# Rotational Projection Statistics

### Local reference frame (LRF)

##### Define the LRF by calculating the scatter matrix of all points lying on the local surface

### RoPS feature description

##### Obtained by rotationally projecting the neighboring points of a feature point onto 2D planes

##### Calculating a set of statistics of the distribution of these projected points

### 3D object recognition

##### A hierarchical 3D object recognition algorithm

# Object recognition

#### 13-- A parts-based method for articulated target recognition in laser radar data (Guo)

#### 99-PAMI-Using spin images for efficient object recognition in cluttered 3D scenes (Johnson)

#### 13-PR- An efficient 3D face recognition approach based on the fusion of novel local low-level features (Lei)

#### 10-ECCV- Unique signatures of histograms for local surface description

# The aim of object recognition

### Present in a scene

### Recover their pose

# 2D Object recognition

#### 03-ICCV-Recognising panoramas (Brown and Lowe)

#### 04-IJCV-Distinctive image features from scale-invariant keypoints (Lowe)

#### 04-IJCV-Scale&affine invariant interest point detectors (Mikolajczyk and Schmid)

# 3D Object recognition

### Global feature based

##### Construct a set of features which encode the geometric properties of the entire 3D object

##### Require complete 3D models and are therefore sensitive to occlusion and clutter

### Local feature based

##### Define a set of features which encode the characteristics of the local neighborhood of feature points

Feature matching

Hypothesis generation and verification

Pose refinement

# 3D Object recognition

#### 10-ICPR-Shape index SIFT: Range image recognition using local features (Bayramoglu and Alatan)

#### 08-Computer Graphics- Sparse points matching by combining 3D mesh saliency with statistical descriptors

#### 11-CVIU-Local shape descriptor selection for object recognition in range data (Taati & Greenspan)

### Global feature based

##### Geometric 3D moment

00-Signal Processing- Description of shape information for 2-D and 3-D objects (Paquet)

##### Shape distribution

02-TOG-Shape distributions (Osada)

##### Spherical harmonics

03-TOG- A search engine for 3Dmodels (Funkhouser)

### Local feature based

##### Point signature based

97-IJCV- Point signatures: A new representation for 3Dobject recognition (Chua and Jarvis)

##### Spin image based

99-PAMI-Using spin images for efficient object recognition in cluttered 3D scenes (Johnson)

##### Tensor based

06-PAMI-Three-dimensional model-based object recognition and segmentation in cluttered scenes (Mian)

##### Exponential map

12-IJCV-D geometric scale variability in range images: Features and descriptors (Bariya)

# Two requirements

### Descriptiveness

##### Ensure an accurate and efficient object recognition

### Robustness

##### Noise

##### Varying mesh resolution

##### Clutter

##### Occlusion

##### Holes

##### Topology changes

# Feature without LRF

### Without LRF, most of these methods generate a feature descriptor by accumulating certain geometric attributes into a histogram

### most of the 3D spatial information is discarded during the process of histograming, the descriptiveness of the features without LRF is limited

#### 92-PAMI-Structural indexing: Efficient 3D object recognition (Stein and Medioni)

##### Record the relationship between the normal of the geodesic neighboring points and the feature point

##### Encode the relationship into a 3D vector

##### Transformed into curvatures and torsion angles

#### 01-CVPR-3D object recognition from range images using local feature histograms (Hetzel)

##### Constructed a set of features by generating histograms using

Depth values

Surface normal

Shape indices

Their combinations

##### Results show that the surface normal and shape index exhibit high discrimination capabilities

#### 02-PAMI-Surface signatures: An orientation independent free-form surface representation scheme for the purpose of objects registration and matching (Yamany and Farag)

##### Encoding the surface curvature information into a 2D histogram

##### Used to estimate scaling transformations and recognizing objects in 3D scenes

#### 07-PRL-3D free-form object recognition in range images using local surface patches (Chen and Bhanu)

##### Propose a LSP feature that encodes the shape indices and normal deviations of the neighboring points

#### 08-IET Computer Vision-Local 3D structure recognition in range images (Flint)

##### Introduced a THRIFT feature by calculating a weighted histogram of the deviation angles between the normals of the neighboring points and the feature point

#### 07-ICCV-Variable dimensional local shape descriptors for object recognition in range data (Taati)

##### Considered the selection of a good local surface feature for 3D object recognition as an optimization problem

##### Proposed a set of variable-dimensional local shape descriptors(VD-LSD)

##### Time comsuming

#### 12-CVPR-Intrinsic shape context descriptors for deformable shape (Kokkinos)

##### Proposed a generalization of 2D shape context feature to curved surfaces,namely intrinsic shape context(ISC)

# Feature with LRF

### None of the existing LRF definition techniques is simultaneously unique, unambiguous, and robust to noise and mesh resolution

