WebcamPaperPen:
A Low-Cost Graphics Tablet

Graduation Project
Computer and Information Engineering

Gustavo Thebit Pfeiffer

Supervisor: Prof. Ricardo Guerra Marroquim, D.Sc.
Examiners: Prof. Antonio Alberto Fernandes de Oliveira, D.Sc.
Prof. Fernando Gil Vianna Resende Junior, Ph.D.

LCG/COPPE/UFRJ

Outline:

1. Introducing WebcamPaperPen
2. Method and Development
3. Results
4. Conclusions and Future Work

1. Introducing WebcamPaperPen

# Motivation – Project *Libera Akademio*

- Video lectures to the masses
- Similar to *Khan Academy*
  - ➔ But using a low bit-rate format
- Requires the **graphics tablet**

Khan Academy video
(http://www.youtube.com/watch?v=kpCJyQ2usJ4)

Motivation – Project *Libera Akademio*
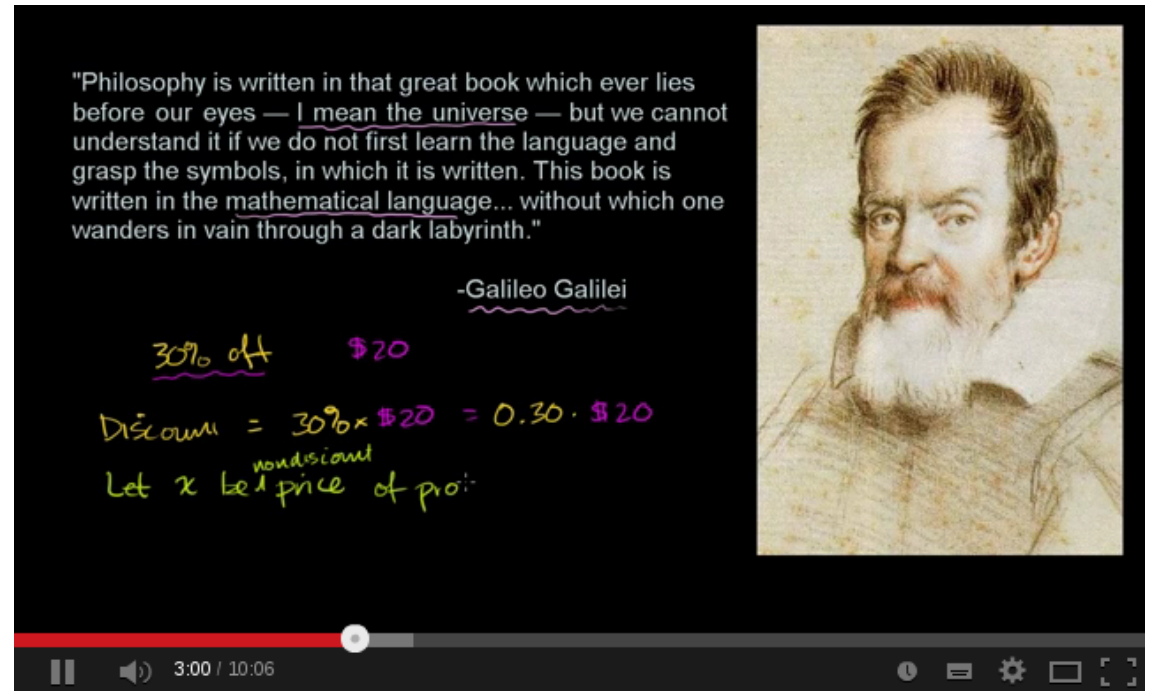
- Video lectures to the masses
- Similar to *Khan Academy*
  - ➜ But using a low bit-rate format
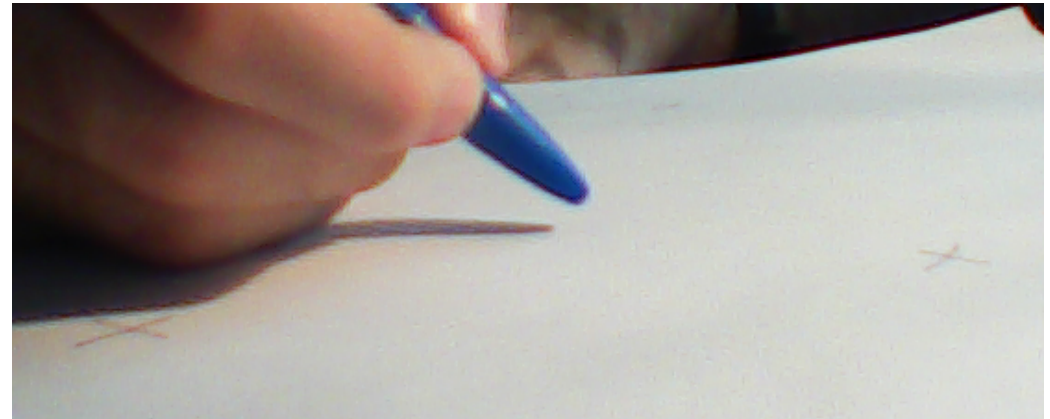- Requires the **graphics tablet**

Khan Academy video
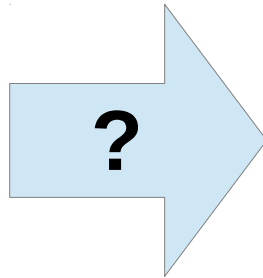(http://www.youtube.com/watch?v=kpCJyQ2usJ4)
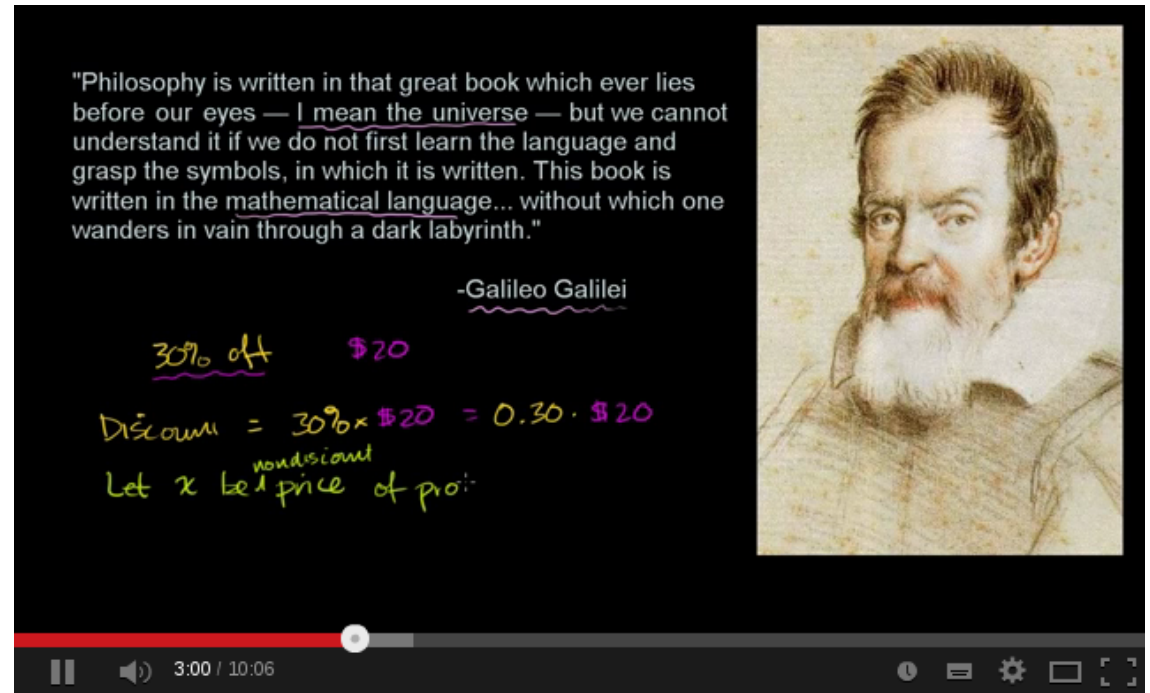
(http://en.wikipedia.org/wiki/File:Wacom_
Bamboo_Capture_tablet_and_pen.jpg)

➜ Device used to draw and handwrite
➜ Also controls the mouse cursor

Project *WebcamPaperPen*

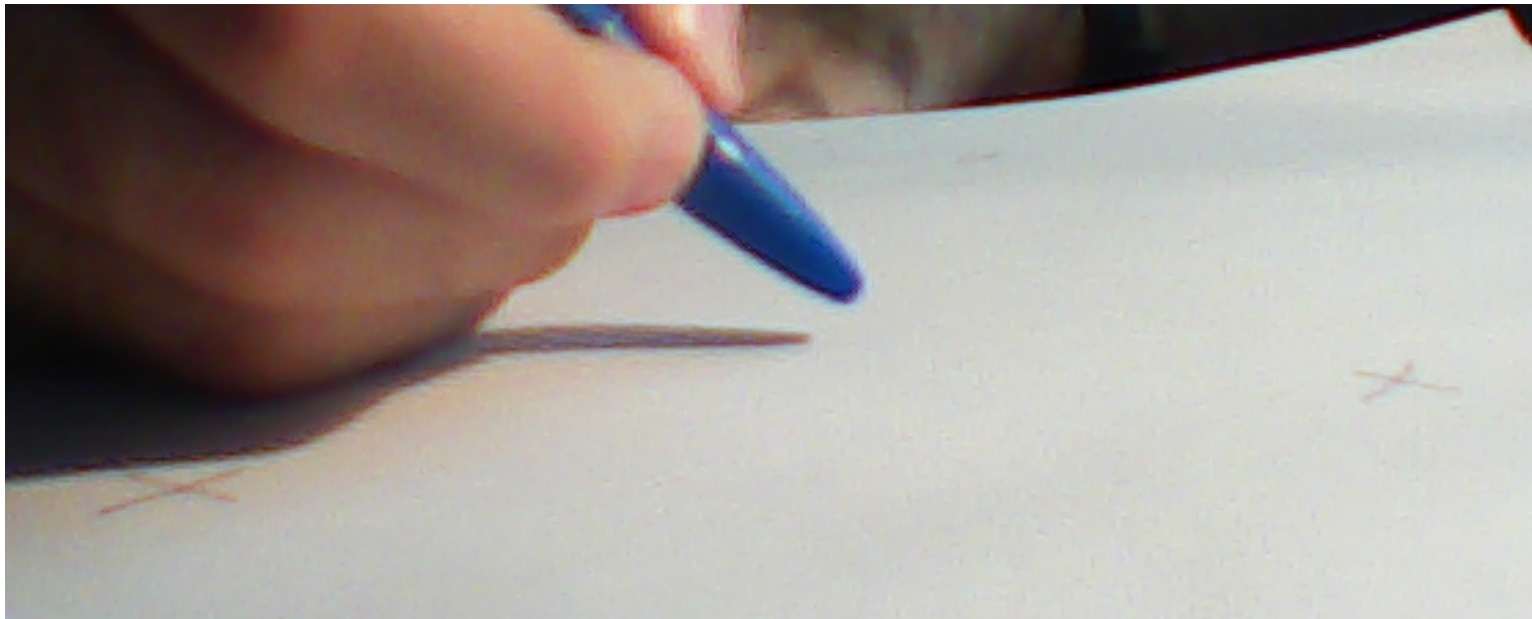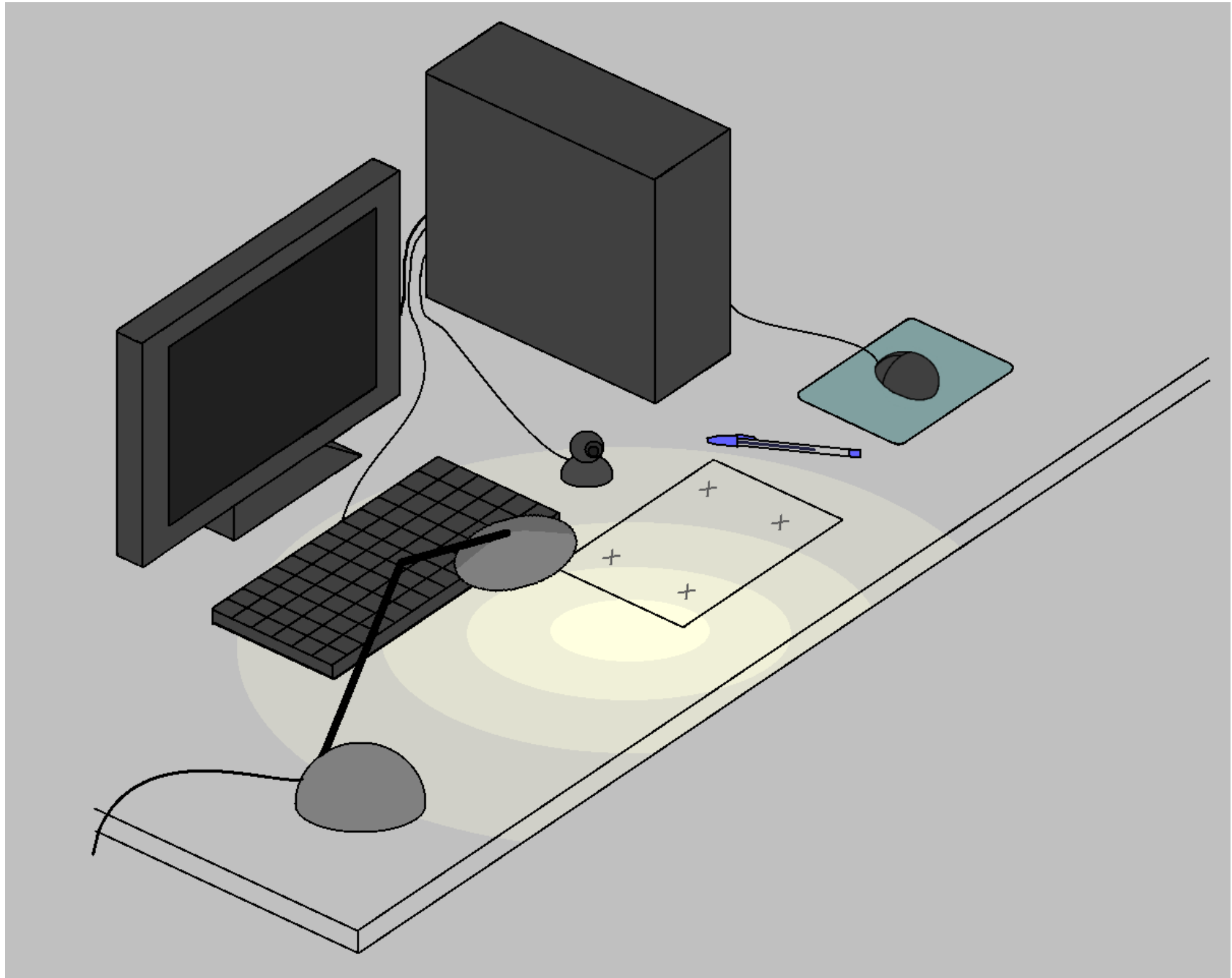- Challenge: Replace the **graphics tablet** by **webcam, paper and pen**

