3D Environment Reconstruction

Using Modified Color ICP Algorithm by Fusion of a Camera and a 3D Laser Range Finder

The 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems
October 11-15, 2009 St. Louis, USA

3D Reconstruction Background

Building rich 3D maps of environments is an important task for mobile robotics, with applications in navigation, virtual reality, medical operation, and telepresence.

Most 3D mapping systems contain three main components:

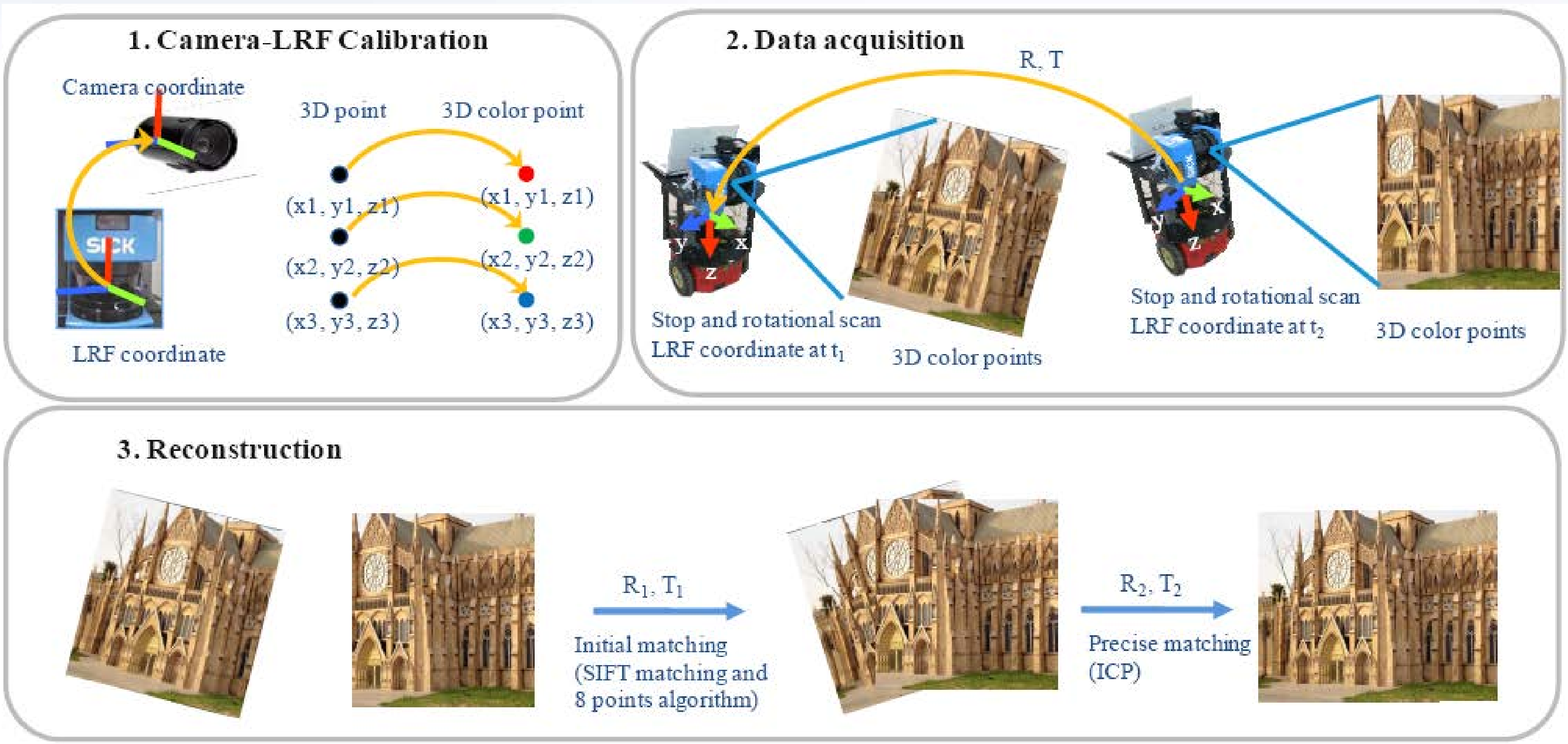
1. the spatial alignment of continuous data frames;
2. the detection of loop closures;
3. the globally consistent alignment of the complete data sequence.

