Entropy Assisted Automated Terrain Navigation using Traveling Salesman Problem

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Abstract

Navigation in 3D terrain is considered to be a challenging task and requires virtual camera control skills such as zooming, panning and tilting. Novice users can easily get distracted and disoriented that may result with lost in space. Methods to overcome the virtual environment exploration problems are still being researched to assist users during their journey inside virtual environments. Assisted camera control techniques require viewpoint computation and path planning. This paper introduces a novel approach to navigate over a 3D terrain with minimal loss of information. We exploit the concept of the Viewpoint Entropy for best view determination and use our Greedy N-Best View Selection for visibility calculations. We integrate road network data to extract regions for detailed visibility analysis in subsections of the terrain. In order to connect the calculated viewpoints an evolutionary programming approach for Traveling Salesman problem is used where the distance objective is minimized. The generated tour is presented using Google Earth framework for terrain exploration where we can get real data streams.

The computed and planned viewpoints reduces human effort when used as starting points for scene exploration or generating the representative images of the terrain dataset. The proposed framework can be integrated into 3D game engines or any urban visualization system to give quick glimpse or tour of the environment for the novice users without the help of prior planning.

CR Categories: I.3.7 [Computer Graphics]: Picture/Image Generation—Viewing algorithms;

Keywords: viewpoint entropy, navigation, virtual environment

Links: DL PDF

1 Introduction

3D object exploration and camera control have been actively studied in recent years, [Mühler et al. 2007], [Ji and Shen 2006], [Klomann and Milde 2011] and have applications in many areas including medical analysis and training, robotics, image based rendering, virtual reality and scientific visualizations. The goal is to perceive as much as information available for recognizing objects, detecting regular or non-regular patterns, and executing the required tasks in efficient thus time-saving way instead of trial-and-error searches during navigation in the virtual space.

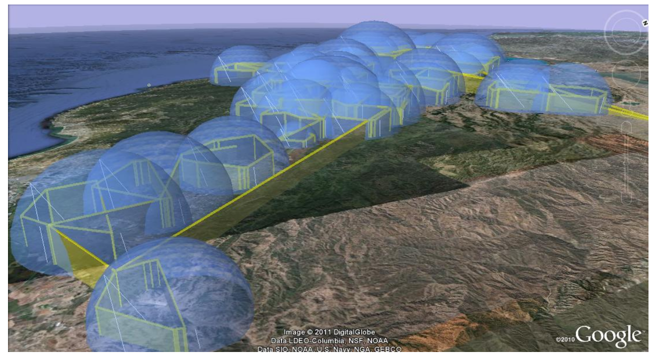

Figure 1: *An automatically generated path by our algorithm for San Francisco shown in Google Earth framework.*

Camera control in 3D environments is still a challenging task which requires viewpoint calculations, path planning and editing. An excellent survey by [Christie et al. 2008] explain the motivation and methods for camera control in virtual space. Although the methods are developed to solve the requirements of different domains, they share common problems and difficulties such as degrees of freedom, computation complexity and lack of generic measures.

Camera control techniques vary from user input reaction based ones to fully automated controls. The approaches and techniques presented do not provide a solution for a camera control in large terrain dataset. In this paper we propose a novel technique to control the camera for large terrain dataset visualization where the calculated viewpoints can be used as initial starting points for exploration. The proposed camera set contains the best views in the extracted subregions and the framework can be integrated into 3D game engines or any urban visualization system to give quick glimpse or tour of the environment for the users.

Our navigation in virtual space depends on information and a measure to quantify that information. Here we borrow the concept of viewpoint entropy which is introduced by [Vázquez et al. 2001]. The viewpoint entropy is an information theoretical measure and used to determine the amount of information from a viewpoint. Viewpoint entropy depends on the model presented by [Shannon 1948] for a general communication system. We model the environment exploration as a communication between user and the virtual environment in computer. The entropy lets us to quantify the amount of information from the points on viewing-sphere from which we can select a set that receives the maximum in amount.

We use viewpoint entropy and Greedy N-Best View Selection techniques for descriptive and informative view determination in subregions of the terrain surface. We integrate road network data to extract regions for detailed visibility analysis in subsections. In order to connect the calculated viewpoints an evolutionary programming approach for Traveling Salesman Problem is used where a single objective function i.e. distance is minimized.