- Dilemma: Cap shut X Cap open?

Why use the cap shut?

- Easier to track
- Users won't look at the paper, but at the monitor
- More applications
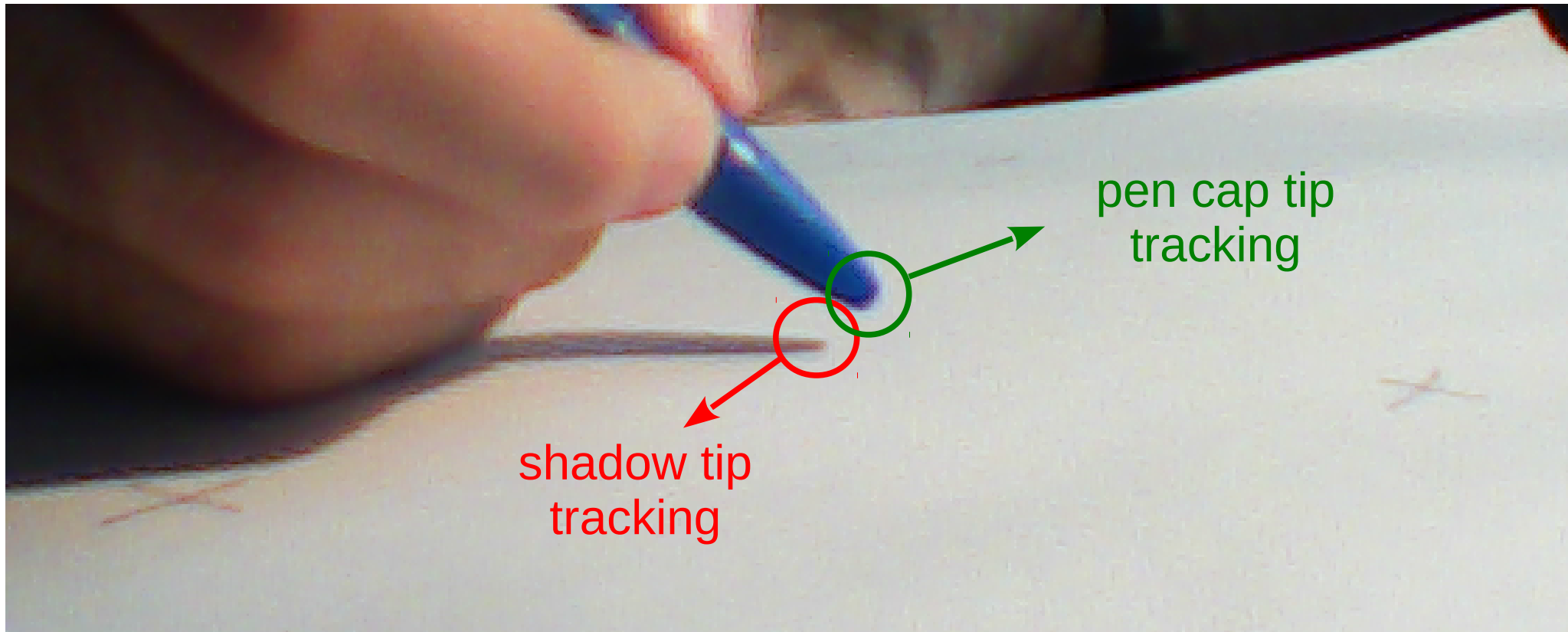 - ➔ If you can look at the paper, you need no online processing
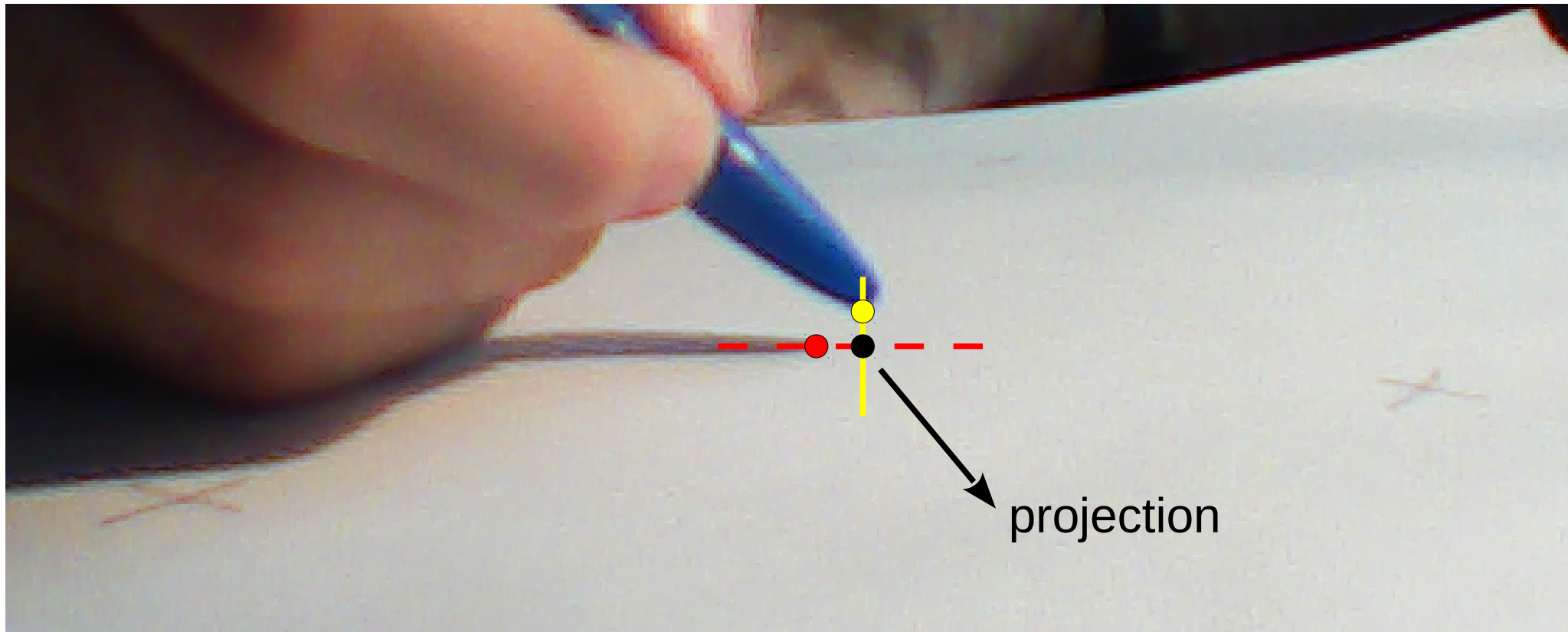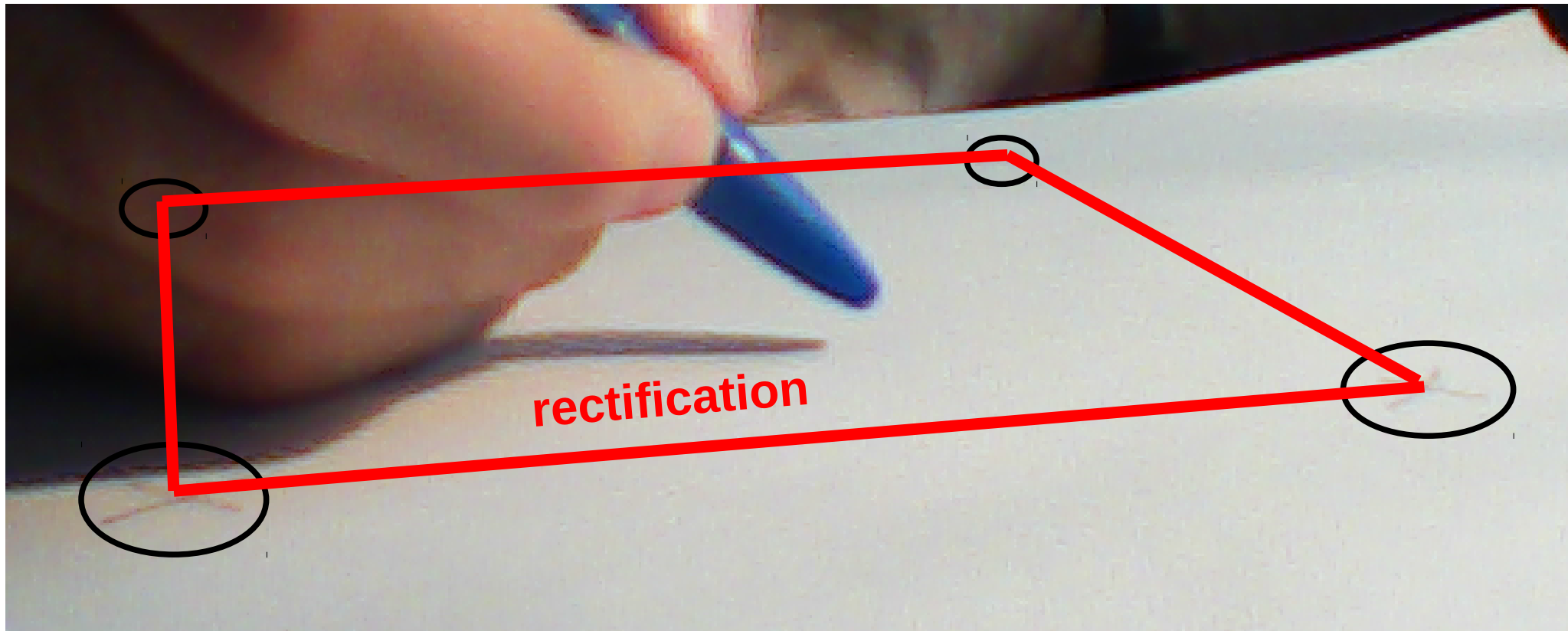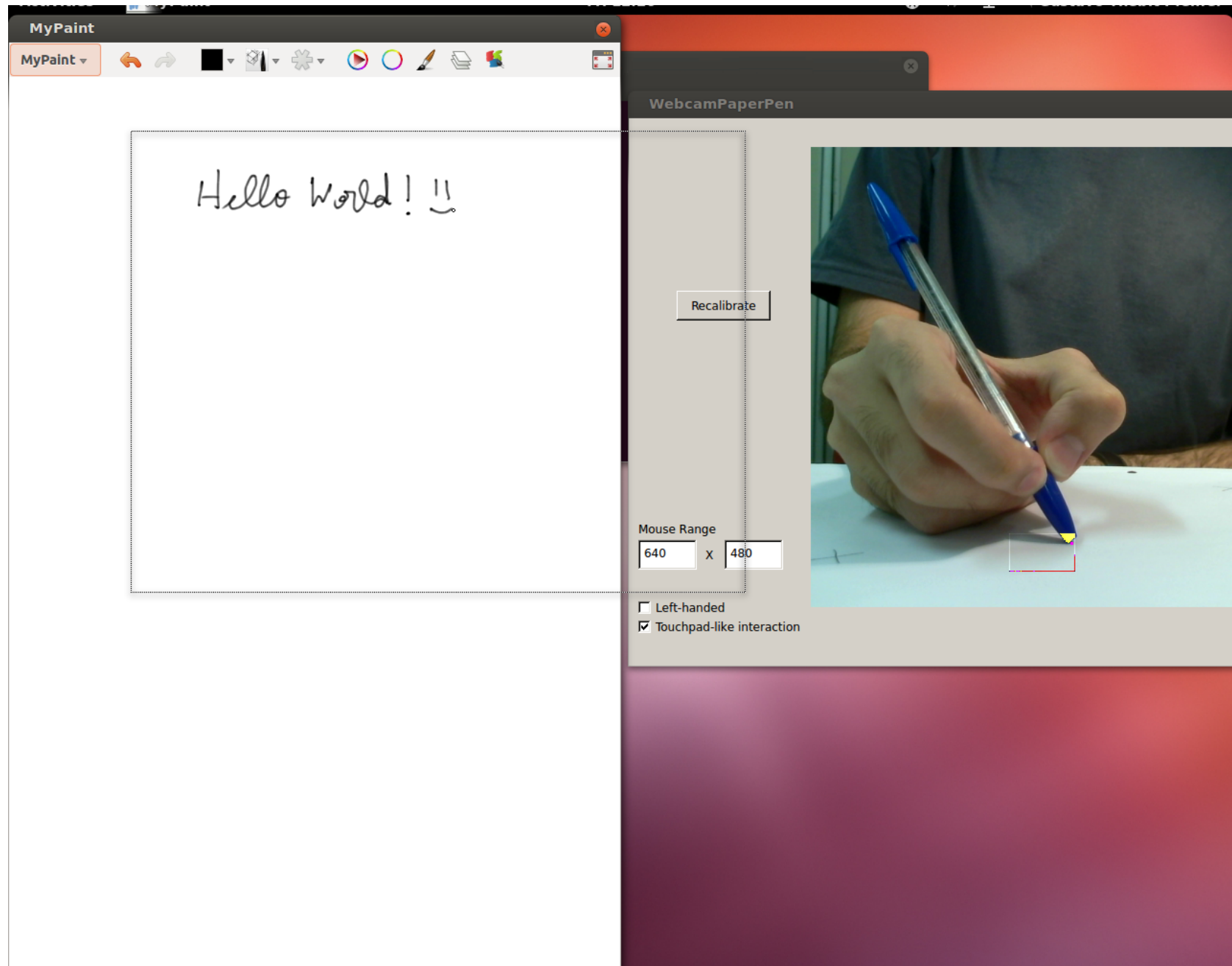- Less paper is consumed

