

Streaming Route Panoramas for Large Area Visualization

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Abstract

This paper introduces new developments of route panoramas in data transmission, visualization and area indexing. The route panorama is a compact, continuous, and complete image representation archiving scenes along streets. We model large geospatial areas with route panoramas at a more detailed and complete level than before. Various visualization tools of the route panoramas are designed for flexible observation of environment on different platforms. We stream the route panoramas on the Internet in response to the viewer's interaction so that viewers can move around in the virtually established space. In addition, we develop data indexing scheme to make the representation a powerful index to geospatial information. The embedded view-to-space links in the route panoramas guides the transition to detailed spaces. Combined with other image media, viewers can look around, traverse in a grid of routes, and retrieve information associated to various locations. Several applications are presented for E-business, E-education, and E-living.

1. Introduction

Although multimedia techniques are providing video clips, snapshots, and image based retrieval functions for vivid information accessing of geographical spaces, the visual data are still in sparse and discrete formats, and have less spatial relation to each other. Providing seamless visualization of an environment on the web is still difficult when the visual data are not archived systematically. Capturing scenes pervasively in a large area such as a town or a city requires tremendous effort and huge storage space. Current cyber spaces thus only highlight sightseeing spots, which is inadequate for other activities such as finding locations and exploring unknown areas.

In this work, we use route panoramas to provide complete and continuous visual data as a viewer traverses a route (Fig. 1). We capture route panoramas for long distances by scanning scenes continuously with a pixel line in the image frame, when the camera is moving along the route [1,6]. This forms a long, continuous image belt. A four-wheeled vehicle, a ship, a train can provide a smooth path for the camera.

The route panorama has no redundant coverage of scenes along the route and thus is much more compact than the video shooting the same scenes. In our experiment, it is 1/200~1/300th of the video data taking the same route. This produces an ideal visual index that summarizes scenes briefly, and is possible for the real time Internet transmission and interactive web accessing. Applications beneficial from it range from georeference, virtual tour, city navigation, to real estate, heritage presentation and preservation. The route panorama will have broad impact on e-business, e-learning, and e-living.

We scan every street in a large area for cityscapes registration and visualization. With widely captured route panoramas, we explore and design a uniformed scheme to distribute, index, and visualize spatial data. A large space is defined as a hierarchy of spots (0D), routes (1D), and regions (2D); each of them is associated with visual information and is linked with other spaces. Remote visitors can traverse the space freely on the Internet with the awareness of their virtual positions. The data can also be downloaded to PDA or transmitted to wireless devices for interactive guidance of a real space.

This work aims at developing the route panorama as a new digital medium broadly transmitted on the wired and wireless network and displayed on different platforms. In the image acquisition, we increase the camera scanning heights and viewing aspects, which includes high-rises and side surfaces of objects into the route panorama. This makes the representation more general. Other related works on environment visualization include video, various mosaicing, and panoramic views. Due to the large scenes overlap in consecutive frames and huge data sizes, videos are impracticable to be taken pervasively along every street in a city, if we consider the current bandwidth of the Internet and wireless connection. On the other hand, image based rendering (IBR) approaches [3] generate continuous views from prerecorded images or generate new views from the video sequences. These approaches avoid 3D model construction by image interpolation [4] or view composition [10]. Nevertheless, these algorithms normally require storing video or largely overlapped images for arbitrarily requested point of view. Some algorithms use image matching, tracking, and deformation, which are not suitable for the Internet based real time rendering. Most IBR approaches so far have only worked on limited local scenes. Panoramic views,