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The rest of the paper is organized as follows, in Section 2 we discuss about the related work in the field of view selection and automatic camera control in virtual environments, in Section 3 we elaborate on the theoretical background of our work, in Section 4 and in Section 5 we present the details of computations, in Section 6 we elaborate on the presentation with Google Earth framework and in Section 7 we discuss about the results and show the images generated and finally we conclude our work with some remarks at the end.

2 Related Work

The related work section will be discussed in two different subsections. The first subsection will elaborate on the viewpoint generation, informativity and quality of views, the second subsection will present the camera control techniques used in virtual environments.

2.1 Viewpoint Generation

In recent years many methods have been developed for measuring the quality of the views and have tried to describe an optimum point to place the camera on a scene which can be viewed the best way. Unfortunately the translation of term best or good into measures or numbers is not an easy task. [Kamada and Kawai 1988] were one of the pioneers in defining a good position to place a camera in a 3D scene. They define a parallel projection of a scene to be good, if the number of surface normals orthogonal to the view direction is minimal. The method has several drawbacks, first it does not guarantee that user will see as much details as possible and will fail when comparing equal number of degenerated faces.

[Barral et al. 2000] use a modification of the coefficients introduced by Kamada-Kawai in order to cope with perspective projection. They introduce different exploration coefficients, that are combined to determine the quality of a perspective projection. However, they can not find a good weighting scheme for those factors. This algorithm fails with objects of genus one and larger.

[Vázquez et al. 2001] propose a metric based on the entropy of the scene. They define the best viewpoint as the one with the highest entropy, i.e. the one that sees the maximum of information. They apply the ratio of the projected area of each face to the area covered by the projection of all faces in the scene. Vazquez et al. suggest the technique in 2001 and make improvements in following years.

[Vázquez 2009] proposes a technique to select the views automatically by using depth-based stability analysis. In this work he introduces a new view descriptor which uses depth maps to have three-quarter oblique views for 3D objects. He claims that psychophysical experiments have shown users often prefer oblique views between frontal and profile views as representative views for 3D objects.

[Sokolov and Plemenos 2006] propose a high level technique and claim the techniques presented above as low-level. They step in the direction of semantic description of a 3D scene and use hierarchical decomposition of them. They define the viewpoint quality as the sum of observation qualities of each decomposed object.

Mesh Saliency is another aspect of viewpoint generation which is also actively studied in viewpoint generation as well as mesh simplification. Salient features including luminance, pixel colors or geometry are deliberated. [Koch and Ullman 1985] suggest that salient locations in 2D images will be different from its neighbors. [Itti et al. 1998] propose a method for calculation of saliency map using 2D images. They combine information from center-surround mechanisms applied to different feature maps and assign a saliency value to each pixel. [Lee et al. 2005] propose a geometrical approach for calculation of mesh saliency in 3D models. Their method uses the curvature attribute of the object and Itti *et.al.*'s center-surround mechanism to highlight the regions that are different from their surroundings. [Takahashi et al. 2005] propose a method to locate optimal viewpoints for volumetric objects by decomposing the entire volume into a set of feature components. [Bordoloi and Shen 2005] use view goodness, view likelihood and view stability concepts to locate viewpoints for volume rendering where viewpoint goodness measure is based on entropy that uses the visibility of the voxels.

2.2 Camera Control

The camera control can be classified into four different methods by their control techniques; direct control, through the lens control, assisted control and automated control [Christie et al. 2008]. The key issues for researchers include the management of the control in the high degrees of freedom, handling of exponentially growing computation complexity and finding effective and reactive measures to avoid the occlusions in the scene. In this work we present the assisted and automatic camera control techniques as related because they depend on the knowledge about the environment or feedbacks from different sensors.

