Cumulative Evidence for Scene Change Detection and Local Map Updates

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***Abstract*—This supplementary material provides extra information regarding the experiments, i.e., results, figures, and other configuration details.**

I. Experiments

A. QMCHNAGE - additional visualization results.

In this section, we show more results of the D285 dataset of our QMCHANGE algorithm. The qualitative result is shown in Fig. 1.

B. QMPOST - detailed description.

Query-Map image pair change masks can be noisy (Fig. 2), due to a variety of reasons:

- Visual segmentation not necessarily aligns with change boundaries.
- Due to D2NET feature sparseness, a matching query feature is not guaranteed to exist for each unchanged map feature. Even if exists, descriptor matching does not always produce a distance below the provided threshold.

Therefore inferring change from a single mask is not recommended. For the D457 dataset, our pairwise change detection yields 1914 change masks. Due to the strict viewpoint proximity criteria of QMGIPS, not all changed map images have corresponding change masks. In fact, for the D457 dataset, the change masks cover 159 map images with 1-to-85 query-map pairs each.

1) Change Mask Aggregation: To overcome these limitations, we aggregate multiple query-map change masks into "Master Map Change Masks". Given a map image with at least 20 aligned query-map pairs we can aggregate / average all change masks, aligned to that map image. Fig. 3A and Fig. 3B show on their right side the results of such averaging that look smooth and robust.

To visualize the actual change on the query size, we align all related query images to that same map image and average, as can be seen on the left side. To create a binary change mask that will tag changed map features, we apply a threshold to the average change mask. Therefore, if we accumulate 24 query-map change mask, a threshold of 50% means that we require a final mask pixel to appear in 12 individual masks (see Fig. 3B (Right) marked as red color).

2) Indirect Change Detection: For the D457 dataset only 26 map images have made is to the Master Change Mask level with 20 or more supporting query-map features. What about the remaining map images? As mentioned above, most changed map images do not participate in QMGIPS and cannot have a change mask, let alone a master change mask. We propose to create change lists for other map images, aiming to cover all significantly changed map image. We define a significant change when at least a certain percentage (5%) of original features (with legit 3D coordinates) are changed. We combine global similarity and common Field-of-view (FOV) to find a Master Change Mask that can be used to infer feature change indirectly. We then use 3D proximity to tag specific features as changed. For every map image: we review all master map images, requiring:

- Minimum NetVLAD global descriptor similarity (correlation: $\rho \geq 0.25$).
- Maximum FOV angular separation (≤ 0.4 radians).

Many of the map images are far away from the change area and we want to avoid pairing and modifying them based on a falsely matched master change mask.

Among these matching candidates, we take the one with highest global descriptor similarity. Fig. 4A denotes the master map image, while Fig. 4B shows non-master map image. For each 3D point on the image in Fig. 4A, if a changed 3D point from the Fig 4B image is found within a preset search radius (1.0m) that point is tagged as changed.

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Fig. 1. **Change Detection algorithm results**. Examples of change detection pipeline results, and images from the two traversals. A. QMGIPS pair - query with groundtruth change (purple contour) left, map image right. B. Common area (QMALIGN) further limited by semantics (left), Map image with Query common area highlighted right (purple contour). C. Combined Changed Mask left (purple contour), map features changed (red dots) / unchanged (green dots) decision in semantically meaningful and geometrically common region right (blue dots have no 3D values).

