Cooperative Object Tracking with Multiple PTZ Cameras

Ivo Everts

PhD student at UvA

University of Amsterdam
Supervision: Theo Gevers (MSc), Nicu Sebe (PhD)
ISIS / ISLA
http://www.science.uva.nl/research/isla/

Kingston University London
Supervision: Graeme Jones
DIRC
http://www.kingston.ac.uk/dirc/

Overview

- Introduction
- Calibration
- Tracking
- Segmentation
  - Target handover
- Conclusion

Introduction

- Current research in Visual Surveillance
  - Scene understanding
- Sensor networks
  - heterogeneous
- Advantages of PTZ cameras
  - Active
  - High resolution imaging

Introduction

- Current research on Visual Surveillance
  - Scene understanding
- Sensor networks
  - heterogeneous
- Advantages of PTZ cameras
  - Active
  - High resolution imaging

Introduction

- Current research on Visual Surveillance
  - Scene understanding
- Sensor networks
  - heterogeneous
- Advantages of PTZ cameras
  - Active
  - High resolution imaging

Introduction

- Current research on Visual Surveillance
  - Scene understanding
- Sensor networks
  - heterogeneous
- Advantages of PTZ cameras
  - Active
  - High resolution imaging

Introduction

- Current research on Visual Surveillance
  - Scene understanding
- Sensor networks
  - heterogeneous
- Advantages of PTZ cameras
  - Active
  - High resolution imaging

Introduction

- Current research on Visual Surveillance
  - Scene understanding
- Sensor networks
  - heterogeneous
- Advantages of PTZ cameras
  - Active
  - High resolution imaging

- Goal: PTZ tracking with target handover

Calibration

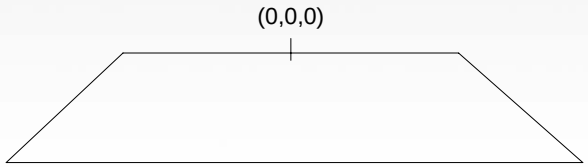
- Communication about target location
- Cameras calibrated wrt common ground plane

Calibration

- Communication about target location
- Cameras calibrated wrt common ground plane

Calibration

- Communication about target location
- Cameras calibrated wrt common ground plane

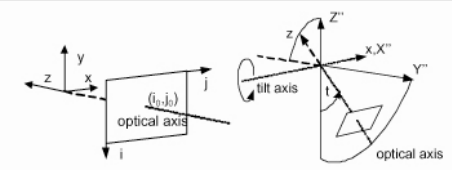


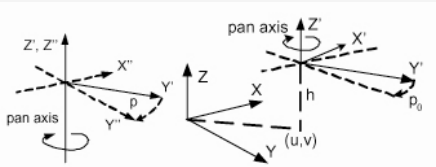
Calibration

- Geometry!

Calibration

- Geometry!





Calibration

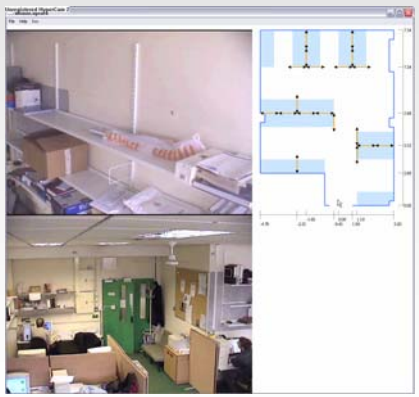
- From pixels to world coordinates

$$\mathbf{X} = \mu \begin{bmatrix} \cos p' & -\sin p' \cos t & \sin p' \sin t \\ \sin p' & \cos p' \cos t & -\cos p' \sin t \\ 0 & \sin t & \cos t \end{bmatrix} \begin{bmatrix} \alpha_x^f \Delta j \\ -\alpha_y^f \Delta i \\ -1 \end{bmatrix} + \begin{bmatrix} U \\ V \\ H \end{bmatrix}$$

- H,p0,U,V resolved by least squares (p'=p+p0)

Calibration

- Example



Tracking

- Let camera move along with target
- Problems with motion detection
- Mean Shift
  - Assumed initialised
  - Target representation & localisation