Assisted camera control technique exploits local or global knowledge about the environment to assist the users through their navigation. It can be classified into two metaphors such as object aware and environment aware assistances depending on their knowledge type [Christie et al. 2008]. In object aware assistance the proximal object inspection is used for collision avoidance such as ray casting, and in environment aware assisted camera control metaphor the global knowledge about the scene is used to avoid obstacles or direct the user to interesting parts. [Elmqvist et al. 2007] use scene voxelization, connectivity graph and TSP-like algorithm to assist the user in their guided navigation framework. [Andjar et al. 2004] exploit the concept of Viewpoint Entropy for indoor navigation. They use cell and portal decomposition together with the calculated viewpoints in each cell. This work resembles most to our work however, instead of indoor portals, our environment is large scale terrains, we use our Greedy N-Best View Selection algorithm for calculations in the regions extracted by the help of road network data. We also utilize the evolutionary programming paradigm to find the path between the calculated viewpoints. The details of our approach will be discussed in subsequent sections.

In automated camera control, the transformation and rotational attributes of the camera is directly computed using either the generated image, or the fitness function that needs to be optimized. Visual servoing or target tracking is one example of the automated camera control using image analysis technique. Visual servoing uses the feedback information extracted from a vision sensor to control the motion of a robot [Espiau et al. 1991]. In optimization based automated camera control the deterministic or non-deterministic optimization methods are employed to find the camera configuration. For instance [Bares et al. 2000] propose the use of a complete search space where it can be called as global optimization approach. In our technique we employ the divide and conquer metaphor. We calculate camera positions for sub-regions of the terrain and utilize a non-deterministic approach such as population-based genetic TSP to calculate the final camera path.

3 Theoretical Background

3.1 Viewpoint Entropy

The entropy [Shannon 1948] of a discrete random variable *X* with values in the set $\{x_1, x_2, ...x_n\}$ is defined as

$$\mathbf{H(x)} = \sum_{i=1}^{n} p(x_i)I(x_i) = -\sum_{i=1}^{n} p(x_i)\log_b p(x_i) \tag{1}$$

Even though the entropy is expressed as a function of the random variable *X*, it is actually a function of the probability distribution p of the variable *X* over the number distinct symbols *N*. Entropy function has two important properties, the maximum entropy occurs for the distribution p_{eq}, where $\{p_0 = p_1 = ... = p_{N-1} = 1/N\}$ and Entropy is a concave function which implies that the local maximum at p_{eq} is also the global maximum [Bordoloi and Shen 2005]. The properties of the entropy function give us that the calculated viewpoints in extracted regions will be the global maximum points where the object surface is percepted equally.

Viewpoint entropy [Vázquez et al. 2001] using Shannon Entropy is defined as

$$\mathbf{I(S,p)} = -\sum_{i=1}^{N_f} \frac{A_i}{A_t}\log_b \frac{A_i}{A_t} \tag{2}$$

where A_i is the projected area of face *i* over the sphere, A_t is the total area of the sphere and *b* is the base of logarithm which is taken as $b = 2$ in this case the result is bits/symbols. Since we use orthogonal projection in our application we selected the formula presented in [Vázquez et al. 2006] which is the orthogonal viewpoint entropy version of equation (2) shown above. In that equation A_i is taken as the number of pixels belong to each face of the object and A_t is the number of pixels in the image. The techniques to compute the viewpoint entropy using Graphics Processing Unit can be found in the paper Castello et al. [Castelló et al. 2006]. We will discuss about calculation of viewpoint entropy using the texels of the 3D terrain for our approach in subsequent chapters.

3.2 Travelling Salesman Problem

The traveling salesman problem(TSP) is an NP-hard problem of combinatorial optimization studied in Operations Research and Computer Science. Given a list of cities and their pairwise distances the task is to find the shortest possible tour that visits each city exactly once [Reinelt 1994].

3.2.1 Euclidian and Spherical TSP

In our framework we use two versions of TSP problem, hence Euclidian space TSP, and spherical TSP. Euclidian space TSP is used to enumerate the sequence of the extracted regions to be traveled on the texture surface. The calculated tour will have N extracted regions with M computed best viewpoints for that region. We can formulate the concept of a tour,

$$\mathbf{T} = \{R_1, R_2, ...R_n : n \in Z\} \tag{3}$$

$$R_i = \{c_1, c_2, ...c_n : m \in Z\} \textit{such that} R_i \in T \tag{4}$$

where T denotes a tour of N different regions and R_i denotes the region i on the surface of terrain.