Setup

How it works

How it works

projection

How it works

rectification
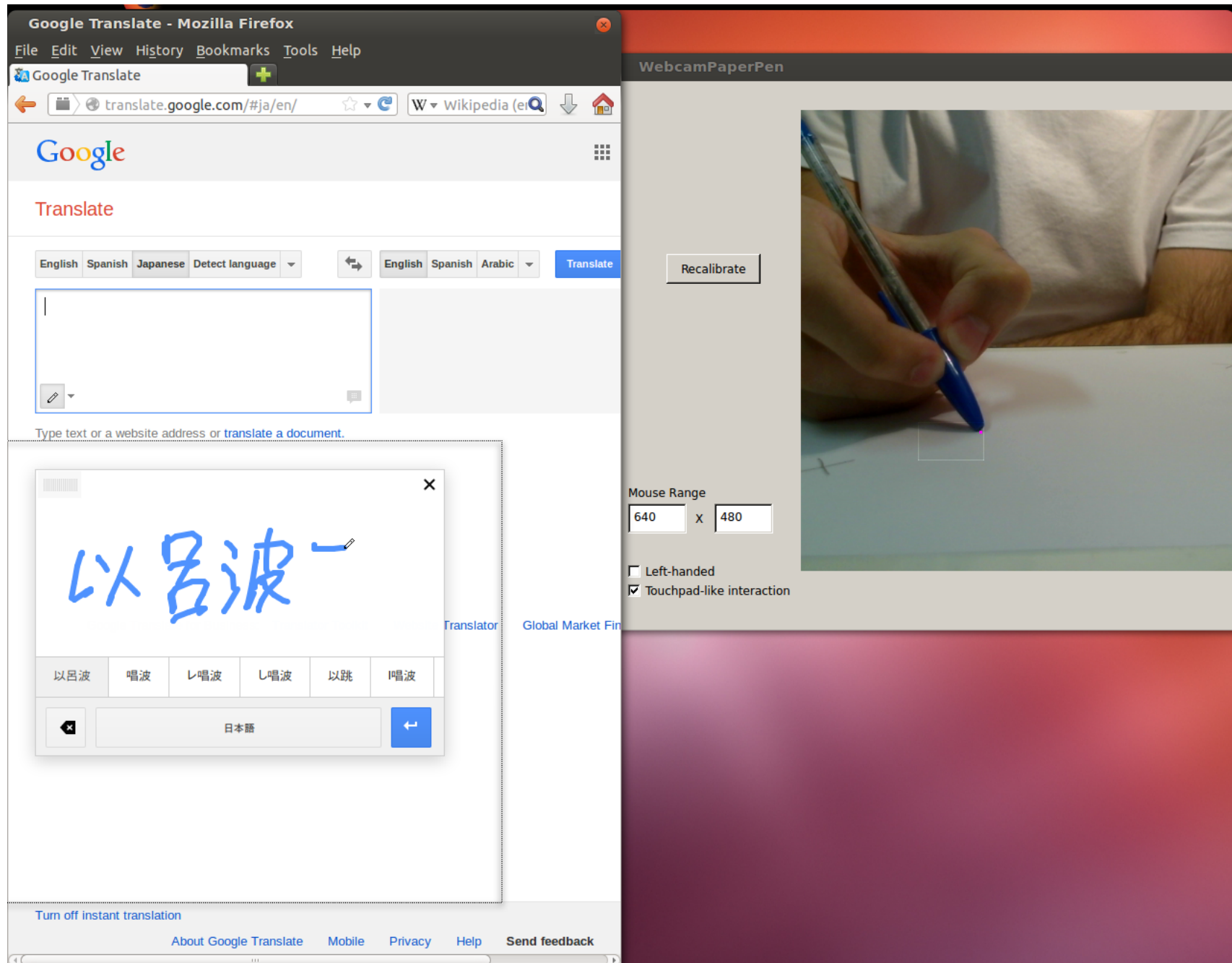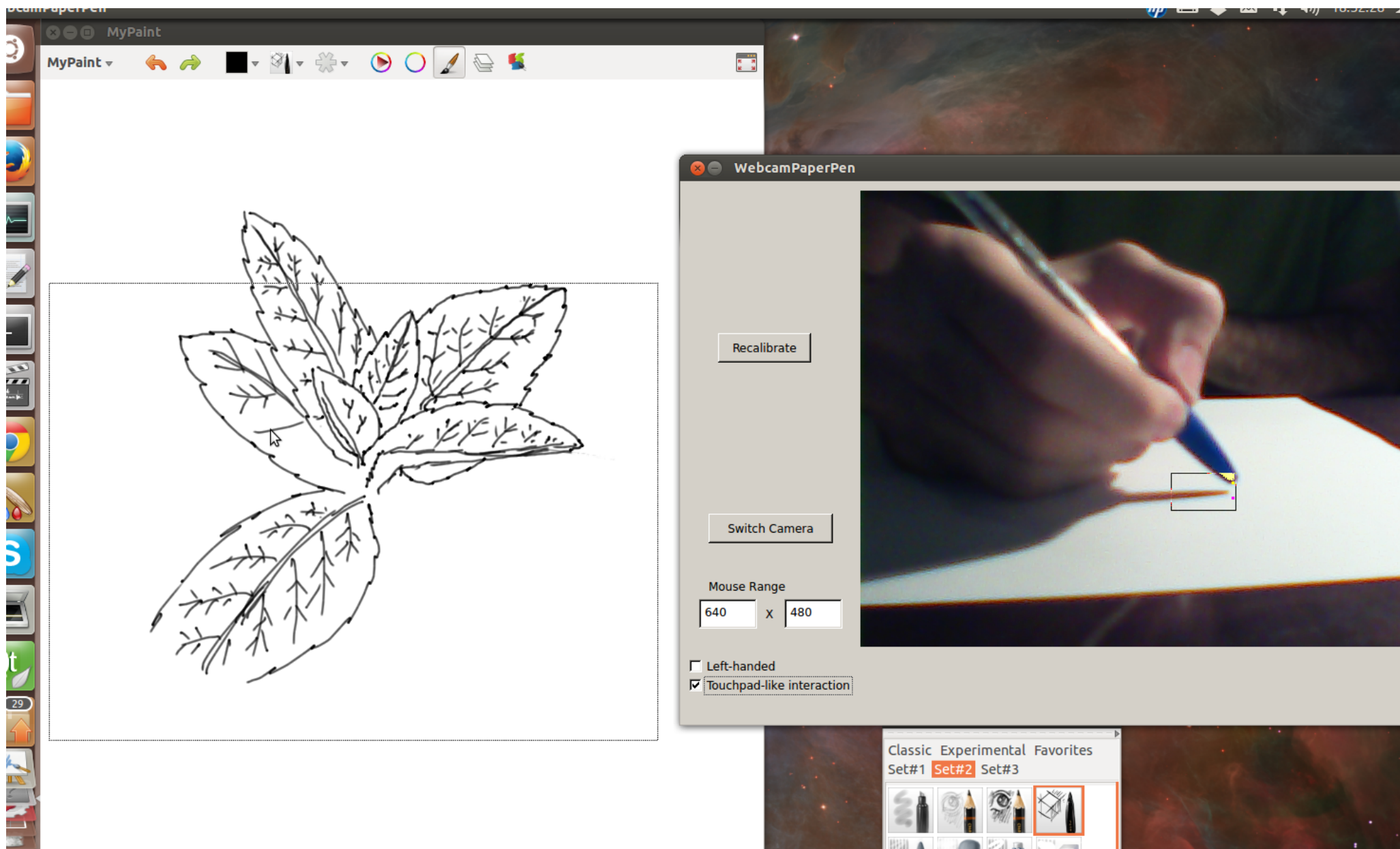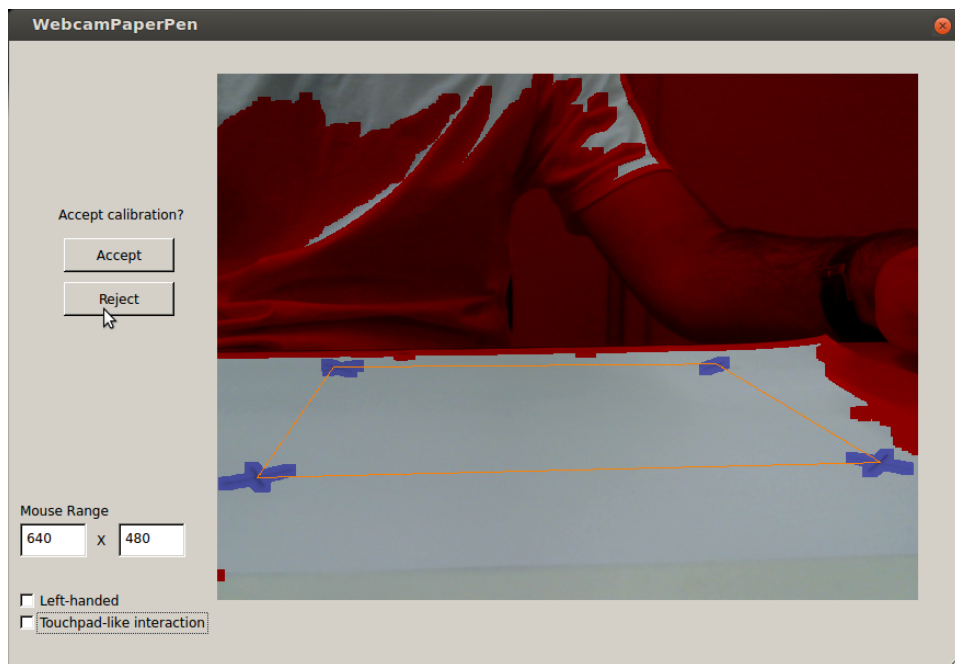
Applications