Concept explain

1. **Scale-invariant feature transform (SIFT):**
   Detect and describe local features match in images.
2. **Random Sample Consensus (RANSAC):**
   An iterative method to estimate parameters of a mathematical model from a set of observed data which contains outliers.
3. **Iterative Closest Point (ICP):**
   employed to minimize the differences between two clouds of points.
4. **K-D Tree**
   a space-partitioning data structure to organize points in a k-dimensional space for range searching and nearest neighbor searching

Processing of Color ICP

Step of algorithm: SIFT → RANSAC → Color ICP



Processing of Color ICP, Cont.

SIFT ↓

1. Create image feature match

RANSAC ↓

1. Filtrate “Poisoned Point” and get motion Information
2. Get low accurate position information for the initial estimation of ICP algorithm

Color ICP

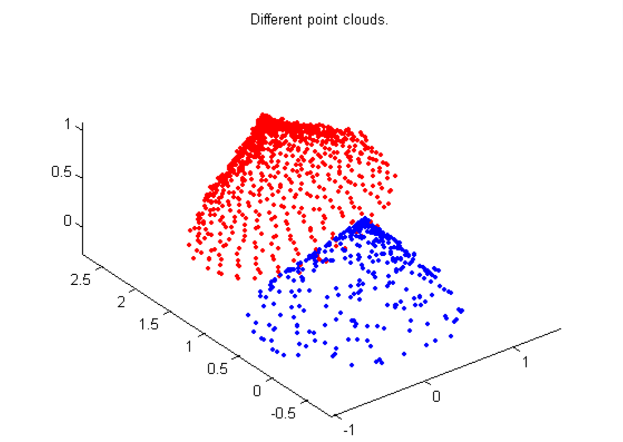
1. Create 3D Environment
2. Get Higher accurate position information

Normal ICP algorithm Introduce

- ICP mathematical expression

$$S_o = \{p_1, \cdots, \mathrm{p_m}\} \quad \text{observe set}$$

$$S_f = \{q_1, \cdots, q_j\} \quad \text{reference set}$$



$$E_{dist}(\alpha, T) = \min_{R_\alpha, T, j \in \{1,2,\cdots,n\}} \left(\sum_{i=1}^{m} \left\| (R_\alpha p_i + T) - q_j \right\|_2^2 \right)$$

- Euclidean distance

For position:

$$d_{\text{position}} = \left\| p_{\text{position}} - q_{\text{position}} \right\| = \sqrt{(p_x - q_x)^2 + (p_y - q_y)^2 + (p_z - q_z)^2}$$

Normal ICP algorithm Introduce, Cont.

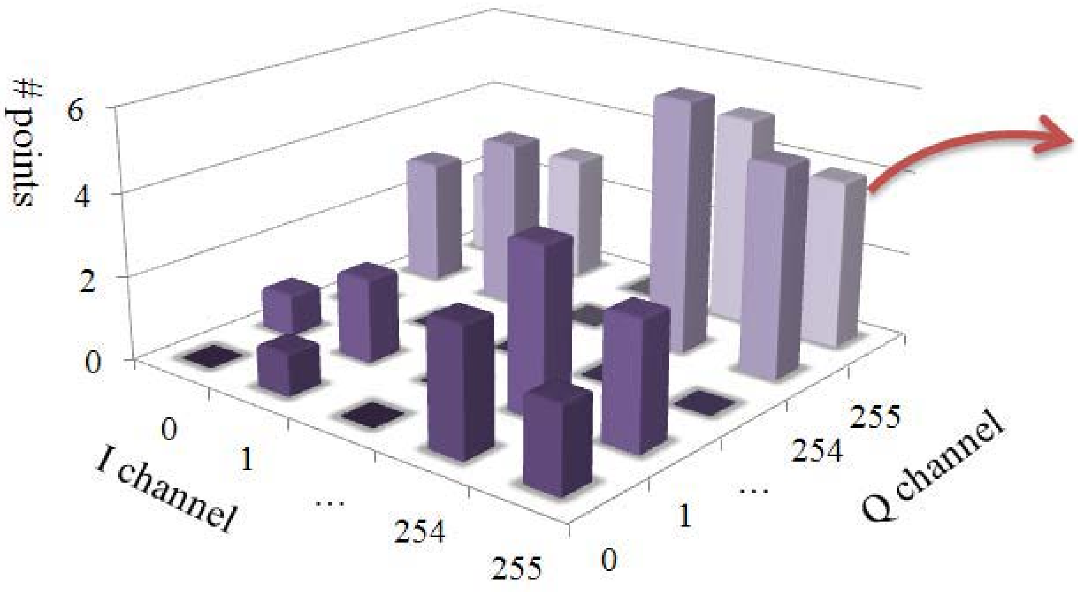
1. Get two sets of match S_o and S_f which include n matches from **RANSAC** algorithm.
2. Transfer the S_o to $S_o^{'}$ by translation and rotation matrix equation. Build the **KD-Tree** and k = 0.
3. Select a point randomly q_f in S_f. Find the points which satisfy the distance (γ) constraints between q_f and $p_k^{'}$ by using the nearest neighbor search algorithm. Then calculate translation and Rotation matrix.
4. Calculate the $E_k(\alpha, \mathrm{T}) = \sum_{i=1}^{m} \|(R_\alpha p_i + T) - q_j\|_2^2$
5. If $E_k(\alpha, \mathrm{T})$ is smaller than previous minimum $\mathrm{E}(\alpha, \mathrm{T})$ of match, update the translation and rotation matrix by using Least squares method.
6. k = k +1. Repeat 3) to 4) until search all points.

