**Summary:**

**Gait Authentication on Mobile   
Phone Using Pattern Recognition and   
Biometric Cryptosystem**

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1. **Overview:**
   1. Data acquisition using built-in sensors (accelerometer,magnetometer) of mobile devices;
   2. Data preprocessing (time interpolation, noise filtering);
   3. Data analysis (gait cycle detection, pattern extraction);
   4. Feature extraction in both time domain and frequency domain;
   5. Classification: Machine Learning method
      * Support Vector Machine (SVM) classifier
2. **Problems and solutions:**
   1. Data acquisition, preprocessing and classification method selection (Template Matching method vs. Machine Learning method)

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| *Paper title* | Gait identification using accelerometer on mobile phone |
| *Appeared in* | International Conference on Control, Automation and Information Sciences (ICCAIS), IEEE, 2012 |
| *Data acquisition* | * *Mobile device:* Google Android HTC Nexus One * *Sensor:* Bosch Sensortec’s 3-axis BMA 150 accelerometer * *Sampling rate:* 27Hz * 11 volunteers (24 year-old), 12 laps with 26 seconds each lap for each person |
| *Data Preprocessing* | * *Linear interpolation:* to acquire fixed interval length (32Hz) signal * *Noise elimination:* Daubechies orthogonal wavelet (Db6) decomposition at level 2 |
| *Data analysis* | * Gait cycle partition using peak detection on the Z-dimensional signal |
| *Feature extraction* | * ***Time domain feature****:* average gait cycles (AGCs) is a sequence of values where one value is an average distance between one gait cycle to others (calculated by using DTW) * ***Frequency domain features:*** the first 40 FFT coefficients form a feature vector |
| *Classification* | * ***Template Matching method:*** DTW is performed to match two AGCs templates * ***Machine Learning method:*** SVM with feature vector is first 40 FFT coefficients |
| *Results* | * *Identification accuracy:*   + *DTW:* 79.1%   + *SVM:* 92.7% , additional validation is needed |

* 1. Examining the impact of different sampling rates (from different devices) on the preprocessing steps

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| *Paper title* | Adaptive Cross-Device Gait Recognition Using a Mobile Accelerometer |
| *Appeared in* | Journal of Information Processing Systems 9(2), 2013 |
| *Data acquisition* | * *Mobile devices:* Google Android HTC Nexus One and LG Optimus G * *Sensor:* accelerometer * *Sampling rates:* 27Hz (Google HTC) and 100HZ (LG Optimus) * 14 volunteers (23~28 year-old), 12 laps with 36 seconds each lap for each person |
| *Data preprocessing* | * *Linear interpolation:* to acquire signals with fixed interval length at 32Hz and 100Hz * *Noise elimination:* Db6 decomposition at level ( for 32Hz signal and for 100Hz signal) |
| *Data analysis* | * *Data segmentation* by using autocorrelation |
| *Feature extraction* | * ***Time domain features:***   + Average maximum acceleration   + Average minimum acceleration   + Average absolute difference   + Root mean square   + 10-bin histogram distribution   + Standard deviation   + Waveform length   + Time of a gait cycle   + Gait cycle frequency * ***Frequency domain features:***   + First 40 FFT coefficients   + First 40 DCT coefficients |
| *Classification* | SVM with Radial Basis Function (RBF) kernel |
| *Classification result* | 99.81% (Google HTC, Db6 at level 2) and 97.53% (LG Optimus, Db6 at level 3) |
| *Feature validation* | * *Measure:* Average Error Rate (AER) and Intra-class Correlation Coefficients (ICC) * ***Time domain features:***   + High ICC values (0.7~0.996) => time domain features are high reliable regardless of sampling rate   + Low AER => not influenced by the sampling rate * ***Frequency domain features:***   + Fair to good values of ICC (0.666~0.804) => reliable   + High AER => very sensitive to the sampling rate |
| *Sampling rate examination* | * *Sampling rate =* {16+4k} with k = 1,2,...,21 * *Result:* best classification result with sampling rate of 32~36Hz, noise filtering at level 2 |
| *Noise filtering* | Higher levels of decomposition will eliminate noise better   * *Level 1:* 12~48Hz * *Level 2:* 12~100Hz (accuracy rate decreases when the sampling rate increases, best classification achieved at sampling rate 32~36Hz) * *Level 3:* best accuracy rate of 97.53% at the sampling rate of 100Hz |

* 1. Preprocessing step: Handling mobile installation issues: disorientation and misplacement of mobile phone in side the trouser’s pocket

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| *Paper title* | A Lightweight Gait Authentication on Mobile Phone Regardless of Installation Error |
| *Appeared in* | Security and Privacy Protection in Information Processing Systems 405:83-101, 2013 (SEC 2013) |
| *Data acquisition* | * *Mobile phone:* Google Android HTC Nexus One (sampling rate of 27Hz) * *Sensor:* accelerometer, magnetometer * 38 volunteers (24~28 year-old), 18 laps with 36 seconds each lap for each person, three types of footwear (sleeper, sandal and shoe) |
| *Data preprocessing* | * *Signal transformation:* rotation by using magnetometer to detect the roll, pitch and yaw angles * *Linear interpolation:* to acquire fixed interval length (32Hz) signal * *Noise filtering:* DB6 wavelet decomposition at level 2 |
| *Data analysis* | * *Segmentation:* based on gait cycles (2,4,8) |
| *Feature extraction* | * Feature extraction in both time domain and frequency domain * Feature subset selection by using Sequential Forward Selection (SFS) algorithm and Sequential Floating Forward Selection (SFFS) algorithm |
| *Classification* | * SVM with RBF kernel |
| *Result* | * *Accuracy:* 94.93% (SFFS) * False-Match-Rate (FMR): 0% * False-Not-Match-Rate (FNMR): 3.89% * Authentication time: <4 seconds |

* 1. System security and privacy concerns

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| *Paper title* | Secure and Privacy Enhanced Gait Authentication on Smart Phone |
| *Appeared in* | The Scientific World Journal, 2014 |
| *Data acquisition* | * *Mobile phone:* Google Nexus One (sampling rate of Hz) * *Sensor:* accelerometer * 34 volunteers (24~28 year-old), 18 laps for each person with different types of footwear and clothes |
| *Data preprocessing* | * *Linear interpolation:* to acquire fixed interval length (32Hz) * *Noise filtering:* Db6 wavelet decomposition at level 2 |
| *Data analysis* | * Gait cycle based segmentation |
| *Feature extraction* | * Feature extracted in both time domain and frequency domain. Feature vector is of length 290. * Binary feature vector extraction by using quantization. * Extract reliable bits by integrating Gaussian distribution to each components of the feature vector. Feature vector’s length is reduced. |
| *Key binding* | * Randomly generate a binary secret key * Calculate a the value by using a cryptographic hash function * Encoding using Bose-Chaudhuri-Hocquenghem (BCH) scheme * Binding using exclusive-OR operator |
| *Authentication* | * Decoding using BCH algorithm to obtain the secret key * Calculate the hash value using the equivalent cryptographic hash function * Matching between the two hash values |
| *Result* | Key length = 50 bits:   * False Acceptance Rate (FAR) = 3.92% * False Rejection Rate (FRR) = 11.76% |