Enhanced User Interaction with City-Scale LiDAR and Image Data in Mixed Reality

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ABSTRACT

This presentation demonstrates 3D aware panoramic imagery and its use in mixed reality applications. Recent data scanning technologies are capable of producing 3D aware panoramic images of large scale outdoor environments. These datasets, collected and stored in global geo-coordinates, consist of 360 degree panoramic imagery and real-world shape from LiDAR laser scans. The resulting imagery and 3D scans are unified into 3D aware panoramic images which may be uniquely combined with other external 3D content. We present several unique user interactions based on these mixed mode datasets.

KEYWORDS: user interaction, mixed reality, LiDAR, point cloud, panoramic, Imagery, 3D shape, reality, geo-location, large scale, city scale

INDEX TERMS: H.5.1 [**Information Systems**]: Information Interfaces and Presentation – *Multimedia Information Systems*

1 INTRODUCTION

Recent developments have enabled the collection of large-scale city environments which include both panoramic imagery and 3D image shape. Through precise geo-location, LiDAR 3D scanning and high-resolution image capture, a detailed representation of the 3D city environment is collected. While these new datasets enable increasingly more detailed maps, they are also well suited for mixed reality visualization applications. The imagery and LiDAR 3D models are collected at the same time; providing two datasets which are automatically registered together. Fully positioned image data along with aligned 3D shape of the imaged objects provides many unique opportunities for mixed reality applications.

These datasets provide scenes which can be readily altered and mixed with additional external world content. This is especially convenient for external data content that is also geo-positioned in world coordinates. With such data, we can determine if an inserted object in the scene is partially obstructed by a tree or a parked car. The image of the inserted object can then be partially hidden by comparing the pixel depth of the objects and the depth from LiDAR scan data.

2 DATA COLLECTION

Rather than localized snapshots of individual scenes, these city scale worlds are collected in real-world 3D global coordinates. To collect such a large area, mobile vehicles are employed to drive the city streets. A 360 panoramic camera and LiDAR system are mounted to a vehicle and collection occurs at posted speed limits. Pre-calibration of the hardware sensors provides automatic registration for the collected imagery and LiDAR 3D scan data. The two registered datasets create our 3D aware imagery.

Figure 1. Mobile LiDAR and imagery collection system.

2.1 World Geo-Positioning

Positioning is a key aspect in generating a ready to use 3D dataset. To enable later augmentation of the city scene, both the 3D location and 3D orientation (pose) of the collection is required. The resulting datasets are self-consistent and easier to integrate when properly posed. For example, if we pick a single fixed 3D camera focal point, we expect the camera to look at the same fixed location throughout a sequence of moving images. With inaccurate 3D pose information, the camera focal point appears to 'swim' around the scene instead of remaining in a fixed location.

When combining the collected datasets with external datasets (e.g. a 3D pedestrian route), the precise world positioning of the collection is important. First, we need correct positioning to choose the closest image 'bubble'. Next, we need to ensure correct positioning and orientation to make sure objects added to the scene are shown in their correct locations within the image. Finally, we want the 3D shape of the scene to correctly line up with the external objects.

2.2 Panoramic Imagery

The imagery is collected using multiple cameras and stitched into a 360 panoramic image or ‘bubble’. Each camera stores a full 3D pose (3D geo-position and 3D orientation in world space) so that it can later be positioned and oriented relative to other images, LiDAR 3D point clouds, and other external datasets. Typically, the images are collected at equal distance intervals.

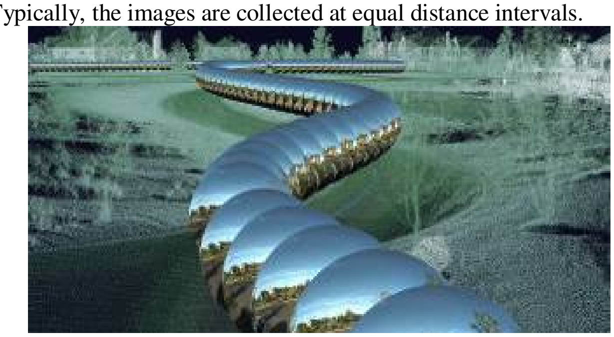

Figure 2. 3D posed panoramic image collection.

2.3 3D LiDAR Shape

3D shape data is collected using a rotating, high density laser scanner which is mounted to the mobile vehicle. The LiDAR system consists of multiple lasers which capture the 3D shape of objects from multiple angles. This provides a dense 3D point cloud of about 1.3 million points per second. Objects up to 100 meters on either side of the mobile vehicle are collected.

Both large 3D objects (buildings, trees) and small 3D shape details (tree branches, sign posts, power lines, window frames) are captured. The pre-alignment of the two datasets enables applications to perform a lookup between pixel and 3D point locations. For example, a simple algorithm may determine a RGB color for each 3D LiDAR point by simply referencing the aligned image pixel's RGB color value. Inversely, the alignment also means that we can obtain a true 3D location for each pixel in the image. Thus, we now have a means to interact with the 3D shape of the image's pixels.