#### 97-IJCV-Point signatures: A new representation for 3Dobject recognition (Chua and Jarvis)

##### Propose a point signature by using the distances from the neighboring points to their corresponding projections on a fitted plane

Merit: no surface derivative is required

Limitation:

The reference direction may not be unique

Sensitive to mesh resolution

#### 98-IVC-Surface matching for object recognition in complex three-dimensional scenes (Johnson and Hebert)

##### Spin image

##### Most cited method

##### Descriptiveness is relatively low

##### Sensitive to mesh resolution

#### 04-ECCV-Recognizing objects in range data using regional point descriptors (Frome)

##### 3D shape context (3DSC)

##### Uncertainty in the rotation around the normal

#### 01-ICCV-Surface matching by3Dpoint’s fingerprint (Sun and Abidi)

##### Introduced an LRF by using the normal of a feature point and an arbitrarily chosen neighboring point

##### Proposed a descriptor named point’s fingerprint by projecting the geodesic circles onto the tangent plane

##### Their LRF is not unique

#### 06-PAMI-Three-dimensional model-based object recognition and segmentation in cluttered scenes (Mian)

##### A tensor representation by defining an LRF for a pair of oriented points

##### Encoding the intersected surface area into a multidimensional table

##### Robust to noise, occlusion and clutter

##### A pair of points are required to define an LRF, which causes a combinatorial explosion

#### 08-ECCV-Scale-dependent/invariant local 3D shape descriptors for fully automatic registration of multiple sets of range images (Novatnack and Nishino)

##### Used the surface normal and a projected eigenvector on the tangent plane to define an LRF

##### Proposed an EM descriptor by encoding the surface normals of the neighboring points into a 2D domain

#### 09-ICCV Workshop-Intrinsic shape signatures: A shape descriptor for 3D object recognition (Zhong)

##### Introduced an LRF by calculating the eigenvectors of the scatter matrix of the neighboring points of a feature point

##### Proposed an ISS feature by recording the point distribution in the spherical angular space

##### Since the sign of the LRF is not defined unambiguously, four feature descriptors can be generated from a single feature point

#### 10-ECCV-Unique signatures of histograms for local surface description (Tombari)

##### Introduced a LRF by performing an eigenvalue decomposition on the scatter matrix of the neighboring points and using a sign disambiguation technique

##### [Unique and unambiguous LRF]

##### Introduced a feature descriptor called signature of histograms of orientations (SHOT)

##### Robust to noise, but sensitive to mesh resolution variation

#### 11-ICCV- On the repeatability of the local reference frame for partial shape matching (Petrelli)

##### Proposed a novel LRF which aimed to estimate a repeatable LRF at the border of a range image

#### 12-IJCV- Key points and local descriptors of scalar functions on 2D manifolds (Zaharescu)

##### Proposed a MeshHOG feature

##### First projecting the gradient vectors onto three planes defined by an LRF

##### Then calculating a two-level histogram of these vectors

# 3D Object Recognition

### Usual Framework

##### Feature matching

##### Hypothesis generation and verification

##### Pose refinement

#### 92- PAMI-Structural indexing: Efficient 3D object recognition (Stein and Medioni)

##### Used the splash features to represent the objects

##### Generated hypotheses by using a set of triplets of feature correspondences

##### Hypotheses are then grouped into clusters using geometric constraints

##### Finally verified through a least square calculation

#### 97-IJCV- Point signatures: A new representation for 3Dobject recognition (Chua and Jarvis)

##### Used point signatures of a scene to match

##### The rigid transformation was then calculated using three pairs of corresponding points

##### Verifying each triplet of feature correspondences is very time consuming

#### 99-PAMI- Using spin images for efficient object recognition in cluttered 3D scenes (Johnson and Hebert)

##### Generated point correspondences by matching the spin images

##### Point correspondences are first grouped using geometric consistency

##### Groups are then used to calculate rigid transformations

#### 02-PAMI-Surface signatures: An orientation independent free-form surface representation scheme for the purpose of objects registration and matching (Yamany and Farag)

##### Similar strategy to 99-Johnson

#### 06-PAMI-Three-dimensional model-based object recognition and segmentation in cluttered scenes (Mian)

##### Obtained feature correspondences and model hypothesis by matching the tensor representations

##### The hypothesis model is then transformed to the scene and finally verified using the iterative closest point (ICP) algorithm

92-PAMI-A method for registration of 3-D shapes (Besl and McKay)

