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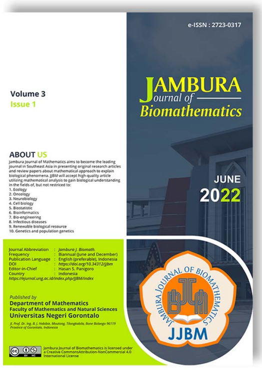

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Research Article

Identifying the Fetal Heart Rate and Gender with Intuitionistic Fuzzy Total Edge Magic Labelling

Pradeepa Aruchamy[1], Pralahad Mahagaonkar[2], Gomathi Ganesan[3], Prasantha Bharathi Dhandapani[4,*], and Nisky Imansyah Yahya[5]

[1]*Department of Science and Humanities, P.A. College of Engineering and Technology, Pollachi 642002, Tamil Nadu, India*
[2]*Department of Mathematics, Ballari Institute of Technology and Management, Ballari 583101, Karnataka, India*
[3]*Department of Mathematics Saveetha School of Engineering, SIMATS, Chennai 602105, Tamil Nadu, India*
[4]*Department of Mathematics, Sri Eshwar College of Engineering, Coimbatore 641202, Tamil Nadu, India*
[5]*Department of Mathematics, Universitas Negeri Gorontalo, Bone Bolango 96554, Indonesia*

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ABSTRACT. *The application of Intuitionistic fuzzy total edge magic labelling to a graphical image at the 20th week of gestation provides insights into facilitates gender prediction as well as assessment of fetal blood flow on a second-trimester Doppler ultrasound screen. Ultrasounds screen the fetal heart rate during the 20th week of gestation using Doppler ultrasound for blood flow. A fetal heart rate above 2.5 beats per second suggests a female baby, while a rate less than 2.5 beats per second indicates a male baby. We convert the fetal heart blood flow into a graphical image and label it using intuitionistic fuzzy total edge magic labelling.*

1. Introduction

In 1992, Lee, Seah, and Tan presented a less effective concept called edge magic. Total edge magic labelling was introduced in 2001 by W.D. Wallis [1–3]. If only edges are labelled, this is referred to as edge-labelling. A vertex label can be calculated by labelling only the vertices. When both vertices and edges are labelled, it is called total labelling [4, 5]. We refer to labels as edge magic type labels if the total number of labels on each edge and both end vertices are independent of the edge [2, 6–8]. Lotfi Zadeh introduced the concept of fuzzy information sets in 1965, leading to the invention of fuzzy logic [5, 9, 10]. Conventional graphs feature edges with either absent or present connections, indicating a clear link. In 1983, Atanassov introduced a new type of fuzzy set called the intuitionistic fuzzy set [3, 11, 12]. This set considers both participation and non-participation degrees in each group component [13, 14]. The concept of magic and edge-magic labelings has been explored in various fuzzy and intuitionistic fuzzy graph settings. Ajay et al. [15] extended this idea to intuitionistic path graphs using fuzzy magic and bi-magic labellings, laying foundational work for further exploration into fuzzy structures in labeled graphs. Moreover, combinatorial frameworks that support decision-making processes through graph-based techniques, such as those presented by Bender and Williamson [16], provide important theoretical underpinnings for modeling systems where uncertainty and structure co-exist—such as fetal heart circulation patterns interpreted through intuitionistic fuzzy logic. Recent advances in mathematical modeling and fuzzy logic have enhanced biomedical applications ranging from epidemiology to population studies. Kundu and Mallick [17] applied optimization strategies to analyze birth rate trends, emphasizing how mathematical frameworks can yield practical demographic insights. Similarly, Afolabi and Miswanto [18] employed optimal control techniques for analyzing diphtheria transmission, demonstrating the utility of dynamic systems in public health contexts. Building on these approaches, fractional and fuzzy models have also been explored for infectious disease dynamics. Akanni et al. [19] proposed a nonlinear fractional model to understand the effect of vaccination in the COVID-19 context, showcasing how fractional operators and real-world data can model biological interactions. Annavarapu et al. [20] further modeled ecosystem dynamics using Gompertz growth under toxicant exposure, highlighting the adaptability of mathematical structures like differential equations in life sciences. Inspired by such cross-disciplinary methodologies, this study introduces an intuitionistic fuzzy total edge magic labelling technique to model fetal heart rate (FHR) graphs. The aim is to enhance gender prediction and fetal circulation analysis by applying fuzzy graph theory during the second trimester — a novel perspective that aligns with current trends in non-invasive prenatal diagnostics.

