Human Gait Analysis and Recognition

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Biometrics

What is it?

- Human identification through the natural biological features of humans, rather than any carried certificates.

Categories:

- Intrinsic / static features: face, iris, finger-print, palm-print, vein-print, ear, etc.;
- Behavior / dynamic features: voice, signature, gait, etc.
Gait Recognition——A Glance

——A young biometric with potential

✿ **Destination**: Automatic human identification and authentication by observation of their walking styles.

✿ **Rationality**: Human’s ability to recognise people by their gait—heavy; humble; weary; gentle… (Shakespeare)

✿ **Advantage**: data acquisition from distance; non-invasive; hard to conceal, comparing to traditional biometrics.
A challenging work

- **Subtle** discriminating features of gait are hiding behind similar motions.
- **Vulnerable** to variations in clothing, illumination, outdoor background, silhouette noise.

**Methods:**

**Model-based**
- Marker-based
  - Cylinder
- Markerless
  - Ellipse
  - Deformable
  - ... ...  

**Appearance-based**
- Silhouette-based
  - Moment
  - Contour
  - Temporal Template
- Optical flow
  - ... ...
Groups with sound

Mark Nixon, Soton@UK
S. Sakar and Z. Liu, USF@US
T.N. Tan, CASIA@CN
D. Xu, NTU@SG
R. Challapa, UMD@US
......
General Technique Framework of Gait Analysis & Recognition
Framework of Computer Vision by D. Marr

- **Basic elements:**
  - Edge, corner, texture;

- **2.5-D elements graph:**
  - From viewpoint of observer's coordinates, the normal, depth (stereo vision), discontinuities for each surfaces;

- **3D model description:**
  - 3D scenario understanding and reconstruction.

![Diagram of the framework of computer vision](image-url)
General Technique Framework of Gait Analysis & Recognition

Two mainstream routes:

- Model free: silhouette analysis
- Model based: Articulated model
General Technique Framework of Gait Analysis & Recognition

Two mainstream routes:

- **Model free**: Silhouette analysis
- **Model based**: Articulated model
Classical method for background modeling —— (GMM)

For some complicated background, i.e. lake wave, leaf swing, drizzle, Uni-Gaussian model is no longer competent.

\[ P(X_t) = \sum_{i=1}^{K} \omega_{i,t} \ast \eta(X_t, \mu_{i,t}, \Sigma_{i,t}) \]
Silhouette extraction—— classical segmentation problem

Typical method: GMM + EM

a two-class problem: \{Foreground=w_1, Background=w_2\}

\[
P(d_k) = \sum_{i=1}^{2} P(\omega_i)p(d_k|\omega_i, \mu_i, \sigma_i)
\]

\[
p(d_k|\omega_i, \mu_i, \sigma_i) = \frac{1}{\sqrt{2\pi}\sigma_i} e^{-\frac{(d_k-\mu_i)^2}{2\sigma_i^2}}
\]
Typical algorithms in model-free gait recognition

- Gait energy image (GEI): represent sequence into image by overlapping;
- Tensor Discriminant Analysis: $S(x,y,t)$, 3D data representation;
- Contour measurement:
- Vertical / horizontal projection.
General Technique Framework of Gait Analysis & Recognition

Two mainstream routes:

- **Model free:** silhouette analysis
- **Model based:** Articulated model
Articulated body motion tracking

- 30+ DoF
- Cylinder model
Kalman filtering based tracking

- **Status equation:**
  \[ x_k = Ax_{k-1} + u \]

- **Measurement equation:**
  \[ y_k = Cx_k + v \]

- **Status updating equation:**
  \[ \hat{x}_k = A\hat{x}_{k-1} + H_k(y_k - \hat{y}_k) \]

- **Limitation:**
  only applicable to linear and Gaussian model.
Particle Filtering (PF)

Importance Sampling:

Bayesian framework of PF:

\[
p_t(x_t|Z_t) = \frac{p_t(Z_t|x_t)p_{t-1}(x_t|Z_{t-1})}{p_t(Z_t)},
\]

\[
p_t(x_t|Z_t) = \frac{p_t(Z_t|x_t) \int_{x_{t-1}} p_t(x_t|x_{t-1})p_{t-1}(x_{t-1}|Z_{t-1}) \, dx_{t-1}}{p_t(Z_t)}.
\]

\[
p_{t-1}(x_{t-1}|Z_{t-1}) \quad \xrightarrow{\text{convolve with}} \quad p_{t-1}(x_t|Z_{t-1}) \quad \xrightarrow{\text{multiply by}} \quad p_t(x_t|Z_t)
\]

\[
\text{dynamics } p(x'|x) \quad \text{observation density } p(Z|x')
\]
Tracking

- Status equation —— description of kinematics characteristics;
- Measurement vector —— low level visual cues: edge detection, foreground segmentation, centroid, color……
Typical algorithms in model-based gait recognition

- Hip rotation model
- Ellipse fitting
- Two-joint pendulum model

Trajectory analysis of rotation angles
Other solutions for gait?
—— extend our mind!
Marker-based motion capture

- Marker’s type:
  - LED, infra-red, radio

- Application
  - Movie production
  - Animation
  - Athlete training aid
  - Human gait analysis
Multiple-Circle Tracking

- Single tracking:
- Multiple Tracking:

Difficulties: Overlapping, Agile-movement, Real-time, ID-confusing …
General Technique Framework of Gait Analysis & Recognition

- **Model free**: silhouette analysis
- **Model based**
  - Markerless: Articulated model
  - **Marker-based analysis**
Look at Another Case: Face Recognition by NIR

- **Why NIR (Near Infra-Red)?**
  - Radiation Spectrum Ranges
  - Robust to illumination variant
  - Non-invasive

- **Active NIR imaging system**
**Model free:**
- Silhouette analysis
- **Near Infra-red image:** Non-invasive

**Model based**
- Markerless: Articulated model
- Marker-based analysis: Invasive
Summary

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Near-IR sensor data

Background modeling

Object Segment

Image Space

Feature Extraction (Dim. Reduc.)