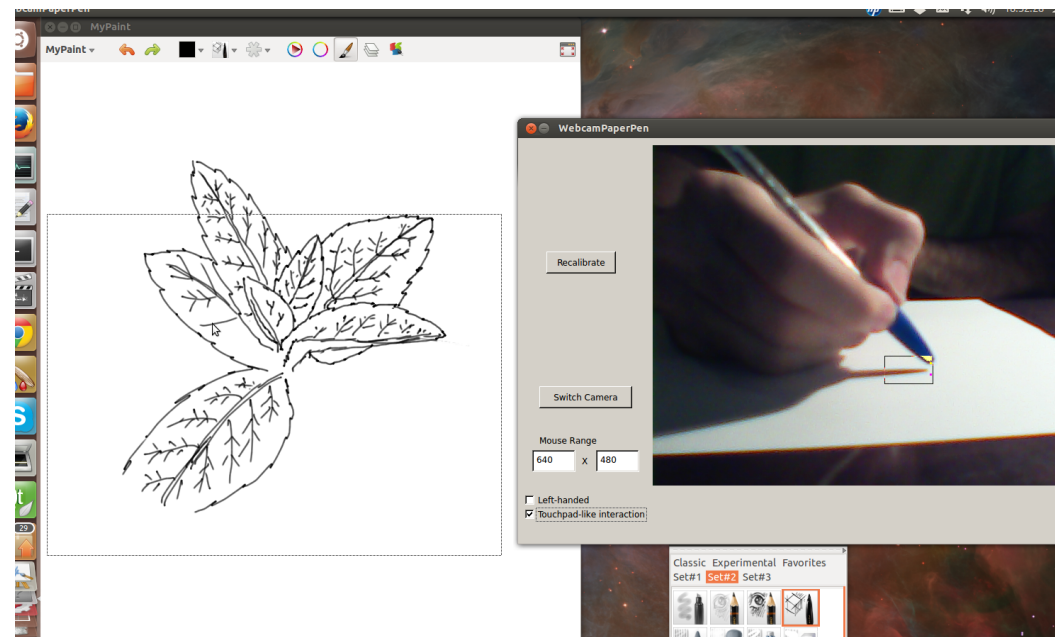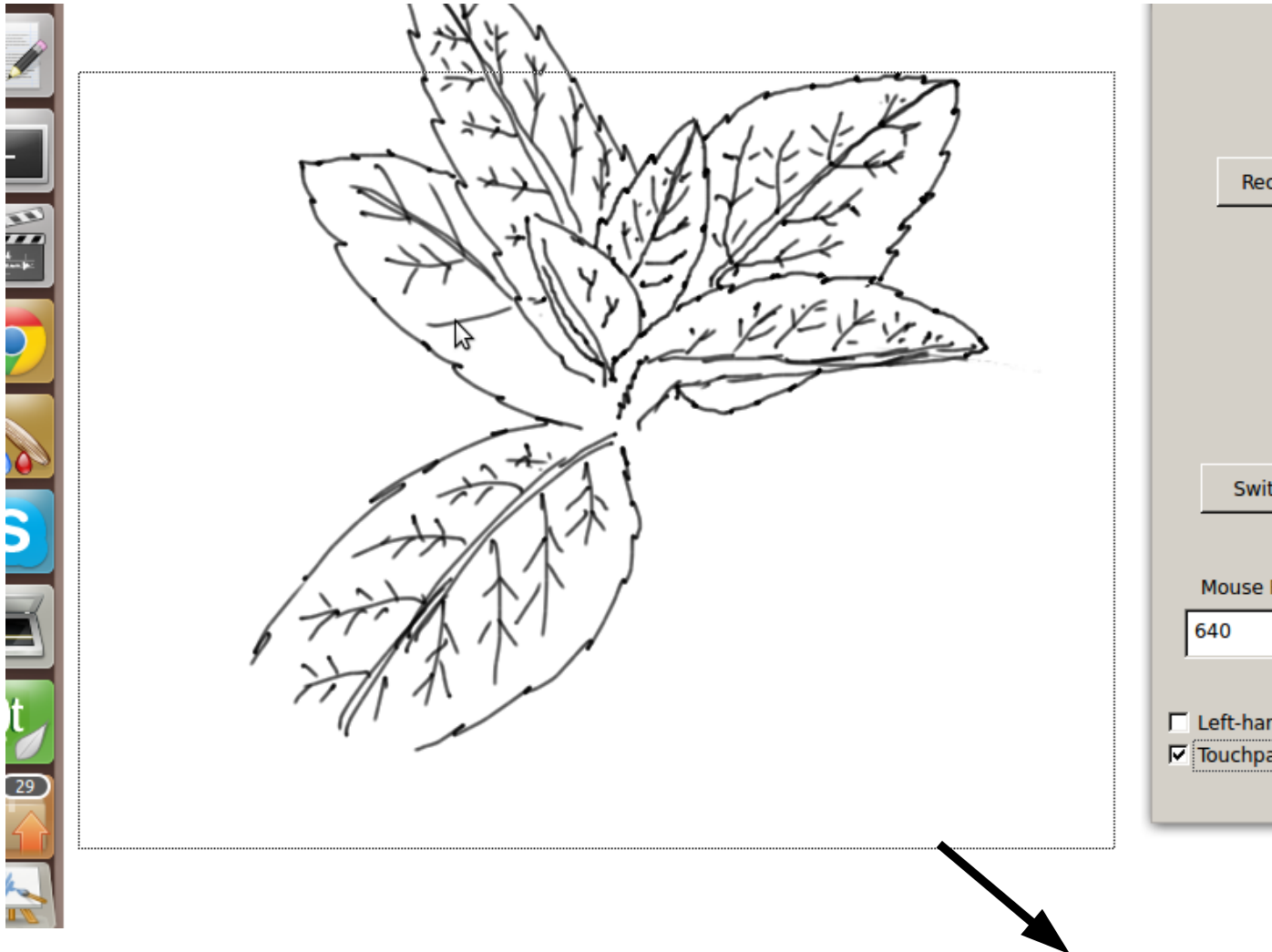# Applications

Applications

User Interaction

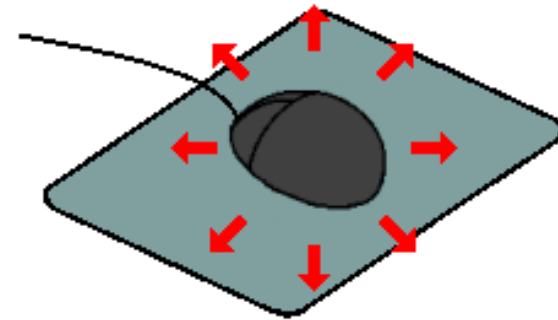## 1. Calibration Step

2. Drawing Step

User Interaction

Mouse range window

User Interaction

move
cursor back

move cursor

click
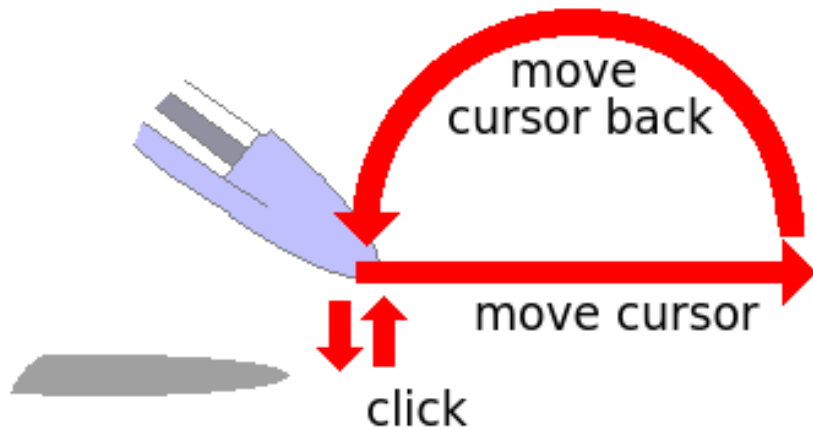
move window
and cursor

Normal mode

move
window

move cursor

click
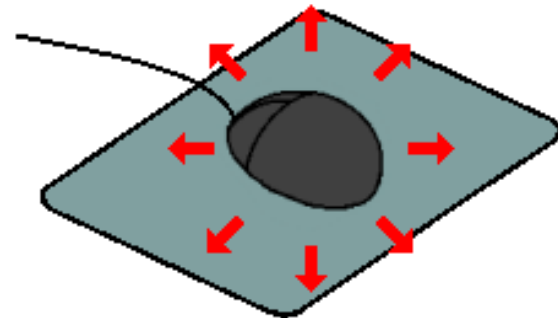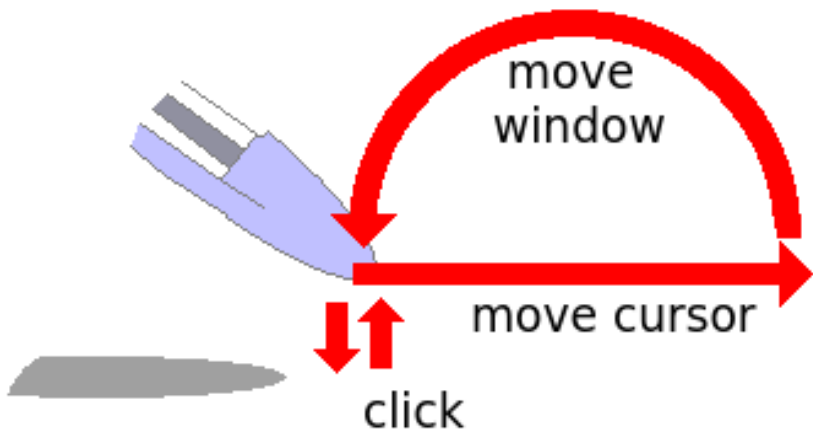
move window
and cursor

"Touchpad-like" mode

User Interaction

Related Work

LED, laser, infrared technology

(PIAZZA, T., FJELD, M. "Ortholumen: Using Light for Direct Tabletop Input". In: *Horizontal Interactive Human-Computer Systems, 2007*. TABLETOP '07. Second Annual IEEE International Workshop on, pp. 193–196, Oct. 2007.)

(http://www.wiimoteproject.com/)

(http://laserinteraction.codeplex.com/)
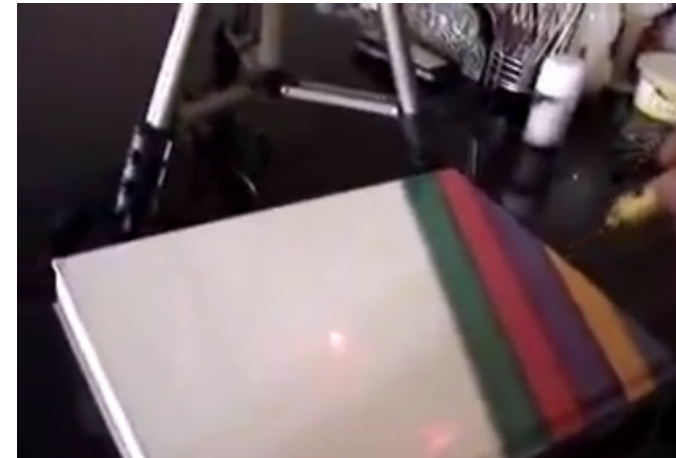
Related Work

Pen tip tracking
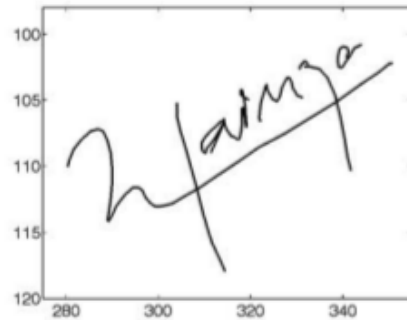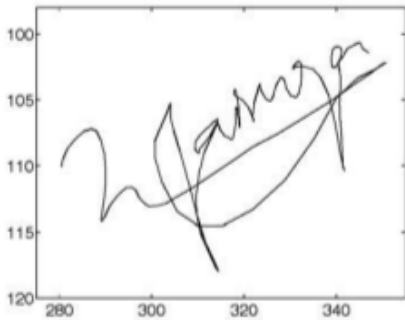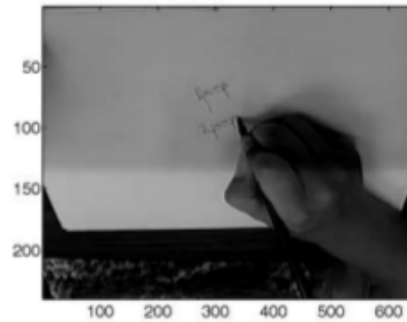
(MUNICH, M. E., PERONA, P. "Visual Input for Pen-Based Computers", *IEEE Trans. Pattern Anal. Mach. Intell., v. 24, n. 3, pp. 313–328*, March 2002.)