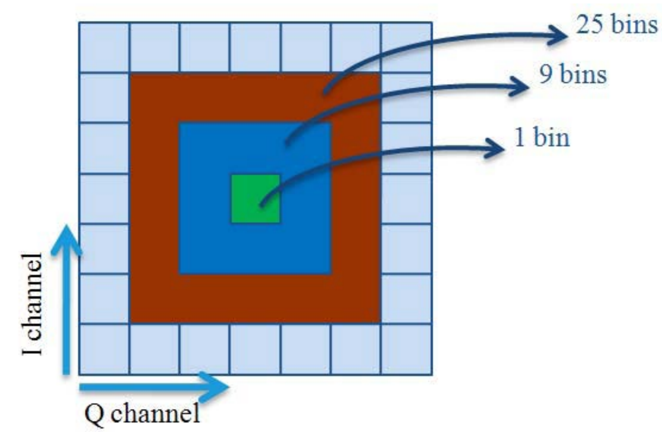
Color ICP Algorithm Improve

Improve the normal ICP algorithm :

1. Transfer the RGB to **YIQ** space. Influence of luminance is decreased.
2. Build the **IQ 2D histogram using I and Q channel** for faster searching.

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.595716 & -0.274453 & -0.321263 \\ 0.211456 & -0.522591 & 0.311135 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



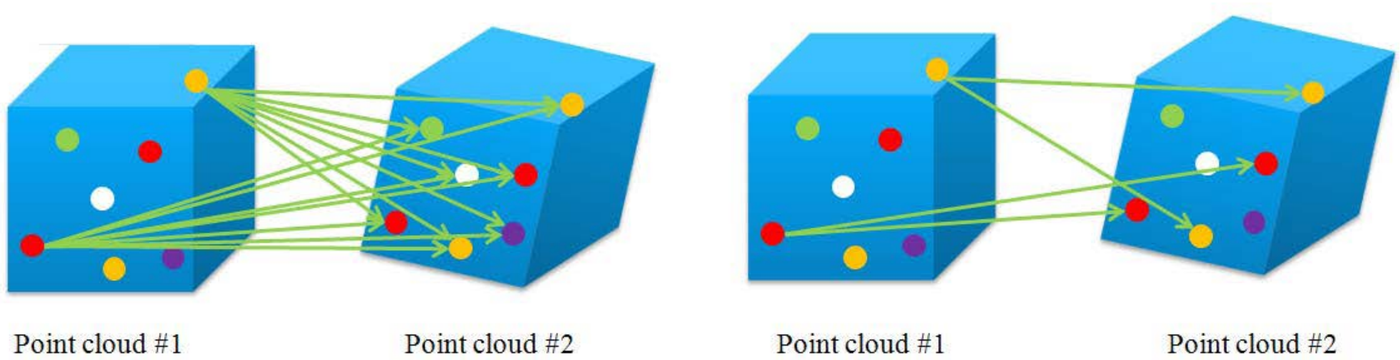


Color ICP Algorithm Improve, Cont.

