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A Comprehensive Study on Approaches of Cell Phone based Gait Biometric Identification

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***Abstract:* - Authentication is one of the most important issues in portable devices. Most of the authentication methods include obtrusive user at tempts where secret information likes Personal Identification Number (PIN), password can be noticed or stolen by others. Consistent user authentication is most important to secure portable devices now-a-days; however most of the authentication methods include obtrusive user attempt i.e. PIN, password which can be noticeable by others. As a result, these devices are accessed for a long time after the successful verification which allows replacing the official user to the benefit of a fraud and this is the case with portable devices. This paper includes a method of continuous user verification by unobtrusive biometrics i.e. gait. Over a period of years, researchers have proposed various methods to protect portable devices, but the security of these devices may not be represented properly by using the conventional methods and other biometrics applications due to its obtrusiveness and inconveniency. Gait analysis and recognition plays vital role in security of portable devices through biometrics as it is an unobtrusive way to secure these devices.**

***Index Terms*— accelerometers, biometrics, gait identification, gait recognition, portable devices.**

I. INTRODUCTION

Portable devices such as Mobile phones, tablets, laptops etc. have become popular among today's generation; almost every human being carries any of the portable devices these days and will be more critical part in years to come. We use these devices not only for ease of communication but also for browsing internet, booking ticket, booking hotel, online banking, online shopping which involves significant personal and financial data like photos, account numbers, passwords, PINs etc. This makes the data on these devices are more valuable than the device. Therefore, security of these devices play essential role for the today's users. Original Equipment Manufacturer (OEM) protect sensitive data of portable devices by using explicit authentication mechanism like PIN, passwords or pattern lock and this authentication takes place only once when the device is switched on, after that the device can be used for a longer period without worrying about user privacy. This method is not much user friendly as these are to be memorized and entered for each authentication, can be stolen or forgotten. To solve these problems, researchers are looking for biometric solutions such as fingerprint, voice, signature, face, gait, ear, iris, vein pattern, palm print etc. Advantage of these biometric is that it can't be stolen or forgotten as it uses person's psychological and behavioral characteristics. Conventionally, biometric requires additional hardware, but now-a-days this hardware is already fixed in portable devices in form of sensors. Biometrics can be either obtrusive or unobtrusive. Biometrics such as fingerprint, voice, signature, face, ear, iris and palm print are obtrusive biometrics as it requires subject's intervention which is used rarely and results in high cost because extra hardware is required to install them. Gait, voice, iris, face are unobtrusive biometrics as it does not require subject's intervention which is used mostly and cheaper because required sensors are already embedded. This paper focuses on identifying user of portable devices from gait pattern with accelerometers because itis unobtrusive and intuitive in which verification process is done implicitly and continuously when the user walks.

II. BIOMETRICS

Biometrics use person's psychological or behavioral characteristics to verify the identity of the person. Psychological characteristics collect data from direct measurement of human body like finger print, finger scan, hand geometry, iris and retina scanning, facial geometry etc. while behavioral biometrics analyze specific actions of a person like his style of walking, talking and doing signature etc. Classification of biometrics based upon characteristics is shown in Fig. 1.

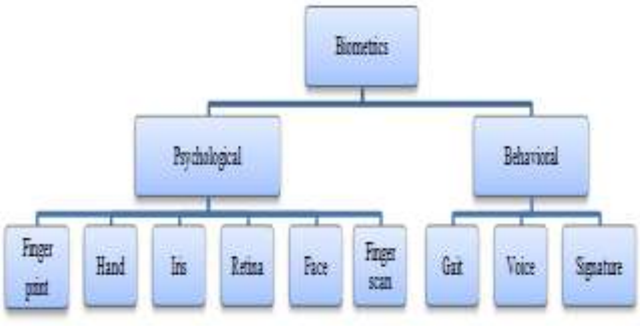

Fig. 1: Types of Biometrics Based Upon Characteristics

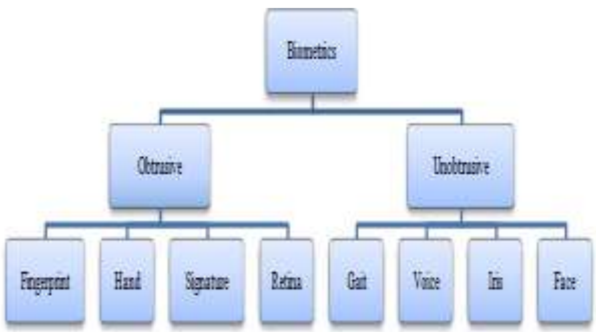

Fig 2: Types of Biometrics Based upon Subject's Intervention

Further, biometrics can be classified into either obtrusive or unobtrusive. Obtrusive biometrics does require subject's intervention and therefore it can be noticeable by anyone. So it is not secure. While Unobtrusive biometrics does not require subject's intervention and therefore it cannot be noticeable by anyone. So it is secure. Fig. 2 shows biometrics classification based upon user's intervention.