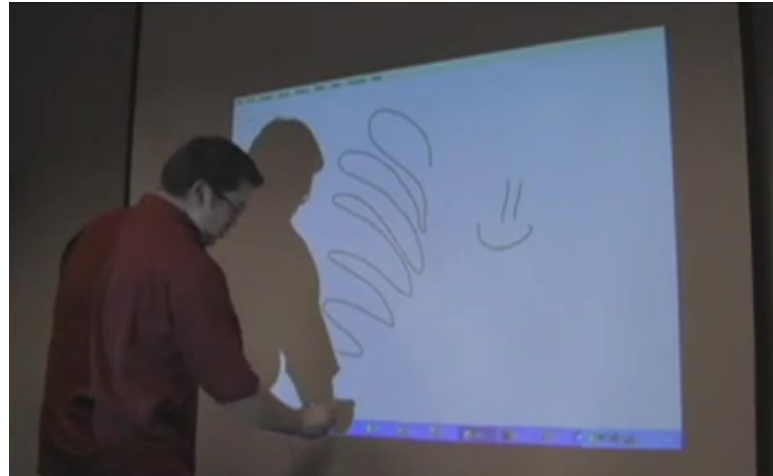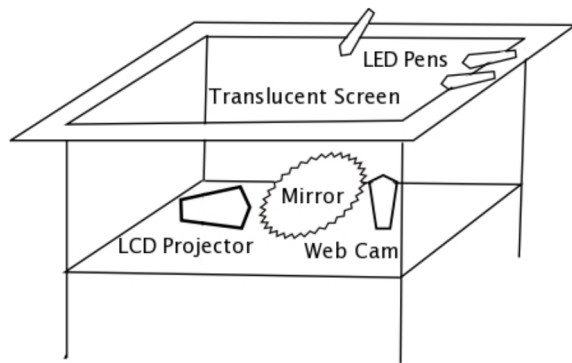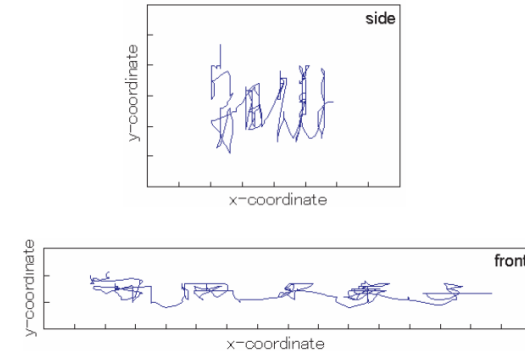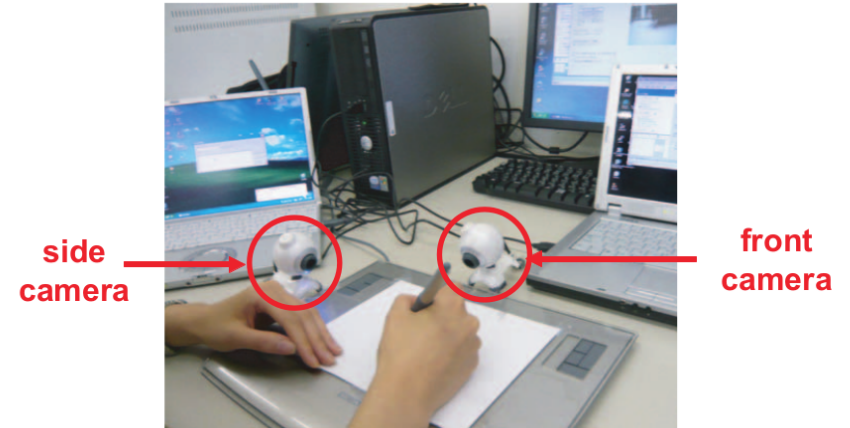(YASUDA, K., MURAMATSU, D., SHIRATO, S., et al. "Visual-based Online Signature Verification Using Features Extracted from Video" *J. Netw. Comput. Appl., v. 33, n. 3, pp. 333–341*, May 2010.)

- Not used for mouse control
- Allow ink and make no use of the shadow

Related Work

Body parts tracking
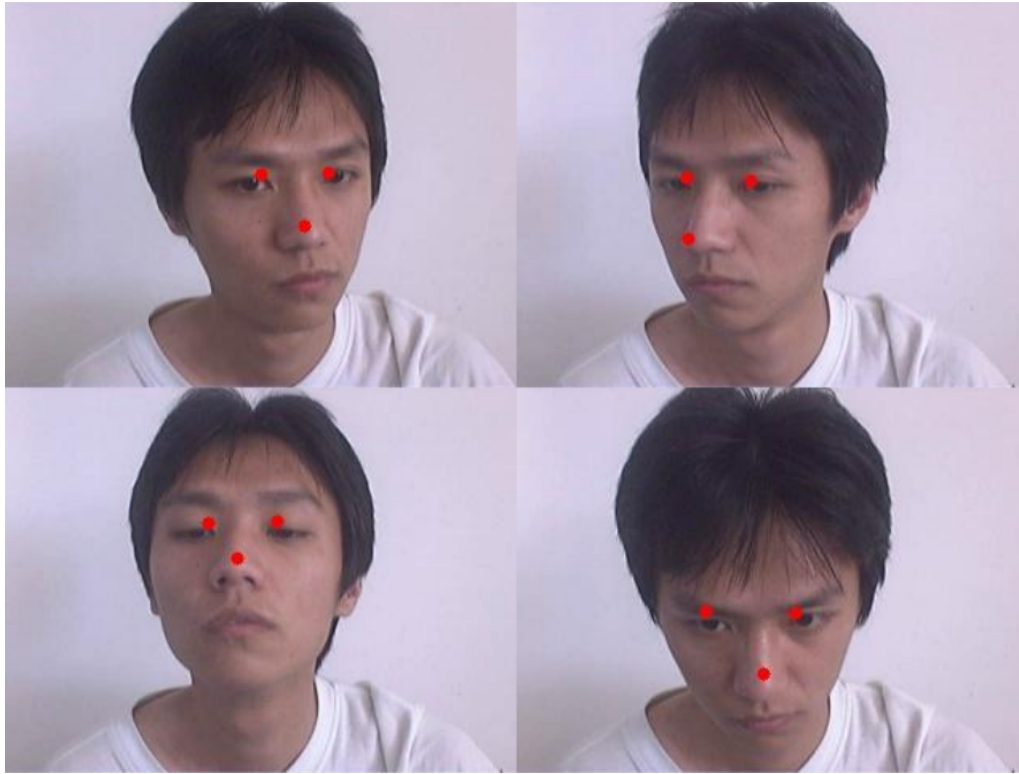
(HAO, Z., LEI, Q. "Vision-Based Interface: Using Face and Eye Blinking Tracking with Camera". In: *Intelligent Information Technology Application, 2008. IITA '08. Second International Symposium on, v. 1, pp. 306–310*, Dec. 2008.)
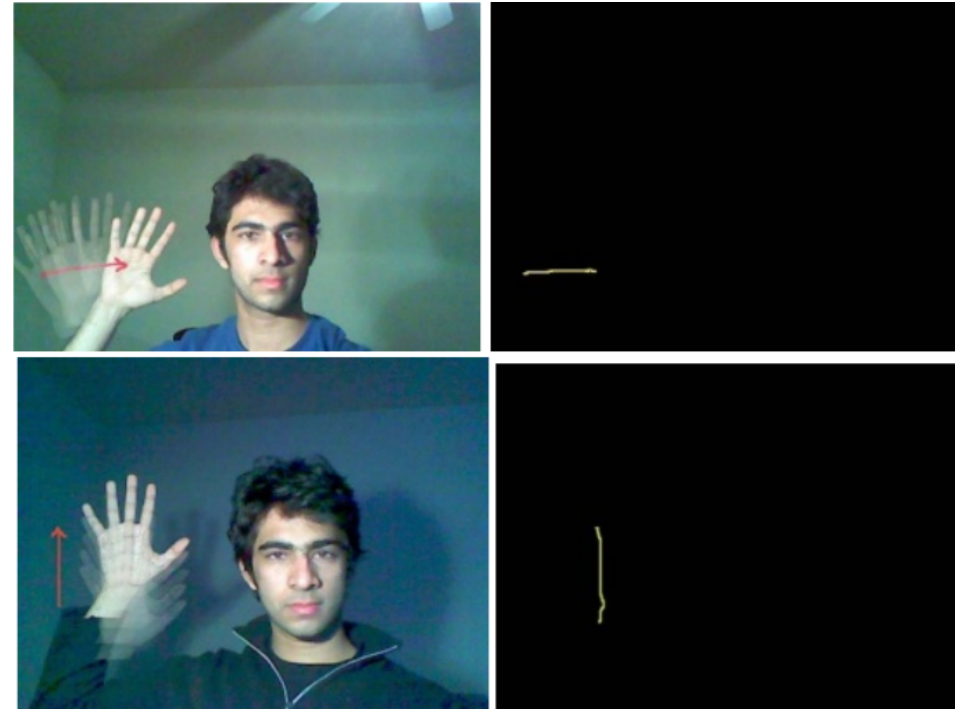
(MANCHANDA, K., BING, B. "Advanced mouse pointer control using trajectory-based gesture recognition". In: *IEEE SoutheastCon 2010 (SoutheastCon), Proceedings of the, pp. 412–415*, March 2010.)

• Inappropriate for handwriting and drawing

2. Method and Development

- **Technologies**
- **Algorithms**
  - → **Calibration**
  - → **Drawing**
    - ◆ **Pen Tracking**
    - ◆ **Shadow Tracking**
    - ◆ **Mouse Motion**
    - ◆ **Mouse Click**

Development

Language: C++
- Single-threaded implementation

Libraries

	Windows version	**Linux version**
Mouse Control	Windows API	X11
Webcam Support	ESCAPI	OpenCV-HighGUI
User Interface	Qt5	Qt4
Linear Algebra	Eigen	