Improve the normal ICP algorithm :

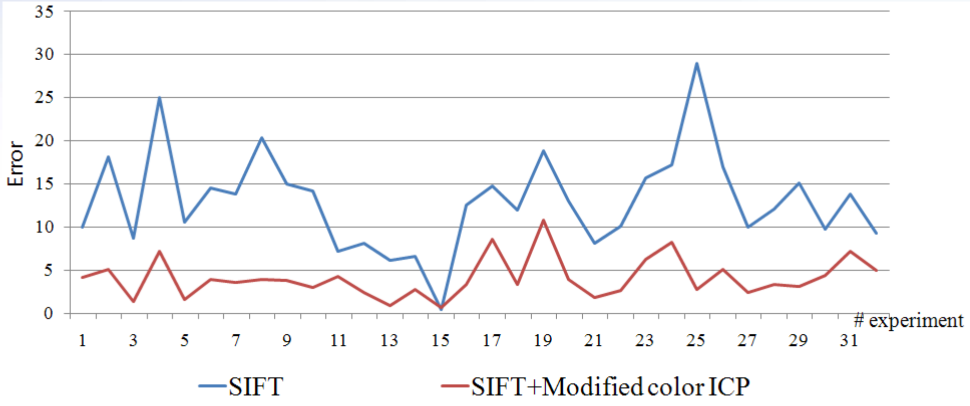
1. Transfer the RGB to **YIQ** space. Influence of luminance is decreased.
2. Build the **IQ 2D histogram using I and Q channel** for faster searching.
3. Consider color distance in nearest neighbor search algorithm.
4. Color dynamic range can compress data size.

$$d_{color} = \|p_{color} - q_{color}\| = \sqrt{a_Y(p_Y - q_Y)^2 + a_I(p_I - q_I)^2 + a_Q\left(p_Q - q_Q\right)^2}$$

