Model-based Analysis of Dynamic Scenes from Range-Color Video

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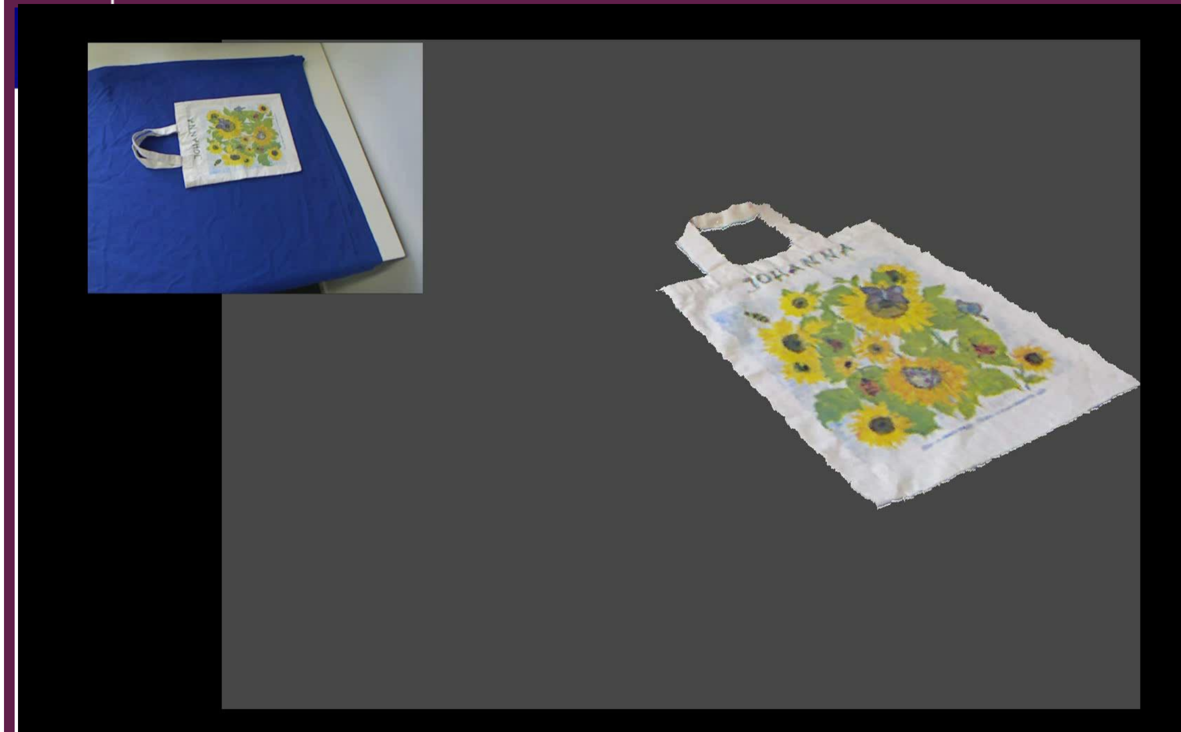
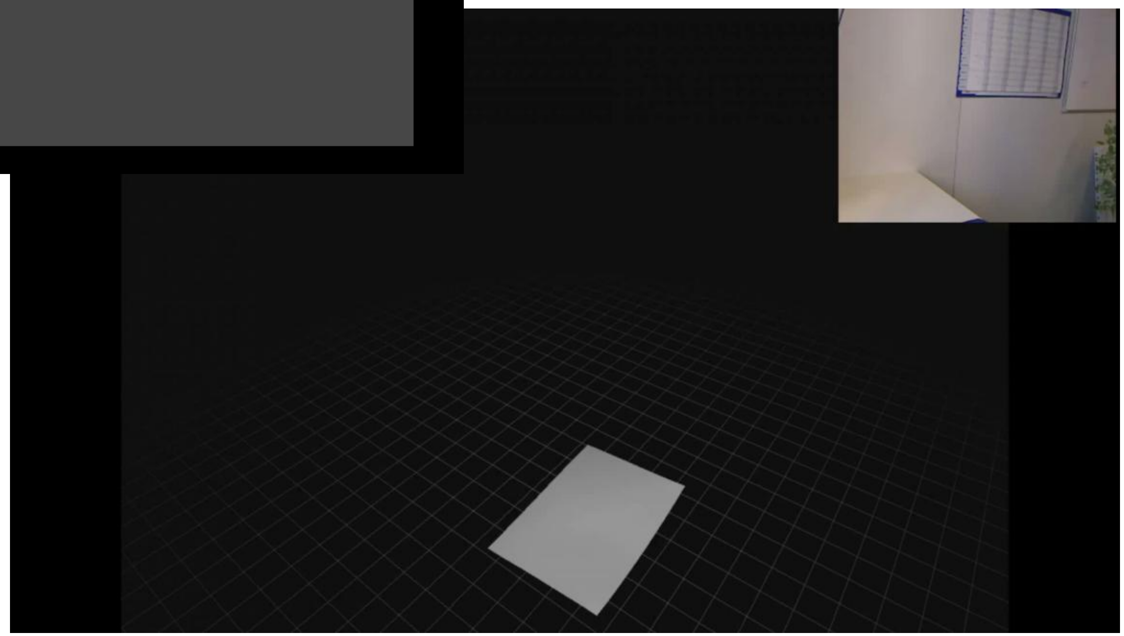


