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Machine learning-based approaches for predicting stature from archaeological skeletal remains using long bone lengths

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ABSTRACT

This paper approaches, from a computational perspective, the problem of predicting the stature of human skeletal remains from bone measurements. There are traditional methods for constructing models that give good results for stature estimation. In this paper, we aim to investigate the usefulness of using machine learning-based models to approximate stature. Assuming that the stature of an individual is indirectly related to bone measurement values, we can derive methods that learn from archaeological data and construct models that give good estimates of the stature. Two novel machine learning-based regression models for stature estimation are proposed in this paper. Experiments using artificial neural networks and genetic algorithms were performed on samples from the Terry Collection Postcranial Osteometric Database, and the obtained results are discussed and compared with the results from other similar studies. The experimental evaluations indicate that the machine learning-based regression models are efficient for the stature estimation of archaeological remains and highlight the potential of our proposal.

1. Introduction

From the perspective of forensic anthropology and archaeology, predicting the stature of an individual based on osteological information is fundamental. The classical mathematical approaches to stature estimation focus on the use of regression methods (Sen and Srivastava, 1997) based on statistical analysis of the data. The aim of this study is to assess the effectiveness of machine learning techniques in predicting stature from bone measurements.

Machine learning (Mitchell, 1997) is a challenging research direction, which deals with developing system models that, based on a set of data, improve their performance through experiences and through learning some specific domain knowledge. In supervised learning scenarios, the learning system receives a set of labelled examples, known as training data, from an external supervisor and learns to infer a function from these.

Estimating stature is important in bioarchaeological and forensic research, firstly because stature is a standard biological attribute together with age and weight. It also enables researchers to assess sexual dimorphism or the general body size of the past population under study (Raxter et al., 2006). Moreover, stature is an important indicator of individual's physical growth and development within its social and natural environment (Boix and Rosenbluth, 2014). Despite the individual's natural genetic potential for physical growth, it is the society that nurtures its members through nutrition, hygiene, physical education, etc., to reach their potential (Boix and Rosenbluth, 2014).

Since we do not have a precise method for the calculation of stature from bone measurements, this paper considers machine learning-based regression models to be appropriate for providing estimates, given the ability of these systems to capture relevant patterns from anthropometric data.

We propose two supervised regression models for stature estimation, one based on *artificial neural networks* and one based on *genetic algorithms*. Numerical experiments were performed on the Terry Collection anthropometric data (Terry, 2015), which were previously used in the archaeological literature for stature prediction.

To the best of our knowledge, the proposed approaches are novel, since there are no similar existing machine learning-based models in the literature for the problem considered in this paper.

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The rest of the paper is structured as follows. Section 2 presents the stature estimation problem, emphasizing its relevance for archaeology, as well as existing approaches for solving it. In addition, we discuss the fundamentals of the models used in our proposal: artificial neural networks and genetic algorithms. In Section 3, we introduce our machine learning-based approaches for predicting the stature of human skeletons. Section 4 provides an experimental evaluation of the proposed models on a publicly available data set that was previously used in the literature for the considered problem. A discussion on the obtained results and a comparison to similar related work are presented in Section 5. Section 6 outlines the conclusions of the paper and indicates some directions for future research.

2. Background

In this section, we present the background knowledge required for our approach. First, the importance of living stature prediction from human remains is discussed. Second, we provide an overview of the approaches to stature estimation that exist within the literature.

2.1. Motivation

Stature estimation is a common topic in anthropological analysis, the generated results having wide applications for making biocultural assessments with regard to archaeological populations. Drawing upon methods and theories from human behavioural ecology, physical and cultural anthropology, sociology, and economy, scholars have used stature as a quality-of-life indicator for inferring the complex relationships between skeletal development and ecology, diet, nutrition, genetics, and physical activity (Larsen and Walker, 2010; Boix and Rosenbluth, 2014).

Together with porotic hyperostosis, cribra orbitalia, and dental enamel hypoplasia, living height is used as a measure of health in bioarchaeological studies (Auerbach, 2011; Moradi, 2009; Pietrusewsky et al., 2014), allowing for inferences about subsistence strategies or social inequality (Boix and Rosenbluth, 2014). The *mean height* of a population is considered in Moradi (2009) to be a marker of its nutritional and health status. In Pietrusewsky et al. (2014) classified stature as an indicator of health, which is attributable to non-specific systemic stress during growth and development.