Method – Calibration
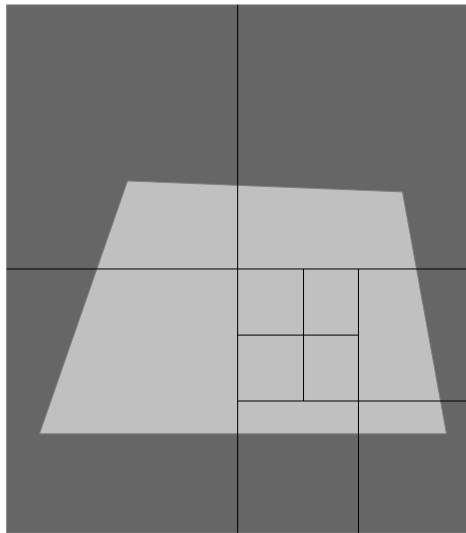
1. Search the paper, get mean intensity

outliers

inliers

$$p(x,y) = Ax^2 + Bxy + Cy^2 + Dx + Ey + F$$
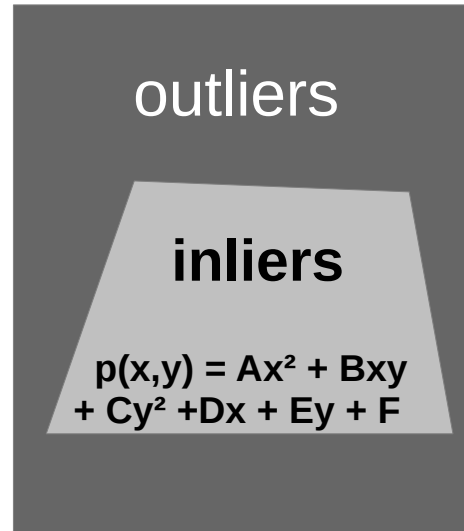
2. fit intensity to a quadratic function
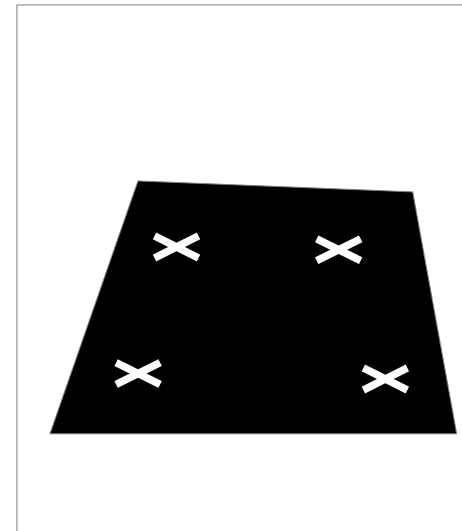
3. Compare pixelwise to fitted function
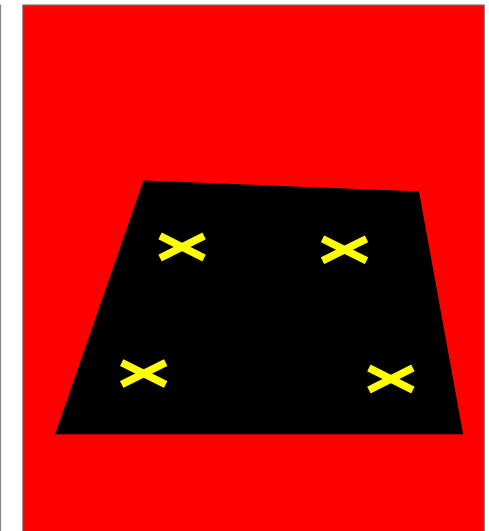
4. Classify connected components
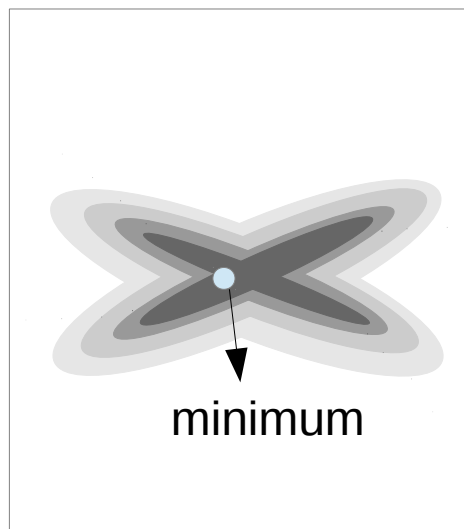
minimum

5. minimum intensity after blur
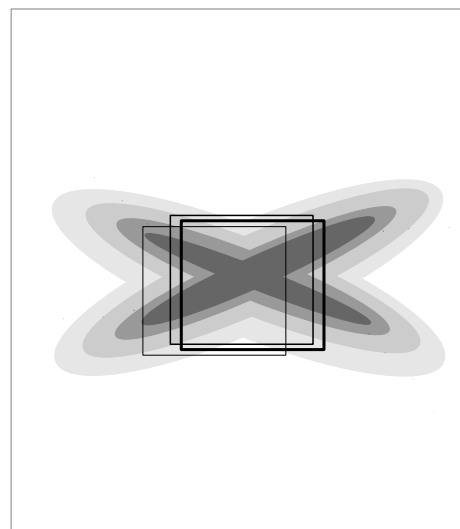
6. update using quadratic fit

top-left   top-right

bottom-left   bottom-right
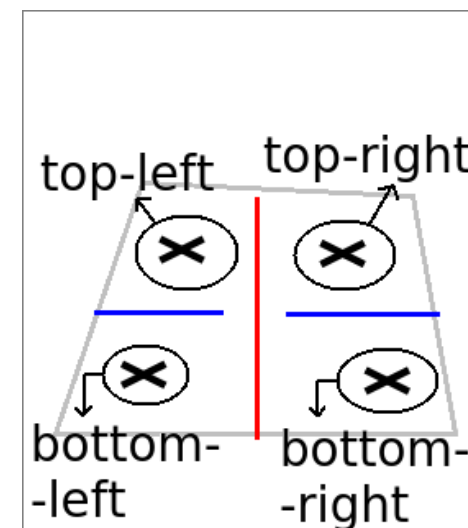
7. Classify crosses

Method – Pen Cap Tip Tracking
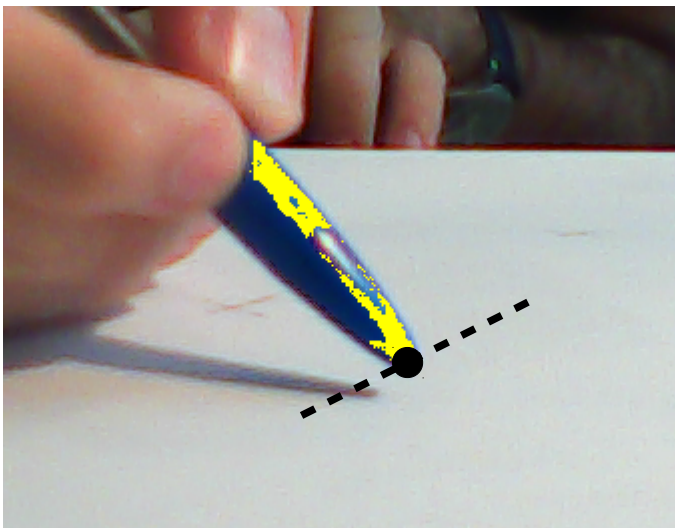
1. Apply blue filter and maximize 2y+x
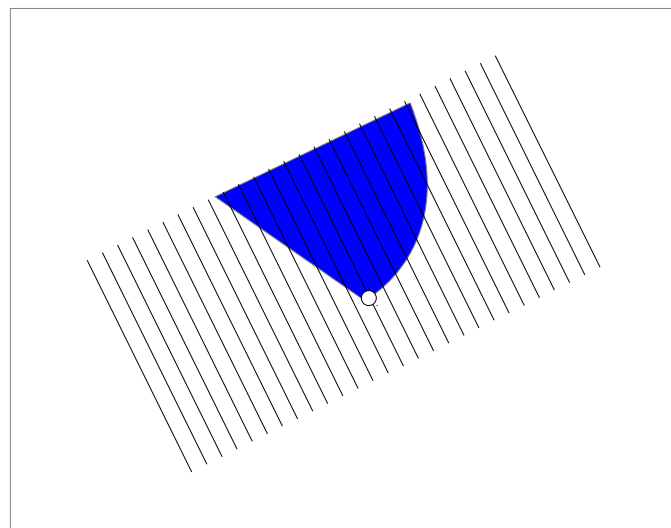
2. Minimize sum (hor.) Maximize Sobel (ver.)
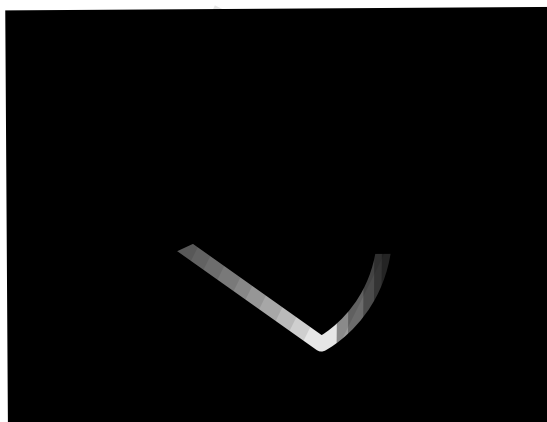
3. Search pixel that maximizes objective function

$$f(x,y) = ax^2 + bxy + cy^2 + dx + ey + f$$
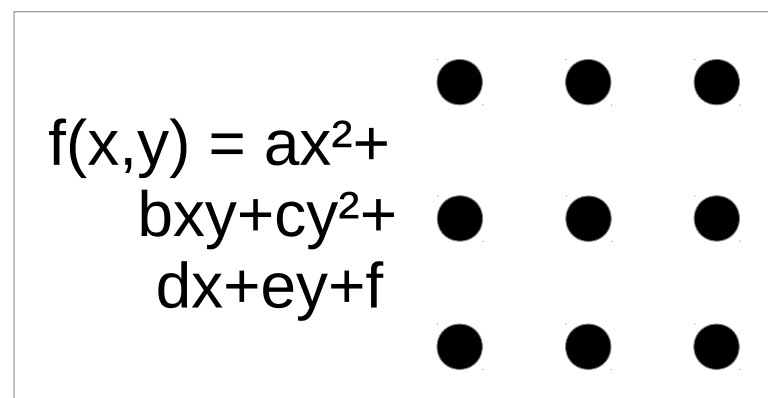
4. Subpixel estimation using quadratic fit

Method – Shadow Tracking

Hitting point calculation:

$h=(z^d)^(l^s)$

Assumption:
$l=(1,0,0)$
$d=(0,1,0)$
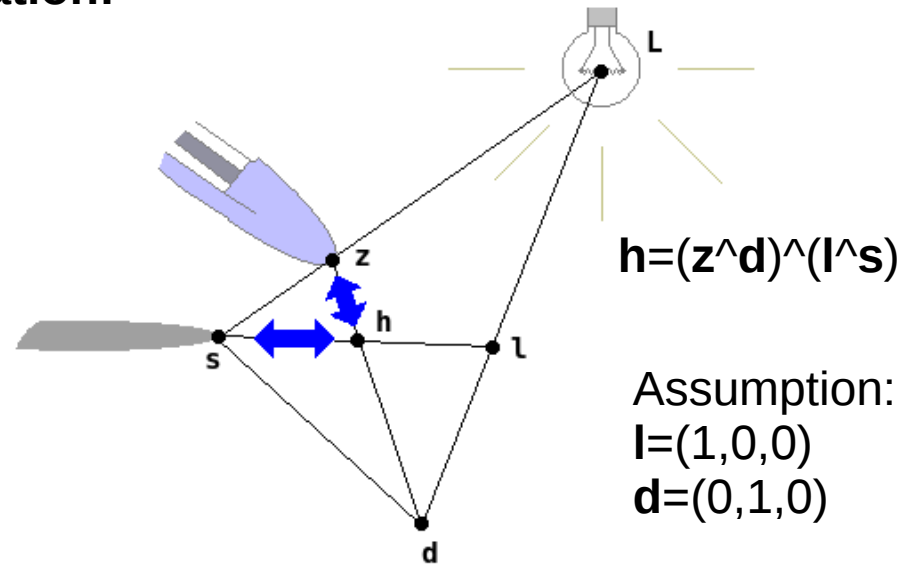
Consequence: restrictions on camera rotation

OK

OK

MUST LOOK FROM THE FRONT

PITCH IS TOO HIGH

ROLL IS TOO HIGH

Method – Shadow Tracking

#paper

70% of the line

Occurrences per line

-y
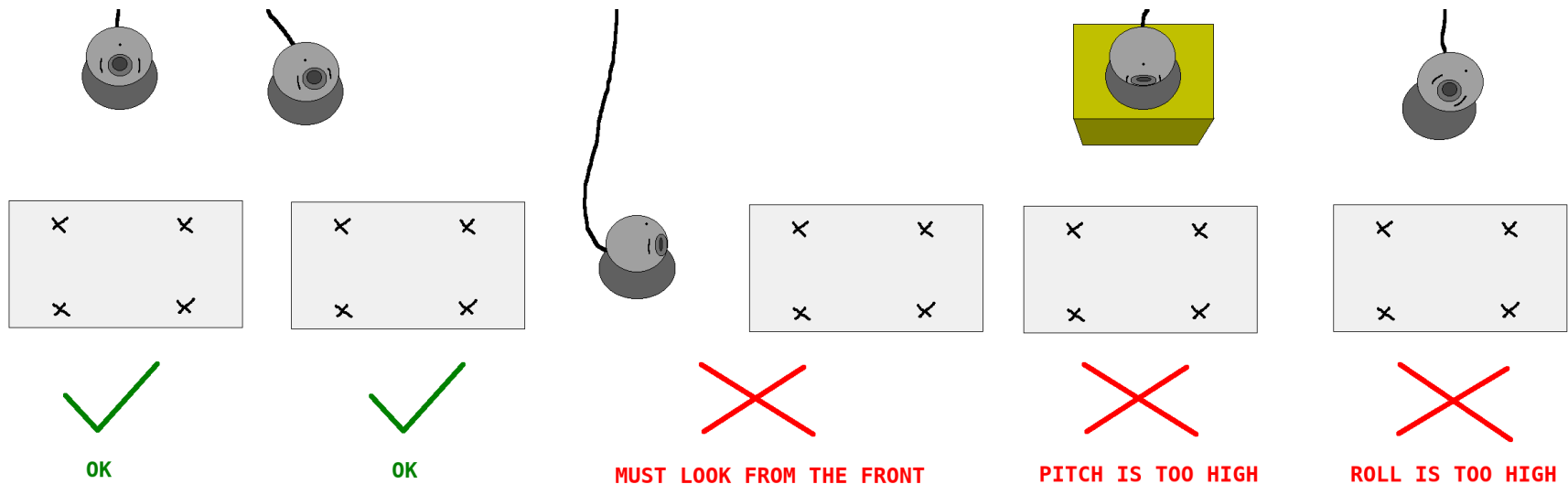
Interpolation by sorting

Threshold: 75% of paper intensity

y

y+1

Linear interpolation after gamma correction

p(x,y)

paper intensity

p(x,y+1)

y

?