Goal:

Handling flexible objects with and without surface texture

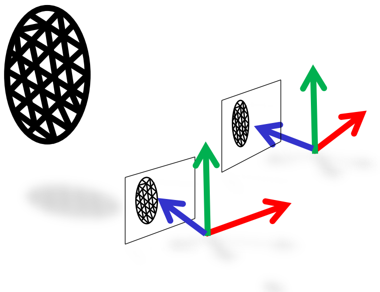


Examples:

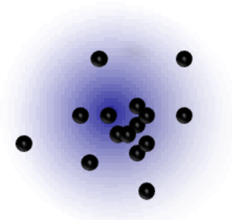
- Cloth
- paper sheets
- rubber material

Outline

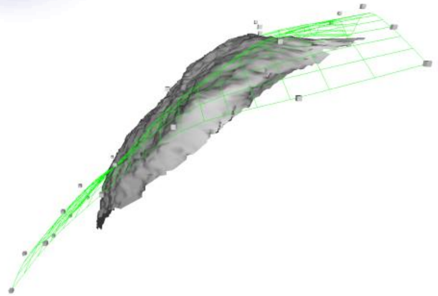
- Approach: Analysis by Synthesis (model-based estimation)



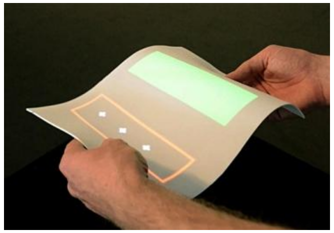
- Solution: Efficient non-convex solvers using stochastic optimisation



- Models: application-adapted deformations and error functions



- Applications: deformation tracking, material property estimation, intuitive user interfaces



Traditional Approach:

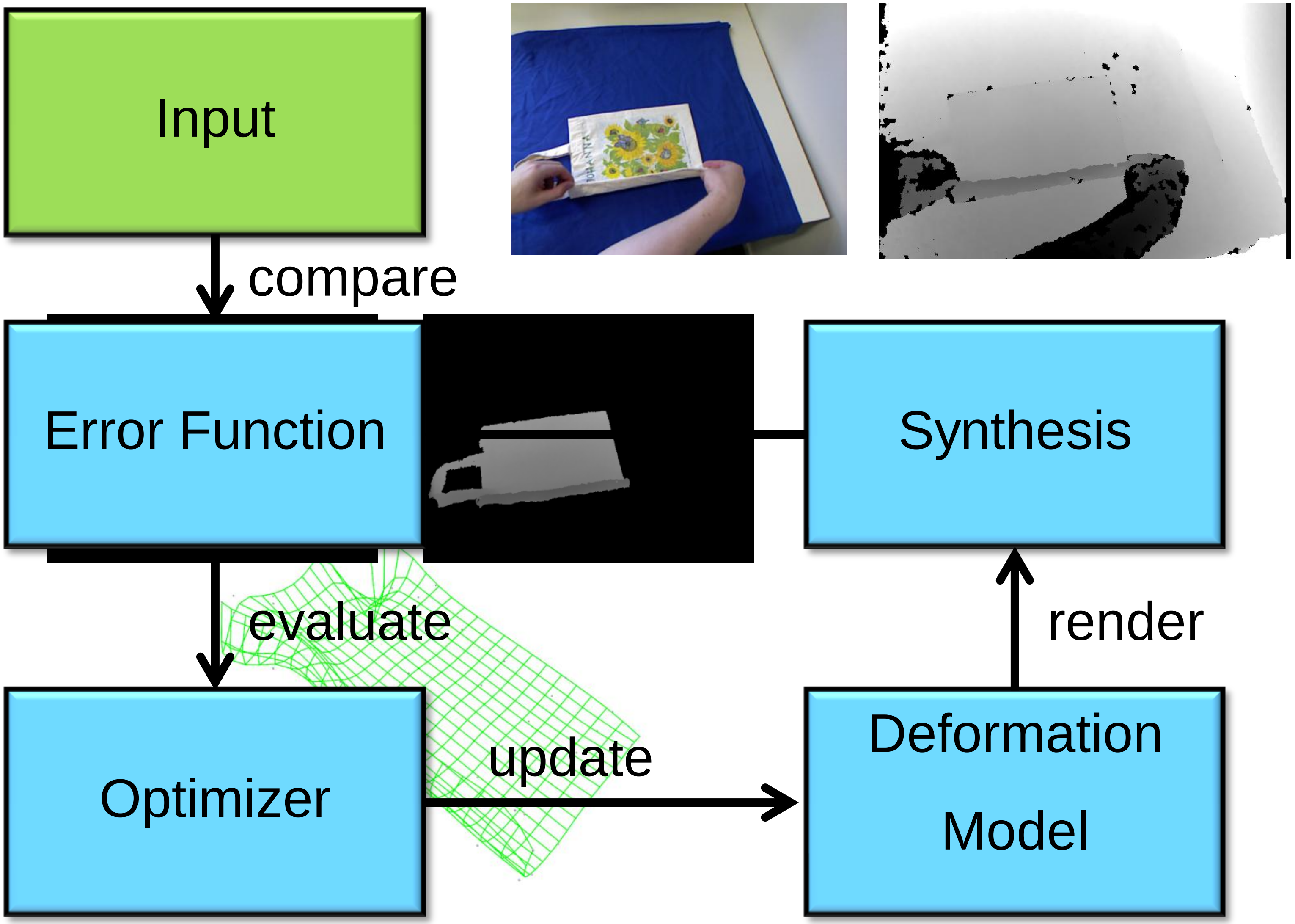
- Use 2D color features and assign depth / 3D position

