Natural Revocability in Handwritten Signatures to Enhance Biometric Security

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***Abstract*- In the field of cancellable (revocable) biometrics much attention has been paid to physiological biometrics (e.g. fingerprint, iris) when compromised. However, the potential for natural revocability in behavioural biometrics (e.g. handwritten signature) is often overlooked, and the lack of databases to support this type of investigation imposes limitations. This paper presents a preliminary study of natural revocability, revealing relationships among established and new signature forms in relation to achievable stability. We study also the implications at the classification level.**

Keywords- Biometrics; Natural revocability; Stability; Signature verification; Security; Variability.

I. INTRODUCTION

Biometric systems are increasingly being used as very convenient and efficient identification systems, even within large populations. Although now sufficiently mature to provide viable practical solutions, this increasingly widespread use also raises some serious privacy and security issues. If not secured, biometric data may be fraudulently obtained or simply stolen, and subsequently misused without a user's consent. Significantly, a compromised biometric is forever compromised if access to the raw information has occurred [19, 5]. Such concerns have in recent years led researchers to study different protection mechanisms such as biometric encryption, 3D signature authentication, combining hard and soft-biometrics etc. [2, 3, 4, 11, 12] and also the introduction of the concept of cancellable biometrics [18] where a fixed and unchanging biometric template is replaced by a revocable one, which can be created, for example, through processing by a unidirectional transformation. In the event of compromise, a new biometric can be created from the raw data simply by invoking a different transformation. This concept of revocability has been studied extensively with respect to physiological biometrics [19], but with rather less attention given to behavioural modalities (e.g. handwritten signatures). There may be many reasons for this, not least that there is no database which holds information which would be required for a rigorous study. However, the principal hypothesis underlying this paper is that the particular characteristics of a behavioural modality open up possibilities for revocability strategies which might prove to be both simple and effective. This paper therefore represents a preliminary study as a precursor to longer term and more detailed investigation of the potential for "natural revocability" in behavioural biometrics to be realised as a practical option. Specifically, we will investigate the handwritten signature as the target biometric modality of interest.

The remainder of this paper has been organized as follows: Section 2 gives a brief introduction to the general idea of natural revocability. Section 3 will describe an initial signature database which captures samples to support the study of this concept, while Section 4 will explain the features extracted for some experimentation using the data available. Section 5 will show the experimental outcomes and, finally, Section 6 will summarise some conclusions.

II. NATURAL REVOCABILITY

Natural revocability is a term we use to describe the fact that most behavioural biometrics, being under the direct control of the "user", can be created at will in multiple forms. The handwritten signature provides a very good illustrative example [17]. Unlike the case when using a physiological modality such as the fingerprint or iris, the handwritten signature form developed by a particular individual can be discontinued at any point in time, and a new signature invented. This natural revocability potentially offers the opportunity to increase security and privacy while simultaneously avoiding the need for developing alternative and more complex protection techniques. Though the dimensions of handwritten signatures can vary with time [7, 8], for most people, the fundamental characteristics of the handwritten signature remain relatively constant over a period when written in a given frame [20]. Since it is a voluntary action to change an original signature to a new one, a new biometric can be created easily, thus paralleling closely a user-manipulated password scenario. However, the stability of the form of the signature is generally acquired with repeated use, and it cannot be assumed that all individuals will easily achieve stability with a newly acquired signature. Even if this can be achieved, it is not known whether this is likely to occur on a sufficiently short timescale to make such a change viable in the context of biometric recognition. Thus, in this paper we address some fundamental questions which need to be considered if we are to exploit the concept of natural revocability as a practical strategy with respect to the signature. Of course, such an investigation also raises a range of other questions of practical importance and we will point to a number of these also in this preliminary study.

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III. COMPILATION OF AN INITIAL DATABASE

To study the natural revocability of the signature it was necessary to establish a database of handwritten samples based first on an individual's current established signature and also of a new signature such as might be adopted should the original need to be withdrawn. Hence, under supervised conditions, samples of both were captured from a group of volunteers using a standard pen of familiar style and feel, and an electronic graphics tablet (here a WACOM Intuos-3 tablet with a resolution of 5080 lines per inch) connected to a computer. The system allows a subject to write normally on a sheet of paper overlaid on the tablet surface, with the pen movement tracked and a representation stored in the computer in the form of a sequence of time-stamped spatial pen coordinates[10].

Handwritten signature samples are initially collected through four sessions with an interval of one week between sessions. In the first two acquisition sessions ten samples, and in the last two sessions five samples, of both the original and new signatures are collected. Although sample collection is on-going, at the time of writing the database contains samples from 41 signers, although only 21 signers have attended all four acquisition sessions. We recognise this to be a small number of users, but this is intended to be a preliminary, rather than a formal and rigorous study.