Tracking

- Let camera move along with target
- Problems with motion detection
- Mean Shift
  - Assumed initialised
  - Target representation & localisation

Kingston University London

Tracking

- Let camera move along with target
- Problems with motion detection
- Mean Shift
  - Assumed initialised
  - Target representation & localisation

Kingston University London

Tracking

- Mean Shift
  - Target representation: colour histogram
  - Target *q*, candidate *p*
  - Weighted by kernel *K(x)*
    - *Profile k(||x||²)*

Kingston University London

Tracking

- Mean Shift
  - Target representation: colour histogram
  - Target *q*, candidate *p*
  - Weighted by kernel *K(x)*
    - *Profile k(||x||²)*

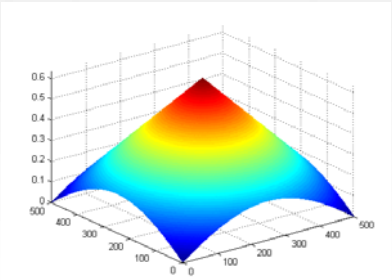
Tracking

- Mean Shift
  - Target representation: colour histogram
  - Target *q*, candidate *p*
  - Weighted by kernel *K(x)*
    - *Profile k(||x||²)*

Kingston University London

Tracking

- Mean Shift
  - Target representation: colour histogram
  - Target *q*, candidate *p*
  - Weighted by kernel *K(x)*
    - *Profile k(||x||²)*
    - Epanechnikov kernel:



Kingston University London

Tracking

- Candidate profile: function of new target centroid y
  - k(||y-xi||²)
- Metric between *p* and *q* function of y
  - Bhattacharya distance

Kingston University London

Tracking

- Candidate profile: function of new target centroid y
  - k(||y-xi||²)
- Metric between *p* and *q* function of y
  - Bhattacharya distance
  - (*p=p(y)*)

$$d(\hat{p},\hat{q}) = \sqrt{1-\rho(\hat{p},\hat{q})}$$

$$\rho(\hat{p},\hat{q}) = \sum_{\vec{b}\in B} \sqrt{\hat{p}(\vec{b})\hat{q}(\vec{b})}$$

Tracking

- Target localisation
  - Minimise *d(p(y),q)* wrt *y*
- New centroid *y*: kernel and data weighted sum over pixels locations

$$\hat{\mathbf{y}}_1 = \frac{\sum_{i=1}^{n_h} \mathbf{x}_i w_i g\left(\left\|\frac{\hat{\mathbf{y}}_0 - \mathbf{x}_i}{h}\right\|^2\right)}{\sum_{i=1}^{n_h} w_i g\left(\left\|\frac{\hat{\mathbf{y}}_0 - \mathbf{x}_i}{h}\right\|^2\right)}$$

$$w_i = \sum_{u=1}^{m} \sqrt{\frac{\hat{q}_u}{\hat{p}_u(\hat{\mathbf{y}}_0)}} \delta\left[b(\mathbf{x}_i) - u\right]$$

$$g(x) = -k'(x)$$

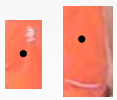
Tracking

- Target localisation
  - Minimise *d(p(y),q)* wrt *y*
- New centroid *y*: kernel and data weighted sum over pixels locations

$$\hat{\mathbf{y}}_1 = \frac{\sum_{i=1}^{n_h} \mathbf{x}_i w_i g\left(\left\|\frac{\hat{\mathbf{y}}_0 - \mathbf{x}_i}{h}\right\|^2\right)}{\sum_{i=1}^{n_h} w_i g\left(\left\|\frac{\hat{\mathbf{y}}_0 - \mathbf{x}_i}{h}\right\|^2\right)}$$

$$w_i = \sum_{u=1}^{m} \sqrt{\frac{\hat{q}_u}{\hat{p}_u(\hat{\mathbf{y}}_0)}} \delta\left[b(\mathbf{x}_i) - u\right]$$

