Preliminary Report on Development and Evaluation of Multi-Biometric Fusion using the NIST BSSR1 517-Subject Dataset

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Introduction and Overview

1 This report presents preliminary results of the evaluation of Cambridge Algorithmica's approach to multi-biometric fusion, which is based on the concept of Biometric Gain against Impostors (BGI), which works by fusion of scores normalised to be the Likelihood Ratio Genuine to Impostor (LRGI). For an introduction to this approach to biometric score normalisation and fusion, see [1] and [2].

2 Evaluation is done using the NIST[2] Biometric Scores Set Release 1 (BSSR1) dataset of multi-biometric scores [3]. In particular, results are reported here using the smallest of the three datasets within BSSR1; that with 517 enrolled subjects.

3 Results are reported for:

(i) multi-modal fusion, of one fingerprint score and one facial score;

(ii) multi-instance fusion, of fingerprints from two fingers;

(iii) multi-algorithmic fusion (possibly including multi-sensorial fusion[3]), of facial recognition by two different commercially available subsystems.

4 This report is preliminary, in the sense that it reports results briefly (in tabular form only, without ROC[4] curves), and only reports the above-mentioned 3 fusions, rather than the more extensive full set of 2-way, 3-way and 4-way biometric fusions. This has been done to have this report available before the next meeting of the USA INCITS[5] M1.2 Ad Hoc Group on Evaluating Multi-Biometric Systems (AHGEMS), which is on 6th June 2005.

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[1] This report is available on the company's website at http://www.camalg.co.uk/s05011_tr0/s05011_tr0.pdf. Copies should only be made for the purpose of scientific research, of the document in its entirety including the copyright ownership.

[2] USA National Institute of Science and Technology.

[3] The BSSR1 documentation does not, in the authors view, make it totally clear whether the facial C and G datasets are of different algorithms operating on the same captured facial images, or of two different image capture and processing subsystems operating on the same faces. However, in the context of this report, that is not a particularly important difference.

[4] Receiver Operating Characteristic.

[5] INCITS, the International Committee for Information Technology Standardisation, with Technical Committee M1 on biometrics and Task Group M1.2 on biometric technical interfaces.

5 A summary of results, and some personal preliminary conclusions, are as follows.

6 All fusion evaluations were done using 317 enrolment subjects (numbered 200..516). For BGI/LRGI score normalisation, the normalisation PDFs[6] were derived from 200 enrolment subjects (numbered 0..199). Thus there was total separation of data used for characterisation and for evaluation. This includes no manual viewing of the evaluation data or results prior to making decisions on all characterisation processing.

7 The multi-modal fusion of fingerprint and face works best with the BGI/LRGI approach, using semi-automatically parameterised models of the genuine and impostor PDFs. The Equal Error Rate (EER) is reduced from 4.1% (facial) and 4.7% (fingerprint) to 0.6% (fused). This is a relative reduction of the EER by 85% over the best single biometric modality, which is thought likely to be very beneficial in some applications. The BGI/LRGI with the semi-automatically parameterised PDFs (referred to here as MAN2C[7]) is noticeably better than the BGI/LRGI approach with the simpler Z-score[8] PDFs, though not at the EER. In particular, the FNMR at an FMR[9] of 0.01% was 3.2% with MAN2C normalisation and was 6.9% with Z-score normalisation.

8 The multi-instance fusion of 2 fingerprints (left and right index fingers) was evaluated with a number of BGI/LRGI parameterised models. As the same sample capture device and algorithms were used for both fingers, simple approaches of addition, multiplication and maximum of unnormalised (raw) scores were also tried. Unnormalised addition and maximum, and all tried BGI/LRGI normalisations (also with fusion by both addition and maximum of the log likelihood ratios) gave very close overall ROC curves. Multiplication of unnormalised scores was less effective. Unnormalised addition is thought to be the best of the tried approaches, as it requires no characterisation data and is less vulnerable, than fusion by maximum, to artefact attack against just a single finger. However, it is the author's intuition that there is significant further scope for improving fingerprint multi-instance fusion.