  → *Unstable depth values at discontinuities*

- Use 3D / depth image features

  → *Not robust when object deforms*

Analysis by Synthesis



Analysis by Synthesis

- No features
  - No need for outlier handling

- Ability to directly apply noise / accuracy measures
  - No need for covariance propagation

Why AbS?

- Deformation problems are high dimensional
  - Use of complete image data

- AbS can combine arbitrary sets of sensors

- AbS does not have to be slow – We show a real-time system

Versatility through Modularity

Synthesis	- Full Rendering, Bayer Pattern Simulation,… - Fast, Sparse Synthesis
Error Function	- Heuristic Error Function - Physical Plausibility Error - Probabilistic Likelihood Function
Deformation Model	- Generic (complex, versatile) - Problem optimized (fast) - Anything in between
Optimizer	- Scalable between thorough and fast search

Optimization

Optimization problem typically has very high dimension (for deformation grid of 4 x 4 3D-control points: 48 dimensions)

High dimensional optimization problem with no derivation available

=> CMA-ES (Covariance Matrix Adaptation – Evolution Strategy)

Samples (Individuals) per Iteration:

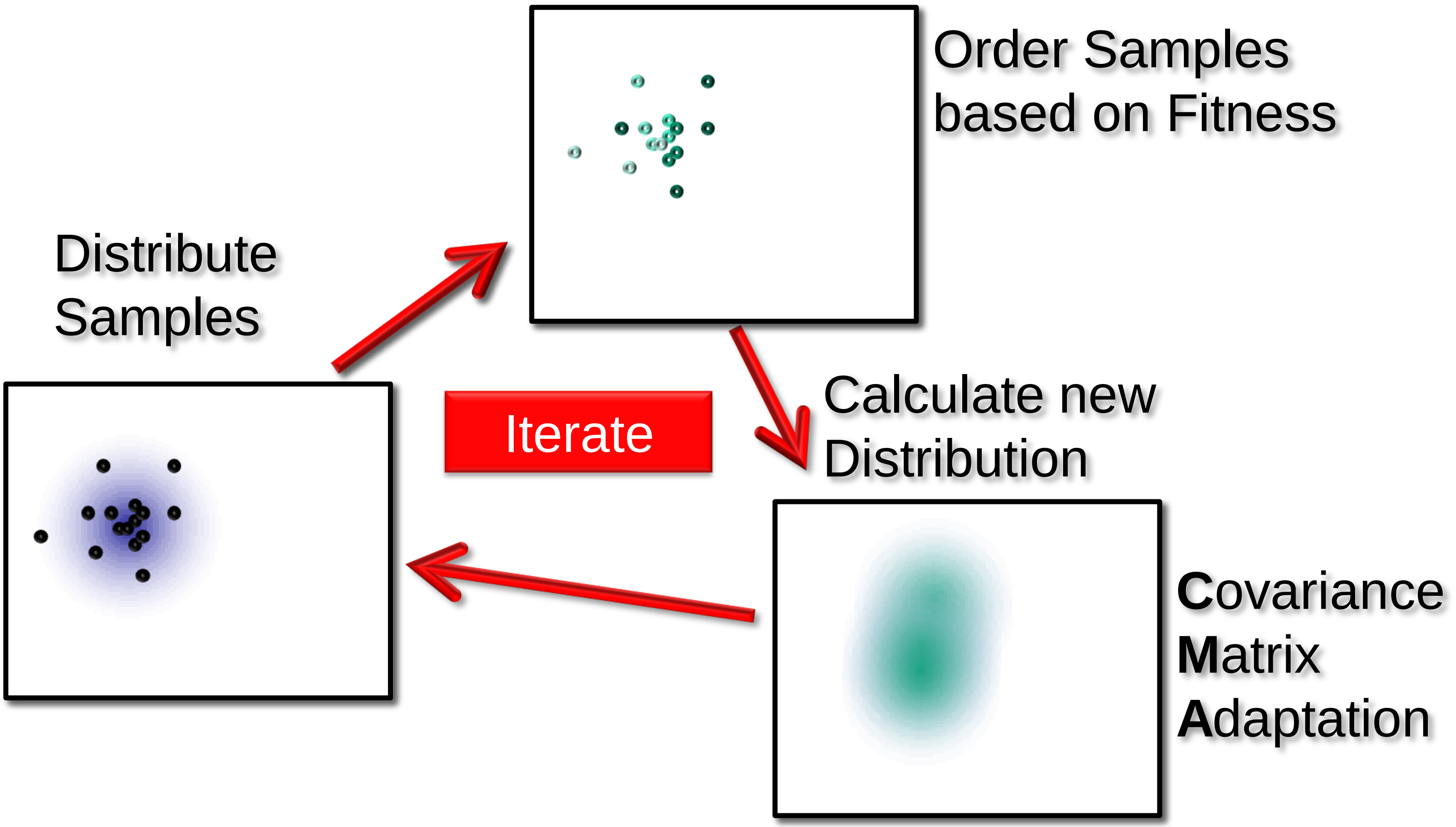
Optimizer

- Scalable between thorough and fast search

4 + floor (3 * log(dim))