y+1
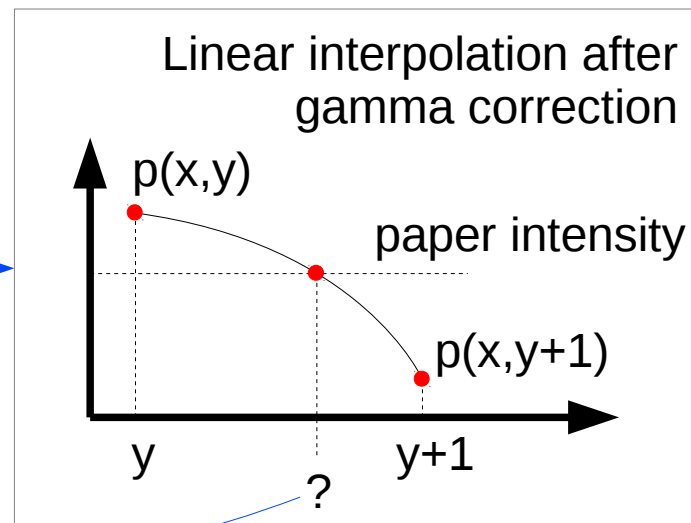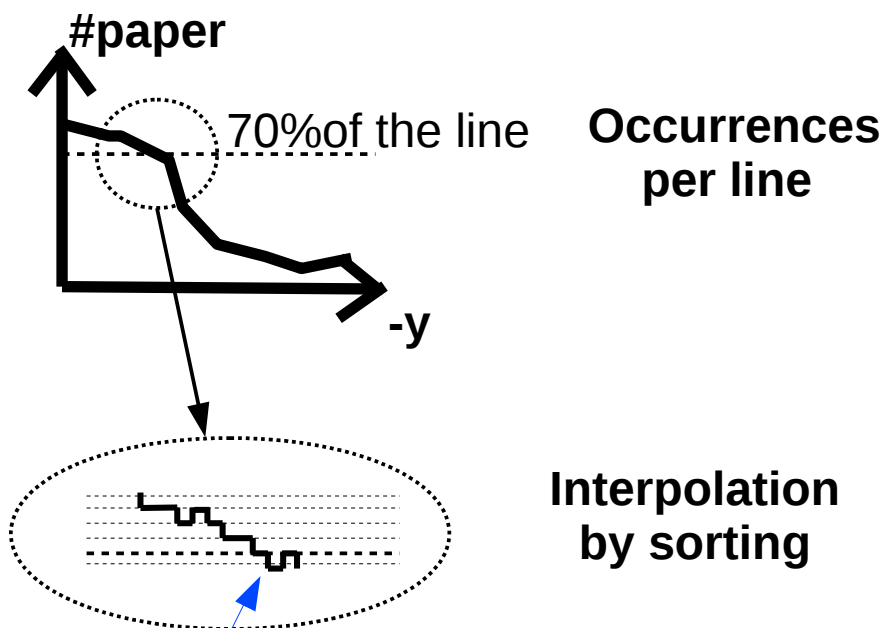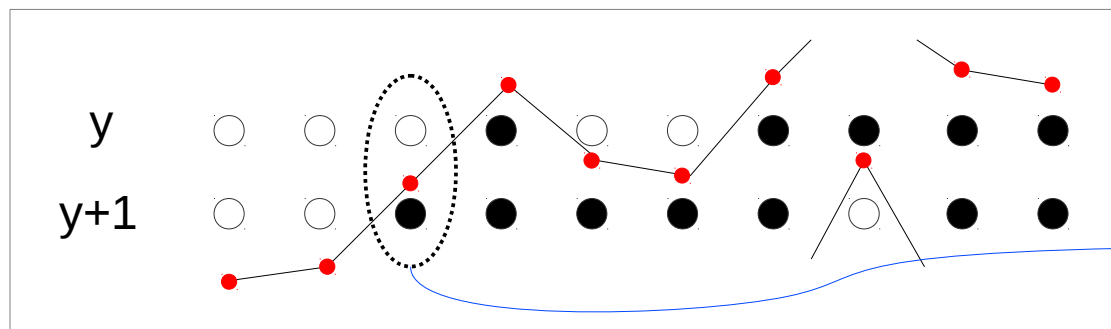
Method – Shadow Tracking

Subpixel estimation step: example curve
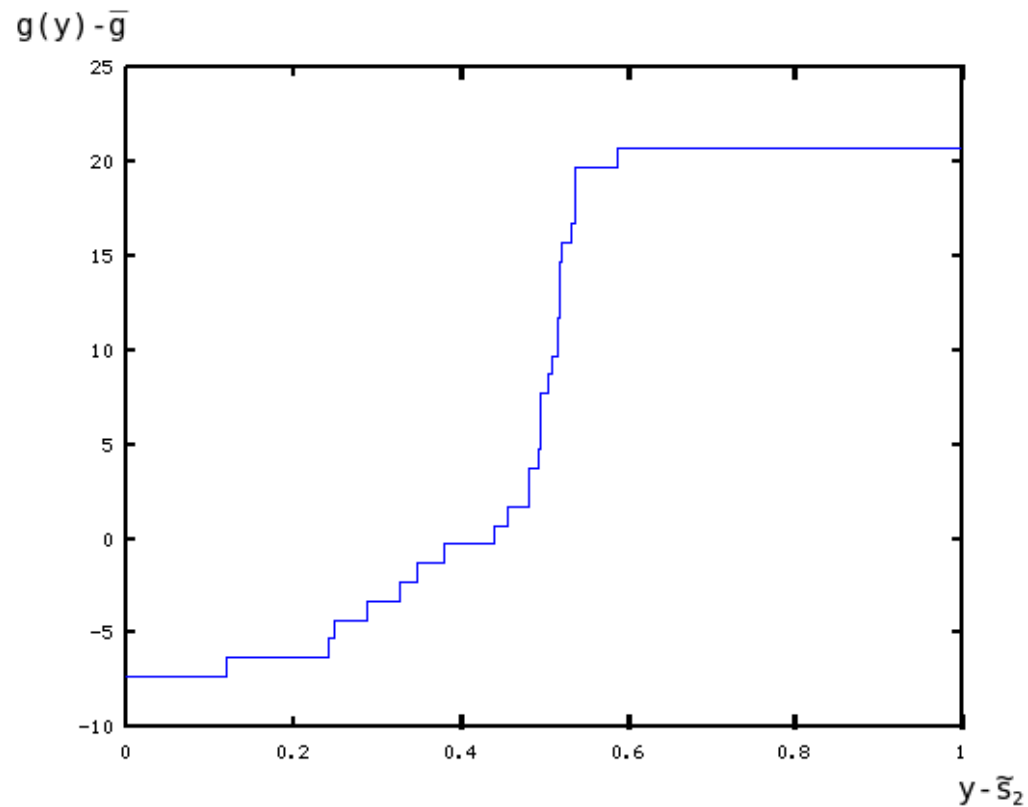
➜ *Not quite linear!*

Method – Mouse Motion
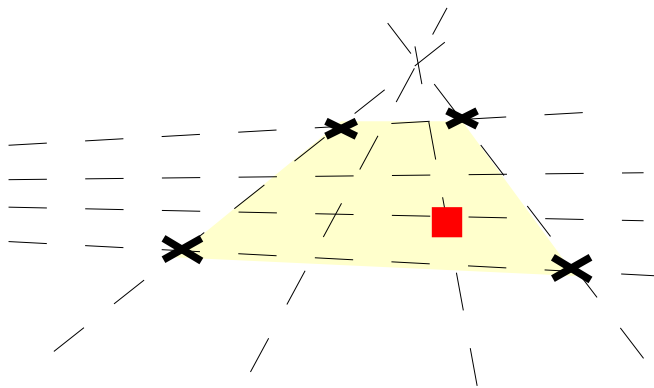
four crosses' convex hull

Rectification
(homography)
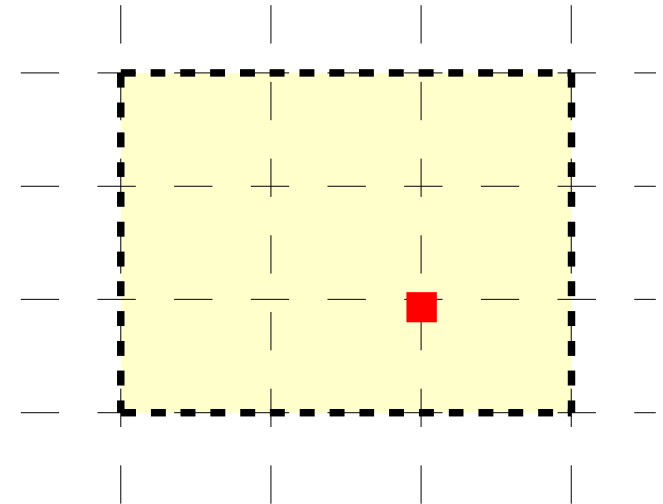
mouse range window

• Rounded off using hysteresis technique

Method - Conditions for Mouse Click
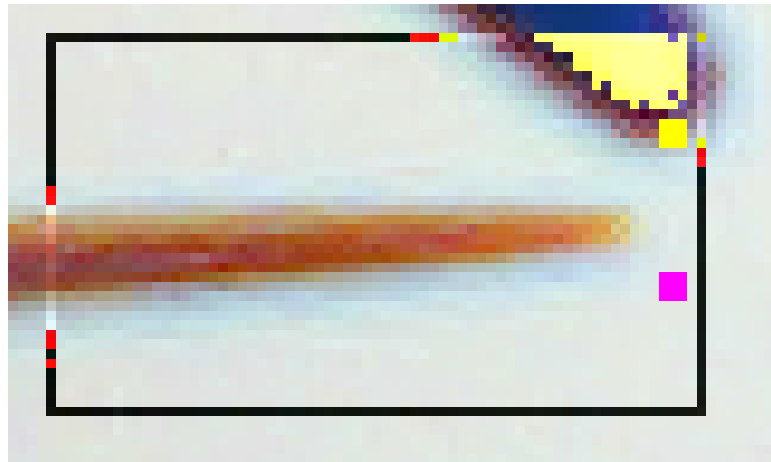
1. Pen and shadow must be near each other

high variance
(σ/μ = H)

low variance
(σ/μ = L)

ignore
pen area
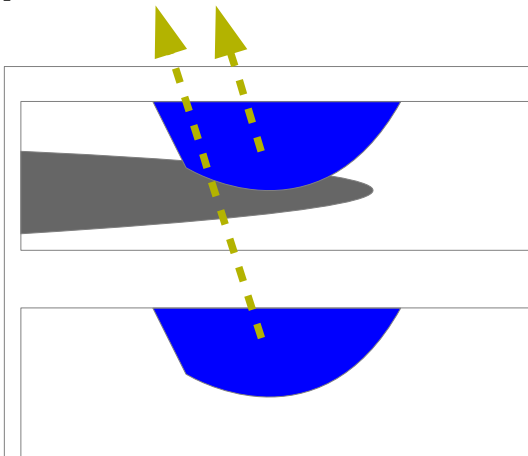
2. Variance must be high

H

σ/μ

threshold

L
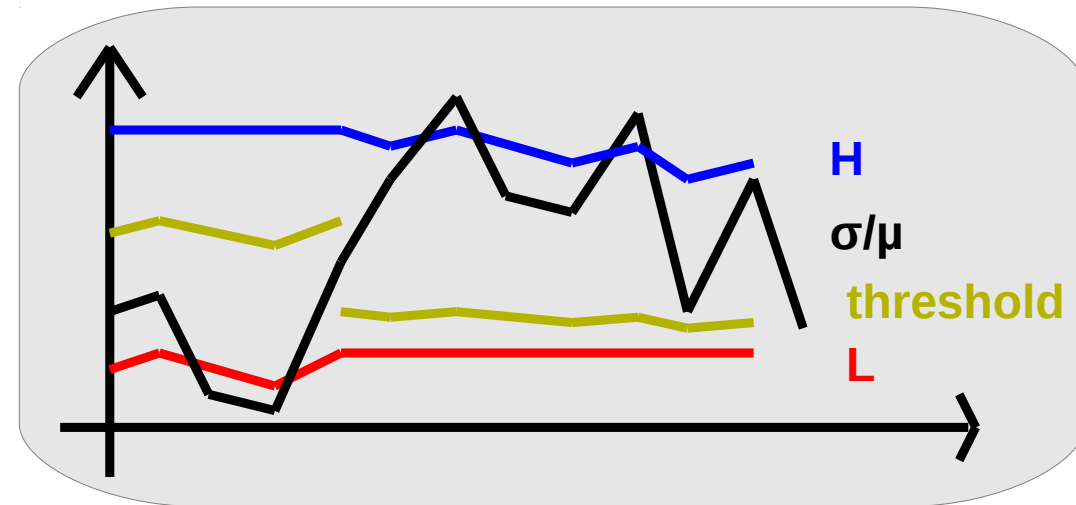
Adaptive Threshold and Hysteresis

3. Results

Problems in Using WebcamPaperPen

- Restrictions in illumination, webcam, etc.