III. GAIT BIOMETRICS

Gait is a particular way of moving on foot. Every person has his or her own way of walking. From early medical studies it appears that there are 24 different components to human gait, and that if all the measurements are considered, gait is unique. This has made gait recognition an interesting topic for identifying individuals by the manner in which they walk. The analysis of biometric gait recognition has been studied for the use in identification, surveillance and forensic systems and is becoming important as it can provide more reliable and efficient means of identity verification.

Gait analysis is the systematic study of human walking, using the eye and brain of experienced observers, augmented by instrumentation for measuring body movements, body mechanics and the activity of the muscles [16].It is used to analyze the walking ability of humans and animals, so this technology can be used for large number of applications. Some of the well-known application areas of gait recognition are listed in Fig 3 below.

Fig 3: Applications of Gait Biometrics

Gait Cycle

The gait cycle is defined as the time interval between two successive occurrences of one of the repetitive events of walking i.e. it is the time interval between the exact same repetitive events of walking. If it is decided to start with initial contact of the right foot, then the cycle will continue until the right foot contacts the ground again. The left foot, of course, goes through exactly the same series of events as the right, but displaced in time by half a cycle. It can be divided into two different phases: the stance phase and swing phase. The stance phase is the component of gait cycle in which the foot remains get in touch with the ground. It includes heel strike, foot flat, mid stance, heel off and toe off movements of the reference foot and therefore it covers the 60% of the gait cycle. While the swing phase is that component of gait cycle in which reference foot doesn't get in touch with the ground. It includes acceleration, toe off and de-acceleration movements and therefore covers the 40% of the gait cycle [16].These phases can be further divided into sub-phases as shown in Fig 4.

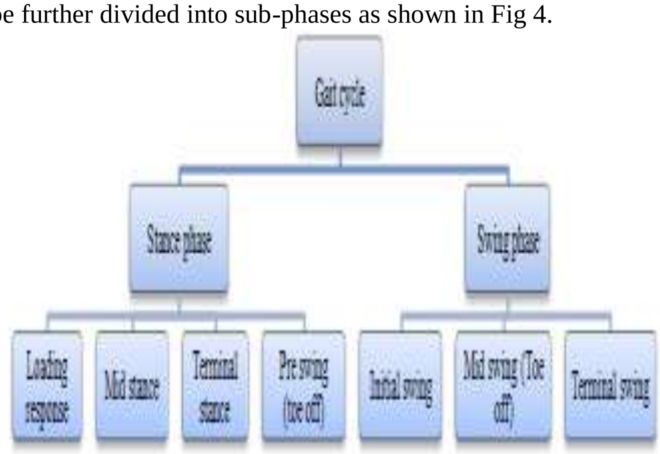

Fig 4: Phases of Gait Cycle

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IV. GAIT RECOGNITION – RELATED WORK

Gait recognition is the process of identifying person by the way they walk. It is the use of a person's unique style of walking to identify or authenticate one's identity and has shown promising results as a biometric tool [1]. It is an interesting area of research due to different areas of application. The bunches of studies for gait recognition are done by using wearable sensors. Several studies have already given evidence that accelerometer wearable sensors are enough for gait recognition which is embedded in portable devices now-a-days. In this section a summary of different factors recognized so far, sensors used for gait recognition and approaches used for identifying human gait has been presented.

A. Experiments

Gait identification is dependent on various factors such as different walking speed, type of ground, shoe size and comfort, position of sensor etc. All the previous studies [1-15] have been carried out using different sensors and now-a-days mostly by accelerometers embedded in wearable sensing devices to collect the data. Accelerometer sensors are incorporated on new models of portable devices such as smart phones, tablet computers, digital audio players, laptop etc., which record the body movement. Different factors such as walking, jogging, climbing stairs, opening door, walking around corners have been studied by many of the researchers using different accelerometers sensors. Table I summaries different activities and test persons by different studies.