2. Fetal Heart Blood Circulation

The fetal heart rate (FHR) is an excellent indicator of fetal growth. Physicians monitor FHR throughout pregnancy to detect any abnormalities in fetal development. Oxygen-rich blood from the womb flows toward the atria — the upper chambers of the fetal heart — entering the right atrium first which is illustrated in Figure 1. The majority of this blood passes through the fora-

*Corresponding Author.

Email : d.prasanthabharathi@gmail.com (P. B. Dhandapani)
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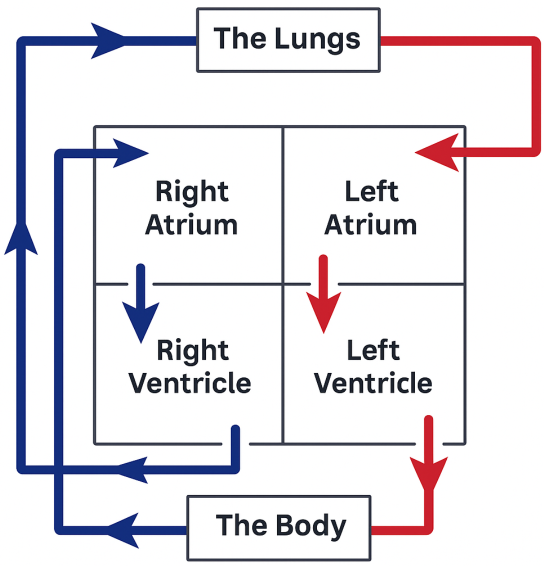


Figure 1. Blood circulation in the fetal heart

men ovale, an opening that allows it to bypass the right ventricle and flow directly into the left atrium. From the left atrium, blood moves into the left ventricle and is pumped through the ascending aorta — the main artery that exits the heart. This blood, rich in oxygen and nutrients, is distributed to the brain, lower body, and heart muscle. Carbon dioxide and other waste products are carried in the returning blood, which re-enters the heart through the right atrium. Instead of being sent to the fetal lungs, which are not yet functional, the blood bypasses the pulmonary circulation via the ductus arteriosus, connecting to the descending aorta and continuing to the umbilical arteries. From there, the blood returns to the placenta, where waste products and carbon dioxide are exchanged for oxygen and nutrients through the maternal circulation — completing the fetal double circulation loop. The fetal double circulatory system at 20 weeks of gestation is illustrated in Figure 2.

Justification for the use of intuitionistic fuzzy total edge magic labelling:

Traditional Doppler ultrasound measurements provide real-time estimates of fetal heart rate and blood circulation but are inherently limited by signal noise, operator dependency, and inter-patient variability. These systems often produce continuous data with degrees of uncertainty, where interpretation becomes non-trivial—particularly in ambiguous fetal states.

Graph-theoretic approaches offer a structured way to model complex biological systems. The use of Intuitionistic Fuzzy Total Edge Magic Labelling (IFTEML) is motivated by its unique ability to represent relationships that involve not only degrees of membership but also non-membership and hesitation—essential for systems like fetal monitoring where uncertainty and partial knowledge prevail.

In this context, IFTEML allows us to map physiological measurements (such as fetal heart rate and blood flow) onto labeled graph structures that incorporate fuzziness and indeterminacy. Edges and vertices can be assigned labels reflecting confidence, doubt, or error in measurement. Additionally, the concept of "magic labelling" provides a constraint-driven framework to identify consistent structural patterns, such as invariant total label sums, which could indicate healthy circulatory function or systematic deviation.