$$g(x) = -k'(x)$$



y0 *y1*

Tracking

- PTZ tracking algorithm

$$\begin{array}{lcl}
R_T & \leftarrow & R_0 \\
\hat{q} & \leftarrow & density(R_T) \\
\mathbf{y}_0 & \leftarrow & \mathbf{0} \\
\mathbf{x}_0 & \leftarrow & groundplane(\mathbf{y}_0, pan_0, tilt_0) \\
 & & \\
for\ t = 1 : nframes & & \\
\quad R_C & \leftarrow & expand(R_T) \\
\quad \hat{p} & \leftarrow & density(R_C, \mathbf{y}_{t-1}) \\
\quad \mathbf{m} & \leftarrow & meanshift(\hat{p}, \hat{q}) \\
\quad \mathbf{y}^* & \leftarrow & \mathbf{y}_{t-1} + \mathbf{m} \\
\quad \mathbf{x}_t & \leftarrow & groundplane(\mathbf{y}^*, pan_{t-1}, tilt_{t-1}) \\
\quad pan_t & \leftarrow & pan(\mathbf{x}_t) \\
\quad tilt_t & \leftarrow & tilt(\mathbf{x}_t) \\
\quad \mathbf{y}_t & \leftarrow & \mathbf{y}_0 \\
end & &
\end{array}$$

Tracking

- Example

Segmentation

- Target handover
- Statistical framework
  - Find target given the colour model and location estimate of the other camera

Segmentation

- Target handover
- Statistical framework
  - Find target given the colour model and location estimate of the other camera

Segmentation

- Target handover
- Statistical framework
  - Find target given the colour model and location estimate of the other camera
- *P(O|c,i)*
  - Proportional to *p(i|O)p(c|O)*

Segmentation

- Classify pixels
- Open image
- Find connected components
- Constrain blob on size

Kingston University London

Segmentation

- Classify pixels
- Open image
- Find connected components
- Constrain blob on size

Kingston University London

Segmentation

- Classify pixels
- Open image
- Find connected components
- Constrain blob on size

Kingston University London

Segmentation

- Classify pixels
- Open image
- Find connected components
- Constrain blob on size

Segmentation

- Playing hide and seek
  - Init cam 1
  - Cam1 tracks target
  - Cam 2 counts to 5
  - Cam 2 seeks target
  - When found: Cam 2 tracks target
  - Cam 1 counts to 5
  - Etcetera

Segmentation

Conclusion

- Successful target handover
  - In real time
- Simple target representation
  - Drawbacks
- Indoor setting
- Need for automation
- Camera quality
- Zoom
- Semantics
- Evaluation

The End

- Thank you

Colour

- The problem with colour
- Different data acquisition processes
- Find out how different
- Experiments

Kingston University London

Colour

- The problem with colour
- Different data acquisition processes
- Find out how different
- Experiments

Kingston University London

Colour

- The problem with colour
- Different data acquisition processes
- Find out how different
- Experiments

Kingston University London

Colour

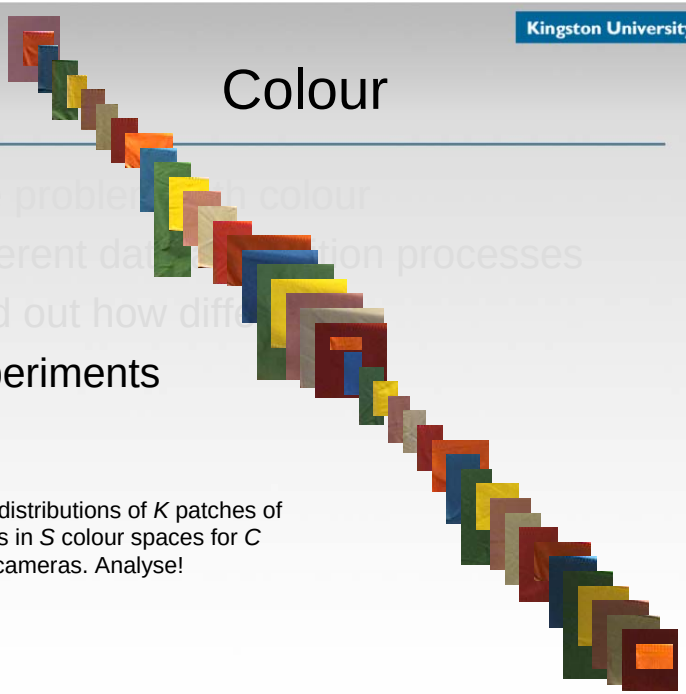
- The problem with colour
- Different data acquisition processes
- Find out how different
- Experiments