9 The multi-algorithmic/multi-sensorial fusion of facial biometrics was evaluated with BGI/LRGI normalisation using the MAN02C and Z-score PDFs, using fusion only by addition of the log likelihood ratios. Here, manual examination of the score distributions of the characterisation data for one of the facial algorithms and all of the parameterised PDFs indicated that PDF modelling (even using the MAN02C approach) would not be very accurate. Accordingly, and noting also that the same biometric modality being used for both fused algorithms would add less discrimination, improvements from fusion were not expected to be at all good. However, when the normalisation approaches (selected on the characterisation datasets) were tried on the evaluation datasets, performance was somewhat better than expected. EERs of each of the single facial biometrics, C and G, were 4.1% and 5.7% respectively; fusion with Z-score normalisation improved this to 3.2% (a relative error reduction of 22% over the best individual facial biometric subsystem); fusion with MAN02C normalisation improved this to an EER of 2.5% (a relative error reduction of 39% over the best individual facial biometric subsystem).

[6] Probability Density Functions.

[7] See paragraphs 10 to 16 below for more information.

[8] See paragraph 12 below for a definition.

[9] FNMR is False Non-Match Rate; FMR is False Match Rate.

PDF Modelling for BGI/LRGI Normalisation

10 As described in [1] and [2], the BGI/LRGI approach requires the scores for each single contributing biometric subsystem to be normalised to the likelihood ratio of the raw score coming from the PDF for genuine scores to the raw score coming from the PDF for impostor scores.

11 Characterisation data is used to model these 2 PDFs as parametric functions, each with a small number of parameters.

12 One of the simpler approaches is Z-score normalisation. Here each PDF is modelled as a Gaussian or Normal distribution; there are 2 parameters for each distribution: the mean and the variance.

13 However, for many biometric systems, scores for the genuine and impostor subsets do not fit well to Gaussian PDFs. This leads to BGI/LRGI normalisation being less effective than might otherwise be the case.

14 Cambridge Algorithmica's current approach to overcoming this problem is to try a variety of parametric functions for each PDF, and parameterise each one by computer optimisation. Then the PDFs are compared against the characterisation datasets that they are derived from. This is done by two methods:

(i) use of the evaluation metric error of the final optimisation stage;

(ii) manual analysis of how well the whole parametric function matches the actual distribution of scores in the characterisation dataset.

15 There are some additional aspects of the analysis which are not described here.

16 The finally chosen genuine and impostor parametric PDFs for each contributing biometric subsystem are based on both, which relies to a significant extent on the expertise of the human decision maker (here the author).

17 Cambridge Algorithmica is currently keeping as proprietary knowledge, greater detail on the above method and its application to various datasets. The approach also makes good use of a suite of computer programs written specifically for this purpose, over the course of the last 2 years.

18 However, the company is keen to use its expertise for the benefit of manufacturers, integrators and users of biometric systems. Accordingly, the company offers a service for designing BGI/LRGI normalisation specific to particular biometric subsystems for which characterisation data is available.

Evaluation Results for Multi-Modal Fusion of Fingerprint and Face

19 The results are given in Table 1 below.

20 Note that, for the 1%, 0.1% and 0.01% columns, change of a single rejection (false non-match) leads to a percentage change in probability of 0.315% (100/317). There is a related, though more complicated, effective quantisation of the EER, through the small dataset size. Thus, here, all EER and FNMR percentage rates are given to only 1 decimal place.

21 The first 2 rows are for the contributing single biometric modalities.

22 The next 2 rows are for the BGI/LRGI approach, first with Z-score normalisation and then with the MAN02C semi-automatic approach. In both cases, fusion is by addition of the log likelihood ratios.