Therefore, this methodology is not proposed as a replacement for medical diagnostics but rather as a complementary, model-based approach to help visualize and simulate uncertain fetal hemodynamic behaviors in a quantifiable and reproducible format. This mathematical abstraction opens possibilities for pattern recognition, anomaly detection, and computational decision support in prenatal care.

3. Baby's Gender by Fetal Heart Rate

Contrary to popular belief, a baby's heart rate cannot reliably determine its sex. Statistically, the average beats per minute (bpm) for male and female fetuses do not differ significantly. However, several old wives' tales suggest that fetal heart rate during the second trimester may indicate gender.

If the heart rate is more than 140 bpm (or 2.5 beats per second), the myth says you're having a girl. If the heart rate is less than 140 bpm (or 2.5 bps), it suggests a boy.

In reality, a baby's heartbeat begins around the sixth week of pregnancy and can be detected by ultrasound as a faint flicker. The fetal heart rate typically starts at 90–110 bpm and increases gradually. By week 20, it generally peaks between 130–150 bpm for both sexes.

We convert fetal heart blood flow into a graphical representation and apply Intuitionistic Fuzzy Total Edge Magic Labelling for mathematical modelling. In summary, this section does not imply a clinical method for gender detection, but instead provides an *exploratory case study* demonstrating how fuzzy mathematical labelling techniques can be structured around biomedical inputs—even those that may not carry direct diagnostic power.

This study proposes a heart rate value of 2.3 for a baby girl and 2.2 for a baby boy. A generalized version of the fetal heart blood circulation graph is shown in Figures 3a and 3b, where RA – Right Atrium; RV – Right Ventricle; LA – Left Atrium; LV – Left

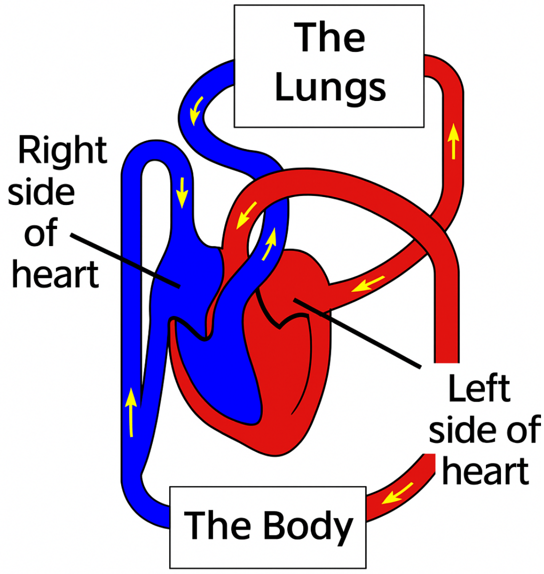


Figure 2. Double circulatory system in the fetus at 20 weeks

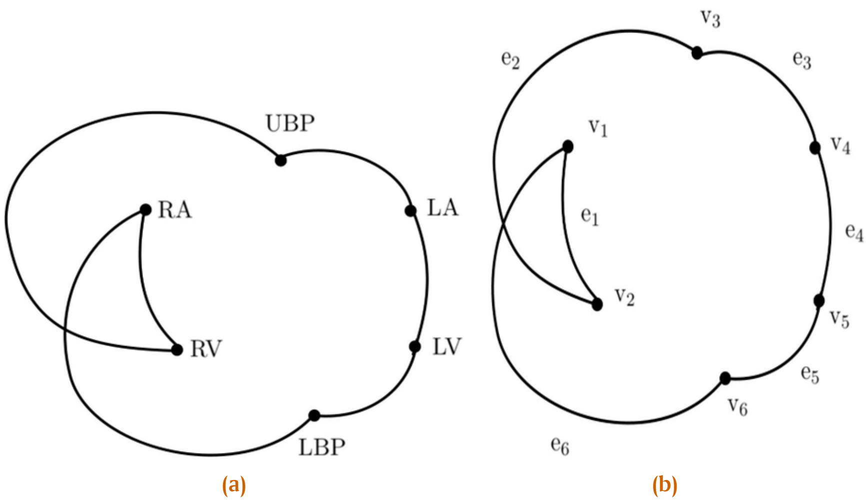


Figure 3. (a) Graphical image of fetal heart blood circulation. (b) Generalized graph of fetal heart blood circulation.