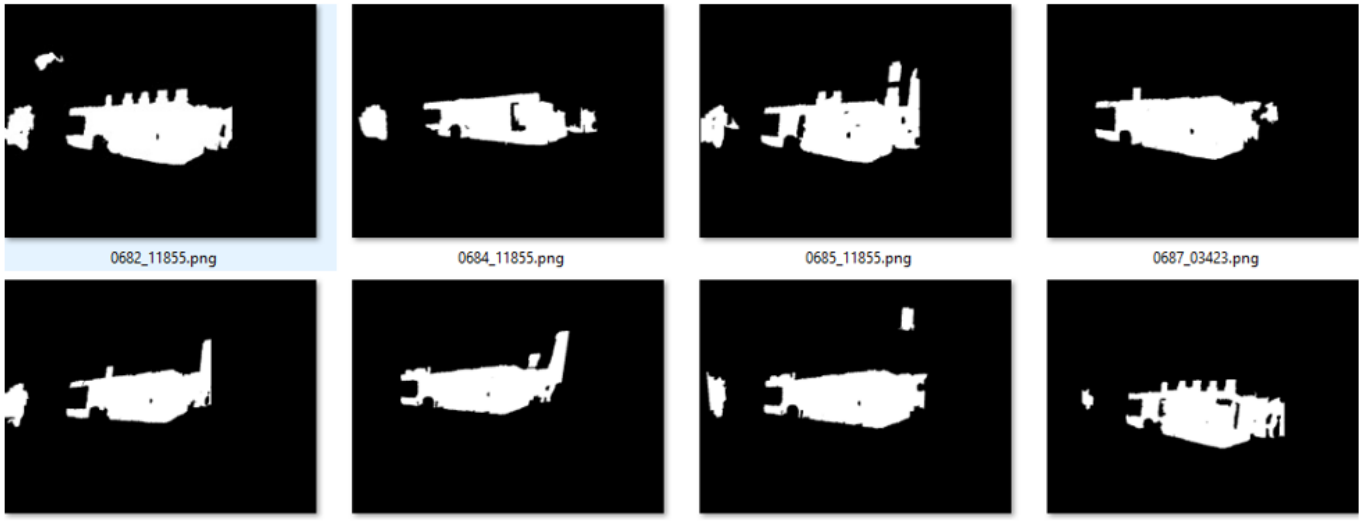

Fig. 2. **Noisy Individual Change Masks**. Examples of noisy change detection mask of the D457 dataset.

Fig. 3. **Change Mask Aggregation examples**. A. Master Mask (Right) and average of the aligned supporting queries (Left) – belong to D457 dataset. B. Master Mask (Right) and average of the aligned supporting queries (Left) – belong to D285 dataset.

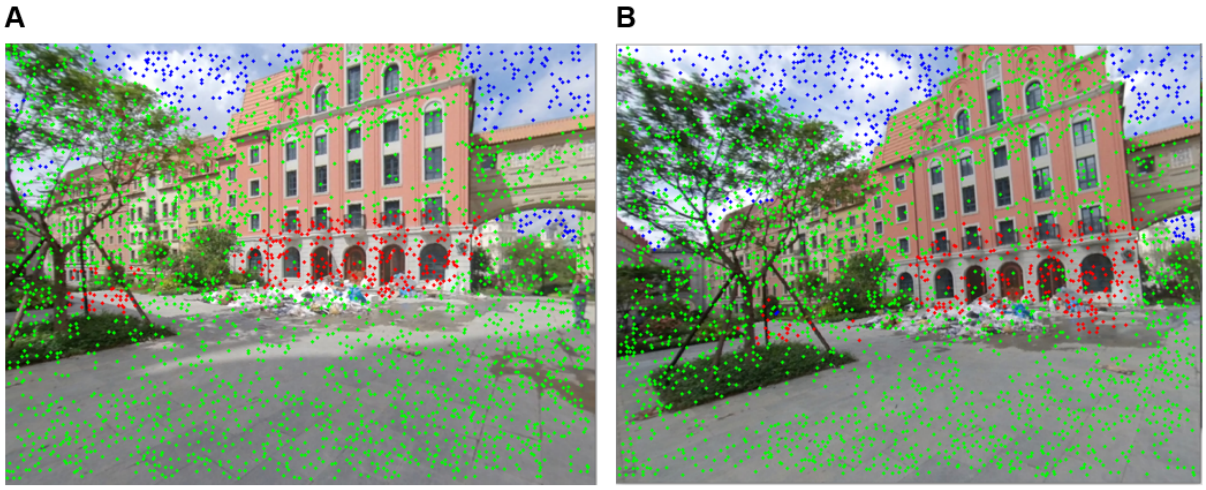

Fig. 4. **Indirect Change Detection** A. Master map image with changed features (in red). B. Indirectly processed map image with feature changed by proximity. Green dots indicate unchanged features, while blue dots indicate no-3D values. All Images are part of D457 dataset.

