Taking Online Maps Down to Street Level

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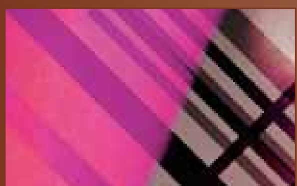

Street View enables simple navigation between street-level images without losing the map context.

Since MapQuest.com's creation in 1996, online mapping systems have rapidly gained worldwide popularity. With Google Maps leading the charge, new sophisticated AJAX (Asynchronous JavaScript and XML) mapping applications began appearing in 2004. These geographic Web 2.0 applications, which continually add new features and improvements, have made online maps almost as essential to our daily lives as the search engine.

A fairly recent offering of the best online mapping systems is aerial imagery. Such imagery takes the so-called GeoWeb to the next level, providing tremendous value to activities such as real estate sales, insurance, environmental management, municipal government, emergency services, and law enforcement, as well as engaging serendipitous Web users. Yet the imagery often is not detailed enough, and viewing buildings and streets from above can be disconcerting.

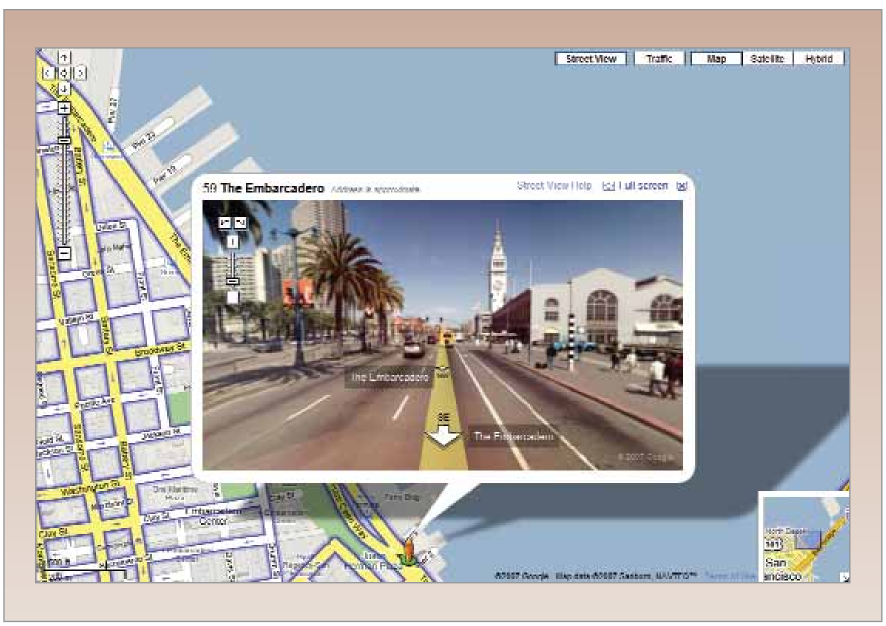

Figure 1. Google Maps Street View interface.

To address this limitation, Google launched the Street View feature of Google Maps in May 2007. The underlying idea is very simple: Provide an interface that can display street-level images in a natural way that enables convenient navigation between images without losing the map context.

Figure 1 shows a screen shot of the interface. To use Street View, you simply point your browser to http://maps.google.com, visit one of the 15 cities that currently has coverage, such as San Francisco or Portland, and move around by either clicking on the map or navigating from image to image.

EARLY RESEARCH EFFORTS

This idea behind Street View is not new. The earliest related project dates back to the late 1970s, when MIT's Andrew Lippmann created a system known as Movie Maps that let users take virtual tours of the city of Aspen, Colorado (A. Lippman, "Movie Maps: An Application of the Optical Videodisc to Computer Graphics," *ACM SIGGRAPH Computer Graphics*, vol. 14, no. 3, 1980, pp. 32-42).

The Movie Maps data-capture system used a gyroscopic stabilizer and four cameras mounted atop a car, with an encoder triggering the cameras every 10 feet. The system digitized the captured panoramic imagery, organized it into several scenes, each covering approximately a city block, and stored it on a laser disk. A user could then virtually navigate Aspen streets using the interface shown in Figure 2.

Several related systems subsequently emerged, with the pace of development accelerating in the late 1990s and early 2000s. One noteworthy offering was BlockView in Amazon's A9.com search engine. Introduced in 2005, BlockView was the first Web-based system to expose large amounts of street imagery to users. However, it was discontinued less than two years later.

More recently, the Street View system itself went through several phases before going online. Google cofounder Larry Page bootstrapped the project by

Figure 2. Movie Maps interface.