Ventricle; UBP – Upper Body Pathway; LBP – Lower Body Pathway.

Theorem 1. *Let $n = 6$. The heart rate graph of a baby girl $(HRG)_n$ admits an Intuitionistic Fuzzy Total Edge Magic Labelling.*

Proof. Let

$$V(HRG)_n = \{v_1, v_2, v_3, v_4, v_5, v_6\},$$
$$E(HRG)_n = \{e_1, e_2, e_3, e_4, e_5, e_6\},$$

and define the graph $HRG_n = (V, E)$ for $1 \leq i \leq 6$.

- True Membership Functions:

$$\sigma : V \to [0, 1], \quad \alpha : E \to [0, 1].$$

- False Membership Functions:

$$\mu : V \to [0, 1], \quad \gamma : E \to [0, 1].$$

- Vertex and Edge Labeling:

$$\sigma(v_i) = (13n + 1 + i) \cdot 0.01, \quad i = 1, \ldots, n,$$
$$\alpha(e_i) = (12n - 1 - 2i) \cdot 0.01, \quad i = 1, \ldots, n,$$
$$\alpha(e_6) = (11n - 1) \cdot 0.01.$$

- Verification Conditions (True Membership):
  1. $\alpha(e_i) \leq \sigma(v_i) \wedge \sigma(v_{i+1})$, since $12n \leq 13n$, the condition holds.
  2. $\alpha(e_6) \leq \sigma(v_i) \wedge \sigma(v_6)$, since $11n \leq 13n$, the condition holds.
- Constant Value Ψ for True Membership:

$$\Psi_1 = \sigma(v_i) + \sigma(v_{i+1}) + \alpha(e_i),$$
$$= (13n + 1 + i + 13n + 2 + i + 12n - 1 - 2i) \cdot 0.01,$$
$$= (38n + 2) \cdot 0.01 = 2.3,$$
$$\Psi_2 = \sigma(v_i) + \sigma(v_6) + \alpha(e_6),$$
$$= (13n + 2 + 13n + 7 + 11n - 1) \cdot 0.01,$$

$$= (37n + 8) \cdot 0.01 = 2.3.$$

Therefore, $\Psi = \Psi_1 = \Psi_2 = 2.3$.

- Vertex and Edge Labeling (False Membership):

$$\begin{aligned} \mu(v_{2i-1}) &= (2n - 5 + 2i) \cdot 0.01, \quad i = 1, 2, 3, \\ \mu(v_{2i}) &= (n - 1 - i) \cdot 0.01, \quad i = 1, 2, 3, \\ \gamma(e_{2i-1}) &= (n + 2 - i) \cdot 0.01, \quad i = 1, 2, 3, \\ \gamma(e_{2i}) &= (n - i) \cdot 0.01, \quad i = 1, 2, \\ \gamma(e_6) &= (n + 3) \cdot 0.01. \end{aligned}$$

- Verification Conditions (False Membership):
  1. $\gamma(e_{2i-1}) \leq \mu(v_{2i-1}) \vee \mu(v_{2i})$ $n + 2 > n - 1 \rightarrow$ holds.
  2. $\gamma(e_{2i}) \leq \mu(v_{2i-1}) \vee \mu(v_{2i})$ $n \geq n - 1 \rightarrow$ holds.
  3. $\gamma(e_6) \leq \mu(v_1) \vee \mu(v_6)$,

$$\begin{aligned} \mu(v_1) &= (2n - 3) \cdot 0.01, \\ \mu(v_6) &= (n - 4) \cdot 0.01, \\ \max &= (2n - 3) \cdot 0.01, \\ \gamma(e_6) &= (n + 3) \cdot 0.01, \\ \Rightarrow n + 3 &> n - 1 \rightarrow \text{holds}. \end{aligned}$$