The spherical TSP is used to enumerate the sequence of the calculated camera points in region R_i. shown in equation(4) The difference between Euclidian space TSP and spherical TSP is the distance function used to determine length between two points.

In Euclidian space the geodesic distance between two 3D points is a straight line, however the shortest distance between two points (p_0, p_1) on a spherical surface is the arc length of the points along the *Great Circle*. So it is the angle of *alpha*(α) between two vectors $\vec{v_0}$ and $\vec{v_1}$ from the origin of sphere to $p_0(\lambda, \theta)$ and $p_1(\lambda, \theta)$ on the surface respectively with and can be calculate directly using *Haversine formula* [Sinnott 1984]. The shortest distance on a sphere between two points is shown in equation(5) where R is the radius of the sphere.

$$\begin{aligned} &\Delta\lambda = \lambda_0 - \lambda_1 \\ &\Delta\theta = \theta_0 - \theta_1 \\ &\mathbf{a} = \sin(\Delta\lambda/2)^2 + \cos(\lambda_0).\cos(\lambda_1).\sin(\Delta\theta/2)^2 \\ &\mathbf{c} = 2.\arctan 2(\sqrt{a}), \sqrt{1-a}) \\ &\mathbf{d} = R.c \end{aligned} \tag{5}$$

The provided distance functions are used during the execution of genetic TSP for the purposes stated above.

3.2.2 Genetic Approach for TSP

Genetic algorithms are one of the computational intelligence methods which are used to find approximate or sub-optimal solutions to the NP-hard combinatorial optimization problems. It is generally inspired from the biological facts and evolution. Genetic algorithms employ the concept of population, gene, crossover and mutation. Population is a set of genes in the current iteration of the algorithm, and a gene is an enumeration of a valid solution to the problem being solved. The crossover concept is inspired from inheritance of two parents, where a child carry the combination of two parent genes. The mutation can be expressed as the effect of the environmental factors over a gene. Evolution concept is applied by terminating the genes that are progressing poorly and creating new genes from a random group of successful genes where the newly created genes will do better eventually.

4 Scene Analysis and Path Generation

Our method employs the divide and conquer metaphor for the scene analysis. It utilizes the help of the road network data to extract subregions, and calculates sub-optimal viewpoints for the regions and exploits the genetic TSP algorithm for connecting the calculated viewpoints.

4.1 Region Extraction

The purpose of region extraction is providing meaningful information to the user by the help of analyzing the road intersection data. We believe that the intersection points give us a heuristic about residential areas which can be considered as significant salient features of a terrain. Although the details of our camera point generation and path construction algorithm will be discussed in subsequent sections, the salient points establishes the base of the analysis for sub-optimal viewpoint generation. Intersection points form the bounding spheres that are used as an enclosed space to decompose the surface to be investigated in detail.

The steps of our region extraction algorithm include the intersection point determination from road segments, intersection points grouping, creating a convex hull from the points in groups and bounding sphere generation. The generated bounding spheres are analyzed for mutual-inclusion, and the spheres that are enclosed by other spheres are removed programmatically.

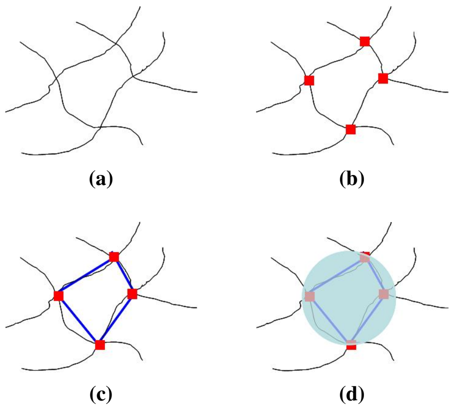

Figure 2: *The region extraction algorithm steps are visualized. In (a) An example road network is shown, (b) Intersection points are marked with red square. In (c) the result of convex hull determination algorithm is presented. The extracted bounding circle is shown in (d)*

We used [cga] line segment intersection algorithm for intersection points extraction that are considered as salient points, and Graham-Andrew Scan algorithm for convex hull determination.

