

SOCOVIFI: Soft Computing and Computer Vision Techniques in Forensic Identification TIN2006-00829

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Abstract

Photographic supra-projection is a forensic anthropology technique for the identification of human beings from their skeletal remains, where photographs of the “missing person” are compared with the found skull. Its main drawback is the lack of a systematic analysis method, so every researcher applies his own methodology. This is both due to the large complexity of the projection procedure and to the inherent uncertainty present in the decision process. The aim of the current project is to design an automatic, computer-based procedure to support the anthropologist in this forensic identification task by means of soft computing and computer vision techniques.

Keywords: Soft computing, Computer vision, Forensic identification, Evolutionary algorithms, Fuzzy systems, Metaheuristics, Image registration, 3D model reconstruction, Craniofacial photographic superimposition.

1 Research project goals

The main goal of this research project is to design an automatic, computer-based procedure to aid the forensic anthropologist in the identification task by photographic supra-projection [2], based on the use of soft computing techniques: evolutionary algorithms (EAs) and metaheuristics (MHs) for the skull-face superposition, and fuzzy logic (FL) and fuzzy systems (FSs) to manage the different sources of uncertainty involved in the process.

To do so, we will: i) take the relation existing between image registration (IR) [6] and the forensic craniofacial superimposition procedure as a base, and will use EAs and MHs to both build the skull 3D model and to computerize the overlaying of that 3D model and the 2D photo of the human being face; and ii) make use of the special abilities of FL tools and FSs to deal with uncertainty and partial truth allowing us to decide if both images correspond to the same subject depending on the landmark matching.

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This general goal is composed of the three following specific objectives:

1. *Design of skull 3D model reconstruction techniques by pair-wise range IR of the partial views generated from the University of Granada Physical Anthropology Lab's scanner.* We aimed to apply EAs and MHs for designing automatic pre-alignment algorithms working on both the matching and the transformation space, not requiring forensic users to own image acquisition skills. Concretely, we originally planned to develop three specific research lines to extend our preliminary work in [4]:

- (a) Design of advanced multi-objective evolutionary, transformation space-based pair-wise IR techniques incorporating problem-specific similarity metrics.
- (b) Proposal of an scatter search (SS)-based IR technique, working in the matching space, incorporating image-specific information.
- (c) Design of an advanced transformation space pair-wise IR approach by real-coded SS.

2. *Design of automatic craniofacial superimposition methods for the 2D subject photo-3D skull model overlying by means of EA and MH-based IR approaches.* The characteristic landmarks of both images were to be considered as heuristic information in order to guide the search and thus improve the IR quality. Namely, our initial planning included working in the following five research lines:

- (a) Extraction of heuristic information about the cranial and facial landmarks.
- (b) Proposal of specific skull-face superimposition approaches by means of evolutionary 2D-3D IR techniques working in the transformation space.
- (c) Design of 2D-3D matching-based skull-face superimposition approaches considering the heuristic information.
- (d) Proposal of skull-face superimposition approaches from 2D-2D IR approaches.
- (e) Design of an advanced EA for fine-tuning the obtained skull-face superpositions.

3. *Design of FSs to aid the forensic anthropologist in the final identification decision from the landmark matching found in the previous craniofacial superimposition.* Two work lines were to be done within this objective:

- (a) Proposal of a forensic identification FS by using fuzzy aggregation operators to combine the partial degrees of matching between each pair of landmarks.
- (b) Design of a fuzzy rule-based classification system (FRBCS) for the current task deriving the fuzzy classification rules either from expert knowledge or automatically.
- (c) Validation of the whole methodology on real-world cases manually solved in the Physical Anthropology Lab.

The originally estimated schedule for the achievement of the previous goals is shown in Table 1. Notice that, each activity is associated with the corresponding described objective.

2 Successful achievements of the project

The next three subsections are devoted to describe the results obtained till now in relation to the three project objectives, together with the publications generated from them.

