Perspective click-and-drag area selections in pictures

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Machine Vision Applications (MVA)
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Traditional click and drag rectangular selection

→ Fails for selecting parts in photos:
Traditional click and drag rectangular selection

→ Fails for selecting parts in photos:
  Cannot capture “New” without part of “Court”.

Man-made environments: many perspectively slanted planar parts.
Perspective click’n’drag

Intelligent UI (= computer vision + human computer interface)

→ Image “parsing” of perspective rectangles
  (automatic/semi-automatic/manual)
Video demonstrations

Perspective click-and-drag + perspective copy/paste/swap
Perspective click’n’drag: Outline

1. Preprocessing:
   Detect & structure perspective parts
   1.1 Quad detector:
      ▶ Image segmentation
      ▶ Outer contour quad fitting
      ▶ Quad recognition
   1.2 Quad homography tree

2. Interactive user interface:
   Perspective quad selection based on click-and-drag UI
   (=diagonal selection)

3. Application example: Interactive image editing (swap)
Preprocessing workflow

- Image segmentation (SRM)
- Extract region exterior contours
- Quad fitting
- External region contour
Quad detection: Sobel/Hough transform

How to detect convex quads in images?
Limitations of Hough transform [8] on Sobel image:

Combinatorial line arrangement $O(n^4)...$
$\rightarrow$ good for limited number of detected lines
(blackboard detection [8], name card detection, etc.)
Quad detection: Image segmentation (SRM)


Source codes in Java™, Matlab®, Python®, C, etc.
Quad detection: Image segmentation (SRM)
Quad detector

- For each segmented region, consider its exterior contour $C$ (polygon),
- Compute the contour diameter, $P_1 P_3$,
- Compute the upper most $P_2$ and bottom most $P_4$ extremal points
- Calculate the symmetric Haussdorff distance between quad $Q = (P_1, P_2, P_3, P_4)$ and contour $C$,
- **Accept** region as quad when distance falls below as prescribed threshold.

All quads convex and **clockwise oriented**.
Quad detection: Image segmentation (SRM)

... any closed contour image segmentation,

→ run at different scales (eg., parameter $Q$ in SRM).

Alternatively, can also use mean-shift [9], normalized cuts [7], etc.

Why? To increase the chance of detecting for some parameter tuning quads.

→ We end up with a **quad soup**
Multi-segmentation

Increases the chance of recognizing quads, but get a quad soup.

\[ Q = 128 \]
\[ Q = 10 \]
\[ Q = 0.3 \]
\[ Q = 0.25 \]
Nested convex quad hierarchy

- From a quad soup, sort the quads in *decreasing order* of their *area* in a priority queue.
- Add image boundary quad $Q_0$ as the *quad root* of the quad tree $\mathcal{Q}$.
- Greedy selection: Add a quad of the queue if and only if it is fully contained in another quad of $\mathcal{Q}$.
- When adding a quad $Q_i$, compute the homographies [2] $H_i$ and $H_{i}^{-1}$ of the quad to the unit square.
Many existing systems first unwarp...

Mobile cell phone signage recognition [5], AR systems, etc.
Perspective click’n’drag: User interaction

Perspective sub-rectangle selection:
**Clicking** on a corner \( p_1 \) and **dragging** the opposite corner \( p_3 \).

find the deepest quad \( Q \) in the quad hierarchy \( \mathcal{Q} \) that contains both points \( p_1 \) and \( p_3 \).

\[
\begin{align*}
\tilde{p}_1' &= H\tilde{p}_1 \\
\tilde{p}_2' &= \begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} \\
\tilde{p}_3' &= H\tilde{p}_3 \\
\tilde{p}_4' &= \begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix}
\end{align*}
\]
Some examples of perspective click-and-drag selections

Regular vs. perspective rectangle UI selection
Implementation details: Primitives on convex quads

By convention, order quads clockwise.
Positive determinant for the two quad-induced triangles:

$$\det = \left| \begin{bmatrix} x_1 - x_3 & x_2 - x_3 \\ y_1 - y_3 & y_2 - y_3 \end{bmatrix} \right|$$

- Predicate $p \in Q = (p_1, p_2, p_3, p_4)$?:
  Two queries: $p \in (p_1, p_2, p_3)$ and $p \in (p_3, p_4, p_1)$.