The handwritten samples have been recorded as .tst files using a general purpose in-house data capture program, suitably modified to adapt its interface for our current purposes and to ensure ease of sample collection.

Figure 1 shows a collected sample of an original and a newly invented signature from each of two writers. On the basis of a simple visual inspection, the first shows a considerable similarity between the two versions, the second much less so.

User	Original	New
E028		
E029		

Figure 1. Sample signatures .

IV. FEATURE EXTRACTION

In order to investigate the nature of natural revocability in the data, a range of features have been extracted from the individual signature response files. The features used were chosen to be a representative set commonly adopted in signature processing experiments, and they include both static and dynamic features. The feature set adopted comprised the following (largely self-explanatory, but formal definitions can be found in [1]):

- Signature length
- Signature height
- Signature height to width ratio
- No. of pen lifts
- Average azimuth
- Average Altitude
- Average pressure
- Maximum pressure
- Average horizontal pen velocity
- Average vertical pen velocity
- Average horizontal pen acceleration
- Average vertical pen acceleration
- Horizontal high pressure region
- Vertical high pressure region
- Average rate of pressure change
- Execution time.

V. EXPERIMENTATION AND RESULTS

The adoption of the handwritten signature as a biometric depends on the reproducibility of signature samples in an individual. In other words the "stability" in signing (the extent to which the "intrinsic properties of rapid human movements that constitute the basic element of each signature" [13] are reproduced) is a principal factor in determining the suitability of the signature for biometric identification. Short-term variability depends on the psychological condition of the writer and on the writing conditions; Long-time variability depends on modification of the physical writing system of the signer as well as on modification of his motor program [14, 15, 16].

To study natural revocability in signatures it is necessary to investigate the signing process in both the original and the new signature domains of individuals since, as with all behavioural biometrics, intrinsic variability within samples of any individual can be considerable, and the existence of *goats* (whose signatures quite naturally vary a great deal) [6] is not uncommon. In assessing a new signature, the principal issue of interest here is to determine whether, and how quickly, the signing process attains a degree of stability in reproduction which makes its use as a biometric viable. Clearly, such an assessment benefits also from knowledge of the stability properties of the original signature.

Although the concept of stability may be difficult to define formally or quantitatively, it is intuitive that, in this context, developing the habits of signing through repetition is important in developing the automatic signing patterns required to decrease the dissimilarity between intra-individual signature samples and hence ensure the degree of reproducibility required for biometric identification. We thus adopt an informal but intuitive notion of increasing stability - referring to the tighter clustering of samples in multi-feature space, - which we expect to observe among the samples of a new signature as time passes. Understanding how stability, described in this way, changes with time, is therefore a primary factor in assessing the value and viability of natural revocability as a practical strategy.

In order to observe the variations in stability in the original and new signatures across different capture sessions, Euclidean distances in multidimensional feature space have

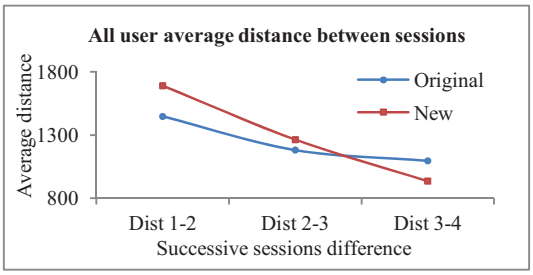


Figure 2. Average distances between sessions .