Table 1: Estimated research project schedule

Activities/Tasks	Start	End
O0. Scanning of partial views of Physical Anthropology Lab's forensic skulls	m1	m2
O1.1. Design of multi-objective evolutionary pair-wise IR techniques	m1	m4
O1.2. Proposal of an SS-based IR technique working in the matching space	m5	m8
O1.3. Design of a real-coded SS-based, transformation space pair-wise IR approach	m9	m12
O2.1. Extraction of heuristic information about the cranial and facial landmarks	m9	m12
O2.2. Proposal of 2D-3D transformation-based skull-face superimposition approaches	m13	m18
O2.3. Design of 2D-3D matching-based skull-face superimposition approaches	m13	m18
O2.4. Proposal of 2D-2D skull-face superimposition approaches	m19	m21
O2.5. Design of an evolutionary technique for fine-tuning the obtained results	m22	m25
O3.1. Proposal of a forensic identification FS by using fuzzy aggregation operators	m22	m25
O3.2. Design of a forensic identification FRBCS	m26	m30
O3.3. Validation of the whole methodology on Physical Anthropology Lab's cases	m31	m36

2.1 Design of skull 3D model reconstruction techniques by EAs (O1)

We have continued working on our previous proposal based on SS [4], which constituted the germ of the current project, to fully automate it and to solve its robustness flaws due the lack of forensic anthropologist's skills on the scanner acquisition process. Three research lines have been developed to do so. The first two of them directly correspond to the second and third planned subobjectives, while the third one substitutes the first subobjective. In addition, extra work on the previous steps to photographic supra-projection have also been developed by the forensics subteam in a fourth research line.

2.1.1 Proposal of an SS-based IR technique in the matching space (O1.2)

We have extracted image characteristic information (crest lines) to design an SS-based 3D IR technique working in the matching space, which considers it as domain information in order to better guide the search. We have successfully validated the designed technique in the 3D IR of human brains magnetic resonance images and of human wrists computerized tomography images. This work has generated a publication in a SCI-JCR international journal:

- IJ1. O. Cordón, S. Damas, J. Santamaría, R. Martí, Scatter Search for the 3D Point Matching Problem in Image Registration. *INFORMS Journal on Computing* 20:1 (2008) 55-68. *Impact factor 2007: 0.907*. *Category: OPERATIONS RESEARCH & MANAGEMENT SCIENCE*. *Order: 20/60*.

2.1.2 Design of an SS-based, transformation space pair-wise IR approach (O1.3)

We have designed a generic architecture which allows us to incorporate the latter heuristic information into whatever evolutionary pair-wise IR technique for 3D modelling. We have applied it to several skulls from the Physical Anthropology Lab obtaining very accurate results in comparison with the ground-truth models. In order to fully automate the methodology, not even requiring the semi-automatic crest lines extraction, we also developed a specific procedure to automatically extract transformation invariant characteristics from the skulls range images.

Eight publications (two national and four international conference contributions, one book chapter, and one international journal submission) have been originated from this work:

- SJ1. M. Calisti, L. Ballerini, O. Cordón, S. Damas, J. Santamaría, Multiscale feature extraction from 3D range images. Submitted to Computer Graphics Forum.
- BC1. L. Ballerini, O. Cordón, S. Damas, J. Santamaría, Automatic 3D Modelling of Skulls by SS and Heuristic Features. In: Avineri E., Koepen M. (Eds.), Applications of Soft Computing, Springer, 159-169, 2009.
- IC1. J. Santamaría, O. Cordón, S. Damas, Evolutionary approaches for automatic 3D modelling of skulls in forensic identification. Proc. EvoIASP2007, Valencia (Spain), LNCS 4448, 415-422, 2007.
- IC2. L. Ballerini, O. Cordón, S. Damas, J. Santamaría, I. Alemán, M. Botella, Automatic 3D Modelling of Skulls by Scatter Search and Heuristic Features. Proc. WSC12, The Internet, 2007.
- IC3. L. Ballerini, M. Calisti, O. Cordón, S. Damas, J. Santamaría, Automatic Feature Extraction from 3D Range Images of Skulls. Proc. IWCF2008, Washington DC (USA), LNCS 5158, 58-69, 2008.
- IC4. L. Ballerini, M. Calisti, O. Cordón, S. Damas, J. Santamaría, Automatic 3D skull reconstruction using invariant features. Proc. CSTST2008, Cergy-Pontoise (France), 444-449, 2008.
- NC1. J. Santamaría, O. Cordón, S. Damas, I. Alemán, M. Botella, Reconstrucción de modelos 3D en antropología forense mediante Scatter Search. Actas del MAEB07, Tenerife, 625-633, 2007.
- NC2. L. Ballerini, O. Cordón, S. Damas, J. Santamaría, Selección heurística en imágenes 3D para la reconstrucción forense de cráneos con búsqueda dispersa. Actas del JAEM (CEDI), Zaragoza, 97-104, 2007.