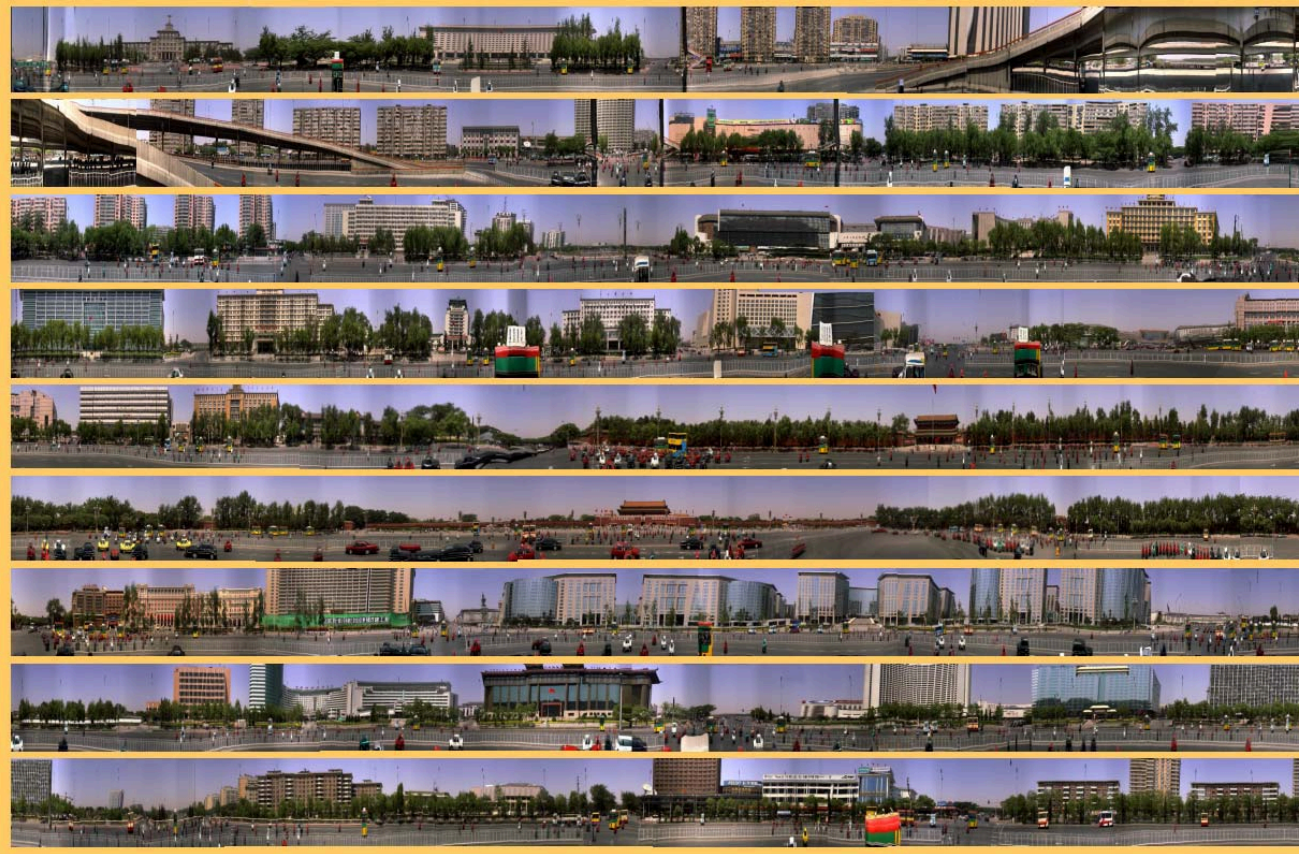


Fig. 1 A 5km route panorama (approximately 84k×640 pixels, rows are connected) on the north side of Chang An Blvd. Beijing, captured from a video taken on a double deck bus. The path is not controlled particularly for the acquisition.

either scanned by slit [1] or stitched from discrete images [2,5] has extended the field of view as compared to images. However, they still confine observation at static locations, and are not connected seamlessly in the display.

In this paper, we address the scene archiving by route panoramas in Section 2. Section 3 introduces the streaming of route panoramas for virtual space traversing on the Internet. We study the indexing scheme in section 4 for exploration and guidance of real spaces. Applications of the route panoramas are given in Section 5.