4.2 Terrain Rendering

In our application DTED Level-1 data is used for the terrain elevation. The data is preprocessed and converted to 2048 x 2048 grid Binary Terrain (BT) format where it is loaded into VTP [VTP 2011] for rendering and viewpoint generation. The generated image depends on CLOD(Continous Level of Detail) algorithm presented by [Snroettg et al. 1998] which uses the dynamic triangulation of hierarchial quadtrees. When the viewpoint moves the triangulation changes continuously and results in a phenomenon called vertex popping. This dynamic behavior of the algorithm conflicts with Viewpoint Entropy when setting a metric to calculate. Projected face area is used as probability mass function(*pmf*) in regular Viewpoint Entropy computation. In order to handle this problem we used texturing instead of colorization of triangles. Each texel is colored uniquely and the projected texel colors are taken as the the *pmf* during entropy computation and viewpoint generation. In Figure.3.a the triangulated elevation data is shown using wireframe mode. The application of uniquely colored texturing to the terrain data is shown in Figure.3.b.

4.3 Best Viewpoints

The term best or good is highly subjective and difficult to quantify, and mostly depends on the application or context. Despite its subjectiveness, researchers may agree that some images created by the tessellation are more informative compared to the others using different criteria. The term informative is chosen on purpose. Because, the information on a communication channel can be quantified by the term entropy. Although there are other measures such as visibility ratio quantified as the ratio of the visible 3D surface area to the total 3D surface area, curvature entropy quantified as the entropy of the Gaussian curvature distribution over the entire surface of the object, or view-dependent measures as silhouette length, silhouette entropy or topological complexity, we selected viewpoint

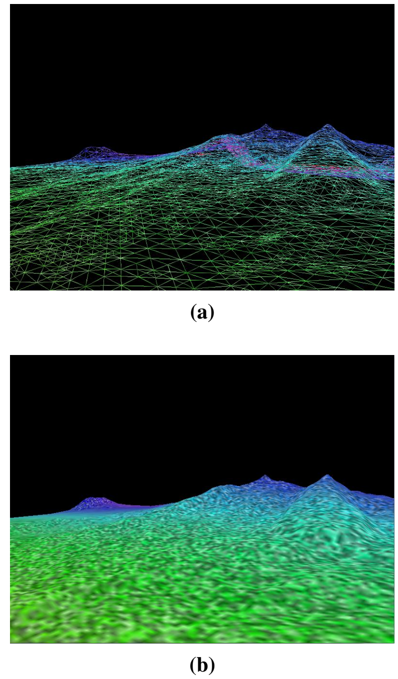

Figure 3: *Wireframe mode for a region of terrain is shown in (a). When the camera gets closer vertex popping phenomenon occurs. In (b) the uniquely colored texturing is applied to the elevation data*

entropy as our candidate to cover polygons of the 3D object by using a minimal set of camera points because it exposes surface area as information to the viewer.

We modified the Viewpoint Entropy calculation technique presented in [Vázquez et al. 2001] to utilize the usage of latitude and longitudes on spherical space, we calculated binary combination of each point in viewset for midpoint calculation where they are entropy weighted. Differences provided us higher sample view points on sphere, which resulted a viewpoint that covers as much polygon as possible.

Although finding N-best view selection is known to be NP-hard, in this work we use our greedy choice algorithm which tries to detect the sub-optimal N-best views to perceive the information communicated by the object. The algorithm is modified to take the previously covered faces as input and to return the currently covered faces as output. The viewpoint entropy computation is also changed not to include the pixels from already visited faces. The major steps of the revised algorithm includes the following steps;

(a) Best view selection algorithm is called with empty polygon coverage set

(b) Accumulate the visited faces into the set from previous best view selection algorithm

(c) Call the best view selection algorithm with the new set

(d) Go to (b) until all faces covered or best view selection algorithm can not output newly covered faces

The algorithm shown above starts from initial points and navigates around the object on each best view selection call. This method resembles to finding the best view of non-visited faces for each call.

5 Camera Path Planning

As mentioned in theoretical background section genetic algorithms find approximate or sub-optimal solutions to the NP-hard combinatorial optimization problems. We treat the planning of a path from the calculated best viewpoints as a tour generation problem over the urban area to be visualized. The tour concept is tightly coupled with a well known NP-hard problem called Traveling Salesman Problem. Given a list of cities and their pairwise distances the task is to find a shortest possible tour that visits each city exactly once. In our urban visualization problem the cities are the calculated viewpoints for the extracted sub-regions of the terrain and the tour is a problem stated as quick urban exploration. We tried to present a plausible solution by optimizing the the total distance traveled with this work.

