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Hierarchical information fusion for decision making in craniofacial superimposition

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ABSTRACT

Craniofacial superimposition is one of the most important skeleton-based identification methods. The process studies the possible correspondence between a found skull and a candidate (missing person) through the superimposition of the former over a variable number of images of the face of the latter. Within craniofacial superimposition we identified three different stages, namely: (1) image acquisition-processing and landmark location; (2) skull-face overlay; and (3) decision making. While we have already proposed and validated an automatic skull-face overlay technique in previous works, the final identification stage, decision making, is still performed manually by the expert. This consists of the determination of the degree of support for the assertion that the skull and the ante-mortem image belong to the same person. This decision is made through the analysis of several criteria assessing the skull-face anatomical correspondence based on the resulting skull-face overlay. In this contribution, we present a hierarchical framework for information fusion to support the anthropologist expert in the decision making stage. The main goal is the automation of this stage based on the use of several skull-face anatomical criteria combined at different levels by means of fuzzy aggregation functions. We have implemented two different experiments for our framework. The first aims to obtain the most suitable aggregation functions for the system and the second validates the proposed framework as an identification system. We tested the framework with a dataset of 33 positive and 411 negative identification instances. The present proposal is the first automatic craniofacial superimposition decision support system evaluated in an objective and statistically meaningful way.

1. Introduction

Craniofacial superimposition (CFS) [1] is the most representative technique within craniofacial identification [2]. It involves superimposing a skull onto a one or more ante-mortem (AM) photographs of a missing person. The consequent analysis of their morphological correspondence determines if they belong to the same subject.

The whole CFS process can be divided into three consecutive stages [3] (Fig. 1): (1) The acquisition and processing of the materials, i.e., skull and AM facial images, and the location of somatometric landmarks on both; (2) Skull-face overlay (SFO), which deals with accomplishing the best possible superimposition of the skull and a single AM photograph of a missing person. This procedure is iteratively executed for each photograph, thus getting different overlays. (3) Decision making process aims to determine the degree of support for a match based on the SFOs achieved in the previous step. The final decision is managed by different criteria based on the anatomical relationship between the face and the skull. These criteria can vary depending on the region and the pose [4].

Designing automatic methods to address CFS and support the forensic anthropologist remains a challenge and dreamed milestone within the anthropology community. In fact, the development of computer-aided CFS methods has increased over the past twenty years [5]. Recent approaches use skull 3D models and soft computing (SC) methods for the first two identification stages. These methods allow us to both automate the task and handle the inherent uncertainty [6–9].

In the third stage, once one or more SFOs are obtained, experts evaluate morphological and spatial skull-face relations, focusing on certain regions demonstrated to be more discriminative. The final decision is provided from an aggregation of the partial decisions.

