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# Automatic localization, segmentation and classification of regions of interest for skeletal maturity assessment using the Tanner-Whitehouse method

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**Abstract** For several medical fields such as pediatrics, orthodontics, etc, the assessment of a patient's bone age is of fundamental importance to complement the necessary information for a diagnosis. The most effective method for skeletal age assessment is proposed by Tanner and Whitehouse (TW), which is up to five times more accurate than other methods used by most medical professionals. Despite being more efficient, the TW method is not widely used, because its manual application is considered complicated by many medical professionals. This work shows the possibility of automating the TW method, and how this automation can contribute to increasing its utilization. The algorithm described in this work uses thresholding and histogram analysis to localize the fingers in a hand radiograph. After localizing the fingers, the algorithm uses Active Shape Models (ASM) for localizing and segmenting epiphyses in the fingers. Epiphyses are some of the regions of interest (ROI) used in bone age assessment. The ASM models also align the segmented epiphyses with reference images and compare them. This comparison classifies the epiphyses according to their skeletal maturity stage. The proposed methods have been tested on 237 hand radiographs obtained from Clinical Hospital of the Federal University of Uberlândia. The results showed that 76.79% of the images were assigned the correct stage, and 98.73% of the epiphyses were classified correctly or lie within one stage of its correct classification.

**Keywords** Localization, Segmentation, Regions of interest, Active Shape Models, Tanner-Whitehouse method, Classification.

# *Localização, segmentação e classificação automática de regiões de interesse para a avaliação da maturidade esquelética utilizando o método de Tanner-Whitehouse*

***Resumo*** *Para diversas áreas médicas como pediatria, ortodontia, etc, a avaliação da idade óssea de um paciente é de fundamental importância para complementar as informações necessárias a um diagnóstico. O método mais eficaz para avaliação da idade esquelética foi proposto por Tanner e Whitehouse (TW), e é até cinco vezes mais preciso que outras técnicas utilizadas pela maioria dos profissionais médicos. Apesar de ser mais eficiente, o método TW não é amplamente utilizado, pois o excesso de trabalhos manuais é considerado complicado por muitos. Este trabalho mostra uma forma de se automatizar o método de TW, e como essa automação pode contribuir para aumentar a sua utilização. O algoritmo descrito utiliza análises por limiares e histogramas para localizar os dedos em uma radiografia da mão. Após a localização dos dedos, o algoritmo usa Modelos de Forma Ativa (MFA) para localização e segmentação de epífises nos dedos. As epífises compõem algumas das regiões de interesse utilizados na avaliação da idade óssea. Os MFAs também alinham as epífises segmentadas com imagens de referência e permitem comparações entre ambas. Esta comparação classifica as epífises de acordo com seu estágio de maturidade esquelética. Os métodos propostos foram testados em 237 radiografias de mão obtidas do Hospital das Clínicas da Universidade Federal de Uberlândia. Os resultados mostraram que o estágio de maturidade foi corretamente definido para 76,79% das imagens e 98,73% das epífises foram classificados corretamente ou se encontram dentro de um estágio de sua correta classificação.*

***Palavras-chave*** *Localização, Segmentação, Regiões de interesse, Modelos de forma ativa, Método Tanner-Whitehouse, Classificação.*

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## Introduction

Bone age assessment is an important tool important to help diagnosing childhood diseases and disorders that cause abnormal growth, and the analysis of hand and wrist radiographs is the most widely used method for this assessment. Among the various methodologies in the scientific literature, the Greulich and Pyle method (GP) is the most used, and consists in a subjective visual comparison between the radiograph under study and a collection (atlas) of radiographs from the 1950s. Despite its considerably inferior precision, it remains in use because alternative methods are more complicated to implement manually (Bontrager, 1999).

The Tanner and Whitehouse method (TW), proposed more recently, assesses skeletal maturity by classifying several hand and wrist bones in well-defined maturity stages, thus providing more accurate diagnoses, since the results are numerical values rather than subjective descriptions. However, the use of this method is not widespread, because the required measurements and calculations are considered a hurdle by many medical professionals (Guglielmi *et al.*, 2001).

