects are more likely to be completely in the field of view [7] or additional sensor input (Kinect) can be used to capture a complete 3D representation of the environment to adjust presented information [8]. Some existing research focuses on larger workspace and outdoor scenarios, but rely on image-based geometry computation [9] that can be computationally expensive for mobile devices. Other works focus on the challenges for legibility that arise from varying environmental

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[1] http://www.openstreetmap.org

[2] http://wiki.openstreetmap.org/wiki/Stats

[3] http://www.google.co.nz/earth/

Fig. 1. Situated Visualization techniques for visualizing labels of buildings. (Left) Using a naïve label placement approach, information related to an object of interest is only visible in frontal views. (Middle) Once the view frustum only contains partial views of an object of interest, labels are not longer visible due to their initial positioning. (Right) Using adaptive label placement based on GIS data, the labels stay visible even for difficult perspectives.

conditions in outdoor environments [5], [10], [11].

However, to our knowledge there is no work that addresses the challenges of information clutter, limited visibility of information for partially visible objects and missing or wrong alignment of information for GIS data in outdoor environments by only relying on spatial information provided by the database. The main idea of this work is, instead of using GIS data exclusively for displaying information, to use it also as input source for adapting the visualization [12]. The main contribution of this paper is VISGIS, a set of Situated Visualization techniques specialized for presenting GIS data on-site for a ”street-view” perspective.

II. RELATED WORK

The visualization of GIS data in 3D environments is a well researched field and has a lot of applications. Besides professional GIS tools, the most popular applications for exploring GIS data in 3D environments are virtual globe applications. Commercial as well as open-source virtual globe applications are nowadays widely used to visualize geo-referenced information in virtual environments.

Recently, there is an increasing interest to explore such geographic data not only from a remote location, such as on a desktop computer, but also to access it directly on-site within its spatial context. Situated Visualizations such as AR visualizations address those needs by overlaying the view of the physical world (e.g. a live camera image) with digital geospatial content from a GIS database [4]. Outdoor AR systems have in particular been used for the on-site visualization of subsurface infrastructure [1]. These applications access databases to receive geo-referenced content of subsurface infrastructure in the proximity of the user.

However, there are still several challenges when visualizing digital information and in particular GIS information in its spatial context on-site as discussed in Section I. Some of those challenges have been addressed by previous research, but a lot of the existing techniques focus on smaller work spaces or indoor environments. The main topics that were addressed in previous research are view management and information filtering and clustering.

A. View Management

View management addresses the aspect of layout and the representation of the digital information. In their early work, Bell et al. focused on how to place digital information in proximity to related virtual objects and how to prevent objects from occluding each other [13]. While their approach addresses similar problem like our research, their techniques target virtual environments or mixed environments with a majority of virtual objects. In this context, accurate 3D representations of the objects of interest are available and can be used for adjusting the arrangement. In contrast, in Situated Visualization of GIS data the majority of objects of interest are physical and for instance part of the camera image, while their digital representation are often only sparse. In this paper, we focus on techniques for this kind of data.

Shibata et al. proposed different layout designs for visualization in mixed reality systems [7]. For instance, they addressed the problem of overlaps by rearranging labels based on their priority. For labels that are only partially visible within one's view, they proposed a technique for rearranging (i.e. flipping to the other side of the object) or removing them. While these techniques work well in a smaller workspace as shown in their work, when applying them outdoors for instance for navigation purposes the user can easily get lost due to missing information. Since these techniques rely on having an accurate geometric representation of the objects of interest available, they are called geometry-based techniques and often have a background in virtual environments. For instance, Maass et al. developed several techniques that focus on view arrangement of annotations in virtual environments [14].

A common issue for outdoor Situated Visualization is the absence of detailed knowledge of the real world. Thus, a lot of AR browsers [15] use only the GPS position for initializing the placement of information labels in the user's view of the environment. This approach often neglects the spatial relationship between digital information and real world objects. Image based-techniques address the lack of accurate 3D knowledge by using information from the video image to control the positioning of the labels. Rosten et al. for instance introduced an image-based approach for optimized label placement [10]. The main idea is to identify unimportant

Fig. 2. Visualization problems: (Left) Information overflow: Labels of buildings that are occluded in the view of the user are visible and may create confusion about the spatial relationship. (Middle) Missing alignment of labels makes a spatial mapping between labels and real world objects challenging. (Right) Visibility of labels: Even though the railway station is in the view labels are not displayed because of their fixed positioning outside the view frustum.

parts of an image by calculating a distribution of feature density in a certain area. Areas of the image with few features are identified as good candidates to place a label.