2. Stable archiving of route scenes

2.1 Complete route panorama scanning

The route panorama is obtained using one or more cameras fixed on a vehicle traversing along a smooth path on a horizontal plane. The camera focuses pass length S along the path, which can be estimated if the moving speed of the cameras is constant or from the positions recorded by a GPS. A *plane of scanning* perpendicular to the moving direction scans scene around the path as the camera moves forward (Fig. 2). If a camera is fixed such that the image frame intersects the plane of scanning, a pixel line can be located as the sampling slit for

continuous data collection. We connect temporal slit values consecutively in another image memory [1,6]. The generated route panorama has the time t as its horizontal coordinate and the coordinate on the slit as its vertical coordinate (y axis). A fixed sampling rate, which is normally selected as the maximum reachable rate, is used during the camera motion.

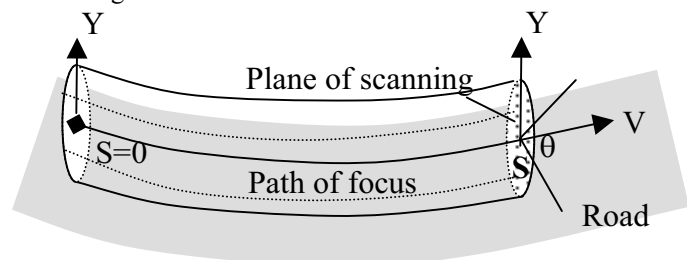


Fig. 2 Mechanism of scene scanning

The slit scanning approach obtains a 2D view directly without any heavy processing. Different from various mosaicing approaches, the slit scanning approach requires no inter-frame matching. Mosaicing stitching overlapped images to obtain a large view generally use the camera focuses at the same or close positions. If the camera translates along a path, consecutive images covering the

common scenes cannot be perfectly overlapped in a 2D space because of the inconsistent disparities at different depths. To obtain a continuous 2D route panorama, a complicated approach equivalent to recovering 3D space has to be taken [4]. Such an approach requires image matching, motion estimation, and intermediate view interpolation, and may suffer from occlusion and lack of features at homogeneous surfaces. It has not extended scene acquisition to a long distance.

If we locate multiple cameras up and down or use a wide-angle lens (even a fish-eye lens), a half tunnel (route panorama with large vertical field of view) is obtained to include high architectures close to the road. We transform y coordinate of each slit to the coordinate on the virtual pixel ring, i.e., angle θ around the trace of the camera focus, and then merge them into a route panorama with all heights. The vertical coordinate is now angle θ around the trace of focus. Further, if cameras are located on both sides of the vehicle, a complete scene tunnel along the route is recorded. This is the generalization of the previous route panoramas with only limited height coverage. Figure 3 shows one side of the scene tunnel capturing entire range in height [12].

In order to produce good shapes of objects in the route panoramas, the plane of scanning is set to be vertical in the 3D space. This ensures vertical structure lines being vertical in the route panoramas when the camera moves along a curved path on the horizontal plane. The curves or lines parallel to the camera path are horizontal in the route panoramas. The slit in the image frame is calibrated using one or several sampling images taken from the same cameras, in which some vertical structure lines are visible for slit localization. The route panorama employs a *bended-parallel-perspective projection* [13] that is perspective in the *planes of scanning*, and the parallel *planes of scanning* are bended if the camera path is curved. Generally, distance objects in the route panorama along a linear path look wider than in the perspective images. Although this can be interpreted in terms of projection, our post processing makes the major objects at each section of the route panorama close to normal perspective images.

2.2 Archiving large areas using route panoramas

We drive a vehicle through every street in a large area to record complete route panoramas. The vehicle moves at a constant speed along the streets. If the vehicle has a variation in speed, a GPS records the vehicle positions, and the route panorama is normalized accordingly. According to the requested resolution, we determine the vehicle speed range from 10 mph to 50 mph. A fixed sampling rate of the slit is set between 30~200Hz.

If a road is uneven which causes the camera shaking, waves and zigzags appear on objects in the route panoramas. The main influence is from the left-and-right

vehicle swing. A wide vehicle can reduce this effect. The second factor is the up-and-down translation, which can be reduced by a long wheelbase. Translation sideways will not happen and forward motion is necessary for the scene scanning. A good vehicle suspension system can reduce the shaking. Besides the system improvement, we have developed an algorithm using the constraints of architecture shapes to extract the jitter lines, and then straighten the route panoramas [11].