2.1.3 Design of advanced skull 3D modelling techniques by memetic algorithms

The aim of the O1.1 workpackage was to improve Silva et al.'s multi-objective EA for 3D modelling [5]. However, we later recognized that was not a good approach since both considered objectives are not conflicting but complementary. As a consequence, we decided to improve the robustness of our method instead by considering other memetic algorithms. The new proposals clearly outperformed both the previous SS-based one and the state of the art in the IR field (based on sequential hybridizations) when obtaining the 3D models of several skulls. As a result of this research, we achieved a SCI-JCR international journal publication:

- IJ2. J. Santamaría, O. Cordón, S. Damas, J.M. García-Torres, A. Quirin, Performance Evaluation of Memetic Approaches in 3D Reconstruction of Forensic Objects. Soft Computing (2009). In press. *Impact factor 2007: 0.607. Category: COMPUTER SCIENCE, ARTIFICIAL INTELLIGENCE. Order: 66/93.*

2.1.4 Identification techniques from the skeleton for the previous sample selection

In order the photographic supra-projection technique can be applied, some basic biological parameters obtained from the study of the bony remains must be known. The forensics subgroup have proposed new techniques that allow estimating the age of death of a subject by means of a morphological characteristics statistical analysis of different bony elements compiled in computerized skeletons' collections, orthopantomographies and tomographies. Six publications have been obtained (two SCI-JCR international and four national journals):

- IJ3. G. González-Colmenares, M.C. Botella et al., Age Estimation by a Dental Method: A Comparison of Lamendin's and Prince Ubelaker's Technique. Journal Forensic Sciences 52:5 (2007), 1156-1160. *Impact factor: 1.037. Category: MEDICINE, LEGAL. Order: 6/9.*
- IJ4. M.I. Landa, P.M. Garamendi, M.C. Botella, I. Alemán, Application of the Method of Kvaal et al. to Digital Orthopantomograms. Int. J. Legal Med (2009). In press. *Impact factor 2007: 3.030. Category: MEDICINE, LEGAL. Order: 1/9.*
- NJ1. P.M. Garamendi, M.C. Botella, I. Alemán, M.I. Landa, Fusión de la epífisis externa de la clavícula en relación con la edad. Aplicaciones en la estimación forense de la edad. Cuadernos de Medicina Forense, 13:48-49 (2007) 143-156.
- NJ2. P.M. Garamendi, M.C. Botella, I. Alemán, M.I. Landa, Osificación del cartílago costal de la primera costilla en relación con la edad. Aplicaciones en la estimación forense de la edad. Cuadernos de Medicina Forense 13:50 (2007) 243-253.

- NJ3. P.M. Garamendi, I. Alemán, M.C. Botella, M.I. Landa, Estudio de la fusión del asta mayor del hioides en relación con la edad y revisión bibliográfica sobre las fracturas del hioides en Medicina Forense. Cuadernos de Medicina Forense 13:50 (2007) 227-242.
- NJ4. M.I. Landa, P.M. Garamendi, M.C. Botella, I. Alemán, Utilidad de la radiografía panorámica dental digital en la estimación de la edad en adultos. Cuadernos de Medicina Forense 14:52 (2008) 127- 135.