Grasset et al. [11] extended on this idea by introducing an image-based approach that combines visual saliency with an edge-based analysis to identify image regions suitable for placing labels. The main idea is to avoid occluding important real world information with annotations, but maintaining readability and understanding of relationships between annotation information and the corresponding points of interest.

GIS data already provides a lot of additional information about the physical surroundings of users. Thus in this paper, we focus on how to use GIS data as input for geometry-based view management techniques approaches for Situated Visualizations.

B. Filtering and Clustering

Data filtering and clustering address the problem of information clutter that is in particular a problem for Situated Visualization. In addition to presenting the digital information of interest, Situated Visualization benefits from the additional information given by the spatial context of the actual information. However, this additional source of information also makes it more likely to be subject to information clutter. Previous research addressed this problem by applying filtering and clustering methods. Feiner et al. for instance, applied knowledge about the users' task to filter for relevant information [16]. In contrast, Julier et al. applied spatial filtering based on the position of users [17]. Recently, Tatzgern et al. proposed a method for information clustering that suits in particular hierarchical information [18]. In navigational applications from a "street-view" perspective, often all visible objects in the scene could be used as reference points, thus in this work we focus on filtering information based on visibility from a user's perspective.

III. TECHNIQUES FOR SITUATED VISUALIZATION

In order to address the challenges that arise from Situated Visualization of GIS data, we propose a set of three dynamic visualization techniques: *Dynamic Label Placement*, *Dynamic Label Alignment* and *Occlusion Culling*.

A. Dynamic Label Placement

One of the main constrains for terrestrial Situated Visualization is the positioning constraint due to physical limits. It is not possible to move as quickly as in VR environments and in order to not lose the spatial understanding between real world and virtual information it is often not desirable to switch to a VR view. This constraint poses a major challenge when exploring spatial information from a terrestrial perspective since fixed annotations will not always be visible for the user even if the object of interest is in view (Figure 1 (Middle), Railway station). In order to address this problem, we propose *Dynamic Label Placement*, a geometry-based technique that uses geometric data from GIS databases as well as the user's position and view direction as input to place annotations in the virtual camera's view. The main idea is to place the label next to the vertex of the object of interest that is closest to the view's center point. The method uses the camera's projection matrix to project the vertices of geometric representation of the object of interest into image space. The resulting 2D coordinates in image space are used to compute the distances to the camera view's center. Finally, we select the vertex with the smallest distance (2D) and update the position of the label with the position of the selected vertex (3D).

This method places labels dynamically as close as possible to the image center while making sure that they are staying attached to the object of interest. Objects that are only partially in view will be identifiable due the dynamic placement (Figure 1, Right).

B. Dynamic Label Alignment

According to the Gestalt law of grouping, objects are perceptually grouped if they have similarities in common [19]. Because of this, colors are often used to create a certain grouping by expressing similarities between entities. In Situated Visualization creating a grouping by using similar colors is challenging due to the varying backgrounds given by different physical environments. Instead, we decided to use similar alignments to create groupings between physical objects of interest and their annotations. The idea is to align annotations according to their corresponding real world objects, such as a building to create a clearer grouping.

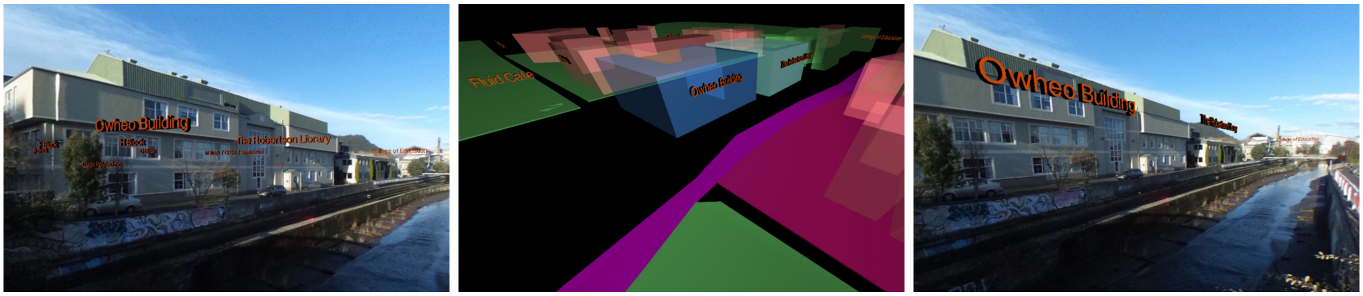

Fig. 3. Dynamic label alignment: (Left) For unaligned labels it is often difficult to understand their spatial relationship the to real world objects. (Middle) Overview of the alignment along the building outlines in 3D. (Right) Alignment supports the understanding of the spatial relationship. Similar orientations support visual grouping.