In addition to the non-redundant property of the route panorama in the scene coverage, we further employ the standard JPEG compression to reduce the data to half or 1/3. Eventually, the route panorama results in 1/400~1/900 of the data size of the original uncompressed video, which is also much less than any compressed video. It is sufficient to be put on the Internet for wide access. The archiving of an area can be carried out frequently with this data size.

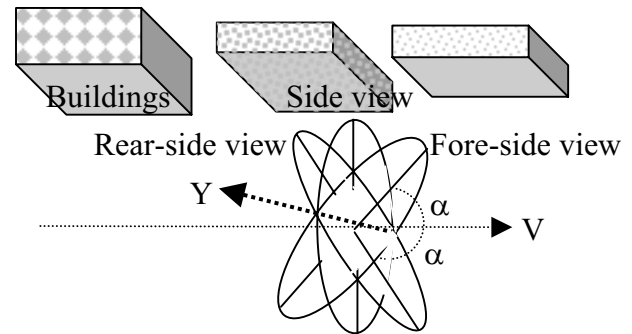


Figure 3 Adding two new vertical planes of sight to capture side aspects of architectures.

For the visualization purposes, the archiving of the route should also include object aspects that were not covered by the previous route panoramas. The plane of scanning orthogonal to the vehicle moving direction mainly captures the front surfaces of architectures along the route. However, the side surfaces visible when the viewer looks forward in street traversing are also important. We add two new planes of scanning with an angle α non-perpendicular to the moving direction (Fig. 3, $\alpha = 30^\circ \sim 45^\circ$). This generalizes the plane of scanning in a selective direction. The planes of scanning are still required to be vertical in order to maintain the good geometry properties in the generated route panoramas, i.e., vertical lines in the 3D space are vertical in the route panoramas. The angle α is also constrained by the frame size of the camera, since the plane of scanning must have an intersection with the image frame. The new route panoramas will be selected for display when a forward scene of a route is requested. Although the route panoramas are tripled, they are still more compact than the entire video and the covered aspects of scenes are more complete than the orthogonal route panorama.

As usual, panoramic views are also taken at locations

of interest. Discrete images are taken for emphasizing special scenes.

3. Streaming RP on the Network

3.1 Visualizing environment by route panoramas

We have designed various rendering tools for visualizing a route. A window over the route panorama is dynamically shifted and scenes in the window are mapped to screen dynamically with certain types of transformation. The window shifting is controlled by traveled distance S .

The first style was a *scrolling window* sliding the orthogonal route panorama back and forth in different speeds, in responding to viewer's input through either mouse clicking or key touching [6]. The same idea has been easily applied on PDA or wireless phone with both sides of street shifted simultaneously. The sections of route panorama are pasted to the screen directly in viewer's specified speed.

With two-side route panoramas, we develop a *panoramic traversing window* showing 360-degree scenes at a route position (Fig. 4). We map the route panoramas $I(t, \theta)$ to a screen with spherical coordinate system $T(\phi, \varphi)$. The range of $I(t, \theta)$ is $t \in (-\infty, \infty)$ and $\theta \in [-90^\circ, 90^\circ]$ on each side, and the range of $T(\phi, \varphi)$ is $\phi \in [-180^\circ, 180^\circ]$, and $\varphi \in [-90^\circ, 90^\circ]$. It is a pseudo 3D display simulating driving through of a street. User can move forward and backward, change moving speed, and look around by clicking a sub-region in the view frame or designated keys. The process to render such a screen is as follows.