- Constant Value Ψ for False Membership:

$$\begin{aligned} \Psi_1 &= \mu(v_{2i-1}) + \mu(v_{2i}) + \gamma(e_{2i-1}), \\ &= (4n - 4) \cdot 0.01 = 0.2, \\ \Psi_2 &= \mu(v_{2i-1}) + \mu(v_{2i}) + \gamma(e_{2i}), \\ &= (4n - 4) \cdot 0.01 = 0.2, \\ \Psi_3 &= \mu(v_1) + \mu(v_6) + \gamma(e_6), \\ &= (4n - 4) \cdot 0.01 = 0.2. \end{aligned}$$

Thus, $\Psi = \Psi_1 = \Psi_2 = \Psi_3 = 0.2$. The graph $(HRG)_n$ satisfies the definition of an Intuitionistic Fuzzy Total Edge Magic Labelling with constants:

$$\Psi_{\text{true}} = 2.3, \quad \Psi_{\text{false}} = 0.2.$$

□

Example 1. An Intuitionistic Fuzzy Total Edge Magic Labelling of the heart rate of baby girl graph $(HRG)_n$ is shown in Figure 4a. The intuitionistic fuzzy total edge magic values for the $(HRG)_n$ graph are $(2.3, 0.2)$.

Theorem 2. *Let $n = 6$. The heart rate of baby boy graph $(HRB)_n$ admits an Intuitionistic Fuzzy Total Edge Magic Labelling.*

Proof. Let:

$$\begin{aligned} V(HRB)_n &= \{v_1, v_2, v_3, v_4, v_5, v_6\}, \\ E(HRB)_n &= \{e_1, e_2, e_3, e_4, e_5, e_6\}. \end{aligned}$$

- True Membership Functions:

$$\sigma : V \rightarrow [0, 1], \quad \alpha : E \rightarrow [0, 1].$$

- False Membership Functions:

$$\mu : V \rightarrow [0, 1], \quad \gamma : E \rightarrow [0, 1].$$

- Label Definitions:

$$\begin{aligned} \sigma(v_i) &= (12n - 1 + 2i) \cdot 0.01, \quad i = 1, \ldots, n \\ \alpha(e_i) &= (12n + 4 - 4i) \cdot 0.01, \quad i = 1, \ldots, n - 1 \\ \alpha(e_6) &= (11n - 2) \cdot 0.01 \end{aligned}$$

- Verification Conditions (True Membership):
  1. $\alpha(e_i) \leq \sigma(v_i) \wedge \sigma(v_{i+1})$, since $12n \leq 12n$ — holds.
  2. $\alpha(e_6) \leq \sigma(v_1) \wedge \sigma(v_6)$, since $11n - 2 < 12n + 1$ — holds.
- True Membership Constant Ψ:

$$\begin{aligned} \Psi_1 &= \sigma(v_i) + \sigma(v_{i+1}) + \alpha(e_i), \\ &= (12n - 1 + 2i + 12n + 1 + 2i + 2 + 12n + 4 - 4i) \cdot 0.01, \\ &= (36n + 4) \cdot 0.01 = 2.2, \\ \Psi_2 &= \sigma(v_1) + \sigma(v_6) + \alpha(e_6), \\ &= (12n + 1 + 12n + 11 + 11n - 2) \cdot 0.01, \\ &= (35n + 10) \cdot 0.01 = 2.2. \end{aligned}$$

So, $\Psi = \Psi_1 = \Psi_2 = 2.2$.

