Heart Rate Variability for Biometric Authentication Using Time-Domain Features

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Abstract. Heart Rate Variability (HRV) is a natural property found in heart rate. Medical science since last two decades has been beholding on it as a diagnostic and prognostic tool. This study is intended towards harnessing the HRV property of heart for authentication purpose. For measuring the RR-Interval for HRV analysis, we used photoplethysmography (PPG) based pulse sensor and in-house designed microcontroller based RR-Interval measurement system. Data acquisition is done on PC via serial-to-USB bridge adaptor. Seven Time domain features are generated using standard statistical techniques. Out of 10 samples of each subject, five are used for template creations and other five are used for testing. The system resulted in 17 % EER. The FAR & FRR graph against threshold and the ROC curve are presented.

Keywords: Heart Rate Variability · PPG signals · Time-domain features · Euclidean distance

1 Introduction

In security research domain there is a recent trend towards the use of biosignals for biometric recognition [1], which focuses on identifying and authenticating an individual based on his heart signal or brain signal properties. Biosignals are known to contain strong subject-specific signal patterns that are hard to forge and can only be assessed if the user is present and alive [2]. Traditional biometrics can be easily manipulated [3], on the contrary biosignals are much harder to manipulate and also they inherently come with liveness detection [4], the data generated by biosignals is so intrinsic to an individual that it is hard to steal and even much harder to mimic or forge. Therefore, biosignals based biometric is robust enough against spoofing attacks or falsification. Heart signals being very specific to a particular individual [5], were under investigation from the point of view of person identity thus brisk research activities went into examining these signals.

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Today the most important research direction in biometric domain is the characterization of novel biometric modalities. HRV is one such heart beat property that can be explored for uniqueness of a person, up till now HRV has been found to be associated with a wide variety of health disorders [6]. In one of our previous article [7] we used five different wrapper algorithms to identify useful features from a large feature set having 101 features. The wrapper algorithms proposed time domain features to be more reliable and effective in recognition systems. Therefore in this article we utilize time domain features obtained from HRV time series data for authentication purpose.

2 HRV Background

Heart Rate Variability is naturally occurring variation in the time gap between two consecutive heartbeats. Figure 1 shows the schematic representation of an ECG showing the prominent components. The highest spike is called as the R peak which represents the occurrence of heartbeat. The time interval between two adjacent R-R peaks is known as R-R interval. The beat-to-beat variation is popularly known as Heart rate variability (HRV). HRV analysis helps in assessing overall cardiac health and the state of the autonomic nervous system (ANS) responsible for regulating cardiac activity [8]. In 1996, a task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology developed and published standards for the measurement, physiological interpretation, and clinical use of HRV analysis [9].

3 Methodology

In the proposed system as seen in Fig. 2, initially the biometric data of subjects is collected in this case it is the raw HRV time series data i.e. the RR-Interval sequence. For data acquisition we designed and developed a RR-Interval measurement hardware

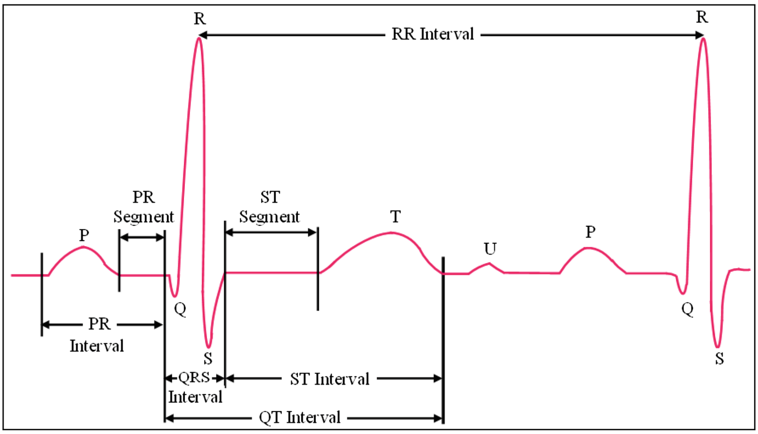

Fig. 1. Prominent components of an ECG signal.

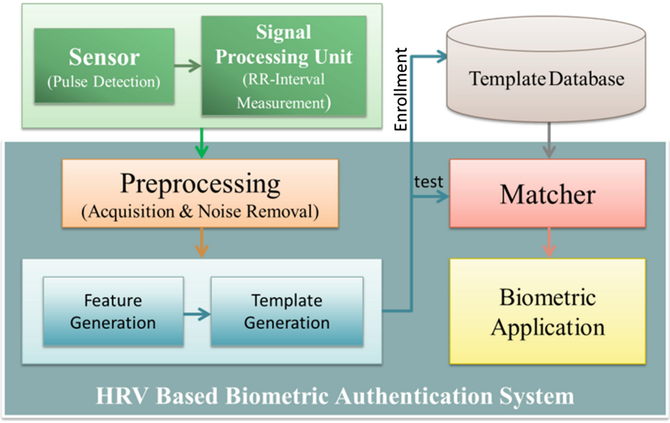

Fig. 2. Proposed system workflow

that is equipped with a pulse sensor to detect the heartbeats. This gave us the freedom to generate our own KVKHRV database, as there is no such specific standard HRV database available for biometric purpose.

