Perspective click-and-drag area selections in pictures

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Machine Vision Applications (MVA)
21st May 2013

Traditional click and drag rectangular selection

→ Fails for selecting parts in photos:

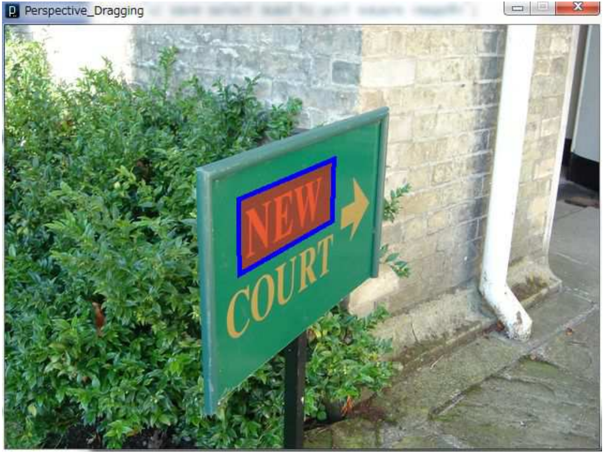
Traditional click and drag rectangular selection

→ 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)

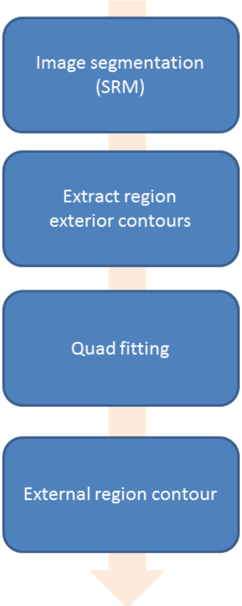
Video demonstrations

Perspective click-and-drag + perspective copy/paste/swap

Perspective click'n'drag: Outline

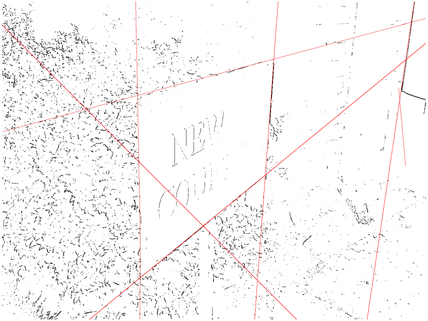
1. Preprocessing:
   Detect & structure perspective parts
   1.1 Quad detector:
       - Image segmentation
       - Outer contour quad fitting
       - Quad recognition
   1.2 Quad homography tree
2. Interactive user interface:
   Perspective quad selection based on click-and-drag UI (=diagonal selection)
3. Application example: Interactive image editing (swap)

Preprocessing workflow



Quad detection: Sobel/Hough transform

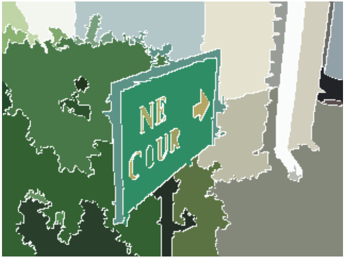
How to detect convex quads in images?
indoor robotics [6] using vanishing point.
Limitations of Hough transform [8] on Sobel image:

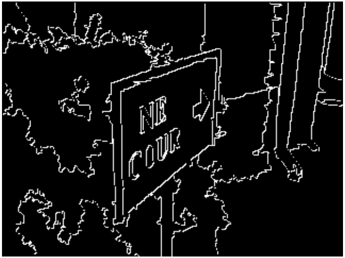


Combinatorial line arrangement $O(n^4)$...
$\rightarrow$ good for limited number of detected lines
(blackboard detection [8], name card detection, etc.)

Quad detection: Image segmentation (SRM)

→ Fast Statistical Region Merging [4] (SRM)



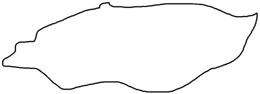


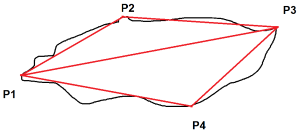
Source codes in Java™, Matlab®, Python®, C, etc.

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 Haussdorf 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,

$\rightarrow$ 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.

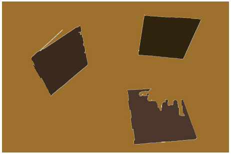
$\rightarrow$ We end up with a **quad soup**

Multi-segmentation

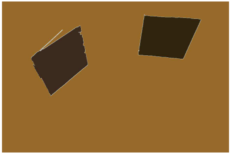
Increases the chance of recognizing quads, but get a quad soup.

$Q = 128$

$Q = 10$



$Q = 0.3$



$Q = 0.25$

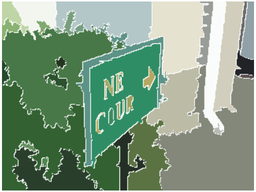
Nested convex quad hierarchy

- 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.