5.1 Path Planning for Intra-Regions

Best viewpoints for the extracted sub-regions are calculated by the help of our Greedy N-Best View Selection algorithm which uses modified Viewpoint Entropy technique. In this algorithm the model or the region to be explored is bounded with a sphere where the region and bounding sphere centers are aligned. Our objective is to find best viewpoints on this bounding sphere where the camera position is denoted by (λ, θ) and the up-vector is perpendicular to the viewing direction along North-pole(+Y). Due to the shortest distance between two points (p_0, p_1) on a spherical surface is the arc length of the points along the *Great Circle*, we exploited the spherical genetic approach for Traveling Salesman Problem to enumerate the tour in this region.

A gene is encoded with a valid tour that contains all the id's of the calculated camera positions. A random population of 10000 genes are created and simulation is run 100000 generations where the mutation ratio is set to be 3%. Evolution concept is applied by terminating the worst two genes and creating two new genes from a random group of successful genes. An example output of the spherical genetic algorithm is shown below where two valid genes A and B are presented which show a tour over a sphere with five points.

$$\begin{aligned} & p_0 = (0,0) \\ & p_1 = (\tfrac{\pi}{4}, \tfrac{\pi}{4}) \\ & p_2 = (\tfrac{-\pi}{4}, \tfrac{-\pi}{4}) \\ & p_3 = (\tfrac{-\pi}{4}, \tfrac{\pi}{4}) \\ & p_4 = (\tfrac{\pi}{4}, \tfrac{-\pi}{4}) \\ & A = (p_0, p_1, p_2, p_3, p_4, p_0) = 7.33 \\ & B = (p_0, p_3, p_2, p_4, p_1, p_0) = 5.75 \end{aligned} \tag{6}$$

The the cost of tour A is 7.33 on unit sphere where the the cost of tour B is 5.75. The tour B is the output of the spherical genetic TSP algorithm. In the case of not using unit sphere, the difference in the cost will increase proportionally with respect to the radius of sphere to be calculated, which complies with the need of finding a sub-optimal solution for camera enumeration. This sub-optimal enumeration of the viewpoints presents that the total traveled distance is minimized in our framework.

After the calculation of enumeration and positional values of the camera points, the next task to handle for path planning is choosing a technique to travel along the curves. The spherical linear interpolation(Slerp)[Shoemake 1985] is used which refers to constant speed of motion along a unit radius of great circle. Since our computations are done on spherical space this technique suits well for our problem design. Its constant speed of motion is natural and produces smooth animation curves which does not distract the users perception.

5.2 Path Planning for Inter-Regions

The path among the extracted regions are arranged using Euclidian TSP algorithm with evolutionary programming approach. The algorithm enumerates the sequence of the regions to be traveled by using region centers as points to be visited in a tour. Similar to genetic approach used for intra-region, a valid gene set called population is constructed. Each gene encodes all the regions to be traveled via a sequence number or region id.

The created population is run for 100000 generations where the mutation ratio is set to be 3%. Evolution concept is also applied by terminating the worst two genes and creating two new genes from a random group of successful genes. When the simulation is done, the enumerated region centers are used to construct the Bezier curve for the camera trajectory in inter-region movement.

5.3 Final Camera Trajectory

The final camera path is constructed by combining the paths generated for intra and inter regions. The tour can be started from a region selected to be initial or any region that the user is interested in. The camera follows the constructed intra-region path and continues onto the next region. When the camera trajectory enters the next region it starts to follow the intra-path constructed for that region. The camera visits all the enumerated region in the same approach.

With the techniques provided with this work, we tried to present a plausible solution for a automatic camera trajectory. Best views calculated from the extracted salient points optimized the user's surface perception, and genetic TSP algorithm enabled us to construct a path that creates a optimal tour for the terrain exploration.