In order to align the labels to their real world counter parts, we again extract geometric information from the GIS database. The extracted information are two-dimensional footprints with several options to align the information. For example, if the building footprint consists of a polygon of four vertices, we have four resulting edges and thus four different options of aligning the label. In order to make the alignment more distinctive, we select the most prominent edge of the object of interest by computing the space that edge will take up in image space. For this purpose, we extract the 3D coordinates of each polygon feature and again project pairs of two 3D points into 2D image space by using the projection matrix of the camera. After the projection step, we compute the distance between the two resulting 2D points. The 3D edge with the longest projected 2D distance will be used a most prominent edge. In order to avoid using hidden edges, we also compute if the 3D points are hidden by other objects in the scene. Since we have the back-projected 2D points for the vertices already available, we simple cast a ray from these 2D coordinates into the 3D scene by using the camera center as ray origin. We check if any scene objects are intersected by the ray. If this is the case, the original 3D vertex is discarded from further calculations for this view setting. An alternative for this computation would be to use the depth buffer to compute if the 3D points are occluded by other scene objects.

C. *Occlusion Culling*

Information clutter originates from having too much (irrelevant) information present in one's view. This often happens when applying naïve approaches for Situated Visualization of GIS by simply displaying all annotations within ones view frustum (Figure 4, Top).

However, we can estimate which objects are within the users' field of view and visible from their position and viewing direction by using the 2.5D building footprints from the GIS database and estimated heights. Furthermore, some databases such as OSM already support the handling of building heights or number of floor levels. Based on this information, we extrude the building outlines to the estimated or stored height and perform a multi-path rendering for culling all annotations that are occluded by other buildings in the view of the user. In the first step of the multi-path rendering, we render the extruded buildings with a disabled color buffer and an enabled depth buffer. In the second step, we enable the color buffer and render the labels. Since the depth buffer now contains information of all the extruded buildings, only labels that pass the depth test (that are closer to the camera than the any of the extruded buildings) will be rendered to screen (Figure 4, Bottom).

IV. SYSTEMS

In order to be able to test the proposed Situated Visualization techniques within different interface environments, we integrate them into two different systems: 1) an Augmented Reality framework based on OpenSceneGraph[4] and 2) an Indirect AR Browser [20]. Both target the application scenario of pedestrian navigation and guidance and provide "street-view" perspectives.

A. *Augmented Reality System*

For applying our visualization techniques in an AR environment, we extended the osgEarth[5] framework. OsgEarth supports the rendering of virtual globes with textures, annotations, extrusions, as well as functionalities to render pictures. We extended the library with the capability to import GIS data from different data sources and to integrate sensor data, such as camera poses and camera images to support an AR testbed. For testing purpose, we used a pre-captured dataset using camera images and poses computed by the localization and tracking method by Ventura et al. [21].

For using the registration within the AR application, we set the projection and view matrices based on the provided registration data. Camera position and orientation define the view matrix, and intrinsic parameters of the camera, such as focal length, principal point and distortions define the projection matrix (Figure 5).

B. *Indirect Augmented Reality Browser*

Accurate tracking based on a combination of high-accuracy sensors and computer vision methods is essential for providing a high-quality AR experience. Low-cost built-in sensors (GPS, compass and gyroscopes) in most commodity hardware such

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[4] http://www.openscenegraph.org

[5] http://osgearth.org

Fig. 4. Occlusion culling of labels. (Top) Scene without using occlusion culling. Labels that are occluded by other buildings are displayed and create information clutter. (Bottom) Occlusion culling removes occluded labels from the display.

as mobile phones come with large positioning and orientation errors. Those errors often create unstable overlays being exposed to lag and digital information jittering and jumping in the user's view. An alternative is to use *Indirect Augmented Reality* [20], which is based on pre-captured panoramic images and has been shown to deliver a convincing information presentation compared to low-cost AR systems [20]. In order to implement an Indirect AR application, we captured a set of panoramic images using a Ricoh Theta panoramic camera[6]. The captured panoramic images contain GPS information and orientation information that provides an alignment with the GIS data. For displaying GIS data within the Indirect AR environment, we used a WebGL based implementation to support a broader audience. The panoramic image is mapped into the user's perspective using a sphere-based mapping and provides the background for the Indirect AR visualization.