Figure 3. Example pushbroom perspective image.

personally collecting a sample of urban video footage from his car using a camcorder. This indirectly led to the idea of creating long, seamless images with somewhat unusual perspectives known as "pushbroom panoramas," an example of which is shown in Figure 3.

In 2006, then Stanford University graduate student Augusto Román developed techniques to create more visually pleasing "multiperspective panoramas" (A. Roman, "Multiperspective Imaging for Automated Urban Imaging," doctoral dissertation, Dept. Electrical Eng., Stanford University, 2006, http:// graphics.stanford.edu/ papers/aroman_ thesis). However, such imagery was difficult to generate and perhaps even harder to use in an intuitive user interface, so 360-degree panoramas took center stage and ultimately led to the current implementation.

MERGING IMAGERY WITH MAPS

Street View literally puts users in the driver's seat. One of the key technical challenges Street View addresses is the merging of street-level imagery with maps in a natural way. In addition, like most Web 2.0 applications, it works across numerous operating systems and browser combinations.

Yet, Street View is more than a pure AJAX application in that it adds Adobe Flash technology to the mix: The "picture bubble" is actually a Flash application that delivers a rich graphic experience without requiring use of a custom browser plug-in. This richness is best experienced by rotating the view right or left 360 degrees or zooming in on details such as parking signs.

The Street View team also tied the imagery to the map in a way that makes navigation easy, whether from the map or from the imagery itself. In particular, the Street View avatar, often referred to as "pegman," rotates and moves along with the map even when navigating from the panoramic image itself.

However, Street View is not merely an exercise in advanced interface design. To collect and process the vast amounts of imagery required for the application, a fleet of custom vehicles such as the one shown in Figure 4 is currently deployed and busily capturing data that will enable coverage well beyond the current 15 US cities. According to *The World Factbook: 2007*, there are more than 19.4 million kilometers of paved roads around the globe, so the Street View data-collection team expects to be busy collecting data for quite a while.

OTHER CHALLENGES

Aside from interface design and data collection, Street View poses challenges related to fleet management, pose optimization, and computer vision.

Fleet management

When more than just a few cars are valid, there is a strong financial incentive to manage them as efficiently as possible. Fleet management is an active area of operations research and of great interest to the transportation industry (T.G. Crainic and G. Laporte, eds., *Fleet Management and Logistics*, Springer, 1998).

Managers and dispatchers can use operations research techniques to optimize the deployment of a fleet of data-acquisition vehicles. Using local planning techniques can also ensure that drivers traverse each road segment as few times as possible, which is difficult given road graph constraints (L. Kazemi et al., "Optimal Traversal Planning in Road Networks with Navigational Constraints," *Proc. 15th ACM Int'l Symp. Advances in*

Figure 4. Street View custom data-collection vehicle.

Geographic Information Systems, ACM Press, 2007).

Pose optimization

When capturing imagery, it is essential to know as accurately as possible each image's location and the camera's orientation. However, the Global Positioning System alone is typically insufficient to provide this data, especially in cities with many "urban canyons," streets flanked with dense tall buildings.

Our solution is to equip the vehicles with additional sensors such as rate gyros, accelerometers, and wheel encoders to capture vehicle speed and acceleration at a high sampling rate. Software such as James Diebel's Trajectory Smoother (http://ai.stanford.edu/~diebel/smoother.html) or the open source Google Pose Optimizer (http://code.google.com/p/gpo) can then be used offline to compute an improved pose estimate from these measurements.

Computer vision

Creating 360-degree panoramas by stitching together a series of digital pictures is not a new problem, and many excellent panorama-stitching packages are available such as Autostitch (M. Brown, "Autostitch: A New Dimension in Automatic Image Stitching," www.cs.ubc.ca/~mbrown/autostitch/autostitch.html).

However, it is one thing to manually create a few panoramas and quite another to automatically generate millions of attractive panoramas across a wide variety of lighting conditions. Solutions involve a pipeline of complex algorithms for camera calibration, vignetting correction, color correction and balancing, image alignment, stitching, blending, and so on.

A project like Street View requires complex engineering but surprisingly little groundbreaking research. What makes it uniquely challenging is its intrinsic scale. This probably explains why few of the dozens of similar projects have reached Street View's still rather modest size. However, as more users and organizations appreciate the value of street-level imagery, similar services are sure to emerge and accelerate innovation in this space.

Such imagery will become increasingly integrated with the overall online map experience and might extend beyond streets to include interiors, real estate, national parks, and more. In fact, not even the sky is the limit: The Street View panoramic viewer is featured in the recently updated Google Moon service (http://moon.google.com) to showcase pictures taken during various Apollo missions. ■

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