TABLE I: GAIT RECOGNITIONSTUDIES

Study by	Activities	Test Data Size (Number of Persons)
Kwapiz, J.R. et. al [1]	Walking, jogging, climbing up & climbing down stairs	36
Nickel, C. et. al [2]	Normal walk Fast walk	36
Nickel, C. et. al [3]	Normal speed with usual shoes	48 including 38 male and 10 female
Mantyjarvi, J. et. al[4]	Fast, Normal and Slow speed	36 including 19 male and 17 female
Nickel, C. et. al [5]	Climbing of stairs, opening doors, walking around corners	48 including 30 male and 18 female
Juefei-Xu, F et. al [6]	Normal speed Fast speed	36 including 28 male and 8 female
Thang, H. M et. al[7]	-	11
Ailisto, H. J. et. al [8]	Normal speed	36
Annadhorai, A. et. al [9]	-	4
Gafurov, D. et. al [10]	Vertical, forward- backward, sideways	21
Gafurov, D. et. al [11]	Vertical, forward- backward, sideways	21
Ngo, T. T. et. al [12]	Different days, sensors, weights being carried, sensor orientation	47 including 32 male and 15 female
Gafurov, D. et. al [13]	Normal walk on floor for 3 rounds	22 including 17 male and 5 female
Frank, J. et. al [14]	Running, Walking up or down stairs, lingering, riding on a vehicle	6
Sprager, S., &Zazula, D. [15]	Slow, normal, fast	6

B. Data Acquisition

Several types of sensors have been used in earlier studies of data acquisition process of gait recognition. As mentioned in the study by [17], accelerometer sensors are adequate and most commonly used for gait recognition. Due to the advantages it offers in gait recognition, most researchers today are using accelerometer sensor to capture the data. This sensor can be attached anywhere on body such as, hip, wrist, arm, ankle, chest, thigh and knee. Table II overviews some of the most widely used sensors and placement of sensor for gait recognition research.

TABLE II: TYPES OF ACCELEROMETER SENSOR USED IN DIFFERENT STUDIES

Study by	Sensor placement	Sensor
Kwapiz, J.R. et. al. [1]	Front leg pocket	Smart phone such as Nexus one, HTC hero, Motorola back flip
Nickel, C. et. al. [2]	Right hip pocket	Motorola Milestone using android operating system
Nickel, C. et. al. [3]	Pouch attached to the belt of the subject	Google G1 smart phone
Mantyjarvi, J. et. al. [4]	on the belt behind at waist	3-D accelerometer composed of 2 perpendicular positioned analog devices (ADXL202JQ)
Nickel, C. et. al. [5]	Inside a pouch attached to the right side of hip	Motorola Milestone Phone
Juefei-Xu, F et. al. [6]	Right pocket Phone facing outwards and oriented vertically	Android smart phone
Thang, H. M et. al.[7]	Trouser pocket	Google Android HTC Nexus
Ailisto, H. J. et. al. [8]	Hip, arm, ankle	High quality dedicated accelerometers of portable devices
Annadhorai, A. et. al. [9]	Ankles	Tri-axial accelerometer Bi-axial gyroscope
Gafurov, D. et. al. [10]	Right lower legs	Tri-axial accelerometer
Gafurov, D. et. al. [11]	-	MEMS accelerometers
Ngo, T. T. et. al. [12]	Foot, hip, pocket and arm	Accelerometer based sensors
Gafurov, D. et. al. [13]	Hip	Accelerometer MEMS
Frank, J. et. al. [14]	Front trouser pocket	HTC G1
Sprager, S., &Zazula, D. [15]	ankle	Nokia N95's 3-axis accelerometer SMLIS302DL

C. Feature Extraction

The input data recorded with the sensors from human body motions is too large for processing, thus it is necessary to convert the bulky input data into a condensed version of features as an initial step. The process of converting the bulky input data into the set of features is known as feature extraction [26]. Therefore features should be chosen carefully in order to take out appropriate information from the input data, as it is a very vital step &will have a strong influence in the results of classification. Features selection is an important and essential step in the design of gait recognition system. Table III shows approaches used for feature extraction.