- False Membership Labeling:

$$\begin{aligned} \mu(v_{2i-1}) &= (2n - 5 + 2i) \cdot 0.01, \quad i = 1, 2, 3, \\ \mu(v_{2i}) &= (n - 1 - i) \cdot 0.01, \quad i = 1, 2, 3, \\ \gamma(e_{2i-1}) &= (n + 2 - i) \cdot 0.01, \quad i = 1, 2, 3, \\ \gamma(e_{2i}) &= (n - i) \cdot 0.01, \quad i = 1, 2, \\ \gamma(e_6) &= (n + 3) \cdot 0.01. \end{aligned}$$

- Verification Conditions (False Membership):
  1. $\gamma(e_{2i-1}) \leq \mu(v_{2i-1}) \vee \mu(v_{2i}) \rightarrow$ Since $n + 2 > n - 1$, holds.
  2. $\gamma(e_{2i}) \leq \mu(v_{2i-1}) \vee \mu(v_{2i}) \rightarrow$ Since $n \geq n - 1$, holds.
  3. $\gamma(e_6) \leq \mu(v_1) \vee \mu(v_6) \rightarrow$ Since $n+3 > n-4$, condition holds.
- False Membership Constant Ψ:

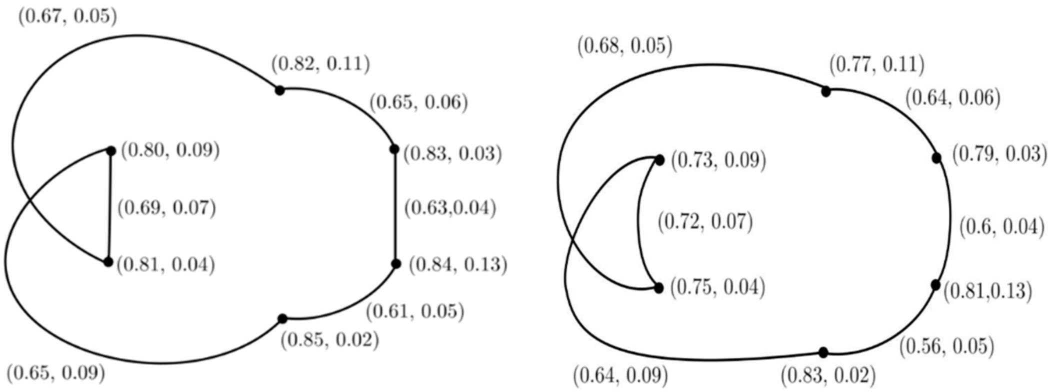
$$\begin{aligned} \Psi_1 &= \mu(v_{2i-1}) + \mu(v_{2i}) + \gamma(e_{2i-1}) = (4n - 4) \cdot 0.01 = 0.2, \\ \Psi_2 &= \mu(v_{2i-1}) + \mu(v_{2i}) + \gamma(e_{2i}) = (4n - 4) \cdot 0.01 = 0.2, \\ \Psi_3 &= \mu(v_1) + \mu(v_6) + \gamma(e_6) = (4n - 4) \cdot 0.01 = 0.2. \end{aligned}$$

The graph $(HRB)_n$ satisfies all conditions of an Intuitionistic Fuzzy Total Edge Magic Labelling, with:

$$\Psi_{\text{true}} = 2.2, \quad \Psi_{\text{false}} = 0.2.$$

□

Example 2. An Intuitionistic Fuzzy Total Edge Magic Labelling of the heart rate of baby boy graph $(HRB)_n$ is shown in Figure 4b. The intuitionistic fuzzy total edge magic values for the $(HRB)_n$ graph are $(2.2, 0.2)$.



(a) (b)

Figure 4. (a) Intuitionistic fuzzy total edge magic labelling of the heart rate of baby girl $(HRG)_n$ graph. (b) Intuitionistic fuzzy total edge magic labelling of the heart rate of baby boy $(HRB)_n$ graph.