#### 10-IJCV-On the repeatability and quality of keypoints for local feature-based 3D object retrieval from cluttered scenes

##### Developed a 3D object recognition algorithm based on keypoint matching

#### 11-CVIU-Local shape descriptor selection for object recognition in range data (Taati and Greenspan)

##### The optimal VD-LSD descriptor is selected based on the geometry of the objects and the characteristics of the range sensors

#### 12-IJCV-D geometric scale variability in range images: Features and descriptors (Bariya)

##### Based on the EM feature descriptor

##### Based on a constrained interpretation tree

### Unusual Framework

#### 04-ECCV-Recognizing objects in range data using regional point descriptors (Frome)

##### Using the sum of the distances between the scene features and their corresponding model features

##### Not able to segment the recognized object from a scene

#### 10-IJCV-Real-time object recognition in sparse range images using error surface embedding (Shang and Greespan)

##### Proposed a potential well space embedding (PWSE) algorithm for real-time 3D object recognition in sparse range images

##### Cannot however handle clutter and therefore requires the objects to be segmented a priori from the scene

### Note

##### None of the existing object recognition algorithms has explicitly explored the use of LRF to boost the performance of the recognition

##### Most of these algorithms require three pairs of feature correspondences to establish a transformation between a model and a scene

Increases the run time due to the combinatorial explosion of the matching pairs

Decreases the precision of the estimated transformation

# Contribution

### Extended version of

###### 13--3D free form object recognition using rotational projection statistics (Guo)

###### 13--RoPS: A local feature descriptor for 3D rigid objects based on rotational projection statistics (Guo)

### Introduce a unique, unambiguous and robust 3D LRF

##### Using all the points lying on the local surface rather than just the mesh vertices

Therefore, robust to noise and varying mesh resolution

##### Use a novel sign disambiguation technique

LRF is unique and unambiguous

### Introduce a highly descriptive and robust RoPS feature descriptor

##### Generated by rotationally projecting the neighboring points onto three coordinate planes and encoding the rich information of the point distribution into a set of statistics

Robust to a number of deformations including noise, varying mesh resolution, rotation, holes and topology changes

### Introduce an efficient hierarchical 3D object recognition algorithm based on the LRF and RoPS feature descriptor

##### A single correct feature correspondence is sufficient for object recognition

##### The proposed object recognition algorithm can work with any of the existing feature descriptors

# Local Reference Frame

### Importance of a unique, repeatable and robust LRF

##### The repeatability of an LRF directly affects the descriptiveness and robustness of the feature descriptor

##### A unique LRF can help to improve both the precision and the efficiency of feature matching

##### A robust 3D LRF helps to boost the performance of 3D object recognition

### Coordinate Axis Construction

##### Scatter matrix

{\overline {\mathbf {x} }}={\frac {1}{n}}\sum _{j=1}^{n}\mathbf {x} _{j}







##### Scatter matrix using all point on the faces

Notifications

A feature point

A support radius

The local mesh with triangles and vertices (in )

The triangle with vertices

Scatter matrix only considering vertices

A point lying within the triangle can be represented as

Scatter matrix considering all the points in *ith* triangle

Weighted Sum：

Where is the area ratio (improve robustness of varying mesh resolutions)

is the weight for the distance to the feature point (improve robustness of occlusion and clutter)

Perform an eigenvalue decomposition in decreasing order

Not repeatable

Sign disambiguation

denotes the weighted sum of dot product between and vector point from to the feature point

Idea: LRF should start from the feature point and point in the direction of the points lying on the local surface

##### LRF evaluation (experiment-Stanford 3D scanning repository)

Compare the corresponding points in models and scenes

Models: Armadillo, Asia Dragon, Bunny, Dragon, Happy Buddha and Thai Statue

Scenes: resampling down to 0.5, add Gaussian noise (0.1 mr)

Randomly selected 100 points, for each pair**,** calculate LRF **,** the error is calculated by

06-IJCV-A novel representation and feature matching algorithm for automatic pairwise registration (Mian)

Comparison

08-ECCV-Scale-dependent/invariant local 3D shape descriptors for fully automatic registration of multiple sets of range images (Novatnack and Nishino)

10-IJCV-On the repeatability and quality of keypoints for local feature-based 3D object retrieval from cluttered scenes (Mian)

10-ECCV-Unique signatures of histograms for local surface description (Tombari)

11-ICCV- On the repeatability of the local reference frame for partial shape matching (Petrelli)

# Local Surface Description

## ||Method||

### 

### Rotation around x axis

##### Multi-viewpoint

### Projected to xy,xz,yz plane (distribution matrix) and normalization

##### 2D projections clearly preserve a certain amount of unique 3D geometric information of the local surface from that particular viewpoint