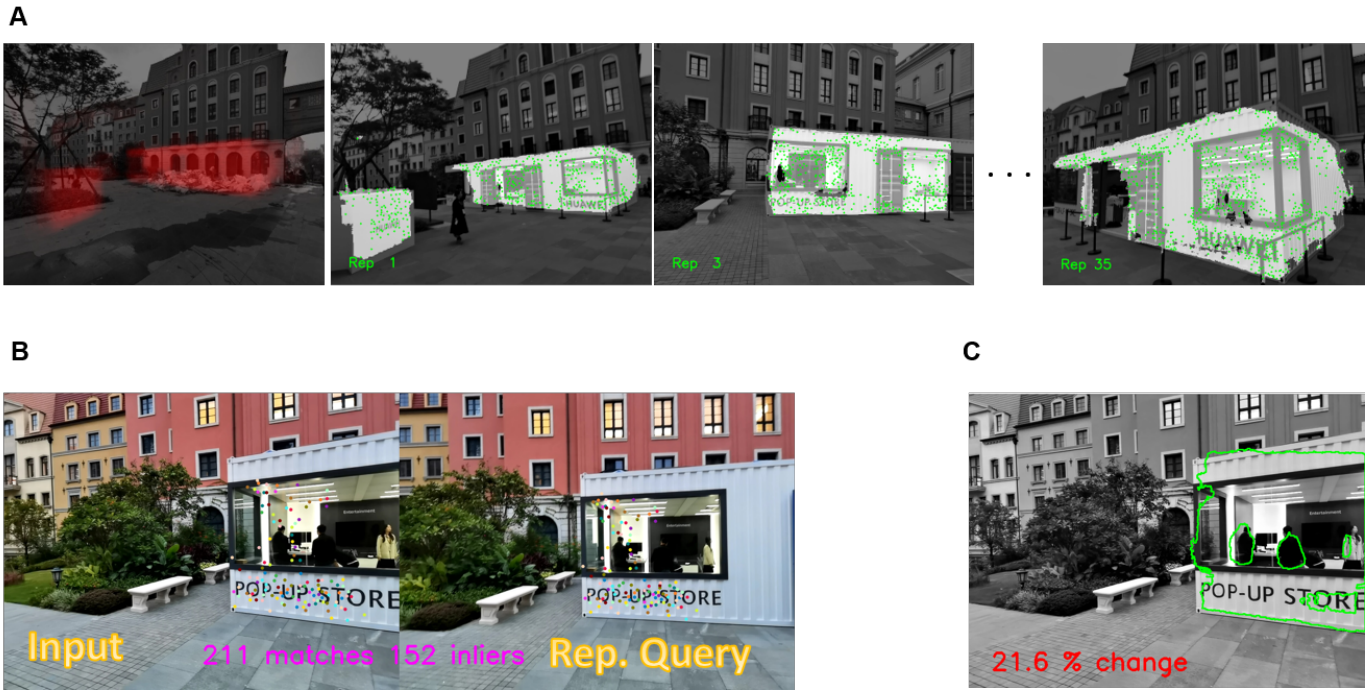

Fig. 5. **Detect Changes in Arbitrary Query Images.** A. A "Master" change map image, and its Representative Queries with projected masks and in-mask features. B. Bi-Directional matches between input image and a representative query, and Similarity Transform RANSAC inliers. C. Compute the matching percentage, and projected area. Input refers to a new query image, and Rep. refers to representative.