Cyber-physical Content Authoring

Goal

devices, their appetite for on-demand content has grown exponentially. Consumers and businesses increase dependence on mobile physical objects around you using a mobile device?

What are the building codes related to this wall?

How do I jumpstart my car engine?

What does this yellow button do?

Fine-grained Localization & Scaling: The system need to detect location relative to a button or a wall. Precision is important for the above applications. Traditional approaches such as GPS would be too coarse-grained. In addition, the physical world constantly changes, we need to guarantee high accuracy, speed, and robustness in the face of physical world changes.

Cyber-physical Content Authoring: Content authoring is non-trivial on a mobile device with limited resources, low-accuracy positioning, and limited screen real estate. We need to deliver a content authoring environment on a mobile device that can position cyber-information in the real world.

QoS Optimization & Scaling: The resources available on a mobile device is limited. The cyber-information needs to be delivered fast/reliable enough to the end use within these constraints.

Feature extraction: prominent points in the image are extracted and represented using descriptors. Various methods are tested such SIFT, SURF, FREAK.

Feature matching: Approximate Nearest Neighbors (FANN) is used to quickly find which multi-dimensional feature descriptors are closest and potential matches. RANSAC algorithm and 8-point method is used to estimate a fundamental matrix between image pairs and points more than a pixels from an epipolar line are eliminated.

Structure from Motion (SfM) is used to derive 3D coordinates of image features and produce a point cloud. Bundle Adjustment is used to globally optimize the camera parameters and track locations in order to minimize the overall re-projection error.

Localization: after the 3D point cloud is generated, when user selects on a single photo to annotate cyber-information locations. Homography is used to estimate annotation location in other images.

Augmentation: HD4AR uses a cloud back-end to do the computationally intensive image processing tasks. Photos are uploaded to a cloud server. 2D image to point cloud matching is performed to determine camera parameters. Cyber-information in view is returned to the device with information on correct 2D rendering locations.

HD4AR in Amazon EC2

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Max Parallel Augmentations per Node</th>
<th>Total Image Augmentations</th>
<th>Total Sites</th>
<th>Augmentation Success Rate</th>
<th>Average Augmentation Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>88 EC2 Compute Units</td>
<td>64</td>
<td>~1,000</td>
<td>~400</td>
<td>96.76%</td>
<td>1.676s</td>
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</tbody>
</table>

Hybrid 4-dimensional augmented reality (HD4AR): HD4AR uses a fused cyber-physical model to associate cyber-information with real world 3D objects and localize/render cyber-information in photographs.

1. User takes 15+ photos with their phone, uploads them to the cloud, and processes them with HD4AR.

2. The user annotates one or more photos by drawing on them and associating cyber-information.

3. When a new photo is taken of the same real world object, it can be uploaded to the cloud and HD4AR can render the cyber-information into the new photo.

• HD4AR has been licensed to PAR Works. PAR Works is a venture-backed startup, founded by Drs. White, Golparvar-Fard, and Hyojoon Bae, focused on commercializing HD4AR. PAR Works has received ~1.2M in seed funding from Allied Minds Inc.

• Retail Applications. HD4AR allows users to apply Amazon-style product filtering and search to the real world. Take a photo of the cereal aisle and see all of the gluten-free cereals highlighted in your photo. Snap a picture of washing machines and the ones highlighted that have 5 star customer ratings, are under $600, and were recommended by Consumer Reports.

• Construction Monitoring: HD4AR allows construction field personnel to use mobile devices to take pictures for accurate localization. HD4AR reduces project and company risk by allowing field personnel to automatically access the latest plan and, as-built information, visually document progress, and communicate information with other personnel involved in the project on or off site.

CONCLUSION

We have developed an advanced computer vision solution that is able to achieve three dimensional object recognition and tracking in photos along with precise overlays of digital content. By providing nearly instantaneous overlay of information on real-world imagery with millimeter precision, HD4AR expands mobile augmented reality applicability to a number of important real-world problems.

More examples and demos can be found at:
- http://magnum.io
- http://www.parworks.com/

For algorithmic details, refer to:
- Bae, Hyojoon, Mani Golparvar-Fard, and Jules White. "High-precision vision-based mobile augmented reality system for context-aware architectural, engineering, construction and facility management (AEC/FM) applications."Visualization in Engineering (2013)