##### Concise and efficient

##### Normalization to achieve invariance to variations in mesh resolution

### Use central moment and Shannon entropy to encode

##### Central moment

62--Visual pattern recognition by moment invariants (Hu)

00-CVIU-The first absolute central moment in low-level image processing (Demi)

Mathematical simplicity and rich descriptiveness

##### Shannon entropy

Strong power to measure the information contained in a probability distribution

##### Achieve computational and storage efficiency

### Concatenate the sub-features of all the rotations into a vector

## ||Related work||

### View-based method

###### 06--Towards stable and salient multi-view representation of 3D shapes (Yamauchi)

###### 08--Salient local visual features for shape-based 3D model retrieval (Ohbuchi)

###### 10--3D object retrieval using salient views (Atmosukarto and Shapiro)

##### Originate from the 3D shape retrieval

##### Sensitive to occlusion and clutter

### Compare with Spin Image and Snapshot

###### 99-PAMI-Using spin images for efficient object recognition in cluttered 3D scenes (Johnson)

###### 07-PAMI-Snapshots:A novel local surface descriptor and matching algorithm for robust 3D surface alignment (Malassiotis and Strintzis)

##### Single view -> multi view

##### Spin image discard cylindrical angular information and snapshot is prone to rotation ->unique LRF

##### More compact

## ||Evaluation – 1 –precision curve||

### Given a scene, a model and the ground truth transformation

### A scene feature is matched against all model features to find the closest feature

### The ratio between the smallest distance and the second smallest one is less than a **threshold**, then the scene feature and the closest model feature are considered a match

### a match is considered a true positive only if the distance between the physical locations of the two features is sufficiently small

## ||Detail||

### The Combination of Statistics

### The Number of Partition Bins

### The Numbers of Rotations

### The Support Radius

## ||Experiment||

### …

# 3D Object Recognition Algorithm

### 

### Model representation

##### Given a model

##### seed points are evenly selected from the model

##### Enforce a resolution control strategy

09-ICCV workshop-Intrinsic shape signatures: A shape descriptor for 3D object recognition (Zhong)

##### For each , calculate LRF and descriptor

##### Offline K-d tree for index

### Candidate model generation

##### Input scene

##### is decimated to a low resolution mesh , the vertices of that are nearest to the vertices of are selected s seed points

06-PAMI-Three-dimensional model-based object recognition and segmentation in cluttered scenes (Mian)

##### Enforce a resolution control strategy

09-ICCV workshop-Intrinsic shape signatures: A shape descriptor for 3D object recognition (Zhong)

prune out redundant seed points

##### Apply a boundary checking strategy

10-IJCV-On the repeatability and quality of keypoints for local feature-based 3D object retrieval from cluttered scenes (Mian)

Eliminate the boundary points of the range image

##### Impose a constraint on the ratios of the eigenvalues to exclude seed points with symmetrical local surfaces

Why only ??

##### Every features are matched all model features using k-d tree

Ratio strategy

##### Each feature correspondence votes for a model

##### These models which have received votes from feature correspondences are considered candidate models and ranked

### Transformation hypothesis generation

##### A rigid transformation is calculated by the LRF for each feature correspondence

Given a scene feature and LRF , A corresponding model feature and LRF , the transformation is calculated by:

Compared with the existing algorithms (splash, point signature and spin image), eliminates the combinatorial explosion of feature correspondences and improves the reliability of the estimated transformation

Vectorize the plausible transformations

is converted into three Euler angles

Keep

Grouped the similar transformation into cluster for each transformation

With distances from less than (set to 0.2)

With distances from less than (set to 30mr)

Calculate the confidence score

Where is the number of correspondence, and *d* is the average distance

Sort by score, and prune out the ones smaller than half the maximum

Starting from the highest scored one and discarding the nearby clusters (with )

The remaining clusters are considered as Hypothesis

### Verification and segmentation

##### Given a scene, a candidate model and a hypothesis

##### The transformation is further refined using the ICP algorithm, results in a residual error

92-PAMI-A method for registration of 3-D shapes (Besl and McKay)

##### Calculate the visible proportion

is the number of corresponding points is the total number of scene

Points are considered corresponding if distance is less than twice the model resolution

06-PAMI-Three-dimensional model-based object recognition and segmentation in cluttered scenes (Mian)

##### Double threshold

Hypothesis are accepted where

##### Continues until either all the candidate models have been verified or there are too few points left in the scene for recognition

# 想法

### 尽管文中在关键点提取的将可能产生歧义的点去掉，但LRF的唯一性并不完美

### 既然LRF可以用所有面，能描述子是否也可以呢？