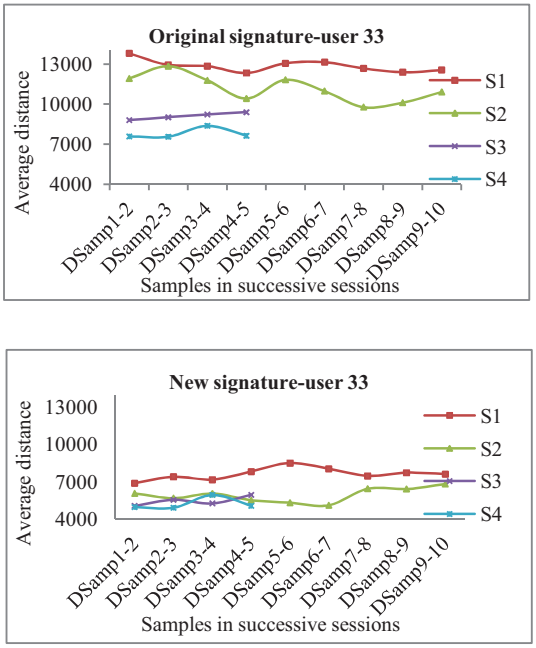


Figure 3. Distances between samples for each session

been measured, and Figure 2 shows the variation of both the original and new signatures in each of the capture sessions, measured as the mean distances between samples captured in successive sessions. From this Figure it can be observed that the distance between the first and second sessions (Dist1-2) is higher than the distance between the second and third sessions (Dist2-3) and the third and fourth sessions (Dist3-4). Although it is likely that there is an effect here of unfamiliarity with the tablet writing environment, it is clear that stability increases with time and that signature variability stabilises as the sessions proceed. A similar analysis of a signer's original and new signature is shown in Figure 3. This also shows that the value of first session (S1) distance is higher than for the other sessions and the second (S2), third (S3) and fourth session (S4) distance values gradually decrease, although the sample distances do not vary substantially across different sessions. It is striking that comparing the original and new signature executions (Figure 3), the dispersion in the distance values measured are lower for the new signature than for the original. This may reflect a greater degree of care and caution on the part of the signer when developing a new signing style but, more importantly, it indicates that stability in a new signature can be achieved on a relatively short timescale.

As noted earlier, the database development is ongoing with respect both to increasing its number of users and also in extending the data acquisition period beyond the current four collection sessions. Figure 4 shows examples of two users' original and new signatures over a greater number of sessions, here seven and six acquisition sessions respectively. While it is, of course, inadvisable to generalise from individual examples, these results do indicate, on the one hand, that behavioural biometrics are always open to the possibility of somewhat unpredictable characteristics, but also that if a sufficient time period is allowed then there is a possibility of convergence in stability between a highly practised and long-standing signature and an alternative new representation.

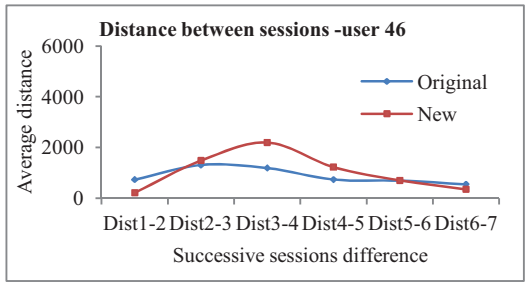


Figure 4. Distances between sessions for longer period .

A. *Categorised analysis*

In order to investigate the characteristics of potential revocability in the signature modality, it is useful to analyse performance by invoking the "biometrics menagerie" notation for individual behaviour first introduced by Doddington in the context of speaker recognition [6]. In our study we are especially interested in characterising individuals as sheep or goats, designated according to the following definitions:

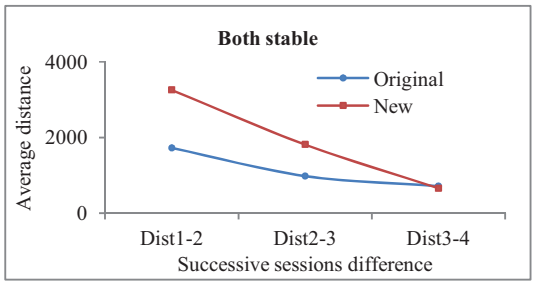
• **Sheep**: Sheep, in this model, are those signers who show relatively little variability in their signature samples over time (i.e. those whose signatures are generally stable).

• **Goats**: Goats are those signers whose signature samples have a tendency to considerable variation over time (i.e. those whose signatures are generally unstable).

In this way both original and newly invented signatures have been observed to determine the extent to which the characterisation of an individual's signing behaviour remains constant between the original and new signature style, or whether and how individuals change category. To this end an analysis of each individual's signatures was carried out with respect to their signature stability category, with results summarised in Figures 5 and 6. Here we use a rather subjective and intuitive interpretation of "stability" for the purpose of a qualitative analysis. For example, if the mean distances measured between signature samples captured in successive sessions gradually decrease or do not vary significantly with time then this signature can be deemed stable in this context. Figures 5 and 6 show the different groups of signers within the test population categorised according to the relationship between the original and new signing characteristics.

The signer population can then be divided into four categories, as follows:

• Category 1- In our current context, this category defines those individuals who are consistently sheep according to our qualitative definition (i.e. those for whom both the original and new signatures are stable - Figure 5(a)).



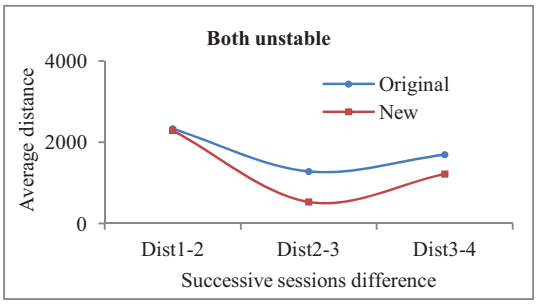
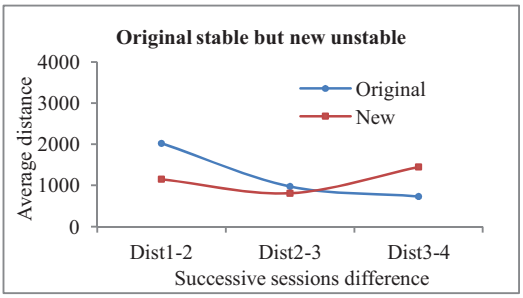


Figure 5. Users' (a) both original and new signature stable (b) both original and new signature unstable

• Category 2 - These are those signers who are consistently goats (i.e. those for whom both original and new signatures are unstable - Figure 5(b)).