Figure 3. 3D geo-located LiDAR point cloud examples.

2.4 Depth Aware Street Imagery

The 3D LiDAR data may be directly projected onto each posed image bubble and stored as a depth map for later use. These pre-aligned depth maps allow 3D integration of the color imagery with external 3D objects. Many new opportunities for user interaction are made possible with the combination of this depth aware imagery.

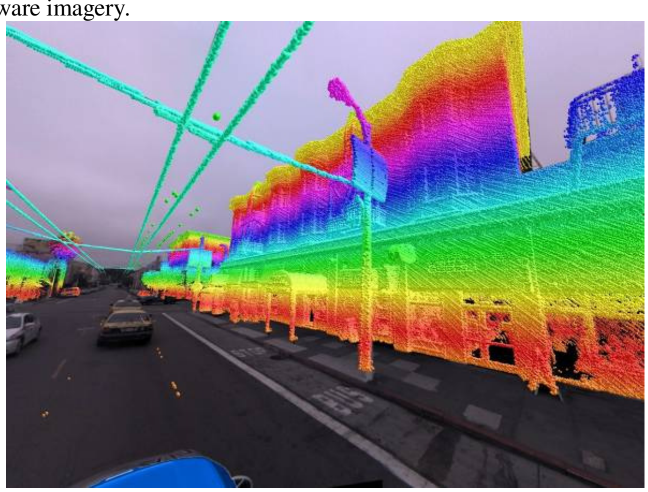

Figure 4. Demonstration of the alignment between pre-registered LiDAR and Imagery datasets.

3 Examples

3.1 3D Positioned and Orientated Imagery

Figure 5. Fixed 3D point focus example. Geo-registered, posed images allow us to automatically look at a fixed world 3D location for any image. In this example, we select a point on the Sears/Willis Tower and step through various images. Our camera always appears to focus on the same fixed point on the building.

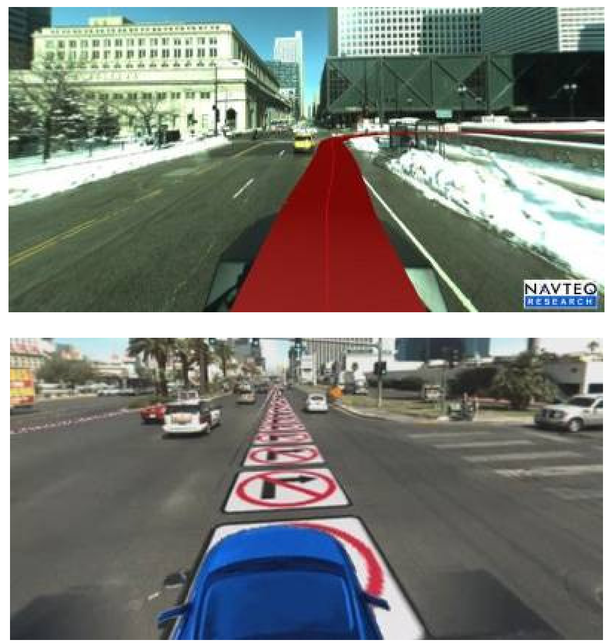

Figure 6. Mixed panoramic imagery and guidance a route. The second example demonstrates how one might display external road attributes such as traffic restrictions.

3.2 Panoramic Imagery and 3D LiDAR

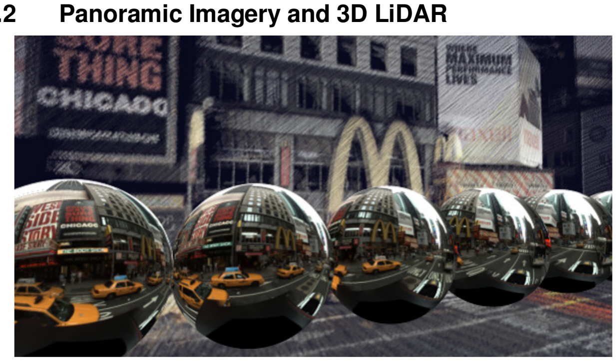

Figure 7. Posed panoramic image collection and colorized LiDAR point cloud alignment in 3D world space.

Figure 8. The cross section of a LiDAR point cloud is mixed with the panoramic imagery. This demonstration exposes the 3D structure of the image by moving a cross section through 3D space.

3.3 Panoramic Imagery and External 3D Models

Figure 9. 3D lane marking example, Sign and bridge models are mixed with the panoramic imagery.

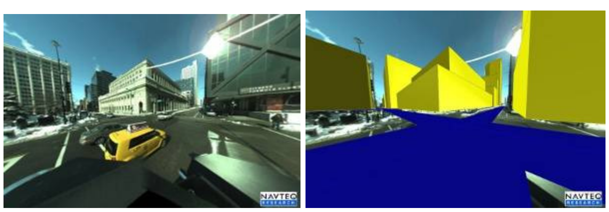

Figure 10. 2D road models (blue) and 3D building models (yellow) are added to the original (Left) image.