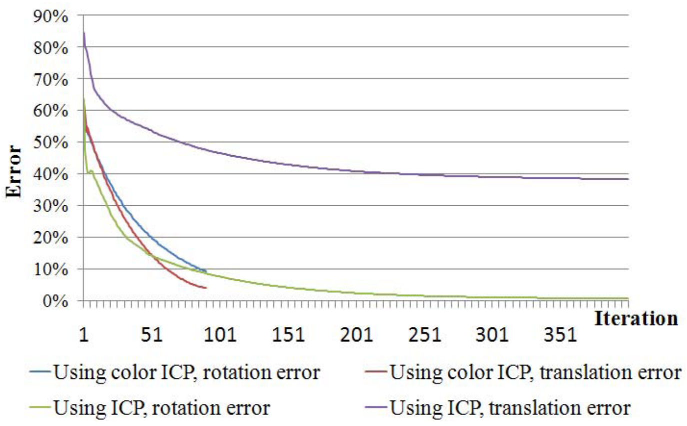


Higher Accuracy Location

- Compare the rotation error graph of SIFT and Color ICP + SIFT algorithm



- Compare the rotation error graph of ICP and Color ICP algorithm

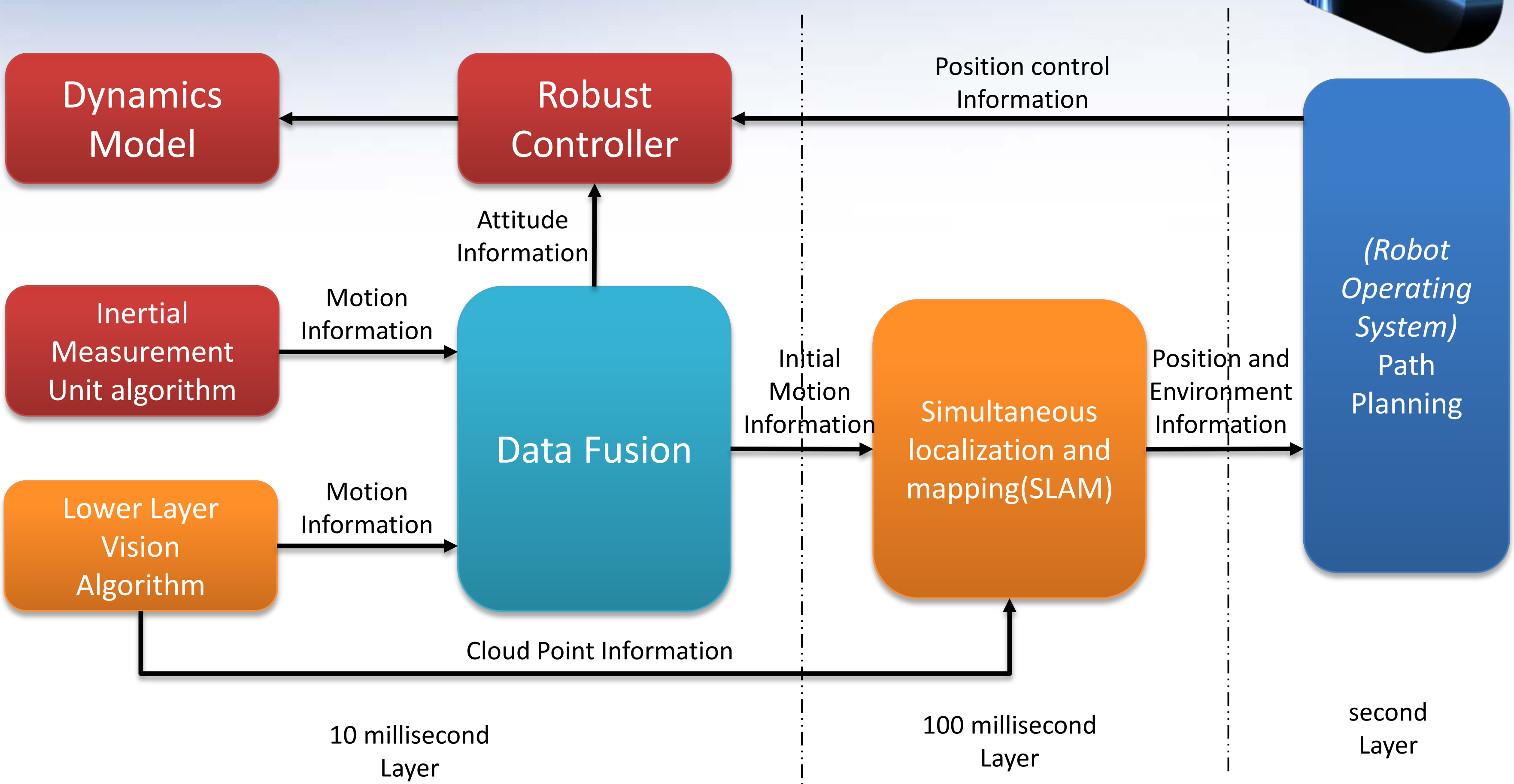


Time Complexity

- Comparison of searching time to find the closest points

	Number of search bins		
	1 bin	9 bins	25 bins
Full search (ICP and color ICP)	15985 ms		
Fixed range with 2D histogram	647 ms	3203 ms	6235 ms
Dynamic range with 2D histogram (modified color ICP)	315 ms	542 ms	1000 ms

UAV System Structure



High accuracy attitude information
And low accuracy position information

Higher accuracy position information

References

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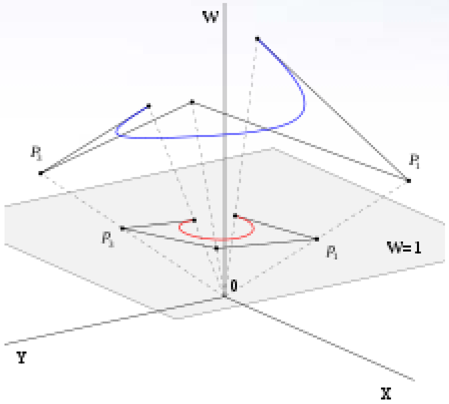
- *T.Lindeberg, "Scale-space theory: A basic tool for analyzing structures at different scales"*
- *Jon Louis Bentley, "Multidimensional Binary Search Trees Used for Associative Searching", Stanford University 1975 ACM Student Award*
- *P. Henry, M. Krainin, E. Herbst, X. Ren, and D. Fox. , "RGB-D Mapping: Using Depth Cameras for Dense 3D Modeling of Indoor Environments", Proc. of International Symposium on Experimental Robotics (ISER), 2010*
- Lu F and Milios E "Globally consistent range scan alignment for environment mapping" ,Autonomous Robots 4: 333–349, 1997

Thank You!