2.2 Design of craniofacial superimposition methods by EAs (O2)

The initially proposed research lines for this second objective also suffered some changes when the project team tackled them. We first decided to review the state of the art of the different (and usually non automatic) computer-based approaches proposed for craniofacial superimposition in the forensics community. Then, we focused on the first three subobjectives in order to propose a fully automatic technique to accurately put it into effect. After several incremental designs, we largely succeeded on that aim. Hence, O2.4 and O2.5 became meaningless, since they were supposed to be alternative and tuning approaches to the latter, respectively. All the work developed in relation to this objective is reviewed in the following two sections.

2.2.1 Study of the state of the art on computer-based craniofacial superimposition

We realized that there is some misunderstanding in this area, related to the use of computers by forensic anthropologists in the different stages of the photographic supra-projection task. In view of that, we proposed a new taxonomy which classifies the different existing contributions according to their actual computer use in each of the three photographic supra-projection stages. We only found two existing automatic craniofacial superimposition proposals [3, 1], which are moreover ineffective for their use in real forensic identification cases. This work line has provided a paper submitted to a SCI-JCR journal:

- SJ2. L. Ballerini, O. Cordón, S. Damas, J. Santamaría, I. Alemán, M. Botella, Identification by computer-aided photographic supra-projection: a survey. Submitted to Journal of Forensic Sciences.

2.2.2 Proposal of skull-face superimposition approaches by evolutionary and MH-based 2D-3D IR techniques (O2.1 to O2.3)

Taking [3] as a base, we formulated this complex task as a numerical optimization problem by modelling the required perspective transformation as a set of geometric operations involving translation, rotation, scaling, and projection. That registration transformation is thus defined by 12 parameters which are encoded in a real-coded chromosome and the search for the best transformation is guided by a number of pairings between cranial and facial landmarks located in the skull and the face, respectively. Then, we progressively designed five different EAs to solve that problem. They gave outstanding results in real-world identification cases.

This research line has concluded in five publications: two international conference contributions (one of them still submitted), two edited book chapters, and a paper recently accepted for publication in a highly rated SCI-JCR international journal:

- IJ5. O. Ibáñez, L. Ballerini, O. Cordón, S. Damas, J. Santamaría, An Experimental Study on the Applicability of EAs to Craniofacial Superimposition in Forensic Identification. Information Sciences (2009). In press. *Impact factor 2007: 2.147. Category: COMP. SCIENCE, INF. SYSTEMS. Order: 10/92.*
- BC2. L. Ballerini, O. Cordón, S. Damas, J. Santamaría, I. Alemán, M. Botella, Craniofacial Superimposition in Forensic Identification using GAs. In: K. Franke et al. (Eds.), Computational Forensics. Methods, Applications and Challenges in Computer-Assisted Criminal Investigations, Springer (2009). In press.

- BC3. O. Ibáñez, O. Cordon, S. Damas, J. Santamaría, Multimodal GAs for Craniofacial Superimposition. In: R. Chiong (Ed.), *Nature-Inspired Informatics for Intelligent Applications and Knowledge Discovery*, IGI Global (2009). In press.
- IC5. L. Ballerini, O. Cordon, S. Damas, J. Santamaría, I. Alemán, M. Botella, Craniofacial Superimposition in Forensic Identification using GAs. *Proc. IEEE IWCF2007*, Manchester (UK), 429-434, 2007.
- SIC1. J. Santamaría, O. Cordon, S. Damas, O. Ibáñez, 3D-2D image registration in forensic identification using evolution strategies. Submitted to *IEEE ICIP2009*, Cairo (Egypt), 2009.

