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 formed 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.

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.

Gaze Analysis

Head pose detection to 3D gaze vector:

\[ g_w = g_{im} \cdot (R^{-1})^T \]

\[ \alpha = \arctan\left(\frac{x_g}{y_g}\right) \]

\[ \beta = \arctan\left(\frac{z_g}{\sqrt{x_g^2 + y_g^2}}\right) \]

Kalman filter gaze tracking:

Operates on individual’s angular gaze coordinates (\( \alpha, \beta \)).

Gaze state \( \Theta \):

\[ \Theta = \begin{bmatrix} \alpha & \beta & \dot{\alpha} & \dot{\beta} \end{bmatrix}^T \]

State transition model from time \( k-1 \) to \( k \):

\[ \Theta_k = F \cdot \Theta_{k-1} + w_{k-1} \]

State transition matrix \( F \) using constant velocity mode:

\( w \): Gaussian distributed process noise

\( v_k \): Gaussian distributed measurement noise

\[ F = \begin{bmatrix} 1 & 0 & \Delta t & 0 \\ 0 & 1 & 0 & \Delta t \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \]

Gaze measurement:

\[ \begin{bmatrix} \alpha \\ \beta \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \cdot \Theta_k + v_k \]

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 \( h_i \) and person track \( t_j \):

\[ \eta(h_i, t_j) = \exp\left(-\frac{d(h_i^x, t_j^x)}{\sigma_x} - \frac{\lambda(h_i^\Theta, t_j^\Theta)}{\sigma_\Theta}\right) \]

Euclidean distance between head & track’s location

Geodesic distance between gaze & track’s direction

- Hungarian algorithm to minimize \( \eta \) to find the best association of detected faces and person tracks.

Experimental Results

Single person

Two people

Three people

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