e.g. 10 for dim=100

CMA-ES

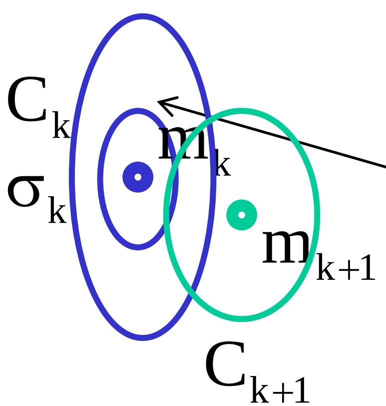


Hansen (Springer 2006) – The CMA Evolution Strategy: A comparing Review

Covariance Matrix Adaptation

- m_k • Mean at iteration k
- C_k • Covariance Matrix at iteration k
- σ_k • Search size at iteration k

$$C_{k+1} = (1 - \ldots \|p_c\|)C_k + \ldots \sum_i w_i \frac{x_i - m_k}{\sigma_k}\left(\frac{x_i - m_k}{\sigma_k}\right)^T$$



$$m_{k+1} = \sum_i w_i x_i \qquad \sigma_{k+1} = \sigma_k \cdot c_\sigma \left(\|p_\sigma\| - 1\right) \cdot (\ldots)$$

$$x_i \sim N\left(m_k, \sigma_k^2 C_k\right)$$

$$\downarrow$$

$$f(x_i) \rightarrow w_i, \sum_i w_i = 1$$

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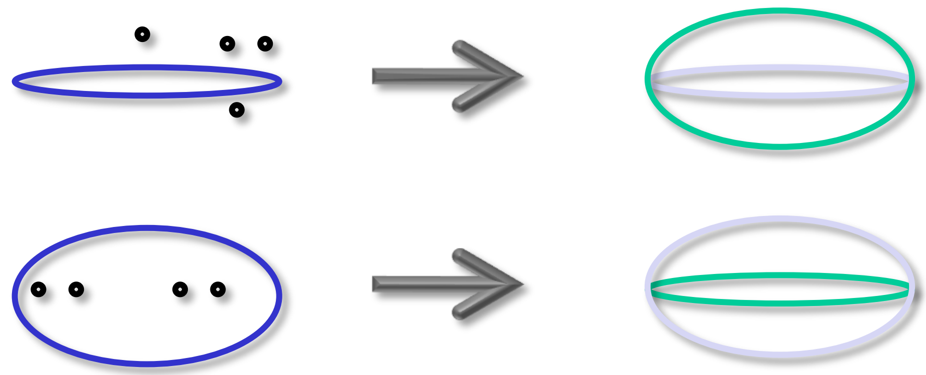
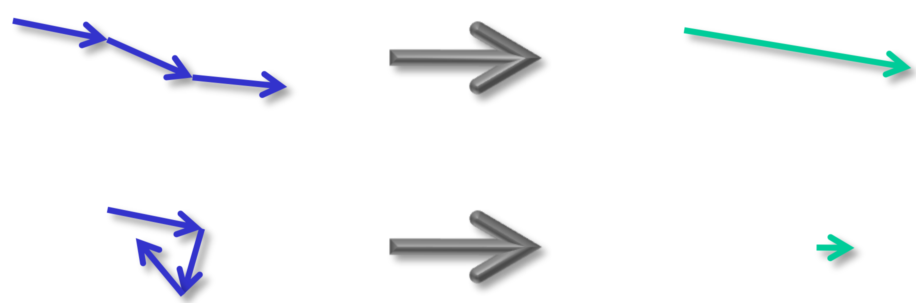
Search Paths

p_c Evolution path



=> Fast adaptation of relevant subspace

p_σ Evolution path

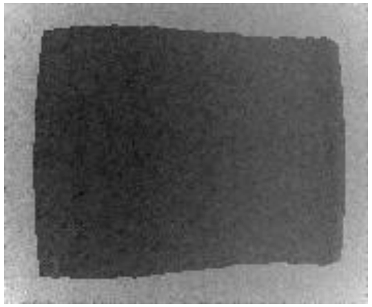


Hansen (Springer 2006) – The CMA Evolution Strategy: A comparing Review

Error function: ToF Noise Handling

Synthesis	- Full Rendering
Error Function	- Probabilistic Likelihood Function
Deform. Model	- Any
Optimizer	- Problem dependent