Articulated model

Tracking

Para. Space

FR

Template pond

Classifier (NN, SVM)

ML

Signal Layer

Feature Layer

Symbol Layer

Marker sensor data

Videos

Object Segmentation

Feature Extraction (Dim. Reduc.)

Classification (NN, SVM)

Template pond

ML
From Gait to body motion analysis —— possible future trends

- Tensor based approaches
- Abnormal behavior detection
- Body motion capture & driven
- .......

[Diagram showing Hot Topic trends from 2002 to 2010]

[Image of the movie Avatar]
Selected our work on gait recognition

- Gait history image (GHI)
- Silhouette Quality Quantification (SQQ)
Temporal Template

**Definition:** In template image, each pixel value is defined as a function of time (frame number) along whole silhouette sequence.

**Purpose:** Binary image sequence can be represented as a compact image with temporal information reserved.
Temporal Template: Some examples

A scenario of pendulum’s motion

- **Motion Energy Image (MEI):**
  \[ E_{\text{MEI}}(x, y) = \bigcup_{t=1}^{\tau} D(x, y, t) \]

- **Motion History Image (MHI):**
  \[ E_{\text{MHI}}(x, y, t) = \begin{cases} \tau & \text{if } D(x, y, t) = 1 \\ \max(0, E_{\text{MHI}}(x, y, t-1) - 1) & \text{otherwise} \end{cases} \]

- **Gait Energy Image (GEI):**
  \[ E_{\text{GEI}}(x, y) = \frac{1}{\tau} \sum_{t=1}^{\tau} I(x, y, t) \]
Comparison of GHI with other templates

<table>
<thead>
<tr>
<th></th>
<th>MEI</th>
<th>MHI</th>
<th>GEI</th>
<th>GHI</th>
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<tr>
<td>Temporal Info</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
</tbody>
</table>
Gait History Image

**Aim:**
A novel temporal template should have finer representing ability for gait motion.

**Definition:**
\[
E_{\text{GHI}}(x, y) = \begin{cases} 
\tau & \text{if } S(x, y) = 1 \\
\sum_{t=1}^{\tau} D(x, y, t) \cdot (t - 1) & \text{otherwise} 
\end{cases}
\]

Where \( S(x, y) = \begin{cases} 
1 & E_{\text{GEI}}(x, y) \geq th \\
0 & \text{otherwise} 
\end{cases} \)

\( th = \max_{(x, y)} (E_{\text{GHI}}) \times 80\% \)

**Merit:**
- Static and dynamic characteristics can be represented;
- spatial and temporal variations can be represented.
Some examples of GHI

\[ \mathcal{E}_G^O \]

\[ \mathcal{E}_G^C \]

Subject 1  Subject 2  Subject 3
Gait Recognition using GHI

- **Training phase:**

- **Classification phase:**

  - Nearest Center of Class (NCC) criterion is used here:

  \[
  \chi_p = \arg \min_{1 \leq i \leq c} \left[ D(\tilde{G}^o, G^o_i) + D(\tilde{G}^c, G^c_i) \right]
  \]
Experimental results

Cumulative Matching Score (CMS) results on CASIA dataset

CMS scores on USF dataset
Selected our work on gait recognition

- Gait history image (GHI)
- Silhouette Quality Quantification (SQQ)
Motivation

✦ Most gait recognition approaches are designed based on binary images (silhouettes).
  ➢ Simpler compared to articulated model.
  ➢ clothing color / texture information contribute nothing to identification;
  ➢ So, many gait datasets opened public provide silhouette versions.

✦ However, In reality, silhouette noise occurs inevitably after Background Subtraction.
Periodicity and Cycles in gait sequence

- **Time duration of a full walking cycle:**

- **Foreground sum signal & its Autocorrelation signal:**
Observation

What is FS signal?

Definition:

\[ x(t) = \sum_u \sum_v s(u, v, t) \]

Observation
The noise in FS signal is correlated to noise in silhouettes.
**Silhouette Quality Quantification (SQQ)**

- **Idea:** Using FS signal to measure the quality of silhouette sequence.

- **Modeling the FS signal:**
  \[ x(t) = a_0(t) + a_1(t) \cos \omega t + a_2(t) \cos 2\omega t + z(t) \]

- **Proposed a silhouette quality evaluation function:**
  \[ Q(i) = \sigma_s^2 - \sigma_z^2, \text{ over } f_i(t), \text{ for all } f_i \subset f \]

  by using the autocorrelation matrix eigenanalysis approach.
Visualization of the evaluation

- SQQ curve upon simulated data:
  - $f(t)$

- SQQ curve upon real silhouette data:
  - $Q(i)$
Silhouette Quality Weighted (SQW) Gait Recognition

- Extending the application of SQQ for gait recognition.
- Proposed the Silhouette quality weighted (SQW) gait recognition algorithm:

\[
k = \arg \min_i \left( \text{Sim}_i(S_P, S_i) \right), \text{ with } S_i \in \{S_G\}
\]

\[
\text{Sim}'(x) (\langle S_P, Q_{S_P} \rangle, \langle S_G, Q_{S_G} \rangle)
\]
Experimental results

(a) Histogram of SQQ scores for the Baseline algorithm

(b) Identification performances on the USF ver.1.7 dataset.
My Advises on GR system building

- Frontal view is more discriminative,
- Never discard static feature —— cascade
- Room is harder than corridor,
- The more sensor uses, the less complexity in algorithm.
Thank You!