V. DATA FLOW

For both systems, we use a similar workflow for extracting data from the GIS database and displaying it. It consists of data querying and data transcoding. After the transcoding step, we apply the dynamic Situated Visualization techniques from Section III.

A. Database handling

We store all geospatial data in a PostgreSQL database and use PostGIS as extension for supporting the handling of geographic data such as spatial queries for a certain area of interest. For the AR system based on OpenSceneGraph, we extended the framework to directly perform structured query language (SQL) queries to access data. For the Indirect AR Browser, we use a node.js[7] server application that performs the spatial queries based on HTTP request performed by the Indirect AR browser.

B. Transcoding

The data in the GIS database are stored in a 2.5D representation based on longitude and latitude coordinates and optional heights. In order to transform this data into a representation suitable for Situated Visualization, we apply a transcoding step that extracts information and converts it into a 3D representation. We support the following kinds of data:

- Buildings geometries and corresponding labels,
- Street outlines and corresponding labels,
- Labels for points of interest

An important step in the transcoding is the conversion of global coordinates into local ones to make them suitable for visualization purpose to avoid precision problems. Geospatial information is often stored in WGS84 (World Geodetic System 1984). The transcoding method maps all information from global world space into a local coordinate system (East-North-Up) depending on a reference position close to the user position. While the osgEarth library already offers methods to transform between the coordinate systems, for the WebGL version we implemented our own conversion methods.

1) Buildings and streets: Buildings and streets are created based on polygon features or polyline features that represent the layout of the building or the street. We use this kind of information primarily as input for the dynamic Situated Visualization techniques, but we also support an option where 3D geometry can be displayed as landmarks for orientation purposes. In order to create 3D geometry for buildings, we use the OSM keys *geometry, height and building:levels* for the layout. The raw data consists of an array of geo-referenced points. Based on the given polygon and the height information, we create an extrusion that represent the objects of interest in 3D. If height information or information about the levels of the building is available we use this as input. There are also options for accessing roof information from OSM but currently this information is infrequently stored. Therefore, we do not support roof information in the current systems.

2) Annotations: For many objects (e.g. buildings, points of interests, streets) additional information is stored, such as the name of the building or the name of the street (Figure 5, Left). Initially, we will place those labels at the centroid position of the object of interest and will place them dynamically according to the proposed Situated Visualization techniques.

VI. CONCLUSION AND FUTURE WORK

In this paper, we presented a set of Situated Visualization techniques adjusted for the needs and opportunities for GIS data. The idea is to use GIS data not only for displaying but also as input for adapting the visualization. The main goal was to address presentation issues, such as limited information

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[6] https://theta360.com/en/

[7] https://nodejs.org/

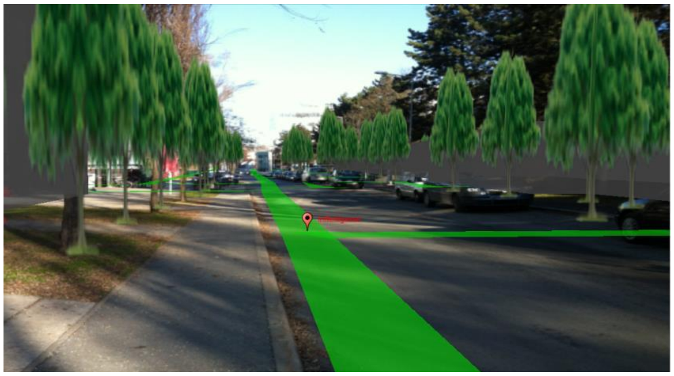

Fig. 5. Transcoded buildings, streets and annotations displayed in the Augmented Reality system.

visibility, information clutter and limited understanding the spatial relationship between displayed information and the underlying real world object.

For this purpose, we introduce Dynamically Placed Annotations, Dynamical Label Alignment and Occlusion Culling all based on scene information extracted from a GIS database. All three proposed techniques are geometry-based approaches that make use of spatial information stored in GIS. The main goal is to support the user when exploring GIS data on-site in its spatial context – for instance, for navigational purposes.

In addition, we discussed two different frameworks that we implemented to test and work with the developed dynamic Situated Visualization techniques. Our test frameworks allow for fast prototyping and testing of new visualization techniques and supports the usage of GIS databases such as OSM to access and display buildings, streets, as well as annotations.

The proposed Situated Visualization techniques exclusively use geometry as input. As part of the future work, we plan to extend the methods by integrating image-based information [11] to find an optimal information placement. Such a combination of geometry and image-based information would adjust the visualization to real-time changes, for instance caused by changing environmental conditions, while still providing an optimal understanding of the spatial relationships.

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