3.4 3D Aware Imagery with Depth Maps

Figure 11. The mouse controlled 3D projection assumes the shape of the underlying depth map. Curved and complex surfaces are correctly represented.

Figure 12. The mouse cursor interacts with the 3D shape of the Image. Based on user selected depth, the cursor moves in front and behind objects in the scene based. In this image, the cursor's depth is further than the fountain, but in front of the building.

Figure 13. Sketching on 3D objects. Since both the sketch and images are referenced in 3D, the same 3D sketch is valid for other images and viewpoints and is shown with correct perspective scaling. The image depth information is used to determine if the sketch is occluded by objects in the scene (e.g. the car occludes part of the blue sketch).

Figure 14. A scene combined with a 3D pedestrian route. Instead of a simple 2D image overlay, the route appears to be part of the 3D scene since the image depth is used to determine where the pedestrian is not visible (e.g. hidden by cars, tree, and building).

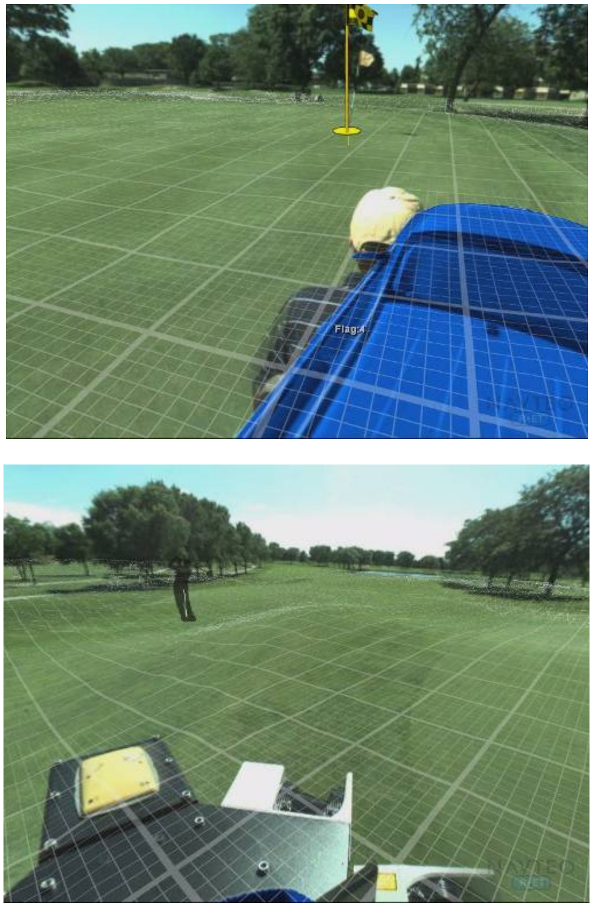

Figure 15. A golf course mapped with LiDAR. The ground elevation grid and flag location are aligned with the imagery.

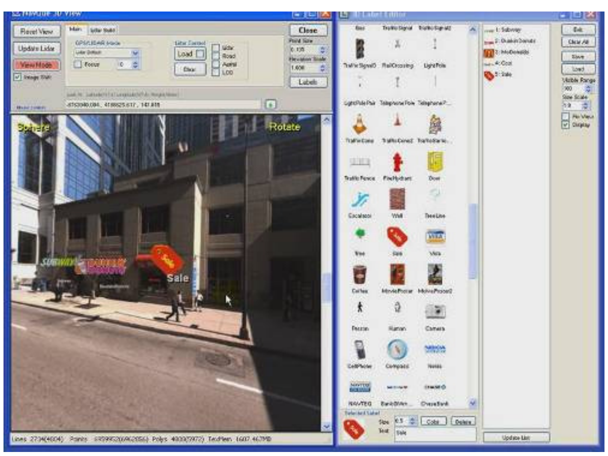

Figure 16. 3D tags. Icons are attached to user selected 3D geo-location (using the depth map). The tags are valid from any other image location and are perspective scaled based on their distance from the posed image. Image depth is also used to determine visibility occlusion of the tags so that they do not show through building walls.

Figure 17. Spot lights alter the panoramic image based on the aligned depth map. User defined spot lights are used to retarget the image brightness based on the light source and each pixel's 3D image depth. In the first case, the user has defined three moving spot lights. In the second case, a top-down spot light is focused on a specific point of interest. Pixels away from the focus position are darkened based on the 3D pixel depth distance from the cone of the light source.

4 Conclusion

We have shown that 3D sensor shape data and panoramic imagery may be combined into 3D aware Imagery; providing a more true-to-life visual representation of the real world. This depth aware imagery has been shown to enhance the user experience though extended visual feedback. Mixed reality applications will continue to benefit in the future as expanded coverage and ease of access to these types of real world 3D datasets become available.