2.3 Proposal of a forensic identification FS (O3)

The work on the third project goal was planned to consider FL tools to deal with the inherent uncertainty present in the third photographic supra-projection stage, the decision making process. Nevertheless, since the second stage is a significantly more complicated task for the forensic experts and in view of the very accurate results obtained by our craniofacial superimposition methods, the forensics subteam recommended us to focus on incorporating FL to model the landmark uncertainty in that stage. We are thus extending our approach to make it capable to deal with problematic cases presenting low quality (old) subject photographs or very lateral poses not allowing the forensic expert to properly allocate a valid landmark set.

Two sources of uncertainty have been identified: the *location uncertainty*, related to the extremely difficult task of locating the landmarks in an invariable place with the accuracy required for this application, and the *matching uncertainty*, involved in the matching of landmarks of two different objects: the face and the skull (due to physiognomic characteristics, some of them will perfectly match, some will partially do so, and some others will not).

We have successfully tackled the former kind of uncertainty obtaining two international (one of them still submitted) and one national conference contributions:

- IC6. O. Ibáñez, O. Cordon, S. Damas, J. Santamaría, Craniofacial superimposition based on GAs and fuzzy location of cephalometric landmarks, *Proc. HAIS 2008*, Burgos (Spain), LNAI 5271, 599-607, 2008.
- SIC2. O. Ibáñez, O. Cordon, S. Damas, S. Guadarrama, J. Santamaría, A new approach to fuzzy location of cephalometric landmarks in craniofacial superimposition, Submitted to *IFSA-EUSFLAT2009*, Lisbon.
- NC3. O. Ibáñez, O. Cordon, S. Damas, J. Santamaría, Superposición craneofacial basada en AGs y localización difusa de puntos de referencia cefalométricos. *Actas del ESTYLF2008*, Langreo-Mieres, 323-329, 2008.

In the remaining project time we are willing to improve our superimposition results by tackling the matching uncertainty. In addition, we aim to propose a forensic identification FS by using fuzzy aggregation operators. Finally, we will tackle the global methodology evaluation even if two of its three components have already been individually tested.

3 Indices to measure the quality of the obtained results

Relevance and originality of the obtained results: We have succeeded at providing valuable soft computing-based tools to assist the forensic experts in forensic identification by photographic supra-projection. A fully automatic 3D skull modelling approach for non expert users and some craniofacial superimposition methods have been obtained. They have been validated on six different real-world identification cases previously solved by the Physical Anthropology Lab staff in collaboration with the Spanish Police with very satisfactory results: competitive superimpositions were obtained (which even outperformed those obtained by the forensic experts for some specific photos) in an extremely lower time (less than two minutes in

the worst case in comparison with the 24 hours the manual identification requires in most of the occasions) showing a high robustness in the thirty runs performed for each problem.

The obtained developments are of great interest to the four currently binded EPOs —the Scientific Police Unit of the Guardia Civil, the Anthropology Unit of the Spanish Police, the Legal Medicine Institutes of the Andalusian Justice Department, and I.T.A. Aquateknica S.A. company— to apply them for forensic identification (the former three) and to spread a new application field for their Konica-Minolta scanners (the latter).

On the other hand, their originality is clearly demonstrated in view of the large number of dissemination activities performed. Drs. Cordón and Damas have been invited to give lectures about the project in different computer science and forensic anthropology PhD programs (Universities of Valladolid, Huelva, Rey Juan Carlos, Complutense, and Santiago de Compostela) and in some Asturian high schools. Moreover, last December 2008 they both organized a scientific marathon on the topic supported by the CajAstur Science Promotion Program with the participation of Dr. Alemán and of representatives of the Spanish Police and Guardia Civil.