- (1) The horizons in the two side route panoramas are determined first during the slit calibration. Its position in the traversing window denoted by h is used for aligning route panoramas correctly. The sky areas in the route panoramas are cut off or made transparent.
- (2) A global panoramic view of an area is taken from the top of a building or at an open space. It is mapped to the background of the window with its horizon aligned with h . The global panorama captures possible skylines including mountains and high landmarks for indicating the global orientation of the route in the area. If there is no distinct landmark visible, a sky image is prepared.
- (3) The sections of the two route panoramas close to the viewer's position are then projected onto the panoramic traversing window, aligning their horizon with the background at h . The route panorama has no depth information; we assume a virtual width of the street for this mapping.
- (4) A view port is located on the combined route scenes for generating the local view in the traversing window. The view port is movable and scaleable

according to viewer's input to realize the change of viewing direction and zooming.

- (5) The displayed route panorama sections are shifted in the 3D space according to viewer's position on the route and projected to the window constantly. This dynamic rendering provides the correct optical flow direction in the panoramic window.
- (6) At the registered locations of the route panoramas, viewers can click to turn to another intersecting route. The current traversing window is rotated at the turning point towards the intersecting street and then switched to the street.

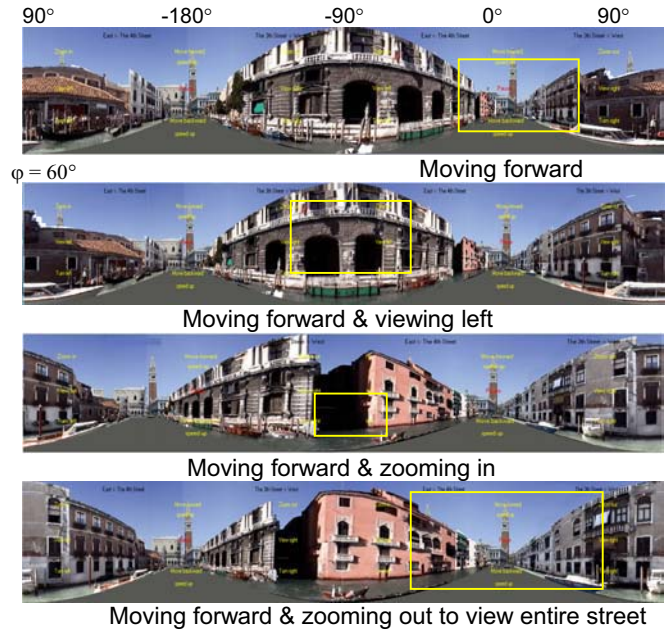


Figure 4 Panoramic traversing windows combining global panorama and two-sides route panoramas.

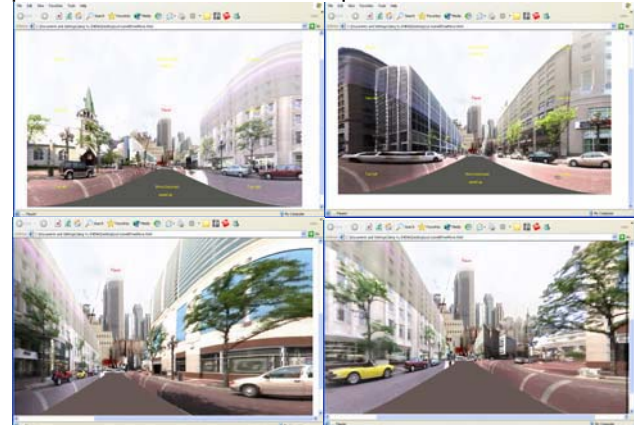


Fig. 5 Traveling in a downtown area on the Internet with the traversing window.

Figure 5 displays several views of the dynamically rendered traversing window in a web browser. The control of the virtual movement is embedded in the window for the viewer to move back or forth, speed up or stop, view left or right, zoom in or out, and turn at next possible turning point. Although the traversing window is

only a pseudo 3D display, it gives major scenes along the route. Despite the missing depth information, the visibility and topological shape of objects are preserved. We transmit route panoramas progressively over the network. Image transformation and rendering are implemented with JAVA. During the displaying of a segment, the following segments are transmitted and buffered. The arrived image segments are connected again for the seamless display. Viewers can have a sensation that they are traveling along a route. The display can be on planar screen, circular screen, or even in the future bending screen.