Unlike the Greulich-Pyle (GP) method, which analyzes the aspect of the entire hand to assess maturity, the method proposed by Tanner and Whitehouse (TW) (Tanner *et al.*, 1962) considers the development status of several hand bones individually. For each bone a set of maturity stages are defined. Each stage is assigned a letter (A, B, C...) and a score. The overall skeletal maturity is computed by the scores of all bones examined. Bull *et al.* (1999) show that the TW method is both more reproducible and more accurate than the GP method.

It is thus interesting to automate the TW method using a computer-aided diagnosis system, which overcomes the obstacles that set back the use of this method. This article discusses methodologies that can be used to implement such a system. The following sections present the TW method, proposed methodologies, experimental results and conclusions.

## Materials and Methods

Steps such as Localization, Segmentation and Classification of Regions of Interest (ROI) are necessary for the automation of the TW method. Several techniques have been proposed in the literature to perform these basic steps. A more detailed chronology of these techniques can be found in Castro (2009). Niemeijer *et al.* (2003) combined some of these techniques to demonstrate the possibility of automating the TW method regarding segmentation and classification, but localization of the ROI is performed manually.

The methods presented in this work are strongly inspired by Niemeijer *et al.* (2003), but also include a stage of automatic localization of the ROI contained within the fingers in the radiograph.

The collection of algorithms is organized as a system named LSCA-TW (Castro, 2009). Localization is based on thresholding techniques and histogram analysis. Active Shape Models (ASM) segment the ROI and align them with reference images of each maturity stage. A measurement of similarity determines ROI classification in a defined maturity stage. These steps are accomplished as follows.

- **Automatic finger localization**: most of the ROI analyzed by the TW method are found within certain fingers, namely the thumb, middle finger and little finger (fingers I, III and V, respectively). In order to localize these fingers, the image is first binarized by a dynamic thresholding technique (Castro, 2009). The binarized image (a white hand on a black background) is used to create a vertical histogram (Figure 1) where peaks represent the fingertips and valleys represent the soft tissue between fingers. Therefore, peaks and valleys determine the position of the fingers that contain ROI.
- **Application of Active Shape Models (ASM)**: among the new deformable model techniques that can be found in the literature, ASM (Cootes and Taylor, 2001) is especially interesting because the model deformation is restricted by statistical information collected from a training set. After training, the ASM algorithm searches for the shape in the image. Our method uses ASM to search previously localized fingers

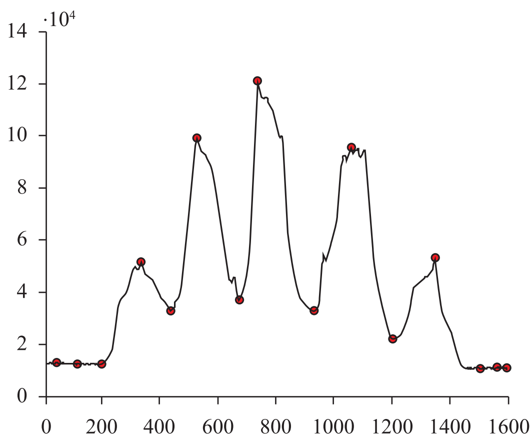


**Figure 1.** Vertical histogram of binarized image.

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and determine areas of the image that contain ROI (epiphyses). These areas are highlighted in Figure 2. The ASM then searches inside those areas using a finer model in order to correctly segment the epiphysis. Figure 3 shows an example of the segmentation of the middle epiphysis for finger III.

- **Skeletal maturity classification**: ROI classification is performed by the comparison between the ROI and a set of reference images. Each reference image represents a maturity stage and is created by the average of several instances of that stage, as detailed in Castro (2009) and Niemeijer *et al.* (2003). The ROI and the reference images are first aligned using ASM. Similarity is determined by the correlation coefficient, defined by Equation 1:

$$\rho = \frac{\mathrm{cov}(X,Y)}{\sqrt{\mathrm{var}(X)\,\mathrm{var}(Y)}} \qquad (1)$$

where $X$ and $Y$ are the gray-level pixel values of the ROI and the reference image, respectively. The greatest correlation coefficient determines the maturity stage classification.

