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Neutrosophic-Based Cephalometric Analysis for Egyptian Population Using Novel Software

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Abstract: Cephalometric analysis is vital for orthodontic diagnosis, yet uncertainties in landmark identification, particularly for Egyptian patients, challenge accuracy. This study proposes the Neutrosophic Egyptian Cephalometric Analysis Software (N-ECA Software), an open-source tool leveraging neutrosophic logic to model truth (T), indeterminacy (I), and falsity (F) in facial, jaw, and dental measurements. The software processes lateral cephalometric X-rays, using neutrosophic sets for robust landmark detection and angle classification. Validated against manual analysis and the Downs program, N-ECA achieves 85-90% accuracy, outperforming Downs ($60-65\%$) and matching commercial tools. Neutrosophic statistical metrics and non-parametric tests confirm their reliability. This is the first application of neutrosophic logic to cephalometric analysis, offering a cost-effective, Egyptian-specific solution.

Keywords: Neutrosophic logic, cephalometric analysis, N-ECA Software, Egyptian anatomy, uncertainty modeling

1 Introduction

Cephalometric analysis, introduced by Broadbent in 1931, assesses craniofacial development through lateral cephalometric radiographs [1]. It involves identifying anatomical landmarks to measure angles and distances, diagnosing dental and skeletal irregularities [2]. Cephalometric analysis is essential for orthodontic diagnosis and treatment planning, enabling clinicians to evaluate skeletal relationships, dental positions, and facial growth patterns. Over time, the field has evolved to incorporate three-dimensional imaging and automated tracing tools, although two-dimensional lateral radiographs remain the standard in many settings due to accessibility and cost [3]. It also supports growth assessment and surgical planning in maxillofacial procedures by tracking longitudinal changes in craniofacial structure [4]. Advances in machine learning have led to semi-automated systems that improve repeatability, but variability in anatomy and radiographic contrast continue to pose challenges [5]. Uncertainties in landmark placement due to anatomical variations, image quality, and operator expertise compromise accuracy, especially for non-Caucasian populations like Egyptians [6]. Manual tracing is time-consuming and subjective, while digital tools, designed for Caucasian anatomies, yield errors for Egyptian patients [7].

Neutrosophic logic, proposed by Smarandache, extends fuzzy logic by modeling truth (T), indeterminacy (I), and falsity (F) independently, making it ideal for handling medical imaging uncertainties [8]. Unlike classical logic which offers binary values, or fuzzy logic which models degrees of truth, neutrosophic logic acknowledges the presence of uncertainty and contradictions within data. This makes it particularly well-suited for medical contexts, where overlapping structures, image noise, and patient variability are common challenges [9]. Neutrosophic logic has been applied across various medical disciplines to filter, segment, and interpret uncertain data. In radiology, it allows for more nuanced segmentation of anatomical regions by incorporating degrees of ambiguity [10]. In cephalometric, it provides a mathematical foundation for more robust landmark detection by managing conflicting pixel information and overlapping anatomical boundaries [11]. The Neutrosophic Egyptian Cephalometric Analysis Software (N-ECA Software) integrates neutrosophic sets to enhance landmark detection and angle classification, achieving 85–90% accuracy compared to 60–65% for traditional methods like Downs [12].

Neutrosophic decision support systems have demonstrated effectiveness in medical image analysis. For instance, F. Smarandache introduced this logic for handling indeterminate information in complex domains [13]. J. Ye applied neutrosophic entropy for optimizing decision-making under uncertainty [14]. Ravi and Manimegalai used it to improve diagnostic accuracy in breast cancer imaging [15]. Saeed and Al-Ali enhanced ultrasound and MRI imaging using neutrosophic filtering [16]. Researchers implemented it in facial recognition, aiding surgical decision-making [17].

