Thesis Project Portfolio

Development of a Novel Fetal Heart Rate Monitor for Twin Pregnancies

(Technical Paper)

Differences in the Utilization of Doppler Ultrasound Contribute to Racial Disparities in Pregnancy Outcomes

(STS Paper)

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Technical Project Abstract

Current Doppler Ultrasound (DUS) technologies struggle to reliably monitor fetal heart rates (FHR) in multiple gestation pregnancies. Common clinical issues include overlapping signal registration when multiple fetal hearts lie within the same sample volume and duplicate FHR readings from the same fetus. This project introduces a novel, stationary monitoring system using a hydrogel-based phantom embedded with two speakers simulating fetal heartbeats at known frequencies (110, 142, 147, 172 BPM) and a circular array of five piezoelectric sensors.

The sensors collect acoustic signals processed using Fast Fourier Transforms (FFT) in MATLAB, isolating heartbeat-relevant frequencies (1.5–3.0 Hz or 90–180 BPM). A Gaussian Mixture Model (GMM) clusters the signals based on Time Difference of Arrival (TDOA) to differentiate coexisting heartbeats, which are then localized via trilateration. The system's FHR estimates are evaluated against known input frequencies. While the target average percent error across trials was <6%, performance varied: FHR estimates were most accurate when rates were either identical or significantly different (e.g., 1.86% error for 147–147 BPM), and least accurate near 110 BPM, especially for similar rates (e.g., 24.98% for 110–147 BPM). Localization accuracy also varied, with source A exhibiting greater spatial spread than source B.

Limitations include the fixed size of the hydrogel phantom and real-world signal noise. Future iterations may incorporate motion tracking, 3D modeling, or wearable sensor arrays for clinical translation. This system represents a promising step toward improving non-invasive, multi-fetus FHR monitoring and addressing key limitations of current DUS approaches.

STS Project Abstract

My STS research examines how inequitable access to and applications of Doppler ultrasound (DUS) technology contribute to racial disparities in pregnancy outcomes. Despite widespread use of fetal monitoring, Black and American Indian/Alaska Native (AIAN) women face pregnancy-related mortality rates more than three and two times higher than White women, respectively. Their infants also experience higher rates of mortality from conditions like fetal growth restriction and placental insufficiency—complications that DUS is designed to detect.

Through scientific journal reviews and an interview with Dr. Christopher Ennen, I found that disparities in Doppler ultrasound (DUS) use stem from systemic issues such as race-based interpretations of fetal growth standards and limited access to care—often due to demanding work schedules among women in minority groups. Studies indicate that Black, AIAN, and low-income women are more likely to be misdiagnosed or under-monitored, largely because of infrequent prenatal visits and diagnostic practices influenced by racial assumptions. Historical mistrust in medical institutions—rooted in past exploitation of marginalized communities—further reduces engagement with prenatal care technologies. This legacy continues to influence healthcare interactions today, reinforcing cycles of poor outcomes. Literature and clinician interviews highlight persistent systemic biases: from race-based growth charts to implicit bias in provider decision-making.

To address these disparities, policy must ensure equitable access to quality prenatal care, including DUS, in underserved areas. This requires increased infrastructure investment, standardized growth metrics that exclude race, and mandatory training for providers on implicit bias. Only through structural change and inclusive medical practices can DUS fulfill its potential as a tool for improving outcomes across all racial and socioeconomic groups.

Integrative Analysis

The technical and STS components of this research project are deeply intertwined, offering complementary lenses through which to assess the challenges and opportunities in fetal heart rate monitoring. While the technical project seeks to address physiological and engineering limitations of Doppler ultrasound in detecting multiple fetal heart rates, the STS project highlights how these technological limitations can have disproportionate consequences across racial and socioeconomic lines. Both projects acknowledge that accuracy in fetal monitoring is not merely a matter of engineering precision but also one of equitable access and unbiased application.

In developing a novel piezoelectric sensor array system, the technical project aspires to overcome core shortcomings of existing DUS setups—shortcomings that the STS project shows to be particularly consequential for communities of color. For instance, if existing DUS devices fail to distinguish between two fetal heartbeats, the consequences are not uniformly felt. As the STS analysis demonstrates, Black and AIAN women are more likely to be affected by misdiagnoses, under-monitoring, or equipment that does not account for the diversity of patient populations.

Moreover, the technical innovation offers a foundation for imagining more inclusive and accessible fetal monitoring tools. If future iterations prioritize affordability, usability, and cultural responsiveness, they can directly address some of the disparities outlined in the STS research. By pairing technological advancement with a critical awareness of social context, this project aims not only to improve clinical outcomes through better devices but also to ensure those improvements reach all populations equitably.