Straight forward implementation of
pixel-wise amplitude based noise statistics



No heuristics needed to combine color and depth

Jordt, Koch (LNCS 8200) – Reconstruction of Deformation from Depth and Color with Explicit Noise Models

Error function: ToF Noise Handling

- Every pixel p in sensor s has its own probability distribution
- Calculate the likelihood of the synthesized depth x_{dr} given a measured depth x_{dm} and a measured amplitude x_{am}:

$$l_{p,s} = L(x_{dr} | x_{dm}, x_{am})$$

- Formulate fitness function as log likelihood over all pixel and sensors:

$$Fitness = \sum_{s \in S} \sum_{p \in P_s} \log(l_{p,s})$$

Jordt, Koch (LNCS 8200) – Reconstruction of Deformation from Depth and Color with Explicit Noise Models

Error function: ToF Noise Handling

Example:

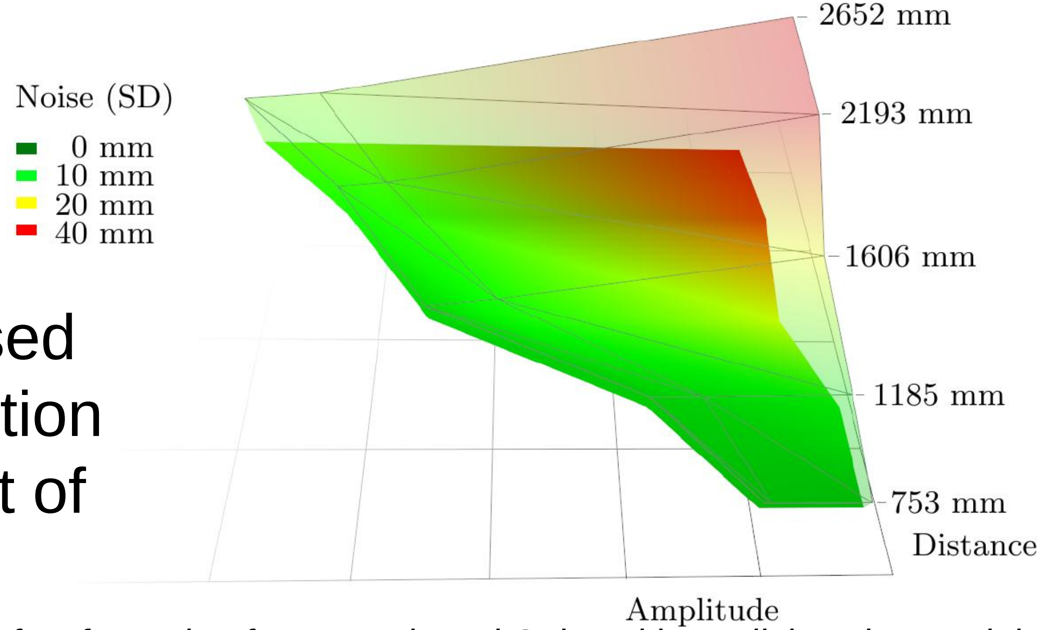
- Assume Gaussian noise in every pixel

- Sample variance and mean for every pixel for different distances (known) and reflectivities

- Interpolate variance and mean for each measurement:

-Calculate likelihood based on interpolated distribution

-Significant improvement of deformation error



Jordt, Koch (LNCS 8200) – Reconstruction of Deformation from Depth and Color with Explicit Noise Models

Example 1: Cloth Tracking

Synthesis	- Full Rendering
Error Function	- Heuristic Error Function (RMS)
Deform. Model	- Generic (NURBS based)
Optimizer	- Thorough search (high individual count)

Jordt, Koch (IJCV 2013) – Direct Model-based Tracking of 3D Object Deformation in Depth and Color Video