TABLE III: FEATURE EXTRACTION APPROACHES

Study by	Approaches
Kwapiz, J.R. et. al. [1]	Divide data into 10 second segments. Average, Standard deviation, Average Absolute Deviation (AAD), Average Resultant Acceleration (ARA), time between peaks, binned distribution
Nickel, C. et. al. [2]	Statistical features: min, max, mean, standard deviation, bin, Root Mean Square (RMS), and cross. Cepstral Coefficients: Mel Frequency Cepstral Coefficients (MFCC), Bark Frequency Cepstral Coefficients (BFCC1), Bark Frequency Cepstral Coefficients (BFCC2) Classifiers: Support Vector Machine(SVM), Hidden Markov Model (HMM)
Nickel, C. et. al. [3]	MFCC, BFCC False Match Rate (FMR), False Non Match Rate (FNMR)
Mantyjarvi, J. et. al.[4]	Correlation, Frequency domain, Data distribution statistics. Genuine Acceptance Rate (GAR)&False Acceptance Rate (FAR), Equal Error Rate (EER)
Nickel, C. et. al. [5]	Majority Voting Module (MV), Cyclic Rotation Metric (CRM), min, max, mean, Detection Error Tradeoff (DET curve)
Juefei-Xu, F et. al. [6]	SVM Continuous Wavelet Transformation (CWT) Cyclostationarity analysis
Thang, H. M et. al.[7]	Time domain features Frequency domain features
Ailisto, H. J. et. al. [8]	Finding individual steps, normalizing and averaging them, aligning them with the template and computing cross-correlation
Gafurov, D. et. al. [10-11]	Histogram similarity & cycle length methods
Ngo, T. T. et. al. [12]	Receiver Operating Characteristics (ROC) curve & EER
Gafurov, D. et. al. [13]	DET curve &EER
Frank, J. et. al. [14]	Principle Component Analysis (PCA)& SVM
Sprager, S., &Zazula, D. [15]	Feature vectors by using PCA & classification by SVM

D. Approaches used in finding accuracy of gait recognition

Different studies have shown different accuracies for gait recognition systems in which the data collection was performed by different sensors placed on different locations of the body. Ailisto, H. J. et. al. [8] achieved Equal Error Rate (EER) of 6.4% in tentative experiments with 36 test subjects. They include method consisting of finding individual steps, normalizing and averaging them, aligning them with the template and computing cross-correlation. Gafurov, D.et. al. [10-11] have applied histogram similarity and cycle length methods and achieved EER of 5% and 9%. They only used different types of accelerometer sensor in both of their work. Gafurov, D.et. al.

[13] used Decision Error Trade-off Curve(DET) and achieved EER of 16%. Terada, S. et. al. [18] have proposed and evaluated an authentication algorithm which uses travelling acceleration at swing phase and achieved EER of 20% by setting threshold value to 1700. Juefei-Xu, F. et. al. [19] analyzed gait at different speed and they were able to achieve 99.4% Verification Rate (VR) at 0.1% False Accept Rate(FAR) for normal v/s normal speed; 96.8% VR at 0.1% FAR for fast v/s fast & 61.1% VR at 0.1% FAR for normal v/s fast speed matching.

Neves, G. M. G.&Correia P. L. [20] achieved FAR and False Reject Rate (FRR) of 2.05% and 5.00% respectively with an EER of approximately 2.5% and concluded that gait can be used to identify individuals and consequently can be used as a biometric trait. Sprager, S., &Juric, M. [21] analyzed accelerometer signals using higher order statistics and obtained gait pattern by transforming this acceleration data in feature space by using higher order cumulants. They used OU-ISIR data set of 744 subjects and achieved EER of 6% to 12% for different parameters and setup. Derawi, M., &Bours, P.[22] presented the result of applying gait and activity recognition on smart-phone where data collection as well as real time analysis was also done on the phone. In their experiments, they created 3 templates for 5 users and tested the system for correct identification of the user or the walking activity with 20 new users and with the 5 enrolled users and the activities were recognized correctly with an accuracy of over 99%. They concluded that the new cross Dynamic Time Warping (DTW) Metric gives the best performance for gait recognition where users are identified correctly in 89.3% of the cases and the false positive probability is as low as 1.4%. Hoang, T., & Choi, D.[23] proposed a novel gait based authentication using biometric cryptosystem and achieved FAR and FRR of 3.92% and 11.76% respectively. Whilethe work of Hoang, T. et. al. [24], achieved 0 FAR and FRR of 16.18% corresponding to the key length and system security level of 139 bits.

V. CONCLUSION AND FUTURE WORK

Biometric gait recognition using accelerometer sensor offers distinctive advantages of a severely unobtrusive capturing of a biometric distinctiveness and is especially interesting for mobile devices that presently are sold with a suitable sensor already embedded. This study proposes an alternative user authentication method for portable devices based on gait biometrics in various situations. The gait characteristics are captured using the built-in accelerometer of a smart-phone. As gait biometrics is behavioral biometrics, it is necessary to perform more conditional testing in order to verify it strongly.

There have been numerous studies for authentication of portable devices considering various factors such as different walking speed, types of ground, shoe size and comfort, position of sensor etc. No significant amount of work has been done for authentication of portable devices under extraordinary circumstances such as subject carrying heavy load and in when he is tired. Future work may be carried out on studying gait under these circumstances.

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