BANSAC: A dynamic BAyesian Network for adaptive SAmple Consensus

Valter Piedade and Pedro Miraldo (valter.piedade@tecnico.ulisboa.pt and miraldo@merl.com)

ICCV23 PARIS

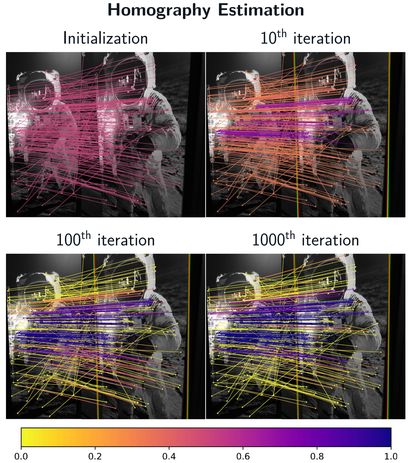
Project page

Introduction/Motivation

- RANSAC is the gold-standard algorithm for robust estimation in computer vision, in tasks such as camera localization, visual odometry, and 3D mapping, among others;
- RANSAC aims at solving a generic problem of type $f(\mathbf{x}, \theta) = 0$;
- It iteratively samples minimal data, estimates the model hypothesis, and runs inlier counting;
- Several RANSAC variants improve the sampling process, the hypothesis generation, the stopping criterion, and the model scoring.

Research Question:
Will changing the scoring weights over iterations help in sampling and defining the stopping criterion?

Homography Estimation



Contributions

- A new adaptive sampling strategy that uses a dynamic Bayesian network to update data inlier scores;
- A new stopping criterion; and
- Our approach outperforms the best baselines in accuracy and efficiency.

Algorithm 1: *BANSAC outline*
Input – Data $\mathcal{Q}$, and (optional) pre-computed scores $\mathcal{P}^0$
Output – Best model θ^*, and $\mathcal{C}^*$

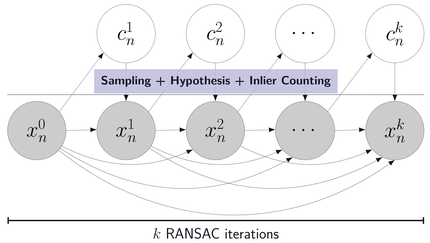
$k \leftarrow 1$;
while $k < K$ **do**
  $\mathcal{S}^k \leftarrow$ weighted_sampling $\left(\mathcal{Q}, \mathcal{P}^{k-1}\right)$
  $\theta^k \leftarrow$ hypothesis $\left(\mathcal{S}^k\right)$;
  $\mathcal{C}^k \leftarrow$ model_evaluation $\left(\mathcal{Q}, \theta^k\right)$;
  $\theta^*, \mathcal{C}^* \leftarrow$ best_model $\left(\mathcal{C}^k, \theta^k\right)$;
  $\mathcal{P}^k \leftarrow$ update_probabilities $\left(\mathcal{C}^k, \mathcal{X}^{0:k-1}\right)$
  if stopping_criteria $\left(\mathcal{P}^k\right)$ **break**
  $k \leftarrow k + 1$;

Notations

Notation	Description
$\mathcal{X}^k \triangleq \{x_1^k, ..., x_N^k\}$	Inlier/outlier guesses at iteration k.
$\mathcal{X}_n \triangleq \{x_n^0, ..., x_n^k\}$	Inlier/outlier guesses for $\mathbf{x}_n$.
$\mathcal{C}_n \triangleq \{c_n^1, ..., c_n^k\}$	Inlier/outlier evidence per iteration for $\mathbf{x}_n$.
$\mathcal{P}^k \triangleq \{P\left(x_1^k \mid C_1^{1:k}\right), ..., P\left(x_N^k \mid C_N^{1:k}\right)\}$	Inlier/outlier probabilities at iteration k.

Probabilistic model

- Each data point $(\mathbf{x}_n)$ inlier probability is modeled by a dynamic Bayesian network as shown on the right;
- Sampling weights are given by $P\left(x_n^k = \text{inlier} \mid C_n^{1:k}\right)$;



- With 1st order Markov: $\phi_k(x_n^{0:k}, c_n^{1:k}) = P(x_n^k \mid x_n^{k-1}, c_n^k) P(c_n^k \mid x_n^{k-1})$.