Random Sample Consensus (RANSAC)

- Build a equation between X image and X' image in the projective coordinates

$$kX_{i-1} = HX_i$$

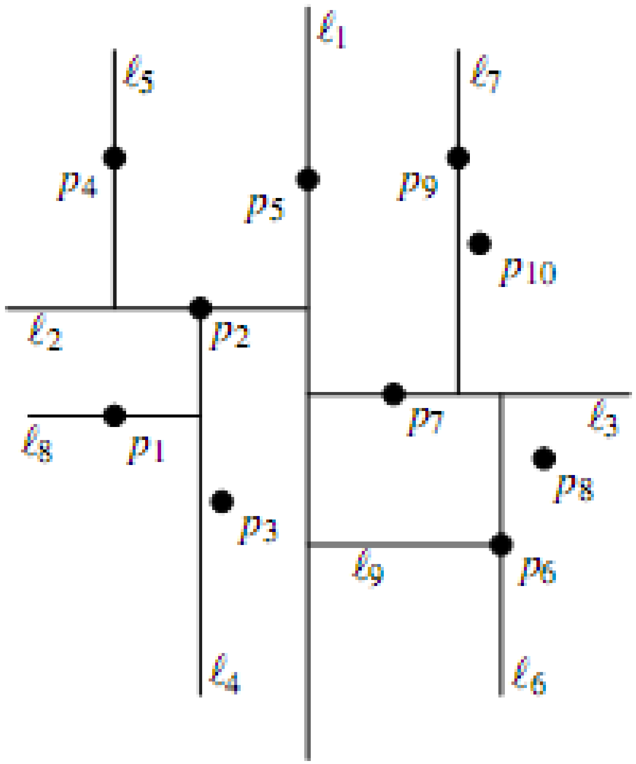


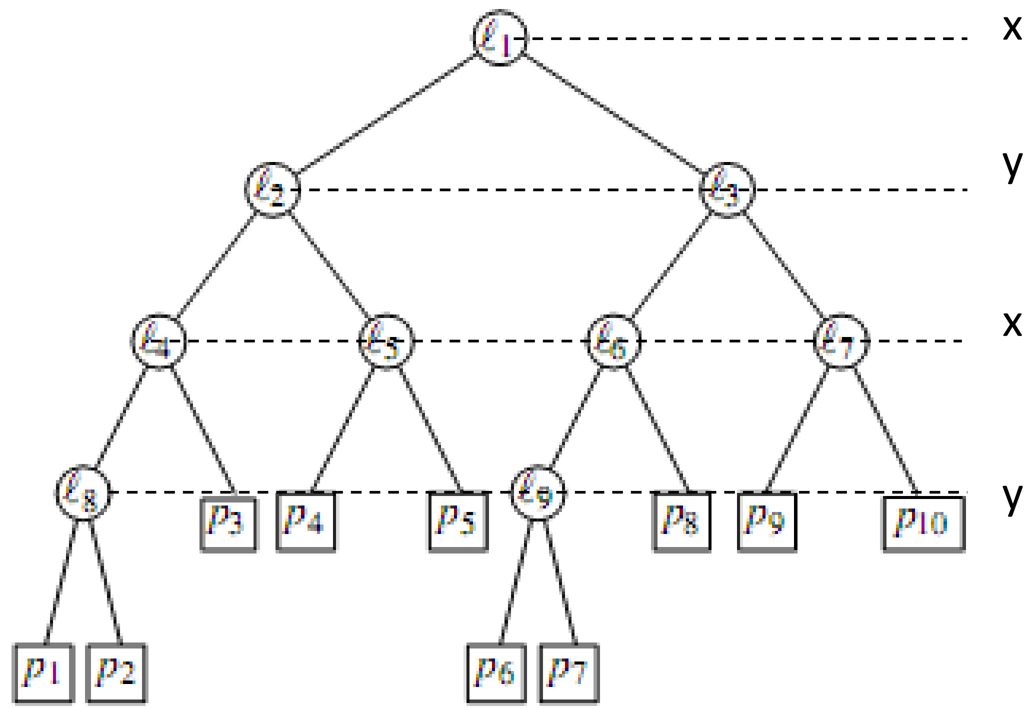
- 1) Randomly selected 5 pairs of match from X_i image and X_{i-1} image to calculate H and K matrix.

- 2) Calculate the distances between from another pairs of X image and X_{i-1} image through the equation which does not include the set of 5 pairs points . If the distance is less than a threshold value, the point will be added to the "inliers" set.

- 3) Repeat (1) and (2) step N times. Count the number of image feature points match for each time. Select the largest number of inliers point in that group. Use the least squares method to update the transformation matrix H.

KD-Tree Introduction





Best-Bin-First(BBF) algorithm