Balasubramanian and Kannan combined fuzzy and neutrosophic logic for tumor segmentation [18]. Tripathy addressed conflicting medical data with hybrid classifiers [19]. Nair and Duraiswamy improved lesion detection in lung CTs using neutrosophic filtering [20]. Hamdi improved cervical cancer screening using neutrosophic morphology [21]

Shereef and El-Doky utilized neutrosophic logic to process panoramic and bitewing radiographs. Their work focuses on segmenting overlapping teeth, identifying impacted third molars, and analyzing arch relationships, all critical in orthodontic treatment planning [22,23]. Bensaid used the approach in diabetic retinopathy diagnosis [24]. El-Dokany fused EEG and MRI data using neutrosophic for epilepsy diagnostics [25].

Applications in dental imaging and cephalometric have gained traction. Datta and Chaki refined landmark precision in restorative dentistry [26]. Smarandache and Albluwi enhanced AI-based landmark detection under ambiguity [27]. Panesar et al. integrated AI and neutrosophic methods in cephalometric landmark systems [28]. Alqahtani et al. automated skeletal pattern recognition for orthodontics [29]. Abdel-Mottaleb and Hamdi explored neutrosophic segmentation for cephalometric planning and intraoral diagnosis [30, 31].

El-Zein and Soliman combined ML with neutrosophic logic for maxillofacial surgery support [32]. Farag and Tarek applied entropy-based neutrosophic to CBCT images, aiding in TMJ diagnosis [33]. Al-Dhaheri and El-Gohary used AI-neutrosophic tools for aligner simulations [34]. These systems outperform traditional models by addressing ambiguity in cephalometric assessment.

The integration of neutrosophic logic into cephalometric decision support systems has shown clear potential to enhance diagnostic accuracy for Egyptian patients, offering a robust alternative to tools built on Western anatomical datasets. The N-ECA Software demonstrates that combining domain-specific image analysis with neutrosophic uncertainty modeling leads to more culturally appropriate and clinically accurate orthodontic planning tools.

2 Preliminaries

This section shows the definitions of single valued neutrosophic numbers (SVNNs). We let two SVNNs such as: $x_1 = T_{x_1}(y), I_{x_1}(y), F_{x_1}(y)$ and $x_2 = T_{x_2}(y), I_{x_2}(y), F_{x_2}(y)$

$$x_1^c = \left(F_{x_1}(y), 1 - I_{x_1}(y), T_{x_1}(y)\right) \tag{1}$$

$$x_1 \cup x_2 = \begin{pmatrix} \max\{T_{x_1}(y), T_{x_2}(y)\}, \\ \min\{I_{x_1}(y), I_{x_2}(y)\}, \\ \min\{F_{x_1}(y), F_{x_2}(y)\} \end{pmatrix} \tag{2}$$

$$x_1 \cap x_2 = \begin{pmatrix} \min\{T_{x_1}(y), T_{x_1}(y)\}, \\ \max\{I_{x_1}(y), I_{x_2}(y)\}, \\ \max\{F_{x_1}(y), F_{x_2}(y)\} \end{pmatrix} \tag{3}$$

$$x_1 + x_2 = \begin{pmatrix} T_{x_1}(y) + T_{x_2}(y) - T_{x_1}(y)T_{x_2}(y), \\ I_{x_1}(y)I_{x_2}(y), \\ F_{x_1}(y)F_{x_2}(y) \end{pmatrix} \tag{4}$$

$$x_1 x_2 = \begin{pmatrix} T_{x_1}(y)T_{x_2}(y), \\ I_{x_1}(y) + I_{x_2}(y) - I_{x_1}(y)I_{x_2}(y), \\ F_{x_1}(y) + F_{x_2}(y) - F_{x_1}(y)F_{x_2}(y) \end{pmatrix} \tag{5}$$

$$qx_1 = \begin{pmatrix} 1-\left(1-T_{x_1}(y)\right)^q, \\ \left(I_{x_1}(y)\right)^q, \\ \left(F_{x_1}(y)\right)^q \end{pmatrix} \tag{6}$$

$$x_1^q = \begin{pmatrix} \left(T_{x_1}(y)\right)^q, \\ 1-\left(1-I_{x_1}(y)\right)^q, \\ 1-\left(1-F_{x_1}(y)\right)^q \end{pmatrix} \tag{7}$$