Score Dataset Evaluated, incl.		FNMR at a Specified FMR of:		
Normalisation/Fusion Method	**EER %**	**1%**	**0.1%**	**0.01%**
Right index finger only (ri dataset)	4.7	6.9	8.8	13.6
Facial C only (faceC dataset)	4.1	6.9	14.2	23.7
BGI/LRGI Z-score normalisation	0.6	0.6	1.9	6.9
BGI/LRGI MAN02C normalisation	0.6	0.6	1.6	3.2

Table 1: Multi-Modal Fusion of Fingerprint and Face

Evaluation Results for Multi-Instance Fusion of 2 Fingerprints

23 The results are given in Table 2 below.

24 Again, all scores are given to only 1 decimal place.

25 The first 2 rows are for the contributing single biometric instances.

26 The next 3 rows are with no score normalisation, and with fusion by: addition, multiplication and maximum.

27 The next (6th) row is for the BGI/LRGI approach with Z-score normalisation and fusion by addition of the log likelihood ratios.

28 The next 2 rows are for normalisation with the semi-automatic approach named MAN02 and fusion by: addition and maximum.

29 The final 2 rows are with normalisation by the MAN02C semi-automatic approach and, again, fusion by: addition and maxium.

Score Dataset Evaluated, incl.		FNMR at a Specified FMR of:		
Normalisation/Fusion Method	**EER %**	**1%**	**0.1%**	**0.01%**
Left index finger only (li dataset)	8.7	12.6	18.3	23.0
Right index finger only (ri dataset)	4.7	6.9	8.8	13.6
Raw score; Add	3.8	4.1	5.0	7.6
Raw score; Multiply	4.1	4.4	6.6	10.7
Raw score; Maximum	3.8	4.7	5.7	7.9
BGI/LRGI Z-score Norm; Add	3.5	4.7	5.4	6.9
BGI/LRGI MAN02 Norm; Add	3.8	4.4	5.0	7.6
BGI/LRGI MAN02 Norm; Max	3.5	4.4	5.4	8.5
BGI/LRGI MAN02C Norm; Add	3.8	4.7	5.4	7.6
BGI/LRGI MAN02C Norm; Max	3.5	4.4	5.4	8.5

Table 2: Multi-Instance Fusion of 2 Fingerprints

30 As can be seen, and is even more apparent from the ROC curves, 7 of the 8 fusion approaches (those excluding raw score fusion by multiplication) have similar performance, with no one approach being consistently better than the others over the whole range of possible operating points (threshold scores) in each fused dataset.

Evaluation Results for Multi-Algorithmic Fusion of 2 Face Subsystems

31 Note that, as mentioned above, these results may be just multi-algorithmic, or they might be both multi-algorithmic and multi-sensorial.

32 The results are given in Table 3 below.

33 Again, all scores are given to only 1 decimal place.

34 The first 2 rows are for the contributing single biometric subsystems, facial C and facial G.

35 The next 2 rows are for the BGI/LRGI approach, with Z-score normalisation and the MAN02C semi-automatic normalisation. In both cases, fusion is by addition of the log likelihoods.

Score Dataset Evaluated, incl.		**FNMR at a Specified FMR of:**		
Normalisation/Fusion Method	**EER %**	**1%**	**0.1%**	**0.01%**
Facial C only (faceC dataset)	4.1	6.9	14.2	23.7
Facial G only (faceG dataset)	5.7	11.0	20.5	29.7
BGI/LRGI Z-score Norm; Add	3.2	3.8	12.9	20.2
BGI/LRGI MAN02C Norm; Add	2.5	3.5	12.6	19.2

Table 3: Multi-Algorithm Fusion of 2 Facial Biometric Systems

References

[1] **The Need for Standardisation of Multi-Modal Biometric Combination**, Nigel Sedgwick, Cambridge Algorithmica Limited, 6 November 2003; available at URL: http://www.camalg.co.uk/s03017_pr0/begin.html

[2] **Multi-Modal Combination using the Biometric Gain Concept**, Nigel Sedgwick, Cambridge Algorithmica Limited, presentation to Biometrics 2004, London UK, 13..15 October 2004; available at URL: http://www.camalg.co.uk/s03017_pr1/ s03017_pr1.pdf

[3] **Biometric Scores Set – Release 1** (BSSR1), available from the USA National Institute of Science and Technology (NIST), subject to their terms, since September 2004, described at URL: http://www.itl.nist.gov/iad/894.03/biometricscores/