Kingston University London

Colour

- The problem in colour
- Different data acquisition processes
- Find out how different
- Experiments

Generate distributions of *K* patches of *J* colours in *S* colour spaces for *C* cameras. Analyse!



Kingston University London

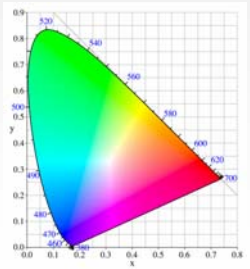
Colour

- Remarkable result in *xy* colour space
- *x=X/(X+Y+Z)* etc
- Experiment: analyse displacement between peaks in quantised spaces of both cameras

Kingston University London

Colour

- Remarkable result in *xy* colour space
- *x=X/(X+Y+Z)* etc
- Experiment: analyse displacement between peaks in quantised spaces of both cameras



Kingston University London

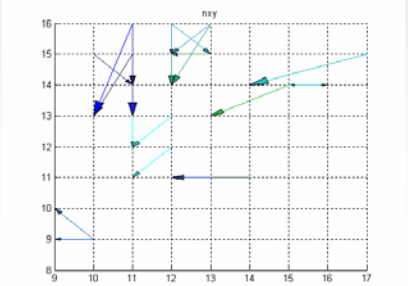
Colour

- Remarkable result in *xy* colour space
- *x=X/(X+Y+Z)* etc
- Experiment: analyse displacement between peaks in quantised spaces of both cameras

Kingston University London

Colour

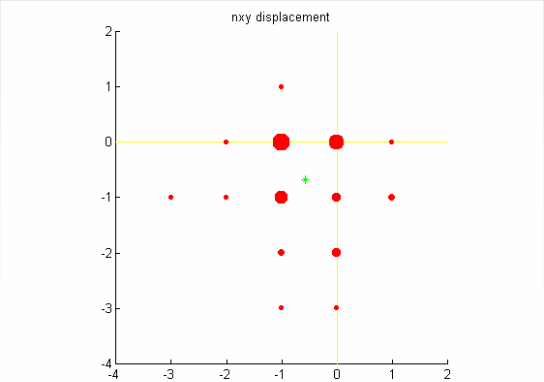
- Remarkable result in *xy* colour space
- *x=X/(X+Y+Z)* etc
- Experiment: analyse displacement between peaks in quantised spaces of both cameras



Kingston University London

Colour

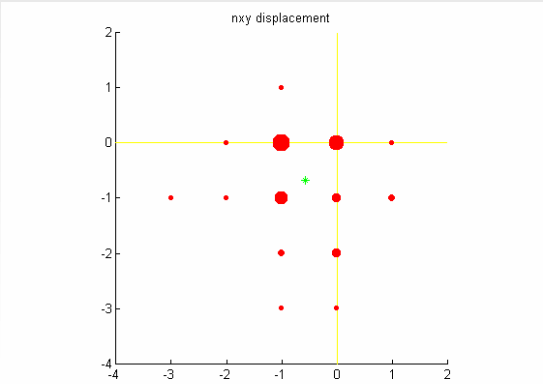
- Displacement plot
- Structure!



Kingston University London

Colour

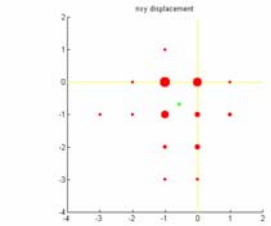
- Displacement plot
- Structure!



Kingston University London

Colour

- Displacement plot
- Structure!
- Compensate for it: colour calibration



Kingston University London

Colour

- Displacement plot
- Structure!
- Compensate for it: colour calibration
- Conclusion
  - *xy* shows hardware difference