Along with the development of artificial intelligence and machine learning, it is natural to research the possibility of building computer programs that do not have predefined algorithms for generating predictions, but instead learn from the available data and adapt their models according to the new data samples that are being processed.

2.2. Related work on the stature prediction problem

Many approaches have been proposed in the literature for estimating the stature of human skeletons.

The following methods can be used for stature reconstruction (Dwight, 1884): anatomical methods and mathematical methods. The anatomical approach involves the reconstruction of cadaveric stature by summing the lengths of a series of contiguous skeletal elements from the skull through the calcaneus and converting them to living stature by incorporating soft tissue correction factors (Fully, 1956). Therefore, as stated by Lundy (1985), when applicable, the anatomical method is preferable to the mathematical one. Its applicability obviously diminishes in contexts where well-preserved and nearly complete skeletons are not always recovered. In these contexts, the mathematical method is effective even with few bones available since it implies regression formulae based on the correlation of specific skeletal elements to living stature (e.g. Trotter and Gleser, 1952). An additional advantage of both the mathematical method and the novel method that we propose over the anatomical one is the speed of investigation (Raxter et al., 2006).

In 1884, Dwight (1884) proposed the first anatomical method for estimating the stature, a method that still causes high degrees of error. The French scientist Etienne Rollet initiated, in the late 19th century, a series of approaches aiming to estimate stature (Rollet, 1888). Using the raw data of Rollet, Manouvrier (1892) introduced in 1892 another method for stature estimation, by determining the average stature of individuals sharing the same length of a given long bone.

The regression formulae introduced by Pearson (1899) in 1899 virtually replaced the abovementioned methods. Subsequent studies performed by Stevenson (1929), Telkka (1950), and Dupertuis and Hadden (1951) identified a restraint regarding the inter-populational applicability of these formulae.

An approach considered to be a milestone with respect to stature prediction was introduced in 1952 by Trotter and Gleser (1952), which is also the source of the data used in the present paper. Several formulae based on measurements of important bones in the human body such as the femur or tibia were computed based on the Terry Collection of both European-American and African-American male and female osteological remains. The regression formulae were tested on actual data obtained from the military with significant accuracy rates. Many of the subsequent approaches, like the one introduced in 2005 by Jantz and Ousley (2005), proposed formulae based on the ones introduced by Trotter and Gleser (1952).

An anatomical method that makes use of the sum of all skeletal elements that directly contribute to living stature was proposed by Fully (1956) in 1956. Soft tissue corrections were added to these so-called skeletal heights to derive living statures. This correction was done by simple addition or via a regression approach, and provided a superior performance compared to the methods that exclude soft tissue corrections.

Lundy (1985) performed in 1985 a study comparing the anatomical and the mathematical methods for stature prediction. Owing to the experimental results, the usage of anatomical methods is recommended in the cases when skeletal remains are sufficiently complete. Otherwise, if this constraint is unfulfilled, the suggested approach remains the mathematical one.

Trying to alleviate the difficulties arising from the cross-application of stature regression equations on populations having different body proportions, Sjøvold (1990) proposed in 1990 a new regression-based method called *line of organic correlation* to estimate stature from stature/long bone proportions, considering that virtually the same slopes characterise the regression lines of distinct populations. The proposed method uses major axis regression instead of the most commonly used ordinary least squares method. The independence with respect to sex and ethnic group constitutes an advantage of this approach.

An alternative method, based on the femur/stature ratio, was later rediscovered, being exposed by Feldesman (1996) in 1996. The fact that the femur/stature ratio is a sex-and-ethnicity-independent ratio represents a significant advantage, along with a small degree of melioration of the performance (except, however, the particular cases when equations specifically designed for the target population have been derived).

In 1996, Kozak (1996) analyzed several stature prediction methods (Fully and Pineau, 1960; Pearson, 1899; Trotter and Gleser, 1952; Gralla, 1976; Sjøvold, 1990; Breitinger, 1938; Dupertuis and Hadden, 1951) on skeletal materials from 9th to 19th century