Scientific and technological production: In summary, a total number of 25 publications has been developed during these 28 months, distributed as follows: 5 SCI-JCR international and 4 national journal papers, 2 papers submitted to SCI-JCR international journals, 3 book chapters, and 11 (3 national and 8 international, 2 of them still submitted) conference contributions. Almost all of them are available in the web page (<http://sci2s.ugr.es>). Besides, *the research team is currently finishing the writing of a patent proposal on the automatic SS-based craniofacial superimposition technique.*

Human resources learning: Dr. Jose Santamaría's PhD dissertation, advised by Drs. Cordón and Damas, was presented in December 2006. It is entitled "Scatter Search for 3D Image Registration: Application to Forensic Anthropology" and it focus on the first project objective. Mr. Oscar Ibáñez is also being advised by them in the second and third project objectives, where he has already obtained several publications (see Sections 2.2 and 2.3).

Participation in European projects: We have been recently granted with a project entitled "Medical Imaging Using Bio-inspired and Soft Computing" within the Seventh Framework Program under the "Marie Curie Initial Training Network" modality (FP7-People-2008-1-1-ITN). It is coordinated by Dr. Cordón and counts with Dr. Damas. Its main objective is to create a four years research training program on the application of SC to real medical imaging problems (as the current one). The consortium integrates 14 partners from different research centers, universities and companies, belonging to 6 different European countries.

Collaborations with other research teams: The following collaborations have arisen:

- Dr. Martí (University of Valencia), coordinator of the Spanish Metaheuristic Network: Joint SCI-JCR paper (see Section 2.1.1). One of the human image datasets included in that work was provided by Dr. J.J. Crisco (Rhode Island Hospital, USA).
- Drs. Kerre and Nachtegaal (University of Ghent, Belgium), coordinators of the SCIP international group (<http://www.fuzzy.ugent.be/SCIP/>): Co-edition with Dr. Damas of a special issue on "Recent Advances in Soft Computing in Image Processing" in the International Journal of Approximate Reasoning, indexed in the SCI-JCR.
- Drs. Schaefer (Aston University, UK), Vlachos (Aristotle University of Thessaloniki, Greece), and Kacprzyk (Polish Academy of Sciences, Poland): Co-edition with Dr. Damas of the book "Soft Computing in Medical Image Analysis. Part 1: Fuzzy Logic" to be published in Springer's *Series on Computational Intelligence*.

- Dr. Franke (Gjøvik University College, Norway), organizer of two conferences on the applications of computer science in the forensics field: IWCF (<http://iwcf08.arsforensica.org/>) and COMPFOR (<http://compfor08.arsforensica.org/>). Dr. Cordon has been a member of the former conference IPC in its three editions (2007, 2008, and 2009), while Dr. Damas did so in the first edition (2008) of the latter.
- Dr. Garamendi (Basque Institute of Legal Medicine): Several joint publications with the forensics subteam (see Section 2.1.4).

Results utility and relations with the socio-economical environment: Our developments have been used for the identification of M^a Luz Cortés (a five years old missing girl whose corpse was found after 55 days from her disappearance). The photographic supra-projection test was carried out at the same time than the DNA analysis, working in collaboration with the Legal Medicine Institute of Huelva. We are waiting for the relatives allowance to disseminate the obtained results for research aims. Besides, they are still under secret of summary.

The members of the forensics subteam have also recently collaborated with the Delegation Office for Justice of Granada in several identification cases of deceased people. In all of them, the trial proceedings are still opened, and thus they are under secret of summary. Finally, we are also using the proposed techniques to identify missing people in the Spanish civil war at several historical memory preservation organizations and town halls request.

Project management issues: Two of the members of the project team, Drs. Cordon (the principal researcher) and Damas, leaved the University of Granada and moved to the European Centre for Soft Computing (ECSC) by the end of the first year. Hence, there was a need to sign a specific collaboration agreement and to ask the Directorate General for Research for the change of its principal researcher (Dr. Botella officially became that by December, 13, 2007).

Of course, an additional coordination effort has been required due to this fact. Even so, we are very satisfied with the obtained project outcomes. We should highlight that it has allowed several researchers from the ECSC (Dr. Ballerini, Dr. Quirin, Dr. Guadarrama, and Mr. Ibáñez) to be involved in the project work at different levels with very fruitful collaborations.

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