## Results

The aforementioned techniques were tested on 237 hand images obtained from scanned radiographs. Contrast and sharpness of these images were not best, due to poor quality of the original films. Additionally, in most radiographs, the hand was not positioned as recommended by the TW method, affecting the automatic localization results of fingers I and V, as shown in Table 1, suggesting the need of a finger localization algorithm that is less sensitive to hand positioning. Bad hand positioning also affected the results of automatic segmentation of the ROI for fingers I and V, as shown in Table 2. Table 3 shows a confusion matrix for the classification stage of the middle epiphysis of finger III, and the results are similar to those found in Niemeijer *et al.* (2003). Considering that, in this work, the ROI localization was performed automatically, and that in Niemeijer *et al.* (2003) the localization was performed manually, the similarity of the results suggests that the automatic localization technique used in this work is at least as good as localizing that ROI manually. Our results also confirm Niemeijer's conclusion that the classification method based on

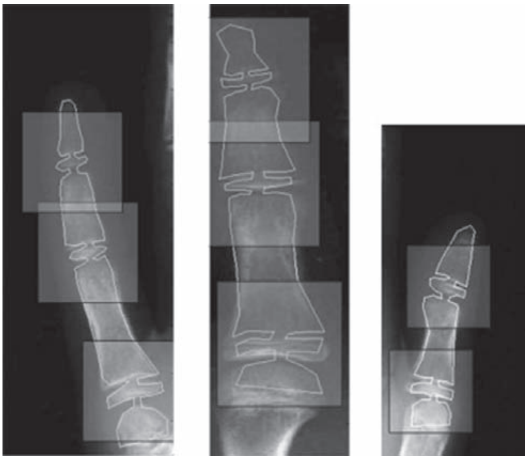

**Figure 2.** Regions of interest contained within fingers I, III and V.

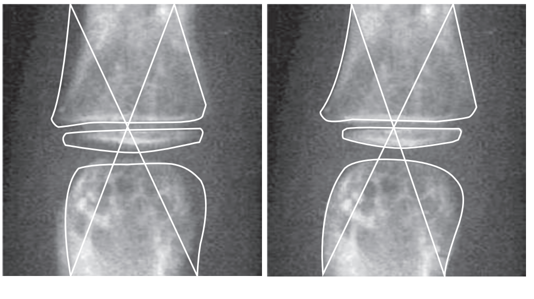

**Figure 3.** Segmentation of the middle epiphysis of finger III.

**Table 1.** Results for the automatic finger localization.

| Finger | Success rate (%) |
|---|---|
| Finger I | 94.5 |
| Finger III | 98.8 |
| Finger V | 90.1 |

**Table 2.** Results for epiphysis segmentation.

| Finger / epiphysis | Success rate (%) |
|---|---|
| I / Distal | 93.7 |
| I / Proximal | 94.6 |
| III / Distal | 96.8 |
| III / Middle | 97.6 |
| III / Proximal | 96.4 |
| V / Distal | 93.0 |
| V / Middle | 93.9 |
| V / Proximal | 88.2 |

**Table 3.** Confusion matrix of skeletal maturity classification of the middle epiphysis of finger III.

| | D | E | F | G | H | I |
|---|---|---|---|---|---|---|
| D | 9 | 3 | 0 | 0 | 0 | 0 |
| E | 2 | 68 | 9 | 1 | 0 | 0 |
| F | 1 | 8 | 65 | 4 | 0 | 0 |
| G | 0 | 0 | 18 | 27 | 1 | 0 |
| H | 0 | 0 | 1 | 0 | 6 | 3 |
| I | 0 | 0 | 0 | 0 | 4 | 7 |

the correlation coefficient does not perform well for maturity stages whose appearances are very similar (e.g. F&G and H&I), which suggests the need for a method that better distinguishes similar stages.

## Conclusions

This work demonstrated the possibility of automating the TW method. The proposed methods showed success rates of up to 98.8% for automatic localization and up to 97.6% for segmentation. Approximately 76.79% of the epiphyses were classified to the correct maturity stage and 98.73% of the epiphyses were classified correctly or lie within one stage of its correct classification. These results encourage further research that could contribute to fully automating skeletal maturity assessment using the TW method.

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