Example 1: Cloth Tracking

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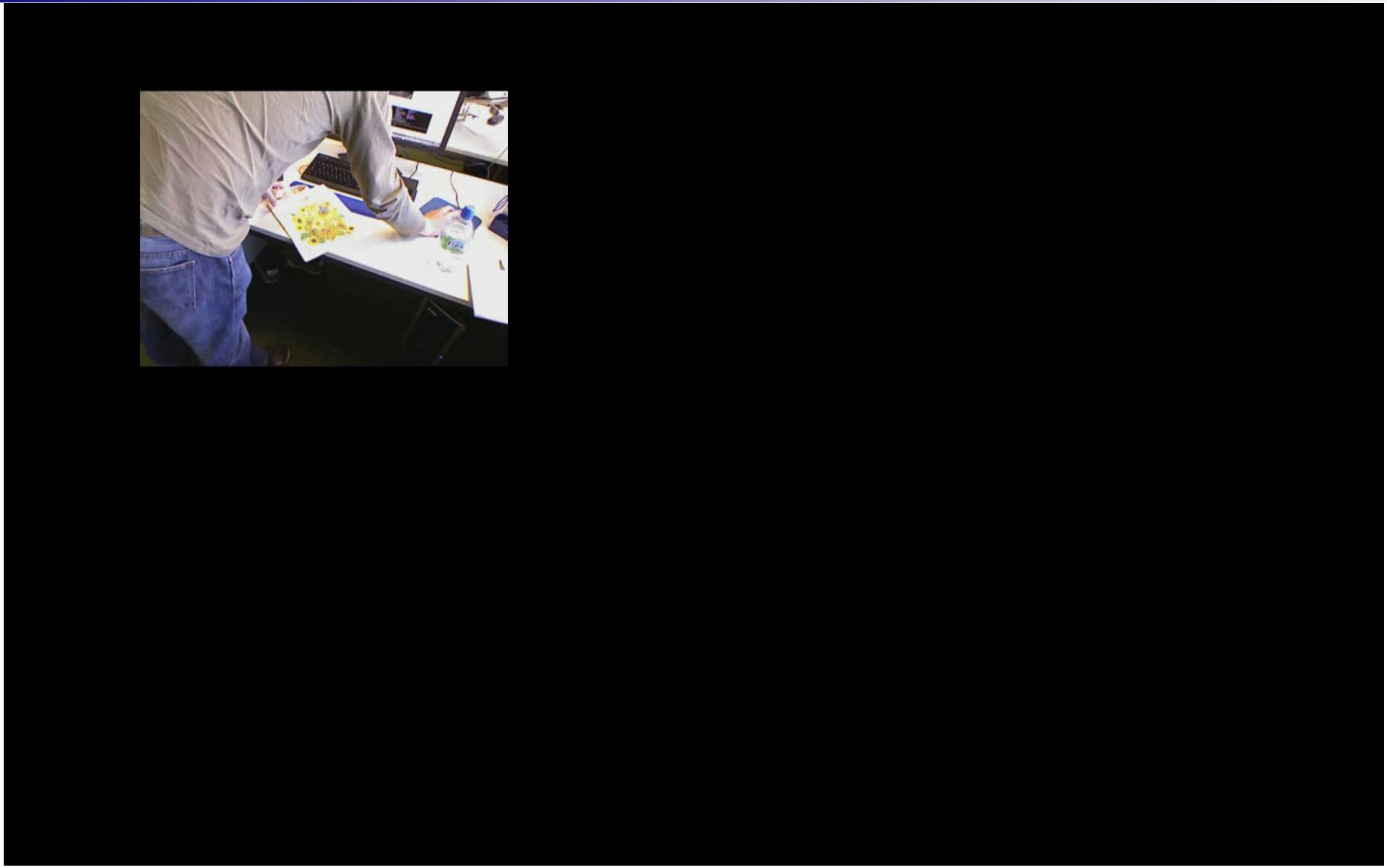
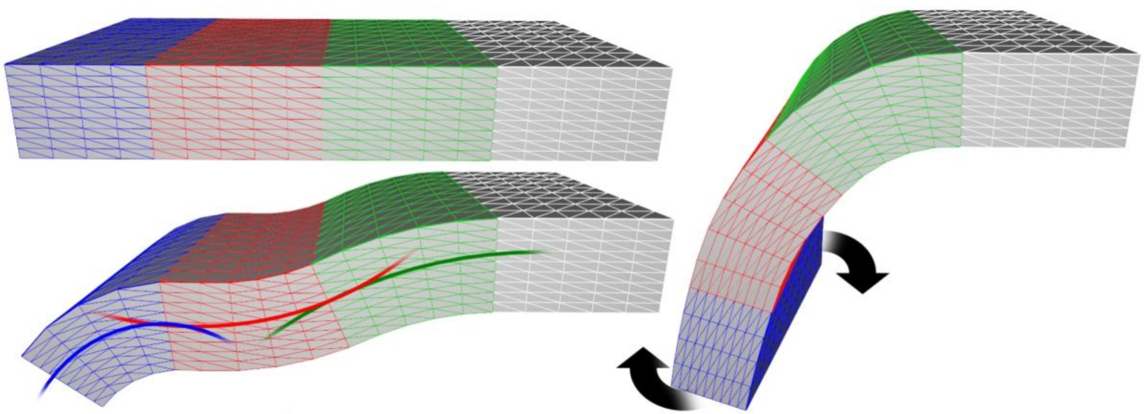


Jordt, Koch (IJCV 2013) – Direct Model-based Tracking of 3D Object Deformation in Depth and Color Video

Example 2: Material Property Estimation

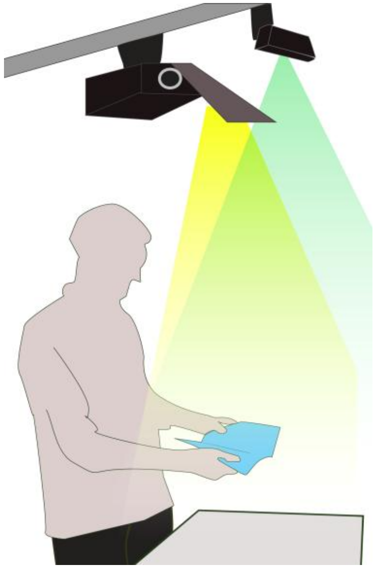
- **Synthesis** - Full Rendering, finite element model
- **Error Function** - physical, Deviation from internal forces
- **Deform. Model** - (curvature based, Young's Modulus)
- **Optimizer** - Thorough search (high individual count)