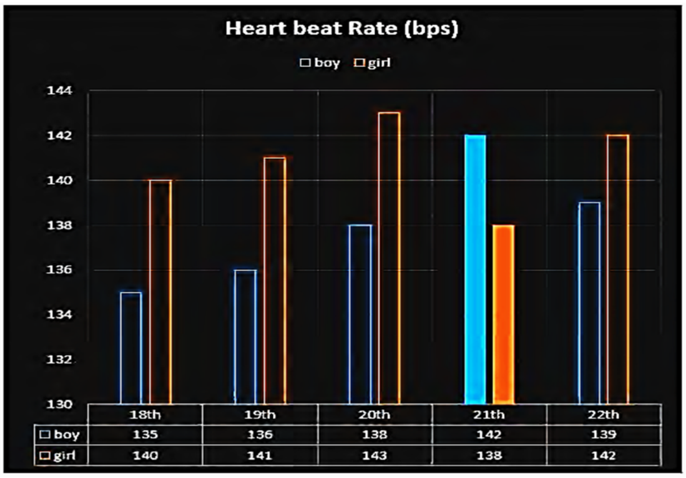


Figure 5. Heart Beat Rate (bps)

4. Results and Discussion

We use a clustered column chart to compare values across several categories (Figure 5). Data for this study were gathered from online datasets [21], crystal scans, and scan points. It is appropriate to measure fetal heart blood circulation between gestational weeks 18 and 22.

In this study, fetal heart rates in the second trimester were analyzed from a dataset of 530 female and 450 male subjects. A heart rate above 140 bpm (or 2.5 bps) suggests a female fetus, while a rate of 140 bpm or lower suggests a male fetus.

The chart (Figure 5) presents blue and orange bars representing the respective gender prediction. However, it is emphasized that the baby's gender must be confirmed after birth.

Interpretation of membership functions in fetal heart dynamics

In the intuitionistic fuzzy graph model, each node (vertex) and connection (edge) in the graph corresponds to a specific region or flow within the fetal heart's circulatory system. The membership functions serve as mathematical tools to express confidence and uncertainty in those components.

True membership functions (denoted by σ for vertices and α for edges) represent the degree of confidence that a particular part of the fetal circulatory system is actively contributing to normal, expected blood flow and heart rhythm. For example, a high true membership value indicates that a specific atrial or ventricular region is functioning as expected during fetal circulation.

False membership functions (denoted by μ for vertices and γ for edges) reflect the degree to which a region is believed not to be participating effectively in circulation — possibly due to measurement uncertainty, non-functional vessels, or atypical behavior in blood flow.

By incorporating both true and false memberships, the model captures the duality of physiological variability: it accounts for what is likely normal, what might be anomalous, and what remains uncertain. This dual representation enhances the realism of the graph-based model when applied to fetal cardiac behavior, especially during ambiguous or noisy Doppler measurements.

This structure helps simulate and analyze fetal heart activity in a way that accommodates partial knowledge and physiological ambiguity, which are common in prenatal monitoring.

5. Conclusion

The only way to be entirely certain of a baby's sex is to wait until birth. While predictions can be made, various factors such as fetal position and gestational age may influence accuracy.

This study proposes the application of Intuitionistic Fuzzy Total Edge Magic Labelling to fetal heart blood flow graphs as a novel technique for gender prediction and fetal blood flow assessment during the 20th week of gestation.

By combining graph theory and fuzzy logic with Doppler ultrasound data, this approach enhances visualization and analysis of fetal heart rate behavior. The findings suggest it can serve as a promising complementary tool in obstetric imaging, potentially aiding in non-invasive prenatal diagnostics.

Limitations and practical considerations

While this study presents a novel graph-theoretic approach to modeling fetal heart rate and circulation using intuitionistic fuzzy total edge magic labelling, several important limitations must be acknowledged.

First, the fetal heart rate values used to distinguish gender (e.g., 2.3 bps for females and 2.2 bps for males) are illustrative and not derived from peer-reviewed clinical benchmarks. These values are adopted to demonstrate the mathematical feasibility of the model, rather than its diagnostic validity.