Probability Update:
Our sampling strategy uses $P\left(x_n^k = \text{inlier} \mid C_n^{1:k}\right)$, for all n. For the inference of $x_n^k = \text{inlier}$, we use evidences $\mathcal{C}_n$, and hidden variables $\mathcal{X}_n \backslash x_n^k$:

$$P\left(x_n^k = \text{inlier} \mid C_n^{1:k}\right) = \alpha \Phi\left(x_n^k = \text{inlier}, x_n^{0:k-1}, C_n^{1:k}\right), \text{ with}$$

$$\Phi(x_n^k, x_n^{0:k-1}, C_n^{1:k}) = \textstyle\sum_{x_n^{k-1}} \phi_k(x_n^{0:k}, c_n^{1:k}) \Phi(x_n^{k-1}, x_n^{0:k-2}, C_n^{1:k-1}).$$

Weighted Sampling:

1. Estimate sampling weights $\mathcal{W}^k$ from $\rho\left(\mathcal{P}^{k-1}\right)$;
2. Generate a weighted discrete distribution using $\mathcal{W}^k$;
3. Sample a minimal set $\mathcal{S}^k$ from the created distribution.

Stopping Criterion:
Before the update:

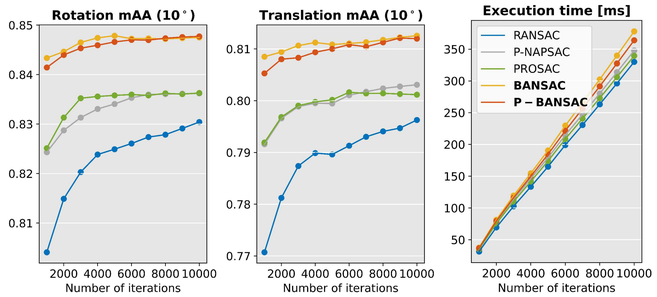
1. Compute the number of outliers from the best model so far $\rightarrow$ O^*;

After the update:

2. Count the number of data points with $P\left(x_n^k = \text{inlier} \mid C_n^{1:k}\right) < \tau \rightarrow \tilde{O}^k$;
3. Stop if $\tilde{O}^k >= O^*$.

Experiments

- **Varying number of fixed iterations:** Without a stopping criterion.



Results

- **Fundamental matrix estimation:**

Metrics	RANSAC	NAPSAC	P-NAPSAC	PROSAC	BANSAC	P-BANSAC
Rotation mAA (5°) ↑	0.467	0.206	0.460	0.464	**0.500**	0.478
Rotation mAA (10°) ↑	0.559	0.308	0.557	0.560	**0.589**	0.571
Translation mAA (5°) ↑	0.267	0.0780	0.260	0.264	**0.292**	0.274
Translation mAA (10°) ↑	0.353	0.129	0.345	0.349	**0.380**	0.360
Avg. time [ms] ↓	14.4	26.3	12.2	12.5	9.80	**7.88**

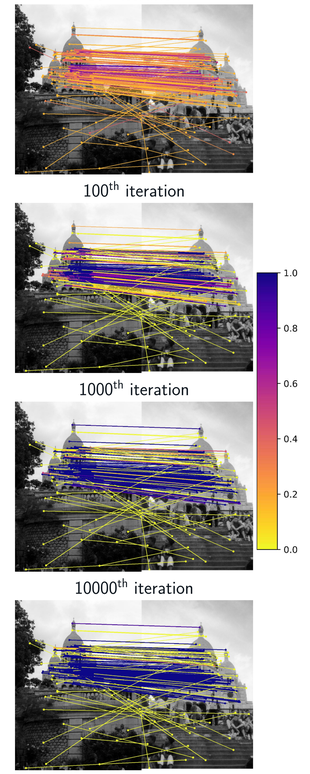
- **Essential matrix estimation:**

Metrics	RANSAC	NAPSAC	P-NAPSAC	PROSAC	BANSAC	P-BANSAC
Rotation mAA (5°) ↑	0.568	0.158	0.551	0.569	**0.610**	0.603
Rotation mAA (10°) ↑	0.645	0.226	0.641	0.653	**0.680**	0.675
Translation mAA (5°) ↑	0.422	0.0810	0.402	0.417	**0.460**	0.454
Translation mAA (10°) ↑	0.532	0.137	0.514	0.527	**0.566**	0.559
Avg. time [ms] ↓	25.5	40.1	20.9	21.5	15.6	**15.2**

- **Homography estimation:**

Metrics	RANSAC	NAPSAC	P-NAPSAC	PROSAC	BANSAC	P-BANSAC
Homography mAA (5 px) ↑	0.422	0.152	0.158	0.210	0.443	**0.446**
Homography mAA (10 px) ↑	0.552	0.208	0.235	0.291	0.569	**0.573**
Avg. time [ms] ↓	**2.30**	2.78	2.96	3.09	4.04	3.07

Fundamental Matrix Estimation



- **Varying inlier ratio:** 60% inliers at a score of 0.82 and 30% at 0.92.