- "Serif" effect:
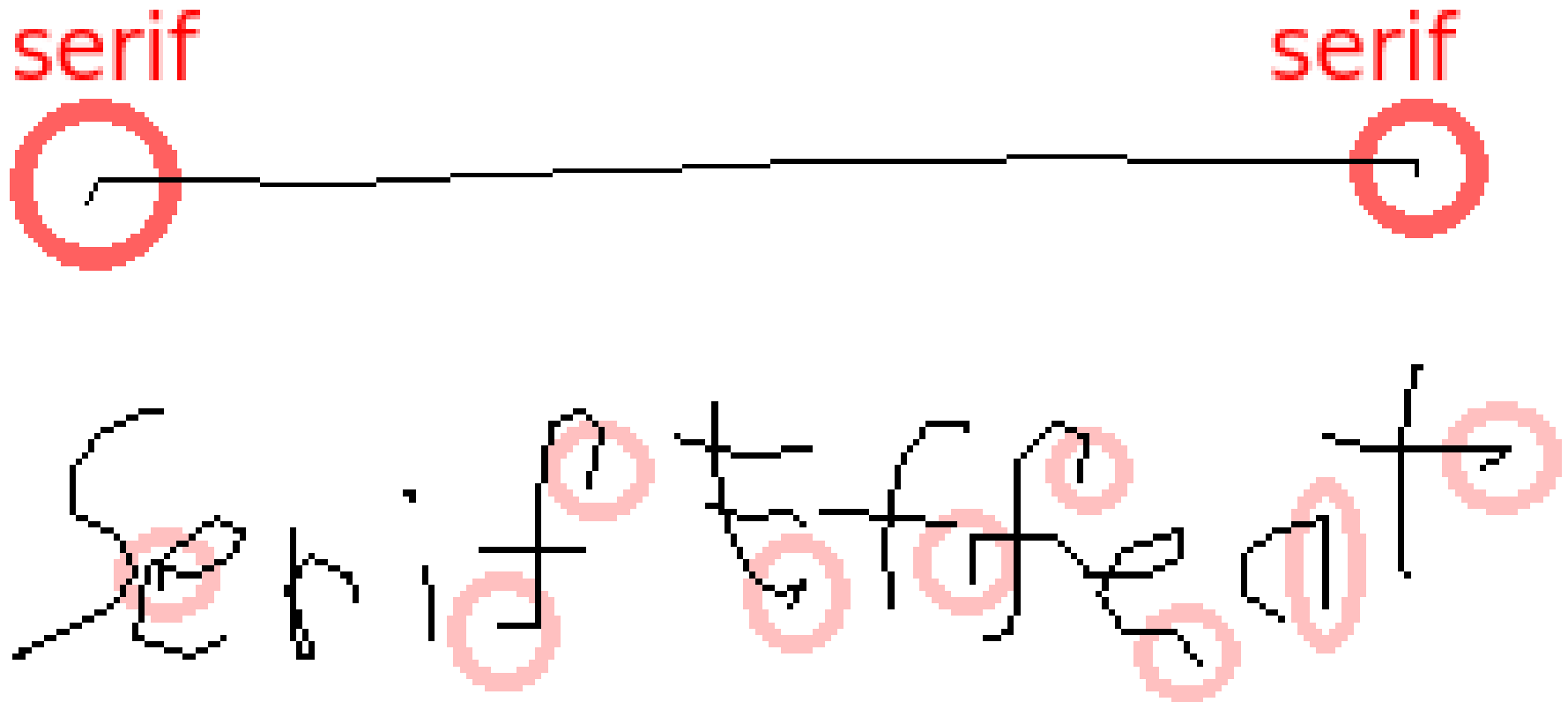
Survey

- Number of participants: 30 persons
- 2 tried at home, 28 at a laboratory
- Most inexperienced with the graphics tablet

- Main problems reported:
  - ➔ undesired click (47%)
  - ➔ "serif" effect (40%)
  - ➔ pen height limit too low (~1cm)
  - ➔ way of holding the pen too restrictive

"Yes, I had no great difficulties." — 67%
"It took me some time calibrating the crosses, but the rest was easy." — 17%
"It is not difficult, but also not easy, I had some trouble..." — 17%
"No, I had a lot of trouble." — 0%
"No, I gave up in the middle." — 0%

"Yes, it replaces the graphics tablet perfectly for me." — 20%
"Yes, the graphics tablet is better but it is too expensive, I would rather use this one." — 47%
"Yes, but I think that after some time I would get tired and would end up buying a proper graphics tablet. OR: If my tablet breaks I would use it, yes, temporarily." — 27%
"No, it does not fit my uses." — 7%
"Not at all." — 0%

"It worked pretty well." — 47%
"It worked well, but I missed the pressure sensor of a graphics tablet." — 20%
"It worked fine sometimes, but it misbehaves too often and is difficult to control." — 30%
"It is cool, but not very useful." — 3%
"I am not satisfied at all." — 0%

Comparisons with Graphics Tablet

Interface	Drawing Time	Output
Webcam-PaperPen	23.82s	The Quick Brown Fox Jumps Over The Lazy Dog
Graphics Tablet	22.72s	The Quick Brown Fox Jumps Over The Lazy Dog
Mouse	62.21s	The Quick Brown Fox Jumps Over The Lazy Dog
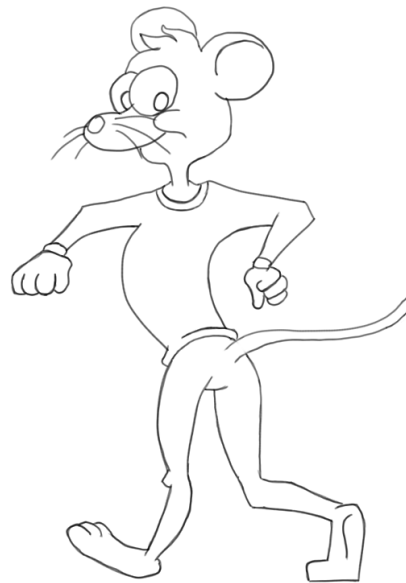
Pencil and Paper   Graphics Tablet   Our Method
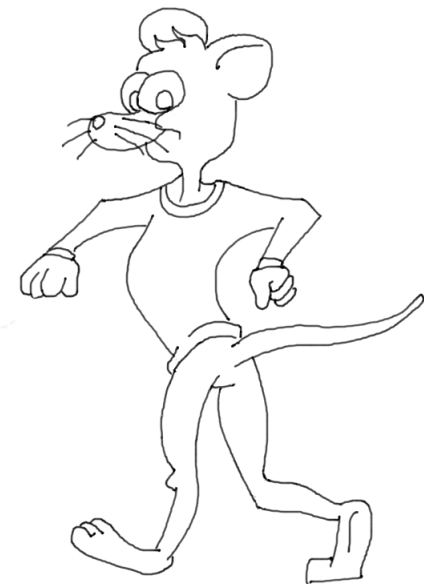
Precision Detail

Graphics Tablet
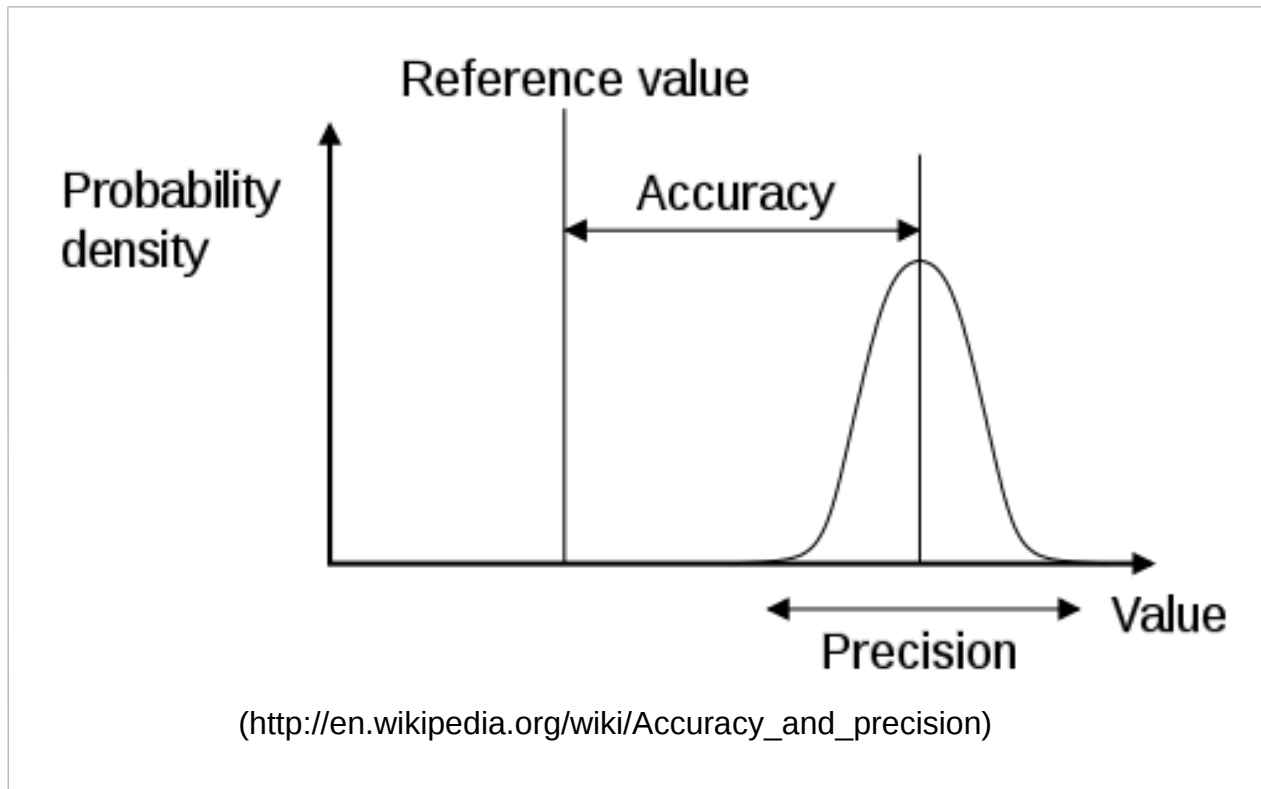
Our Method

Quantitative Precision Measurement

- Asked a user to hold the pen still in some positions and poses

- Estimated σ using $|f(t) - f(t-1)|$

Reference value

Probability density

Accuracy

Precision

Value

(http://en.wikipedia.org/wiki/Accuracy_and_precision)

- Discarded values above 0.5, corresponding to
  - 12.0% of the values for hor. pen tip
  - 9.8% of the values for ver. pen tip
  - 2.1% of the values for shadow tip

- Obtained
  - **σ=0.116** for hor. pen tip
  - **σ=0.103** for ver. pen tip
  - **σ=0.095** for shadow tip

4. Conclusions and Future Work

Conclusions

- Our system is
  - low-cost
  - practical
  - easy to set up
  - modestly precise

- Good for handwriting and simple drawings
  - But not enough for more artistic purposes

Future Work

- Correcting problems reported by users

- Increase flexibility and stability

- Try something with the 3D position of the pen
  - can be easily calculated using the shadow

Thank you for attending!

Questions?
Comments?