3.2 Streaming route panoramas over the Internet

Considering the limited memory of end PCs and small portable devices, it is unwise to download the entire street scenes prior to display. In the database, route panoramas are segmented to consecutive image segments. This also benefit to the local scene editing and error recovery in the transmission of route panoramas.

After a route is selected, an indexing file containing the number and names of the segments is transmitted from the server for each side of the route. It is used in the control of the image segments. The switching of a route to another route loads another set of indexing files for the new route panoramas and the global panorama.

If a *scrolling window* has a horizontal width of W , the route panorama is segmented to $L_i, i=1,2,\dots,n$, with about the same length longer than W . At anytime, at most two segments are involved in the rendering of the window (denoting them by L_i and L_{i+1}). We transmit and buffer one segment L_{i+2} after the current displayed ones for streaming the route panorama. In the backward moving, the segment L_{i-1} just before the current ones is transmitted back again. If a current segment moves out of the window either leftward or rightward, a consecutive image shifts in and a new segment starts buffering. If the time to transmit segment L_i is T_i , the scrolling can reach the highest speed at L_i/T_i , which is approximately a constant.

For a 360-degree *traversing window*, we load five

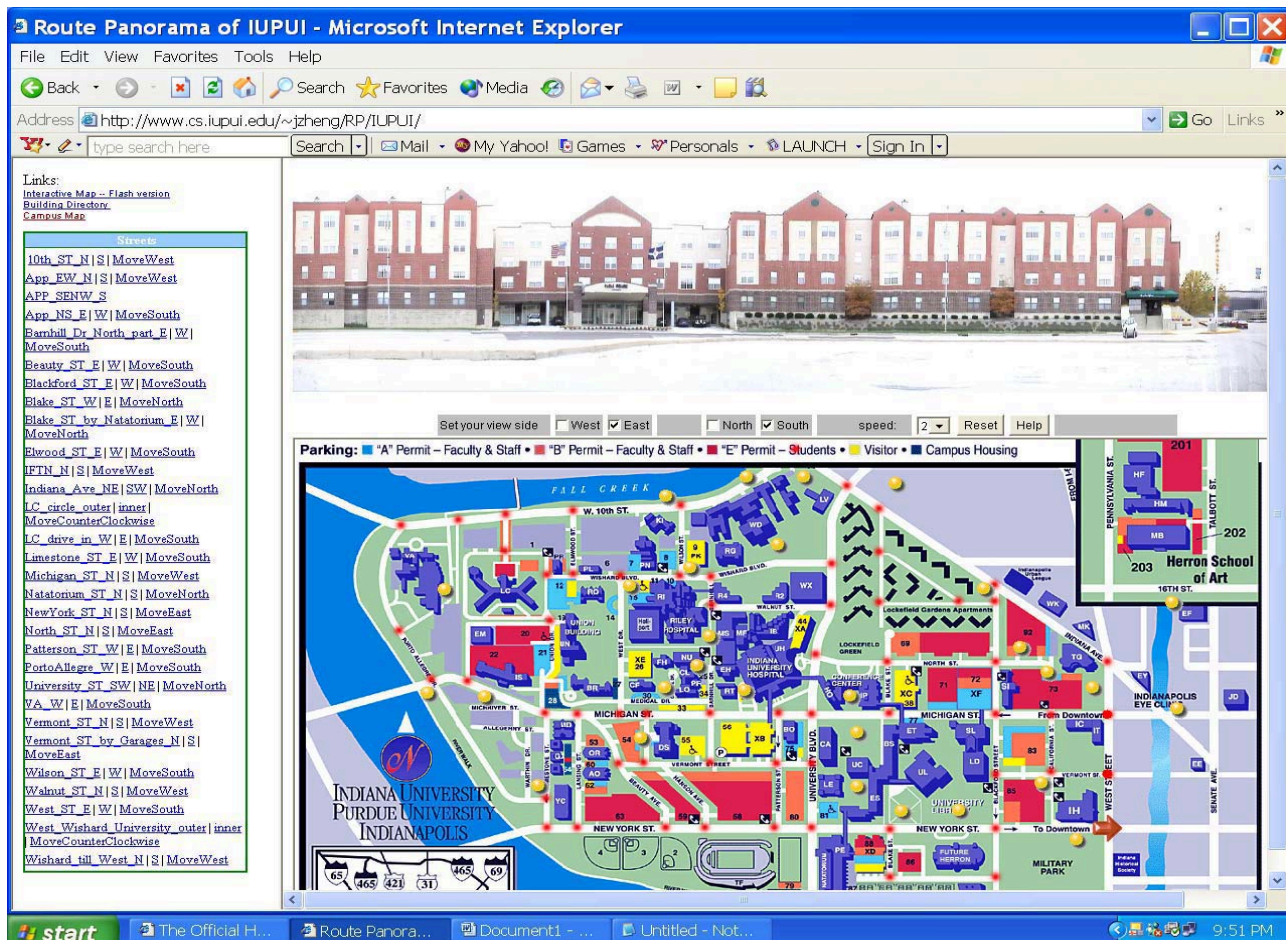


Figure 6 A campus displayed on the Internet for visual traversing. Over 30 streets (*route*), 50 locations (*spot*) and 50 buildings (*area*) are registered. All these spaces are associated with their views in the scroll window either in discrete or in continuous format. Yellow balls are locations with panoramic views. Red points are street crossings for route selection. An arrow in the map indicates viewer's position and observing direction. Indexing from street names are in the left window frame.

segments of a route panorama and three of them are displayed on one side of the route at anytime. As a result, for a high-speed network, the virtual travel of a route can reach a “train” speed if a graphics card performs a fast rendering. A plug in software (rather than Java) can speed up rendering speed for smooth virtual navigation.

4. Indexing spaces with route panoramas

Combining the route panoramas with a map, we build a powerful index of virtual environment on the Internet for spatial information accessing and retrieval. With the pervasively archived visual routes, we provide views at any selected location in a map, display seamless view sequence to a destination, and access spaces linked from the route panoramas.