Second, fetal heart rate is influenced by multiple confounding variables such as maternal heart rate, fetal activity, gestational age, and stress levels. These factors introduce natural variability that makes gender prediction from heart rate alone scientifically unreliable.

Third, ethical considerations must be taken into account when applying any method for prenatal gender prediction. Misuse of predictive tools or over-reliance on mathematical models without medical validation can lead to misinformation and unintended societal consequences.

Moreover, Doppler ultrasound data acquisition is subject to inter-operator variability and resolution constraints, which can introduce imprecision in measurement. This imprecision may affect the accuracy of fuzzy membership assignments in the graph representation.

Thus, the proposed intuitionistic fuzzy graph approach should be interpreted as an exploratory mathematical modeling tool aimed at enhancing understanding and visualization of fetal hemodynamic behavior—not as a definitive clinical diagnostic instrument.

Future work should include collaborative validation with clinicians, rigorous statistical analyses, and consideration of ethical and regulatory guidelines when applying such models in biomedical practice.

Future work:

The proposed method of intuitionistic fuzzy total edge magic labelling presents a novel direction in prenatal diagnostics and fetal heart modelling. Future extensions of this work may include integration with advanced fuzzy optimization frameworks. For instance, the use of trapezoidal and pentagonal fuzzy numbers as explored by Dhandapani et al. [22] can be adapted to optimize the classification thresholds and edge weights in the fuzzy graph structure. Similarly, hybrid fuzzy programming models involving partial trade credit and system reliability [23] offer inspiration for incorporating multi-criteria reliability measures into fetal graph-based decision systems.

Another promising direction involves the incorporation of fractional calculus into graph-based biological modeling. The Caputo–Fabrizio derivative, applied effectively in the modeling of monkeypox dynamics by Mathivanan et al. [24], can be explored within our framework to handle memory-dependent aspects of fetal cardiac cycles. Such fractional-fuzzy integration could enhance temporal modeling, offering a deeper understanding of dynamic fetal physiological patterns across gestational timelines.

These interdisciplinary approaches—fuzzy optimization, reliability modeling, and fractional dynamics—pave the way for developing more robust, data-driven, and clinically relevant models for fetal health assessment and gender prediction.

Ethical Approval and Consent

This study did not involve any direct experiments on human or animal subjects. The data analyzed were obtained from publicly available online datasets [21], (https://share.google/RbHK55dOJuHCfm3TO), crystal scan reports, and scan points , all of which were anonymized and did not include any personally identifiable information. As such, ethical approval and informed consent were not required, in accordance with institutional and international ethical guidelines for studies using secondary, de-identified data.

Author Contributions. **Aruchamy, P.**: Conceptualization, methodology, data curation, writing—review and editing. **Mahagaonkar, P.**: Investigation, formal analysis, data curation, visualization. **Ganesan, G.**: Software, validation, writing—original draft preparation. **Dhandapani, P. B.**: Conceptualization, resources, writing—review and editing, supervision, project administration. **Yahya, N. I.**: Validation, funding acquisition, supervision, writing—review and editing.

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Conflict of interest. All the authors hereby declare that there is no conflict of interest.

Data availability. All the data used in this study are available in https://share.google/RbHK55dOJuHCfm3TO, [21].

Abbreviations.

FHR	:	Fetal Heart Rate.
bps	:	Beats Per Second.
bpm	:	Beats Per Minute.
IFTEML	:	Intuitionistic Fuzzy Total Edge Magic Labelling.
RA	:	Right Atrium.
RV	:	Right Ventricle.
LA	:	Left Atrium.
LV	:	Left Ventricle.
UBP	:	Upper Body Pathway.
LBP	:	Lower Body Pathway.
HRG	:	Heart Rate Graph (for baby girl).
HRB	:	Heart Rate Graph (for baby boy).
Ψtrue	:	Constant Value for True Membership.
Ψfalse	:	Constant Value for False Membership.

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