• Category 3 – This category defines those signers who were sheep with respect to their original signatures, but who turned into goats when generating a new signature form (i.e. those whose original signatures are stable but whose new signatures are unstable - Figure 6(a)).

• Category 4 – These are signers who were goats with respect to their original signature samples, but turned into sheep when developing a new signature (i.e. whose original signatures are unstable but whose changed new signatures are stable. - Figure 6(b)).



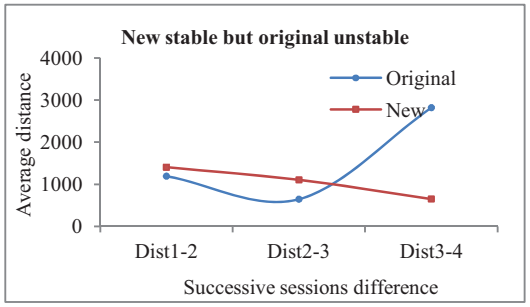


Figure 6. Users' (a) original signature is stable but new unstable (b) original signature is unstable but new stable..

Importantly, Figure 7 shows the percentage of each category of signers within the overall population. This shows that Category 1 contains the largest number of individuals across the population, indicating that stable signers in their original signatures remain stable signers when developing a new signature. Encouragingly, a rather small proportion of the population are unstable signers in their original signature and remain so when moving to a new signature style, but some 14% of the population with an originally stable signature generate a degree of instability when changing to a new signature style - although we have presented evidence that such a group may, in the longer term, still achieve stability. Finally, for 10% of the population who exhibited instability in the original signature the results show that it is possible nevertheless to achieve stability when changing their signature style.

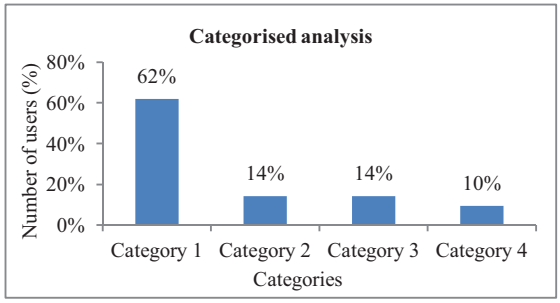


Figure 7. Different groups of signers' population.

B. *Classification results*

A more practically-oriented test of the viability of the natural revocability concept for the handwritten signature may be considered to be the achievable performance directly in a recognition/verification scenario. To observe whether the newly formed signature can be reliably verified or not, and to compare the performance achieved against performance with the original signature, a recognition experiment was performed using Weka [9] classification software. Since for our purposes in the present context, relative performance is more important than absolute performance, for this experiment a simple K-nearest neighbour algorithm was adopted (where k=1 and 10 fold cross validation were used). From the experiment it can be observed that better classification performance has been achieved for the newly invented signatures (92%) than for the original signatures (88%), although the difference is modest.

VI. CONCLUSION

In this paper we have described, first, the acquisition of a small (but developing) database comprising samples corresponding to both an individual's genuine signature, and a signature newly generated to represent a scenario where an individual may wish to revoke a compromised signature and develop a new and different signing style. Importantly, signature samples have been collected over a period of time to allow the exploration of time-dependent changes in both static and dynamic characteristics of the signing process. This has enabled us to investigate, using the current familiar signing pattern of each individual as a reference point, the extent to which deploying a new signature provides a degree of stability on an acceptable timescale to allow the new signature to be adopted as a biometric identifier.

Although using only a small database which does not allow us to assess the wider significance of the results, our observations provide initial indications which suggest, in general, that individuals are able in most cases to develop a new signature which can quickly achieve stability. This provides some evidence that the idea of natural revocability, whereby a compromised signature can be revoked by a user and a new signature form substituted, offers potential viability in a practical scenario. Our results also provide some initial data to show how stability patterns between original and new signatures are likely to change across individuals.

Of course, there are many further issues which need to be investigated, such as correlations between old and new signatures, the relationship between feature choice and performance, resistance to forgery, degree of practice, and so on, but this paper has established some basic indicators of performance in respect of the potential for further development of such principles as a practical option in appropriate applications.

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