We explore a comprehensive indexing scheme in a large-scale area. The existing *map-to-view* index displays a panoramic view or images when a spot (location, considered as 0D space) is clicked, and *map-to-space* index leads to a subspace when a region (an area, considered as 2D space) is clicked. Integrating route panoramas with these methods, view accessing can be achieved on the grid of streets. Route panoramas thus augment *map-to-space* (here space is a 1D route) and *map-to-view* indexes.

As displayed in Figure 6, map, menu, and view windows are placed side-by-side to show the spatial relations of subspaces as well as viewer’s position and orientation. Clicking consecutive crossings of routes (marked in red spots), the viewer’s position indicated by an arrow moves smoothly along the course, and the viewing side is pointed by the arrow direction. The corresponding route panorama is loaded and scrolled continuously in the *view* frame. The position and view are synchronized at a speed selected by the viewer. Other *map-to-space* indexes include a spot clicking for a panoramic view, and a region clicking for transition into a subspace. Text based indexing in the left frame reaches a particular street by name and the entire street view is scrolled in the panoramic traversing window.

The route panorama also enhances *view-to-space* index for its completeness and continuity. Viewers can move around in the virtual environment based on route panoramas as if he/she is wandering a real area. Through links embedded in the route panorama, the viewer can further transit to detailed spaces such as architectures, facilities, and sites of interest that are visible in the route panorama. This transition is accompanied with *view-to-space* indexing, where the space can be 0D, 1D or 2D. In details, the transition includes route-to-spot (1D-to-0D), route-to-route (1D-to-1D), and route-to-region (1D-to-2D) switching, where panoramic view, route panorama, and representative discrete views of the regions will be displayed in the view frame.

The *view-to-space* indexing has not been sufficiently

used because the existing image databases are not complete visual digests of environments. We connect adjacent local spaces (areas, routes, spots) to form a network. The adjacency of two subspaces is established if one is visible in the other’s view. For example, a building is adjacent to a route or spot if it is visible in the corresponding route panorama or panoramic view. A route is adjacent to another route at a visible crossing.