3.1 Sensor and Signal Processing Unit (Data Acquisition)

The Sensor shown in Fig. 3 is basically a PPG signal based pulse sensor, and the Signal processing unit is a microcontroller based processing unit which is not only a low cost user friendly device but is also very portable and can be interfaced with a computer via USB or Serial port. The sensor is reflection type and makes use of the reflected red light from the finger tissues. When a finger is placed on the light transmitter-receiver pair, the red light reflected from finger gets modulated in synchronism with the heartbeat and blood flow. This signal is detected and preprocessed in the processing unit and produces

Fig. 3. Sensor & signal processing unit

a square pulse of 100 ms with every heartbeat. The heart beat pulse is derived after signal conditioning through a microcontroller and the output pulse is TTL compatible that can be interfaced with standard microcontrollers or any other TTL circuit. There are more details to the design and development of this unit which is beyond the scope of this article and hence not elaborated further. Details of the design and development of this unit along with working is presented in [6, 10].

3.2 Preprocessing

Preprocessing is done in the data acquisition software which is a GUI designed in Visual Basic 6 as shown in Fig. 4. It is responsible for four specific tasks i.e. collect incoming RR intervals at serial/USB port, remove ectopy (noise) from the RR data, and convert the received RR interval from milliseconds to seconds and finally store a sequence of RR intervals of fixed duration in a text file for further processing. Ectopy or noise in RR time series may originate due to several reasons like: inherent variability of the heartbeats, improper threshold detection of the beats, amplitude variation, missing beat, double triggering due to beat shape, and electronic noise including pickup. All real time systems are prone to this problem to different extent and therefore ectopy removal from RR time series is a standard practice. Detailed ectopy removal process is presented in [11]. Keeping in line with the convention the RR interval sequence i.e. the RRI file is stored in format with two columns with the first column representing the time from the commencement of the measurement when the RRI is measured and the second column contains the actual RRI measured at that instant of time. The data acquisition software works in four modes the smallest mode is most suitable for biometric purpose while the other modes can be used for short term HRV based medical diagnosis.

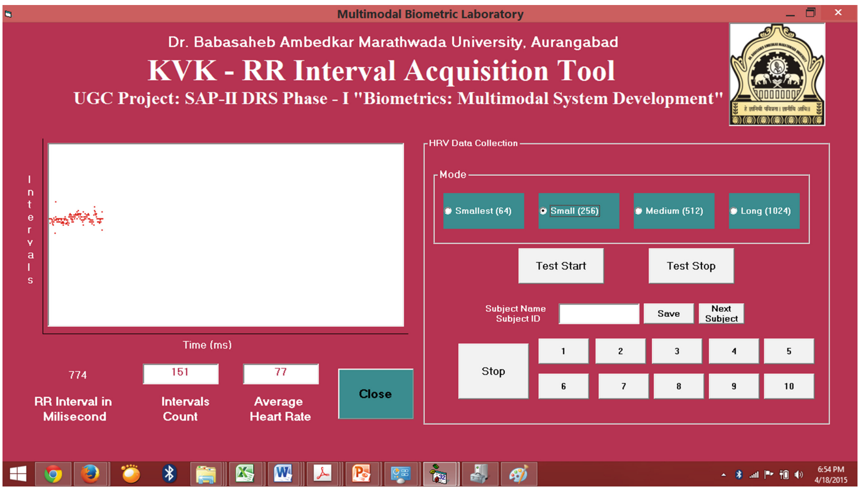

Fig. 4. GUI of the data acquisition system

3.3 Feature Generation

Time-domain measures are the simplest techniques that can be applied on RR-Interval sequence. Standard statistical techniques like mean, median, etc. can be applied on the RR-Interval sequence and time domain measures can be ascertained. These may be separated into two classes: (1) those got from direct estimations of RR- Intervals and (2) those derived from the differences between RR-Intervals [12]. All the features used in experiments are enlisted in the Table 1. These features were selected on the bases of the selected features proposed by five feature selection algorithms proposed in [7].

