

Linear and Quadratic Subsets for Template-based Tracking

Selim Benhmane¹, Alexander Ladikos¹, Vincent Lepetit², Nassir Navab¹
¹Chair for Computer Aided Medical Procedures (CAMP) - TUM, Germany
²Computer Vision Laboratory (CVLAB) - EPFL, Switzerland



Overview

Problem

What is the best pixel subset to consider during template-based tracking?

Solution

- Considering the subset verifying the assumption of linearity of the pixel intensity with respect to the motion parameters (made during the derivation of the tracking algorithm) improves the tracking performances (Matsis et al., ICVGIP 2006).
- However, the search for the optimal subset results in a combinatorial explosion when the templates are large.
- We propose a simple algorithm that efficiently extracts linear or quadratic subsets in large templates. These subsets are able to cope with high inter-frame motions.

Results

1. Reducing the number of pixels considered improves the efficiency of the tracking algorithm.
2. The algorithm provides very reliable subsets: with less than 30% of the template, it is possible to double the convergence frequency for high inter-frame motions.

Faster tracking, higher success rate, better performance

Extraction Algorithm

Basic Ideas

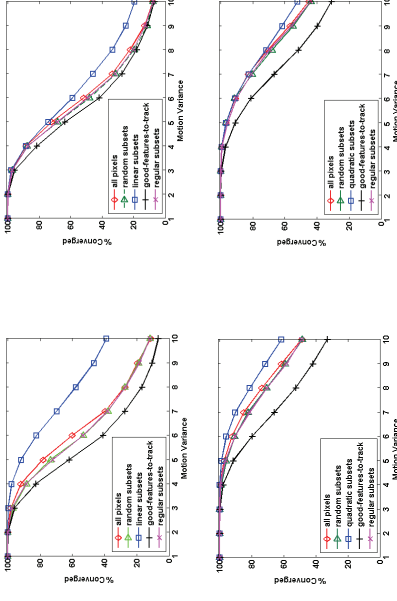
- A linear subset converges in one iteration using the IC algorithm.
- A quadratic subset converges in one iteration using the ESM algorithm.
- Both linear and quadratic subsets are stable under the union operation.

Proposed Algorithm

```

warp the reference template with N random motions (N >> 1)
set a counter c(l) for each pixel l of the template (initialized to 0)
for each random motion Gt
    do one iteration to obtain an estimate Gt of Gt
    compute pt = w(Gt; p) // The true new pixel position
    compute pe = v(Gt; p) // The estimated new pixel position
    if ||pe - pt|| < 1 // Is one iteration enough to converge?
        end if
        c(l) = c(l) + 1
    end for
select the union of the (3 x 3) regions around the pixels of highest
counters value
    
```

Convergence Frequency



First row: results obtained with the IC algorithm; second row: results obtained with the ESM algorithm; left column: without noise; right column: in the presence of noise. With the IC algorithm, the linear subsets performs at least two times better than the other methods for large motions. With the ESM algorithm, the differences are smaller, but the quadratic subsets still outperforms all other methods.

Example of Linear and Quadratic Subsets

Linear and Quadratic Subsets

Template-based Tracking

In an image sequence, find the parameters \mathbf{x} of the relative motion between the camera and an object using the intensity differences: solve

$$\arg \min_{\mathbf{x}} \| \mathbf{y}(\mathbf{x}) \|$$

with $\mathbf{y}_i = \mathbf{I}_c(\mathbf{w}(\mathbf{x})(\mathbf{p}_i)) - \mathbf{I}_r(\mathbf{p}_i)$ where \mathbf{I}_c is the current image, \mathbf{I}_r is the reference image and \mathbf{w} is the warping function.

Inverse Compositional Algorithm (IC)

[Baker and Matthews, IJCV 2004]

The algorithm uses a first-order Taylor approximation of \mathbf{y} with respect to \mathbf{x} . It solves the problem iteratively, at each iteration an incremental warp is estimated:

$$\mathbf{x} = -(\mathbf{J}_{\mathbf{y}_c}^T \mathbf{J}_{\mathbf{y}_c})^{-1} \mathbf{J}_{\mathbf{y}_c}^T \mathbf{y}_c(\mathbf{0})$$

Advantage: Efficient (the Jacobian $\mathbf{J}_{\mathbf{y}_c}$ is constant)
 Limitation: Low convergence frequency and rate

Efficient Second-order Minimization (ESM)

[Benhmane and Matsis, IROS 2004]

The algorithm uses a second-order Taylor approximation of \mathbf{y} with respect to \mathbf{x} . Solves the problem iteratively, at each iteration an incremental warp is estimated:

$$\mathbf{x} = -(\mathbf{J}_{\mathbf{y}_c}^T \mathbf{J}_{\mathbf{y}_c})^{-1} \mathbf{J}_{\mathbf{y}_c}^T \mathbf{y}_c(\mathbf{0})$$

Advantage: Convergence frequency and rate higher than first-order methods
 Limitation: Efficient but less than the IC algorithm ($\mathbf{J}_{\mathbf{y}_c}$ is computed at each iteration)

Definition of Linear and Quadratic Subsets

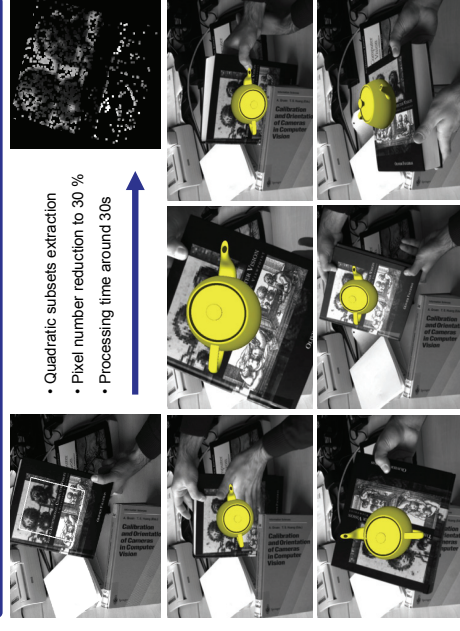
A linear subset $\mathcal{L} = \{p\}$ verifies: for all motion parameters \mathbf{x} :

$$\mathbf{y}_{\mathcal{L}}(\mathbf{0}) = -\mathbf{J}_{\mathcal{L}, \mathbf{x}}$$

A quadratic subset $\mathcal{Q} = \{p\}$ verifies: for all motion parameters \mathbf{x} :

$$\mathbf{y}_{\mathcal{Q}}(\mathbf{0}) = -\mathbf{J}_{\mathcal{Q}, \mathbf{x}}$$

Real-time Template-based Tracking



- Quadratic subsets extraction
- Pixel number reduction to 30 %
- Processing time around 30s

The book is tracked correctly despite partial occlusions, changes in scale and oblique viewing angles. The teapot is stable, showing that the pose is estimated accurately.