Probabilistic Pose Estimation using Mixtures of Projected Gaussians

**Matched Pair**
- **Database Feature**
  - key point & descriptor in 2D
  - 3D position
  - 3D orientation
- **Camera Feature**
  - rotation in image plane
  - RGB-D camera: 3D position

**Strength Evaluation**
- radius match:
  - similarity of matched features
  \[ \lambda \in (0, 1) \]
  - matching strength committed to pose estimation

**Stability Evaluation**
- **Goal**
  - feature stabilization
  - outsorting of outliers
- **Kalman Filter**
  - pose and variance estimation: impact in pose estimation
  - variance respective appearance rate

**Input:**
- strong and stable matched feature pairs

**Sensor Model**
- **ideal world**
  - 6D feature pose determined & matching 6D feature in database
  \[ \Rightarrow \text{object pose} \]
- **real world**
  - camera data only provides uncertain feature pose information
  \[ \Rightarrow \text{information fusion of several matched pairs necessary} \]

**Probability Density over 6D Poses in**
- desired mixtures of Gaussians, but only for translation possible
- rotation on unit sphere \( S^3 \)
- Gaussians on tangent space

**Parameterization of 6D Pose**
- **3D rotation**
  - unit quaternion \( q = a + b \mathbf{i} + c \mathbf{j} + d \mathbf{k} \) with \( a^2 + b^2 + c^2 + d^2 = 1 \)
- **3D translation**
  - imaginary quat. \( q_i = 0 + b \mathbf{i} + c \mathbf{j} + d \mathbf{k} \) translation vector
- **6D rigid motion**
  - dual quaternion \( q_d = q + \frac{1}{2} \mathbf{v} \) with \( \mathbf{v}^2 = 0 \)

**Mixture of Projected Gaussians**
- **definition**
  \[ M = (1 - \lambda)u + \sum_{i} \lambda \text{PG}_i \]
  - unit distribution \( u \) for background noise
- **fusion**
  - similar to fusion of Mixtures of Gaussians
- **composition**
  - used to change coordinate systems
- **element reduction**
  - merge similar elements, drop elements with negligible weights

**Output:**
- probability distribution describing object pose

**Features**
- **SENSOR MODEL**
  - input:
    - strong and stable matched feature pairs
  - parameterization of 6D pose:
    - 3D rotation
    - 3D translation
    - 6D rigid motion
  - mixture of projected Gaussians:
    - definition
    - fusion
    - composition
    - element reduction

**Results**
- probability distribution describing object pose

**Benefits for Perception**
- representation of weak pose information
- efficient calculation
- open to various feature types: surface / object shape features
- allows for forward inference

**Selected publications:**
- M. Lang, W. Feiten, "MPG - Fast Forward Reasoning on 6 DOF Pose Uncertainty", Inproceedings ROBOTIK 2012
- W. Feiten et al., "6D Pose Uncertainty in Robotic Perception", Advances in Robotics Research, Springer Berlin Heidelberg, 2009