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An experimental study on the applicability of evolutionary algorithms to craniofacial superimposition in forensic identification

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ABSTRACT

Photographic supra-projection is a forensic process that aims to identify a missing person from a photograph and a skull found. One of the crucial tasks throughout all this process is the craniofacial superimposition which tries to find a good fit between a 3D model of the skull and the 2D photo of the face. This photographic supra-projection stage is usually carried out manually by forensic anthropologists. It is thus very time consuming and presents several difficulties. In this paper, we aim to demonstrate that real-coded evolutionary algorithms are suitable approaches to tackle craniofacial superimposition. To do so, we first formulate this complex task in forensic identification as a numerical optimization problem. Then, we adapt three different evolutionary algorithms to solve it: two variants of a real-coded genetic algorithm and the state of the art evolution strategy CMA-ES. We also consider an existing binary-coded genetic algorithm as a baseline. Results on several superimposition problems of real-world identification cases solved by the Physical Anthropology lab at the University of Granada (Spain) are considered to test our proposals.

1. Introduction

Forensic anthropology is best conceptualized more broadly as a field of forensic assessment of human skeletonized remains and their environments [32]. This assessment includes both the identification of the victims' physical characteristics and cause and manner of death from the skeleton. This way, the most important application of forensic anthropology is the identification of human beings from their skeletal remains.

Photographic supra-projection [30] is a forensic process where photographs or video shots of a missing person are compared with the skull that is found. By projecting both photographs on top of each other (or, even better, matching a scanned three-dimensional skull model against the face photo/video shot), the forensic anthropologist can try to establish whether that is the same person.

To do so, an accurate 3D model of the skull is first demanded. The forensic experts select some facial anthropometric landmarks in the subject photograph, and cranial anthropometric landmarks in the obtained skull model. Next, the matching of these two sets of radiometric points is considered to guide the superimposition of the skull 3D model and the photograph, through a process known as craniofacial superimposition [30]. Then, a decision making stage starts by analyzing the different kinds of achieved matchings between landmarks. Some of them will perfectly match, some will partially do so and finally some others will not. After the whole process, the forensic expert must declare whether the analyzed skull corresponds to the missing person or not.

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The craniofacial superimposition process is known to be one of the most time consuming tasks for the forensic experts. In addition, there is not a systematic methodology but every expert usually applies a particular process. Hence, there is a strong interest in designing automatic methods to support the forensic anthropologist to put it into effect [46].

On the other hand, image registration (IR) [54] is a fundamental task in image analysis. It aims to find a correspondence (or transformation) among two or more images taken under different conditions, i.e. at different times, from different viewpoints, using different sensors, or a combination of them. Thus, the key idea of the IR process is achieving the transformation (rotation, translation, etc.) that places different images in a common coordinate system bringing the points as close together as possible. This is done by an optimization process which aims to minimize the error of a given metric of resemblance. Evolutionary algorithms (EAs) [5,6,19] in general, and genetic algorithms (GAs) [23,33] in particular, have been successfully applied to tackle different IR problems [16,38,43,50].

A sensible way to design an automatic craniofacial superimposition procedure is through the use of a IR technique to properly align the 3D model and the 2D image in a common coordinate frame. Unfortunately, we can only find one proposal [34] to automate the process and, as we will see in Section 5, the results achieved are not suitable for the forensic experts. From our previous experience on applying EAs to medical IR [14,15] we will formulate craniofacial superimposition as an IR problem. Then we will design different real-coded EAs to tackle this problem, comparing their performance with Nickerson et al.'s binary-coded GA [34], which shows several flaws making it unsuitable for the problem solving. We aim to automate and drastically reduce the time of the superimposition task by means of a systematic method based on EAs. Besides, this proposal can also help forensic experts as a way to obtain an initial automatic superimposition to be manually refined in a second stage, with the consequent saving of time.

The structure of this paper is as follows. In Section 2, we introduce some IR basics and briefly review the state of the art on craniofacial superimposition. In Section 3, the proposed problem formulation is detailed. Section 4 is devoted to describe the designed EAs and to explain their adaption for solving the superimposition problem. In Section 5, we will show the results on real-world cases' experiments, together with an analysis of the performance of the algorithms depending on the parameter values selected. Section 6 collects some conclusions and future works. Finally, Appendix A provides the whole experimental results obtained for the cases studied in Section 5.

2. Preliminaries

The craniofacial superimposition task is so complicated that it worths addressing some important concepts before tackling the problem itself. First we want to clarify the context of this contribution. This work is part of a project that aims to propose an automatic methodology to develop the whole photographic supra-projection process. This process is divided in three stages, somehow reproducing the steps of the procedure employed by forensic experts. The first stage involves achieving the "virtual model" of the physical object (the skull) itself, so that it constitutes an accurate model of the real object we are trying to represent, i.e., a skull model. To do so, we have successfully considered EAs as robust optimizers able to overcome the lack of experience of the forensic anthropologists on the use of the 3D scanners and the high complexity of the problem in real scenarios [39–41].

Likewise, the second step known as craniofacial superimposition aims to properly superimpose the skull 3D model and the photograph. Forensic experts extract different landmarks from the obtained skull model and from the face photograph. In our approach, these two sets of landmarks will guide the automatic search for the registration transformation parameters that accurately overlay them. In this case, that transformation corresponds to a 3D/2D one. Again, we consider EAs as a powerful tool to perform this task (as was shown in some preliminary work developed in [7]). The goal of this contribution is to formulate the corresponding IR problem and to properly solve it by means of real-coded EAs.

Finally, the last stage of the photographic supra-projection technique corresponds to the decision making. Typically, once the best superimposition is achieved, the forensic experts analyze the final correspondence between the significant landmarks of the skull and the face, and make a decision on five possible choices: positive, negative, likely positive, likely negative, or unknown identification. We aim to tackle this last procedure in the short future by means of fuzzy logic techniques reflecting the partial matching nature of the problem.

Since the first and the second photographic supra-projection stages are based on IR techniques, Section 2.1 is devoted to briefly describe the IR problem. Then, in Section 2.2 we review the state of the art on craniofacial superimposition which is the stage this paper is focused on.

2.1. The image registration problem

The key idea of the IR process is to achieve the transformation that places different 2D/3D images in a common coordinate system. There is not a universal design for a hypothetical IR method that could be applicable to all registration tasks, because various considerations of the particular application must be taken into account. Nevertheless, IR methods usually require the four following components:

– Two input 2D or 3D **Images** often named as Scene $I_s = \{\vec{p}_1, \vec{p}_2, \ldots, \vec{p}_n\}$ and Model $I_m = \{\vec{p}'_1, \vec{p}'_2, \ldots, \vec{p}'_m\}$, with $\vec{p}_i$ and $\vec{p}'_j$ being image points.