6 Tour Presentation in Google Earth

The automatically generated tours are presented using Google Earth [Goo] framework. Even though it is possible to show tours with VTP framework, Google Earth provides a better way to demonstrate the tour in a realistic and detailed 3D environment. Google Earth also enables us to define the tours through geospatial data with the ability of smooth flight pass locations and specific flight durations between those points. The tour is mainly defined using KML file format, Google Earth's XML notation for expressing geographic annotation and visualization. With the aid of the tour generated by our algorithm, we automatically export our best viewpoints and their fly-over order into the KML document for touring actions in Google Earth. The authored KML document contains a sequence of *FlyTo* and *Duration* element tags.

7 Results

In this framework San Francisco Bay Area DTED data and major highways road network data is used for automatic path computation. The DTED data is a 2048x2048 grid and road network data is a set of 12084 linestrings which can be considered as real world data.

We extracted 35 regions using the extraction algorithm presented with this work and generated a complete tour with the methods mentioned in previous sections. Our technique is completely automatic and needs no user intervention.

Sketch for the generated path is shown in Figure.4. The circles demonstrate the path followed for intra-region viewpoints and lines show the path followed by the camera on the way from one region to the other. The radius of the sphere depends on the intersection point locations extracted from the road network data. The generated intra-region camera path resembles a circle on the sphere that bounds the region, which is consistent with the expectation from our best viewpoint computation and the spherical TSP. The complete set of the extracted regions using Google Earth framework are shown in Figure.5.

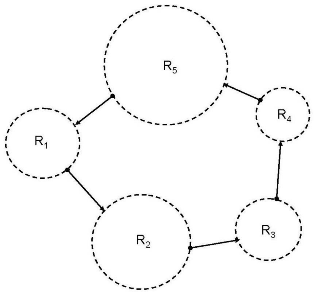

Figure 4: *Sketch for the generated path. Circles show the path for the intra-regions and lines show the path for inter-regions.*

Inter-region tour is shown with connecting lines in Figure.6. Region centers are represented with the placemarks. The length of the generated path is sub-optimal due to the usage of TSP algorithm. The complete tour starts from the first region and follows the camera points generated for that region and moves to the next region. The tour is terminated when all the viewpoints for the final region are visited.

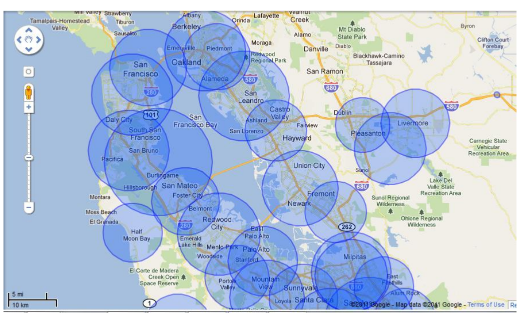

Figure 5: *Extracted regions are presented by the spheres using Google Maps framework.*

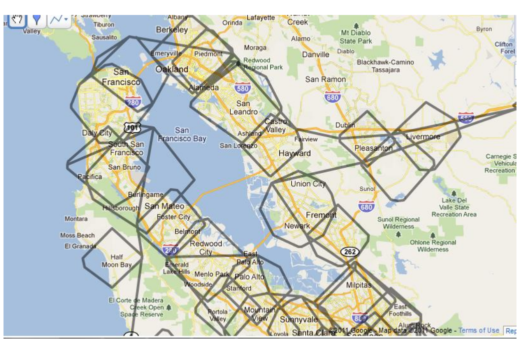

Figure 6: *Inter-region tour shown with connecting lines using Google Maps framework. Placemarks represent the region centers.*

8 Conclusion

With this work we present an entropy assisted solution to explore the terrain dataset effectively. Our technique can provide a quick glimpse or tour of the environment for the novice users and can improve user perception. The computed and planned viewpoints reduces human effort when used as starting points for touring in a scene or generating the representative images of the terrain dataset. The proposed framework can be integrated into 3D game engines or urban visualization systems to introduce the virtual environment for the novice users without the help of prior path planning.

We tested our method using real terrain and road network dataset and exported the generated tour to visualize it with Google Earth framework.

The generated tour visualization has shown that Shannon's entropy model is a promising way to solve viewpoint related problems by providing a measure to *quantify* the information on the communication channel between the user and visual world.

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