Tracking Gaze Direction from Far-Field Surveillance Cameras

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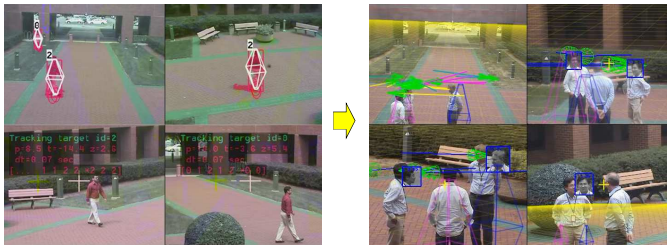
Overview



Main idea: Real-time tracking of the gaze of multiple individuals using a network of far-field surveillance cameras.

- Fixed cameras performing site-wide tracking in unconstrained environments.
- PTZ cameras zooming to faces dynamically.
- Cooperative person tracking and head pose tracking:
  - Person detection, person tracking.
  - Face detection, head pose estimation, *asynchronous* gaze tracking in a centralized tracker.

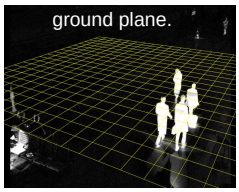
Applications:

- Improve person localization in crowded scenes.
- Real-time understanding of pose, gesture & social interaction.
- Find out what people are looking at (*e.g.*, security, retail apps).

Method

Video person tracking system:

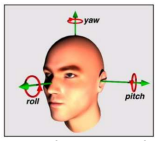
- Multiple calibrated static cameras.
- For each view a set of foreground person detection is form and then projected to a top-down, centralized Kalman filter tracker.



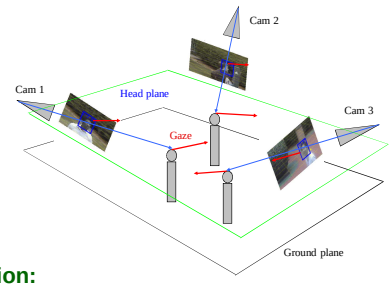
Pan Tilt Zoom (PTZ) camera control:

Real-time, continuously evolving schedule of PTZ camera actions obtained by optimizing toward a set of performance objectives:

- Estimate each PTZ camera's projection matrix based on predicted motion.
- Each schedule is assigned with a probability of maximizing the facial shots of all individuals.
- Quality of facial shot is governed by distance & angle from camera, and person tracking accuracy.



Egocentric gaze angles:
Yaw (left/right)
Pitch (chin up/down)



Face detection & projection:

- Localize face using **Pittsburgh Pattern Recognition** face detector.
- In each PTZ view, each detected face is projected to the *head plane* (1.8m height) to obtain the head position in 3D.

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imagination at work

Gaze Analysis

Head pose detection to 3D gaze vector:

- Convert detected head pose in each camera's Cartesian coordinate $g_{im} = (x_{im}, y_{im}, z_{im})$ to a common centralized 3D world coordinate g_w using camera's rotation matrix $\mathbf{R}$.

$$\mathbf{g}_w = \mathbf{g}_{im} * (\mathbf{R}^{-1})^{\mathbf{T}}$$

- Convert g_w to each individual's egocentric angles in *yaw* α and *pitch* β.

$$\alpha = \arctan(\frac{x_g}{y_g}),$$

$$\beta = \arctan(\frac{z_g}{\sqrt{x_g^2 + y_g^2}})$$

Kalman filter gaze tracking:

Operates on individual's angular gaze coordinates (α, β).

Gaze state Θ :

$$\Theta = \begin{bmatrix} \alpha & \beta & \dot{\alpha} & \dot{\beta} \end{bmatrix}^{\mathbf{T}}$$

State transition model from time *k-1* to *k*:

$$\Theta_k = \mathbf{F} * \Theta_{k-1} + \mathbf{w}_{k-1}$$

State transition matrix $\mathbf{F}$ using constant velocity mode:

$\mathbf{w}$: Gaussian distributed process noise

$\mathbf{v}_k$: Gaussian distributed measurement noise

$$\mathbf{F} = \begin{bmatrix} 1 & 0 & \Delta t & 0 \\ 0 & 1 & 0 & \Delta t \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Gaze measurement:

$$\begin{bmatrix} \alpha \\ \beta \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} * \Theta_k + \mathbf{v}_k$$

Data association for gaze and person tracking:

- Association of multiple face detections with multiple person tracks, by minimizing a cost function reflecting two cues: *head location* and *gaze direction*.

Distance between head observation $\mathbf{h}_i$ and person track $\mathbf{t}_j$:

$$\eta(\mathbf{h}_i, \mathbf{t}_j) = \exp(-\frac{d(\mathbf{h}_i^{\mathbf{x}}, \mathbf{t}_j^{\mathbf{x}})}{\sigma_{\mathbf{x}}} - \frac{\lambda(\mathbf{h}_i^{\Theta}, \mathbf{t}_j^{\Theta})}{\sigma_{\Theta}})$$

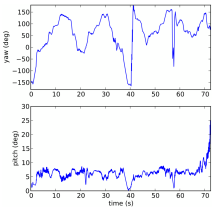
Euclidean distance between head & track's location

Geodesic distance between gaze & track's direction

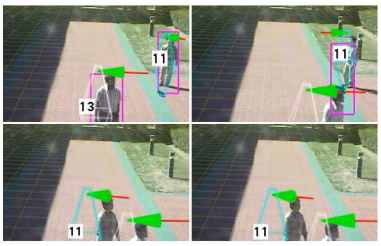
- **Hungarian algorithm** to minimize η to find the best association of detected faces and person tracks.

Experimental Results

Single person



Two people



Three people