- Area of a quad:
  One half of the absolute value of the determinant of the two quad triangles.
In class Quadrangle

double area(Feature p1, Feature p2, Feature p3)
{
    double res;
    res=(p1.x-p3.x)*(p2.y-p1.y)-(p1.x-p2.x)*(p3.y-p1.y);
    return 0.5*Math.abs(res); // half of determinant
}

double area()
{
    return (area(p1,p2,p3)+area(p1,p3,p4));
}

// Clockwise or aligned order predicate
//
boolean CW(Feature a, Feature b, Feature c)
{
    double det=(a.x-c.x)*(b.y-c.y)-(b.x-c.x)*(a.y-c.y);
    if (det>=0.0)
    {
        return true;
    }
    else
    {
        return false;
    }
}

// Determine if a pixel falls inside the quadrangle or not
boolean inside(int x, int y)
{
    Feature p=new Feature(x,y,1.0);
    if ( CW(p1,p2,p) && CW(p2,p3,p) && CW(p3,p4,p) && CW(p4,p1,p) )
    {
        return true;
    }
    else
    {
        return false;
    }
}
Homography estimation

Projective geometry, homogeneous and inhomogeneous coordinates.

\[ \tilde{p}_i' = \begin{bmatrix} \tilde{x}_i' \\ \tilde{y}_i' \\ w_i' \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} \begin{bmatrix} \tilde{x}_i \\ \tilde{y}_i \\ w_i \end{bmatrix} = H\tilde{p}_i, \]

\[ w_i' = h_{31}x_i + h_{32}y_i + h_{33}w_i \]

\[ x_i' = \frac{h_{11}x_i + h_{12}y_i + h_{13}w_i}{h_{31}x_i + h_{32}y_i + h_{33}w_i}, \quad y_i' = \frac{h_{21}x_i + h_{22}y_i + h_{23}w_i}{h_{31}x_i + h_{32}y_i + h_{33}w_i}. \]

\[ A_i \text{ block matrix:} \]

\[ x_i'(h_{31}x_i + h_{32}y_i + h_{33}) = h_{11}x_i + h_{12}y_i + h_{13}, \]

\[ y_i'(h_{31}x_i + h_{32}y_i + h_{33}) = h_{21}x_i + h_{22}y_i + h_{23}. \]

Solve for \( A_i; h = 0 \)
Homography estimation using inhomogeneous system

Assume $h_{33} \neq 0$ (and set $h_{33} = 1$).

\[
\begin{bmatrix}
  x_1 & y_1 & 1 & 0 & 0 & 0 & -x_1x'_1 & -y_1x'_1 \\
  0 & 0 & 0 & x_1 & y_1 & 1 & -x_1y'_1 & -y_1y'_1 \\
  x_2 & y_2 & 1 & 0 & 0 & 0 & -x_2x'_2 & -y_2x'_2 \\
  0 & 0 & 0 & x_2 & y_2 & 1 & -x_2y'_2 & -y_2y'_2 \\
  x_3 & y_3 & 1 & 0 & 0 & 0 & -x_3x'_3 & -y_3x'_3 \\
  0 & 0 & 0 & x_3 & y_3 & 1 & -x_3y'_3 & -y_3y'_3 \\
  x_4 & y_4 & 1 & 0 & 0 & 0 & -x_4x'_4 & -y_4x'_4 \\
  0 & 0 & 0 & x_4 & y_4 & 1 & -x_4y'_4 & -y_4y'_4
\end{bmatrix}
\times
\begin{bmatrix}
  h_{11} \\
  h_{12} \\
  h_{13} \\
  h_{21} \\
  h_{22} \\
  h_{23} \\
  h_{31} \\
  h_{32}
\end{bmatrix}
= \begin{bmatrix}
  x'_1 \\
  y'_1 \\
  x'_2 \\
  y'_2 \\
  x'_3 \\
  y'_3 \\
  x'_4 \\
  y'_4
\end{bmatrix}
\]

Linear system written:

\[ Bh' = b. \]

For four pairs

\[ h' = B^{-1} b \]
Homography estimation using the normalized DLT

\[ H = UDV^T = \sum_{i=1}^{9} \lambda_i u_i v_i^\top, \]

Right eigenvector of \( V \) corresponding to the smallest eigenvalue. (last column vector \( v_9 \) of \( V \))

When \( \lambda_9 = 0 \), the system is exactly determined.
When \( \lambda_9 > 0 \), the system is over-determined and \( \lambda_9 \) is an indicator of the goodness of fit of the solution \( h = v_9 \).
In practice, this estimation procedure is highly unstable numerically[2].
Points need to be first normalized to that their centroid defines the origin, and the diameter is set to \( \sqrt{2} \).
Image editing: Selection swaps

$H_{12}$ from $Q_1$ to $Q_2$ by composition:

$$H_{12} = H_1 H_2^{-1}$$

$$H_{21} = H_{12}^{-1} = H_2 H_1^{-1}$$

→ backward pixel mapping [3] (avoid holes)

forward mapping  
SRC $\rightarrow$ DEST ($H$)  

backward mapping  
DEST $\rightarrow$ SRC ($H^{-1}$)
Image editing: Selection swaps
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Image editing: Selection swaps
Perspective Click-and-Drag UI: Conclusion

- Simple UI system relying on computer vision.
- Extend to other input formats: Stereo pairs, RGBZ images, etc.
- Implemented using processing.org (2500+ lines)

Ongoing work:

- Rely on efficient quad detection: extensive benchmarking (BSDS500, Corel, ImageNet, etc. databases)
- Extend to various perspectively slanted shapes (like ball → ellipsoids, etc.)
- Robust multiple quad-to-square homography estimations [1]?

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