Do not explicit unwarp perspective rectangles

Many existing systems first unwarp...

source



segmented

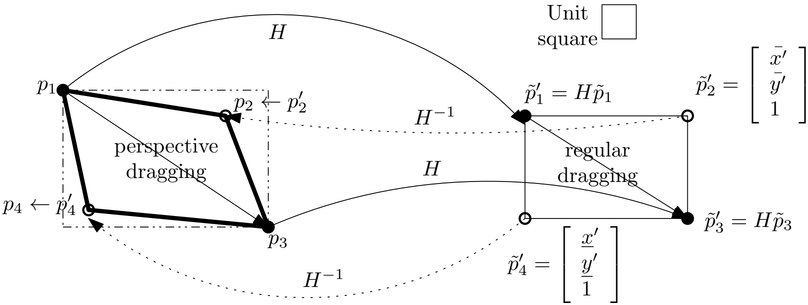
unwarped

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.



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.

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

$$w'_i = h_{31}x_i + h_{32}y_i + h_{33}w_i$$

$x'_i = \frac{h_{11}x_i+h_{12}y_i+h_{13}w_i}{h_{31}x_i+h_{32}y_i+h_{33}w_i}$, $y'_i = \frac{h_{21}x_i+h_{22}y_i+h_{23}w_i}{h_{31}x_i+h_{32}y_i+h_{33}w_i}$.
A_i block matrix:

$$\begin{aligned} x'_i(h_{31}x_i + h_{32}y_i + h_{33}) &= h_{11}x_i + h_{12}y_i + h_{13}, \\ y'_i(h_{31}x_i + h_{32}y_i + h_{33}) &= h_{21}x_i + h_{22}y_i + h_{23}. \end{aligned}$$

Solve for $A_i h = 0$

Homography estimation using inhomogeneous system

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

$$\begin{bmatrix} x_1 & y_1 & 1 & 0 & 0 & 0 & -x_1x_1' & -y_1x_1' \\ 0 & 0 & 0 & x_1 & y_1 & 1 & -x_1y_1' & -y_1y_1' \\ x_2 & y_2 & 1 & 0 & 0 & 0 & -x_2x_2' & -y_2x_2' \\ 0 & 0 & 0 & x_2 & y_2 & 1 & -x_2y_2' & -y_2y_2' \\ x_3 & y_3 & 1 & 0 & 0 & 0 & -x_3x_3' & -y_3x_3' \\ 0 & 0 & 0 & x_3 & y_3 & 1 & -x_3y_3' & -y_3y_3' \\ x_4 & y_4 & 1 & 0 & 0 & 0 & -x_4x_4' & -y_4x_4' \\ 0 & 0 & 0 & x_4 & y_4 & 1 & -x_4y_4' & -y_4y_4' \end{bmatrix} \times \underbrace{\begin{bmatrix} h_{11} \\ h_{12} \\ h_{13} \\ h_{21} \\ h_{22} \\ h_{23} \\ h_{31} \\ h_{32} \end{bmatrix}}_{h'} = \begin{bmatrix} x_1' \\ y_1' \\ x_2' \\ y_2' \\ x_3' \\ y_3' \\ x_4' \\ y_4' \end{bmatrix}$$

Linear system written:

$$Bh' = b.$$

For four pairs

$$h' = B^{-1}b$$

Homography estimation using the normalized DLT

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

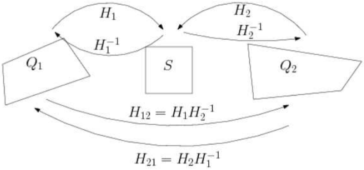
Right eigenvector of V corresponding to the smallest eigenvalue. (last column vector v_9 of V)

When $\lambda_9 = 0$, the system is exactly determined.
When $\lambda_9 > 0$, the system is over-determined and λ_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

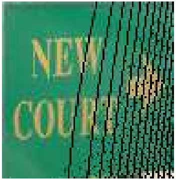
H_{12} from Q_1 to Q_2 by composition:

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

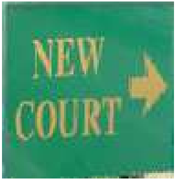


$$H_{21} = H_{12}^{-1} = H_2 H_1^{-1}$$

$\rightarrow$ backward pixel mapping [3] (avoid holes)



forward mapping
SRC$\rightarrow$ DEST (H)



backward mapping
DEST$\rightarrow$SRC (H^{-1})

Image editing: Selection swaps

Image editing: Selection swaps

Image editing: Selection swaps

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 $\rightarrow$ ellipsoids, etc.)
- Robust **multiple** quad-to-square homography estimations [1]?

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