We add text information in the route panorama to enrich the view-to-space indexing. Text information of the route, crossings, buildings, tenants and landscapes are organized and displayed in the *view* window. For a route, the linked spaces are sequentially saved in an index file. A space O_k has its *range* $[s_k, e_k]$ along the route, a *description* including its name and a *URL*. The linkage of the route can direct to an intersecting route or a conventional website of facility, building, site, etc. During the viewer’s traversing, the passed distance S is updated continuously. The text of O_k is displayed if $S \in [s_k, e_k]$. Clicking on the space or a turn button (left or right), the display switches to the route, or stop and pop out another web page of the linked space (e.g., building or park). If the text data can be updated in a database, the route panorama can be further used as a tool of real navigation, which not only provide visual appearance, but also on-line information such as the occupation of parking garage, restaurant, hotel, etc.

5. Applications of Route Panoramas

The route panoramas will have broad applications for business, commercial and social activities such as shopping, navigation, real estate, visiting address, heritage preservation, virtual museum, culture learning, drive training, crisis management, etc.

With the indexing to spaces from route panoramas, we tackle the issue of area navigation based on route panoramas. Current map services have been able to provide shortest route to a destination. With the route panoramas, paths can be visually presented for driving along correct routes, parking at proper locations, and walking the final miles to destinations from the closest public transportation systems. Searching through the locations on the web to determine a route with concatenated streets (Fig. 7), the records can be saved to portable devices for real guidance of trips. Visitors can have seamless maneuvers of routes by replaying the memorized scenes. The same visual sequence can also be transmitted through the wireless network during the traveling. By concatenating the specified route segments including route panoramas, panoramic views at important locations, and discrete images of landmarks, an index file for animating the trip can be sent to visitors in prior to a trip, which is particularly useful for trip planning.

Real estate will benefit from route panoramas. Current discrete outdoor and indoor images are still inadequate to

provide an impression of the entire environment. Providing complete route panoramas in a residential area, homebuyers can have the first glance on the Internet before visiting a particular house. Figure 8 shows an archive of a newly developed community. The total image size of one-mile route panorama is approximately 6~7MB. It is possible to store route panoramas of an entire town in a CD or DVD.



New York St. (one way) heading east, going about 2km.



New York St. (one way), before turn North to West St.



Turn left onto West St. heading north, go 500m.



Turn left onto Michigan St. (one way) heading West, go 500m



Turn right to Blackford St from Michigan St. Garage is on right.



Going north one block on Blackford St.



Turn left to North St. The garage is marked.



Walk 600m West along Michigan St. until destination visible

Figure 7 Screen shots of continuous route scenes towards a destination. Yellow boxes indicate places of parking and destination.

Archiving heritage towns is of importance for cultural

and heritage presentation, preservation and development. Many rapid growing cities face the problem of monitoring changes in urban landscapes. Periodical archiving of cityscapes will provide valuable documents for various studies. Current registering using images and videos only focus on specific locations, sites, or landmarks. Route panoramas can record and archive an area in an efficient way — driving through every street to obtain scenes at a level much detailed than any aerial image. For many heritage towns that may suffer from earthquake and other nature crisis, a pervasive scanning is even critical for their recovery. Recording and visualizing old and destroyed cityscapes are particularly important in urban planning and reconstruction.

6. Conclusion

This work creates a new medium to index and visualize scenes in an urban area pervasively and systematically. The proposed efficient cityscape scanning approach will significantly advance the visual information acquisition and representation in digital cities. This model enables an entire area “visible” on the web and on various portable devices connecting to networks. The compactness of the route panoramas allows continuous area navigation over the Internet. The sequential route panorama forms an index useful for the information retrieval starting from visual data, i.e., view-to-space indexing. A framework based on three types of space definition has facilitated visual and spatial data organization, access and display across different platforms. We have also implemented several applications that are beneficial from the route panoramas.

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(a) Sections from the route panoramas showing the image quality



(b) Entire route panorama in a residential community. The plane of scanning is not perpendicular to the moving direction.
Figure 8 Route panoramas for real estate and address finding.