3 Proposed Neutrosophic Method

The N-ECA Software employs neutrosophic logic to model uncertainties:

1. Data Collection: Lateral cephalometric X-rays (JPEG, 483 × 489 pixels).
2. Neutrosophic Landmark Detection: Identifies 13 landmarks [6]. For a pixel $p(x,y)$ with intensity g :

$$T(p) = \frac{g-g_{\min}}{g_{\max}-g_{\min}}, I(p) = 1-\frac{\left|g-g_{\text{avg}}\right|}{g_{\max}-g_{\min}}, F(p) = 1-T(p)$$

3. Neutrosophic Angle Calculation: Computes triangular angles (points P_1, P_2, P_3):

$$\cos(\theta) = \frac{(P_2-P_1)\cdot(P_3-P_1)}{|P_2-P_1||P_3-P_1|}, \theta_{\text{weighted}} = \theta \cdot \frac{T_1+T_2+T_3}{3}$$

For quadrangular angles (points P_1, P_2, P_3, P_4):

$$x = \frac{(x_1y_2-y_1x_2)(x_3-x_4)-(x_1-x_2)(x_3y_4-y_3x_4)}{(x_1-x_2)(y_3-y_4)-(y_1-y_2)(x_3-x_4)}$$

4. Classification: Classifies angles:

$$\text{Class} = \begin{cases} \text{Normal}, & \text{if } l \leq \theta \leq u \text{ and } T > 0.7, I < 0.3 \\ \text{Abnormal}, & \text{otherwise} \end{cases}$$

Implemented in Python with NumPy and OpenCV [11].

4 Proposed Neutrosophic Algorithm

The N-ECA algorithm:

1. Input: X-ray image and optional landmark coordinates.
2. Neutrosophic Preprocessing: Apply Equation 2.
3. Landmark Detection: Maximize T, minimize I.
4. Angle Calculation: Use Equations 3 and 3.

5. Classification: Apply Equation 4.
6. Output: Save results as CSV.

5 Evaluation Performance

N-ECA was evaluated using 50 X-rays, comparing SNA, SNB, and ANB angles [6].
Neutrosophic metrics:

- Neutrosophic Accuracy:

$$\text{Accuracy}_N = \frac{\sum T_i \cdot I(\text{N-ECA}_i = \text{Manual}_i)}{\sum T_i}$$

- Neutrosophic Standard Deviation:

$$S_N = \sqrt{\frac{\sum T_i (x_i - \mu_N)^2}{\sum T_i}}, \mu_N = \frac{\sum T_i x_i}{\sum T_i}$$

Results are in Table 1.
Kruskal-Wallis tests ($P > 0.05$) confirm no significant difference from manual analysis [12].

Table 1: Neutrosophic Performance Metrics

Angle	Method	Mean (°)	S_N	Accuracy (%)
SNA	Manual	82.3	0.5	-
	Downs	81.8	0.7	65
	N-ECA	82.5	0.4	88
SNB	Manual	80.1	0.6	-
	Downs	79.5	0.8	62
	N-ECA	80.2	0.5	85
ANB	Manual	2.2	0.4	-
	Downs	2.5	0.6	60
	N-ECA	2.3	0.3	90

Table 2: Comparison of Cephalometric Analysis Methods

Criterion	Manual	Downs	Dolphin/QuickCeph	N-ECA
Accuracy (%)	70-80	60-65	75-85	85-90
Efficiency (min/image)	30-60	10-15	5-10	2-5
Cost	Low	Moderate	\$5,000-\$10,000	Free
Egyptian Adaptability Uncertainty Handling	Moderate None	Low Limited	Low Moderate	High Advanced

Table 2 compares N-ECA with other methods [13; 14].

6 Conclusion

N-ECA pioneers neutrosophic logic in cephalometric analysis, addressing uncertainties with T, I, F modeling [5]. It outperforms Downs by 25-30% in accuracy [6]. Future work includes neutrosophic neural networks [9]. N-ECA revolutionizes cephalometric analysis with neutrosophic logic, achieving 85-90% accuracy and Egyptian adaptability [10].

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