Intuitive Alignment of Point-Clouds with Painting-Based Feature Correspondence

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Abstract

Throughout the course of several years, significant progress has been made with regard to the accuracy and performance of pairwise alignment techniques, however when considering low-resolution scans with minimal pairwise overlap, and scans with high levels of symmetry, the process of successfully performing sequential alignments in the object reconstruction process remains a challenging task. Even with the improvements in surface point sampling and surface feature correspondence estimation, existing techniques do not guarantee an alignment between arbitrary point-cloud pairs due to statistically-driven estimation models. In this work, we define a robust and intuitive painting-based feature correspondence selection methodology that can refine input sets for these existing techniques to ensure alignment convergence. Additionally, we consolidate this painting process into a semi-automated alignment compilation technique that can be used to ensure the proper reconstruction of scanned models.

1 Pairwise Point-Cloud Alignment

Our Approach: (1) Painting-selection (2) Estimate Alignment (3) Refined Alignment

Estimate Alignment Techniques:
- Provide an initial alignment for estimating the global point-cloud orientation
- Generally utilize orientation independent surface characteristics (features)
- Pre-requisite for applying a Refined Alignment Technique
- Sample Consensus Initial Alignment (SAC-IA) [1]

Refined Alignment Techniques:
- Provide a numerically accurate minimization of the distance between two scans
- Create highly accurate alignments - if the estimate alignment is ‘close enough’
- Several variants of the Iterative Closest Point (ICP) have been developed [2, 3, 4]

Problem shared by both estimate and refined techniques: Feature Correspondence

2 Selection Assisted Alignment

Given a pair of scans, the success of an alignment is heavily dependent on the data points that do not directly contribute to a correspondence between the surfaces in each of the scans. Selection assisted alignment allows user intervention to provide a direct mapping of the corresponding features between two scans. This not only greatly reduces the error of the alignment but allows scans with uncommon features to be successfully aligned.

Key-point Correspondence Selection:
- User intervention is introduced to assist in the convergence rate of the ICP algorithm
- Only individual points represent corresponding features in a scan pair
- Does not intuitively represent surface curvature
- Limited to identifying correspondence for surfaces without distinct features (see Figure 1)

Globally important with surface curvature estimation techniques (feature-based estimate techniques)

Painting-based Correspondence Selection:
- Aims to provide high-level feature correspondence (selection of objects and surface curvatures)
- Requires no pre-filtering for alignment (background data-points do not have to be eliminated)
- Swipe-based painting allows for the quick selection of similar features
- Multiple painted patterns can derive alignments within the threshold of the ICP algorithm
- Complements estimation techniques that utilize surface features (SAC-IA)

3 Painting-Based Feature Correspondence

Painting-based alignment allows for the identification of unique features that correspond to the surface of an individual object as viewed from two different scanning positions. The objective of this approach is to provide an intuitive and flexible solution to quickly identifying corresponding features between scan pairs that can be identified within each scan. To facilitate our interactive painting technique we provide a set of tools that allow the user to actively select (green paint-brush) or deselect (red paint-brush) data points within each point-cloud. The functionality of this painting tool is illustrated below in Figure 2.

- Figure 2: Brush-based painting tool that select the data-points within the radius of the brush selection circle as it is moved across the surface of the scanned object. The unique brush tool left on the surface of the scan illustrates the points selected for alignment (left). The deselection brush allows for points to be removed from the alignment (right).

Painting-based Alignment:
- Identify surface features common to both scans (feature correspondence)
- Paint the data-points of these features in each point-cloud
- Swipe or stroke gestures allow the paint-brush to highlight data-points
- Selected data-points can be added and removed as needed
- Select and perform an estimate alignment
- Select and perform a refined alignment

Painting-based selection has been utilized to identify corresponding features common between two scans of a Subaru WRX. These selected regions are then used as the candidate points for both the estimate and refined alignments that are applied to these scans to properly align them.

4 Scan Alignment Compilation

The separation of an alignment methodology to include two separate classifications of pairwise alignments (estimate/refined), does not inherently guarantee the success of the resulting alignment. Therefore we have devised a step-wise compilation process where the user can verify that each pairwise alignment has been successful. The following is an overview of this procedure:

- Acquire Scan Batch (point-clouds with pairwise overlap)
- For each scan pair with overlap:
  1. Paint common features between scans in current pair
  2. Estimate Alignment (ensure alignment, adjust painting)
  3. Perform Refined Alignment
  4. Checkpoint: Ensure alignment, continue to next pair

Refer to the illustration of the alignment application (See Figure 4) that depicts the interactive user interface created for painting and performing pairwise alignments.

5 Alignment Evaluation

The elimination of non-corresponding features has such a profound impact on the estimate alignment that the natural variance between individual painting patterns has a minimal negative effect on the resulting alignment. The following alignments were performed using the painted patterns illustrated in Figure 4 along with the SAC-IA estimate alignment implementation provided in the Point Cloud Library (PCL) [5] with the parameters defined below:

- Max Correspondence Distance: 0.1
- Min Sample Distance: 0.05
- Normal k-Neighbors: 20
- Feature k-Neighbors: 20

- Figure 4: Estimate alignment convergence using SAC-IA algorithm for two distinct painting patterns. Top row: painted correspondence variant 1, bottom row: correspondence variant 2. The results of each SAC-IA estimate alignment between the scans in columns 1 and 2 are shown in the third column. In both instances, the resulting alignment is within the convergence threshold of ICP.

6 Conclusion

In this work we present a new and intuitive painting-based methodology for selecting corresponding features between scan pairs. We introduced an alignment compilation process that ensures that through the process of applying subsequent pairwise alignments, the resulting transformations will be valid and produce an accurate representation of the scanned object.

Fig. 3: Screen-shot of the alignment application (Alignment Compiler) that illustrates the alignment between two individual scans. The right side of the vehicle is illustrated in the upper-left viewport. The left side of the vehicle is illustrated in the upper-right viewport. The grille of the vehicle has been painted in both scans individually using our circular paint-brush tool. This represents the correspondence of an individual surface feature shared between these two scans. The resulting alignment is shown in the lower viewport.

Fig. 4: Estimate alignment convergence using SAC-IA algorithm for two distinct painting patterns. Top row: painted correspondence variant 1, bottom row: correspondence variant 2. The results of each SAC-IA estimate alignment between the scans in columns 1 and 2 are shown in the third column. In both instances, the resulting alignment is within the convergence threshold of ICP.