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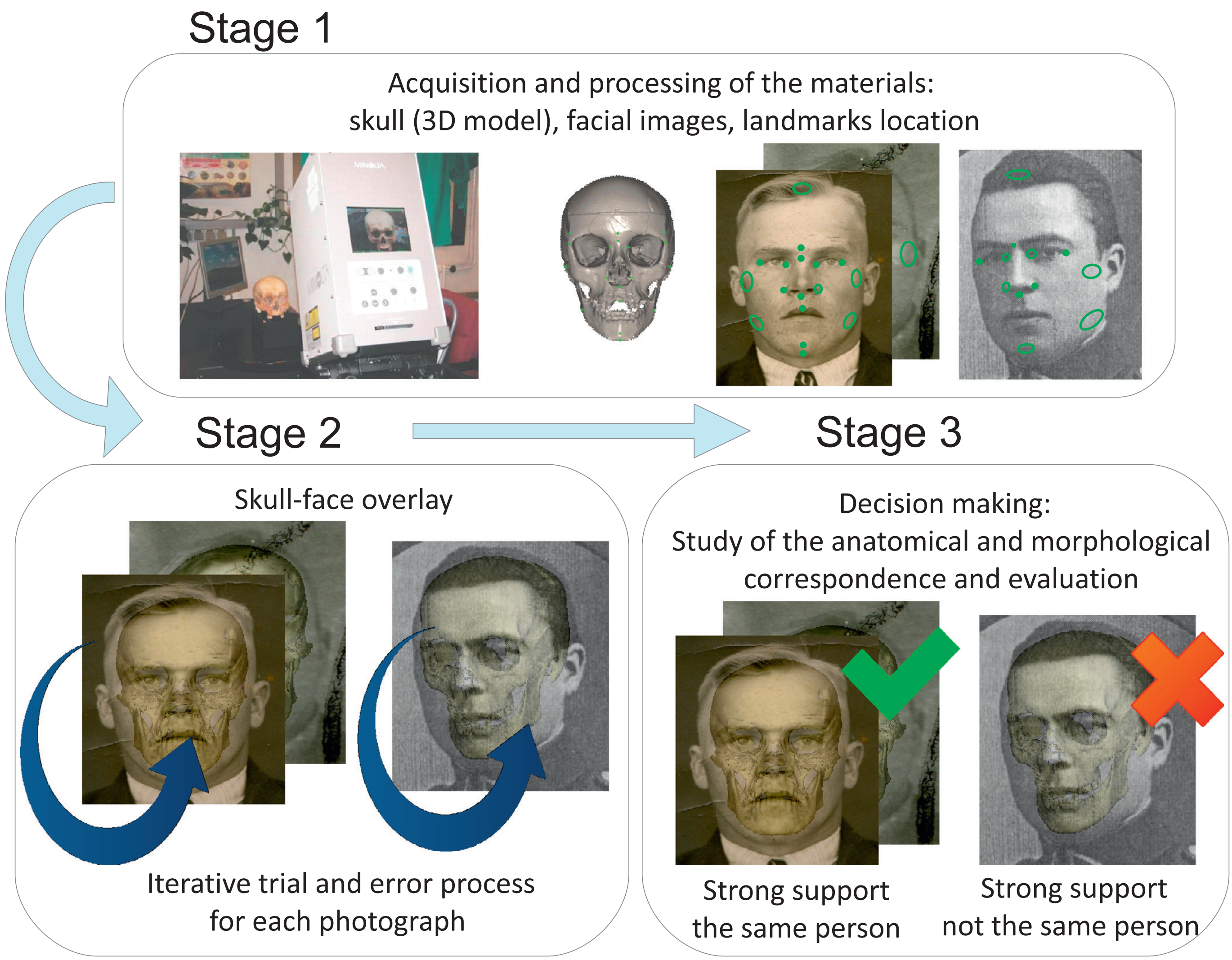

Fig. 1. CFS procedure scheme.

It is taken in terms of limited, moderate or strong support to the assumption that the skull and the facial image belong to the same individual or not [4]. This process is subjective and it relies on the skills of the forensic expert while influenced by the quantity and quality of the used materials. Therefore, there is a need to design a decision support system (DSS) to help practitioners to make their decision based on the fusion of the available information sources in a faster and more objective way. It would also lead to the application of CFS in identification scenarios with multiple comparisons, a possibility not explored yet due to the unaffordable time lapse needed to analyse all possible cross-comparisons. Our long-term and complex goal is the implementation of a DSS by evaluating the spatial and morphological relationships. The system will return a numeric index as output, in order to support the forensic anthropologist to make the final CFS decision while automatically filtering a number of cases in multiple comparison scenarios.

In previous works [10–12], we presented a first preliminary proposal to design a DSS for CFS using computer vision (CV) and fuzzy integrals. We implemented two of the most discriminative criteria to assess craniofacial correspondence, namely, the spatial and the morphological relation between the bony and facial chin, and the relative position of the orbits and the eyeballs.

In this work we present a complete hierarchical DSS for CFS with three connected levels of decision. The previous studies only tackled what we currently identified as the third and simplest level. We only implemented some CV methods aimed to measure two criteria to assess craniofacial correspondence in the corresponding two isolated regions. Thus, previous developments cannot be used for the identification task. Here, for the first time, we propose a complete framework that allows forensic experts to automatically address the final decision making stage. The presented fuzzy DSS develops information fusion concerning skull-face anatomical correspondence at different levels: criterion evaluation, SFO evaluation, and CFS evaluation. Additionally, in this study, we provide an implementation of the SFO evaluation level of the DSS (as explained above, we have already provided an implementation for the criterion evaluation level [10]). Within this level, we distinguish three sublevels with different conditions of aggregation. In each of them, the different sources of uncertainty are modeled, and different aggregation mechanisms account for information fusion and propagation. These sources of uncertainty also provide a mechanism to propagate information and uncertainty from criterion evaluation to SFO evaluation levels.

The uncertainty sources and degrees of confidence involved in the information fusion process are classified into bone, image, SFOs, morphological aspects, and computational methods used to model the criteria. The bone uncertainty refers to the quality of the skull, and the uncertainty of the photograph considers the visibil-