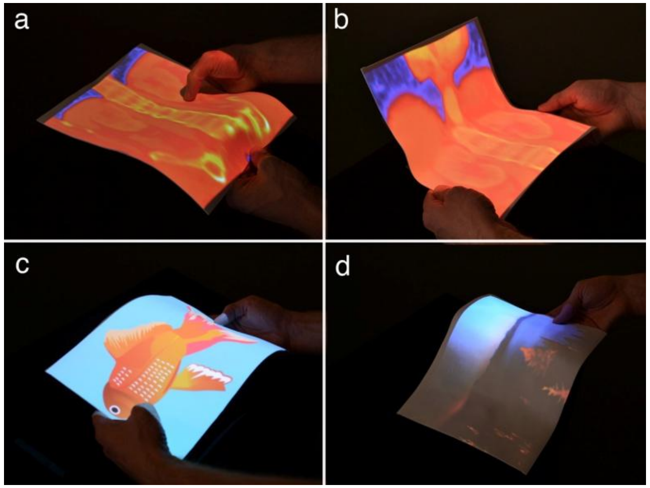


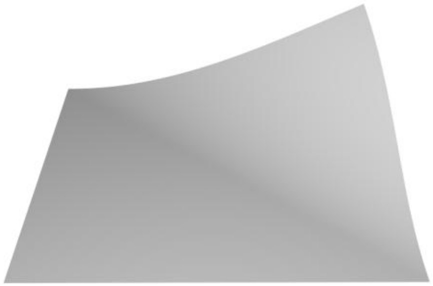

Fugl, Jordt, Koch (DAGM 2012) – Estimation of Material Properties and Pose for Deformable Objects

Example 3: FlexPad (real-time)

Synthesis	- Fast, Sparse Synthesis
Error Function	- Heuristic Error Function
Deform. Model	- Problem optimized (fast)
Optimizer	- Fast (low individual count)





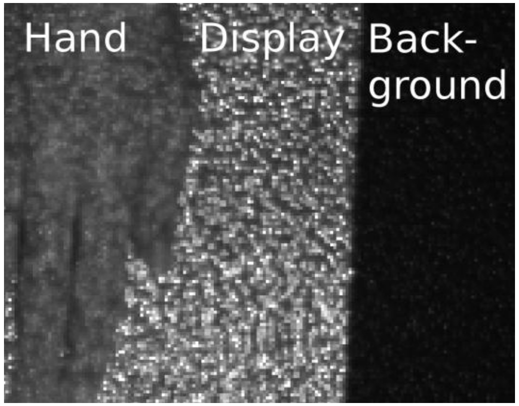


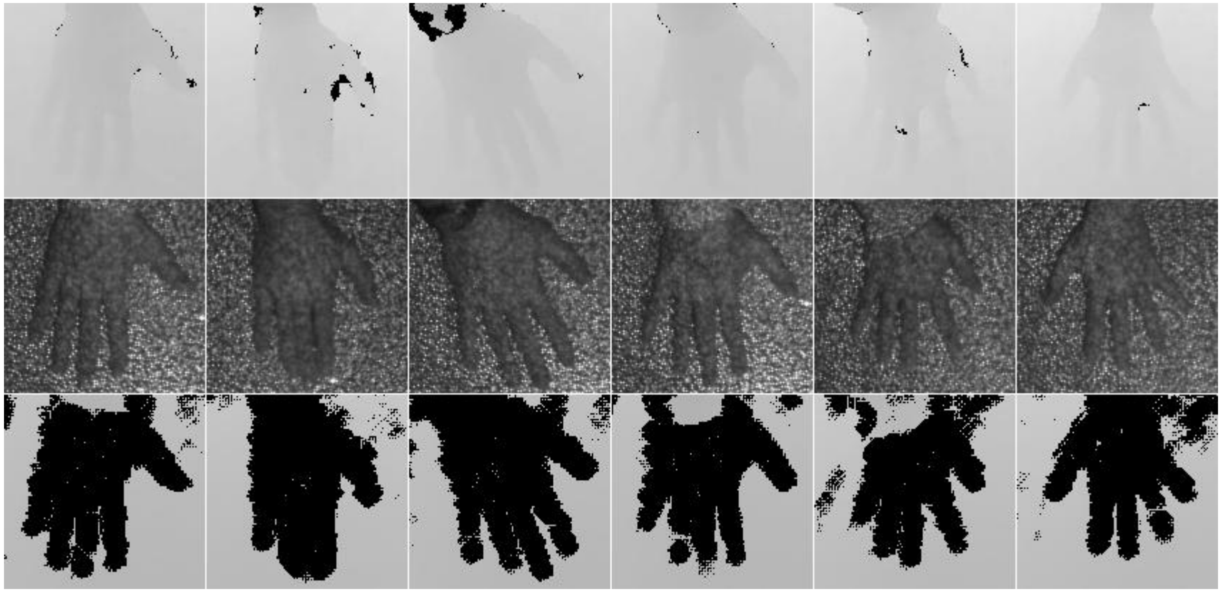
Steimle, Jordt, Maes(CHI 2013) – Flexpad: Highly Flexible Bending Interations for Projected Handheld Displays