3.4 Database Specification

At present our KVKHRV database consists 2430 sequences of RR-Intervals of 81 subjects (47 males and 34 Females) whose 10 samples each of 64 RR-Intervals were measured continuously for 1 min approximately, in three different sessions spread over nine months with time interval of three months between each session. The ages of the individuals varied from 18 to 69 years, with mean and standard deviation of 31 and 11 respectively. As it would be natural in any physiological based biometric recognition system, some subjects would have health issues, we too have few samples of this sort around 9 % of subjects reported hypertension and other diseased conditions. Any biosignal based biometric system is susceptible to effects of mental, physical, physiological and even emotional state of the subject. Hence subjects were first relaxed then data was collected in sitting relaxed position for all the sessions. No psychological stimuli was given and neither any physiological restrictions were applied like not taking of caffeine products and no other similar kind of considerations were adhered since this data is specifically collected only for biometrics applications otherwise such considerations are mandatory if we need to make medical analysis of the HRV data so collected. The subjects were informed of the purpose and their consent was taken before data collection.

Table 1. Time-domain feature obtained from RR-interval sequence

Sr. no.	Feature name	Features description
1	RMSSD	Root mean square of successive differences
2	MeanHR	Mean Heart Rate
3	Max	Maximum Interval duration in a particular RRI
4	Min	Minimum Interval duration
5	Mean	Mean of the whole RRI sequence
6	Median	Median of the RRI sequence
7	SDHR	Standard Deviation of Heart Rate

Table 2. FAR & FRR along with the corresponding thresholds and recognition rates

Threshold	FAR	FRR	Recognition rate
0.02	0.0	100.0	0
0.03	3.3	93.3	6.7
0.04	5.0	80.0	20
0.05	6.6	60.0	40
0.06	11.6	30.2	69.8
0.07	18.3	13.3	86.7
0.08	36.6	6.6	93.4
0.09	43.3	5.0	95
0.10	56.6	5.0	95
0.11	66.6	3.3	96.7
0.12	80.0	3.3	96.7
0.13	86.6	0.0	100

4 Results and Discussions

For this experiment, we randomly chose 60 subjects of out of 81. We used four samples from session one and three each from session two and three making total of ten samples per subject. Then we partitioned the samples in two groups of five each. With first group samples we created the enroll template, by taking mean of all five samples and similarly we the other group we created the test template. We calculate the Euclidean distances between the two templates (enroll & Test) for all the subjects, the test template having the smallest Euclidian distance with enroll template is considered to belong to that same subject. From the distance matrix so obtained we calculated the

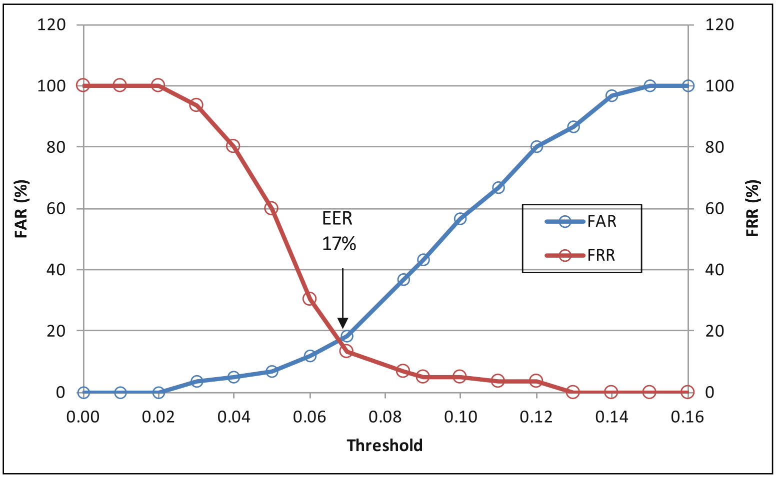

Fig. 5. FAR & FRR against threshold

Fig. 6. ROC curve of the proposed system

maximum and minimum value to decide the threshold. As we increased the threshold, FAR is increased and FRR is decreased, both FAR and FRR are inversely proportional. If we keep threshold value too loose we get recognition rate 100 % but we can't accept this 100 % recognition rate because FAR is more therefor we have to select recognition rate where false acceptance and rejection are low. At a given threshold a biometric system that gives low FAR and Low FRR is good one in our case its 0.07 as can be seen in Table 2 and Fig. 5. Also the ROC Curve can be seen in Fig. 6.

5 Conclusion

One of the important characteristic of the heart is its heart rate variability (HRV) that has been used for different applications including diagnosis and prognosis. We attempted biometric authentication of 60 subjects in this article using the HRV property of heart and time domain features of HRV analysis, with threshold value of 0.07 we got a reasonably good recognition rate of 86.7 %.

6 Future Work

Looking at the performance of the time-domain features, it appears that HRV based biometric recognition is promising research which needs more such prospective studies with larger databases and context aware data conditions. Performance of Euclidean distance is seen in the present work, more distance functions as well classifiers can be experimented to improve the results further. HRV data can also be used in liveness detection hence attempts in those directions would yield interesting results. HRV can also be experiment in multimodal system and is expected to add much needed robustness and efficiency. Due to a simple user friendly device we designed, all these research dimensions look achievable.

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