Example 3: FlexPad (real-time)

Challenge: Segmentation of skin and paper

Solution: Use sub-surface scattering in IR image

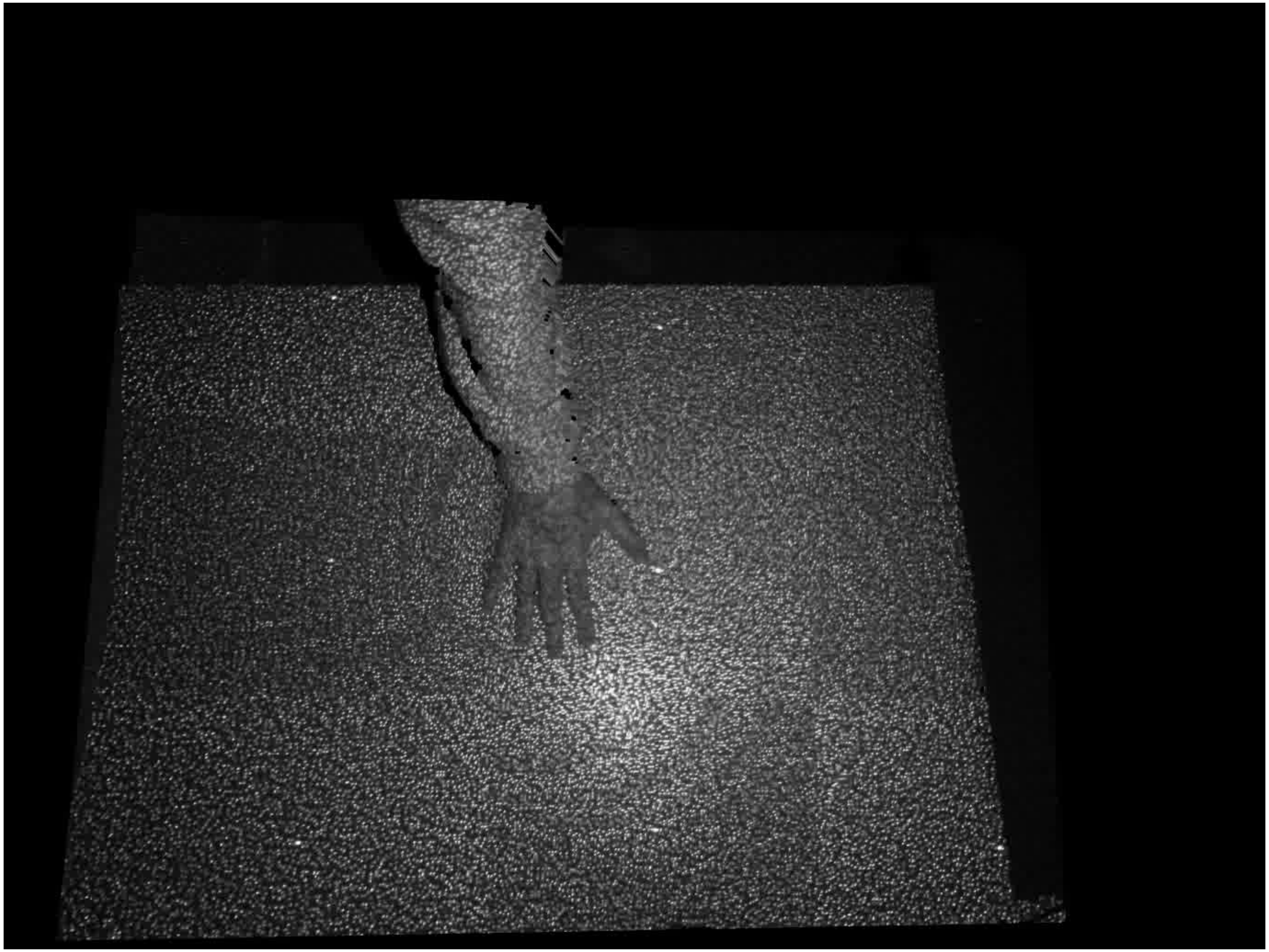




AbS does not have a problem with incomplete data!

Steimle, Jordt, Maes (CHI 2013) – Flexpad: Highly Flexible Bending Interations for Projected Handheld Displays

Example 3: FlexPad (real-time)



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Example 3: FlexPad (real-time)

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Example 3: FlexPad (real-time)

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Summary

- Model-based approaches like analysis-by-synthesis allow to model complex scenes
- carefull analysis of the sensor noise improves estimation results
- combination of application-adapted deformation models with CMA-ES allow real-time performance

Thank You

This work was supported by the Interreg4A programme of the European Union

Relevant publications:

Jordt, Koch (BMVC 2011) – Fast Tracking Of Deformable Objects In Depth and Colour Video

Fugl, Jordt, Koch (DAGM 2012) – Estimation of Material Properties and Pose for Deformable Objects

Jordt, Koch (IJCV 2013) – Direct Model-based Tracking of 3D Object Deformation in Depth and Color Video

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