BabyBelt: A Low-Cost Wearable Uterine Contraction Monitoring Belt Using Velostat Sensors

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***Abstract*—This paper presents BabyBelt, a wearable uterine contraction monitoring system designed to improve maternal care access during late pregnancy, when early detection of labor anomalies like preterm labor is critical. Existing solutions including cardiotocography (CTG) and electrohysterography (EHG), are often expensive, immobile, or sensitive to placement and signal artifacts, limiting their utility in low-resource settings. BabyBelt integrates stretchable fabric with Velostat-based piezoresistive sensors and a passive Wheatstone bridge front-end to enable real-time uterine contraction pressure sensing via off-the-shelf microcontrollers. In simultaneous testing on the same pressure setup, the system achieved waveform correlation with clinical CTG of up to 0.9810 during pressure cycles, demonstrating comparable temporal accuracy using materials costing under 70 USD.**

***Index Terms*—Uterine contractions, wearable sensor, maternal monitoring, piezoresistive materials, Velostat.**

I. Introduction

Preterm labor—the onset of uterine contractions before 37 weeks of gestation—is a key contributor to neonatal complications, accounting for over 75% of perinatal mortality and more than 50% of long-term neurological impairments in children worldwide [1]. Globally, an estimated 15 million preterm labor cases occur annually, disproportionately affecting low- and middle-income countries [2].

Accurate and continuous monitoring of uterine contraction (UC) and fetal heart rate (FHR) is essential for early detection and timely intervention. Cardiotocography, the clinical standard, simultaneously tracks uterine contractions via external pressure transducers and FHR via Doppler ultrasound. While CTG is effective in hospital settings, it is immobile, costly, and requires skilled operation—creating substantial barriers to access in rural and under-resourced areas.

Recent research has explored low-cost, non-invasive alternatives. Allahem and Sampalli [3] proposed a wireless EHG-based system for automated contraction detection, while Hayes-Gill et al. [4] and Muszynski et al. [5] demonstrated the feasibility of EHG for contraction classification. However, EHG approaches are sensitive to electrode placement, require complex signal processing, and remain uncommon in low-resource settings. Pressure-based methods using PVDF films [6] or Velostat sensors [7] offer promising alternatives, but often lack baseline stability and compatibility with off-the-shelf microcontrollers.

In this work, we introduce **BabyBelt**—a wearable, low-cost system for non-invasive monitoring of uterine contractions during late pregnancy. The device integrates piezoresistive Velostat sensors within a stretchable abdominal belt to detect uterine wall strain associated with contractions. Each fabric pressure sensor of the belt is connected through a Wheatstone bridge which enables relative pressure signal acquisition using off-the-shelf microcontrollers. Preliminary evaluation on controlled pressure systems demonstrated that the system captures contraction waveforms with morphology comparable to clinical CTG. The platform offers a portable alternative for maternal monitoring in low-resource or home-based settings.

II. Design Consideration

Wearability and Safety: The belt is constructed from stretchable fabric to ensure ergonomic fit across varying abdominal anatomies. Embedded fabric-based sensors are encapsulated within a protective layer, minimizing skin irritation during prolonged wear. Modular attachment design facilitates rapid removal and reapplication, supporting hygienic reuse through sterilization.

Spatial Resolution of Uterine Activity: Unlike conventional CTG systems that provide only single-point pressure data, the belt integrates three piezoresistive sensors across the abdomen. This layout captures spatial distribution of uterine contractions, offering insights into contraction origin and propagation. The design supports both temporal and spatial tracking, which may aid early identification of abnormal contraction patterns.

Circuit Stability and Integration: Each sensor connects to a passive Wheatstone bridge circuit with tunable resistance for baseline stability. The setup ensures consistent signal quality under low-power operation and supports direct interfacing with standard microcontrollers. The circuit design emphasizes simplicity and robustness for use in variable clinical and field environments.

Cost and Usability: The system is designed with cost-efficiency in mind, using low-cost materials that keep unit production cost of materials under 70 USD, significantly lower than clinical CTG devices. Its lightweight, fabric-based form supports deployment in both clinical and unsupervised low-resource settings.

III. System Design

A. System Overview

An overview of the system design is summarized in Fig. 1

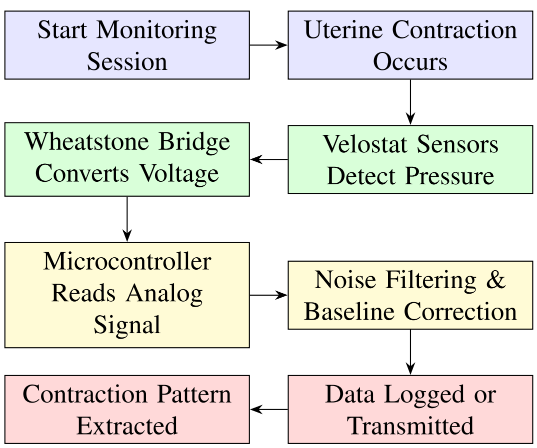

Fig. 1. Workflow of BabyBelt signal acquisition and processing

B. Hardware Design

1) Belt Design and Sensor Specifications: A pregnancy support belt is constructed with pressure-monitoring sensors embedded within the wearable structure. Three sensors are incorporated within the belt at different locations to capture the propagation of UC pressure. The fundus, located at the top center of the belt, is where the highest pressure is usually observed for which the top sensor is positioned there. The other two sensors are placed along the downward pressure gradient, spaced at intervals to effectively track the decrease in pressure. The principle of the sensor can be understood from Fig. 2. where the sensor is shown broken down into its components. The main sensing material is the piezoresistive Velostat sheet which changes resistance in response to applied change in pressure. The Velostat sheet is sandwiched between conductive layers from up and down laid out by conductive tape. The whole conduction pathway is then insulated by using neoprene as base up and down. Dimensions and design specifications are shown in Fig. 3

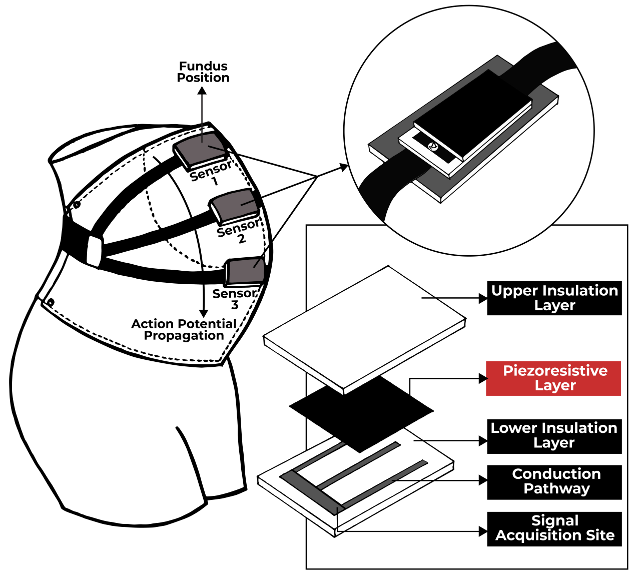

Fig. 2. Design of wearable belt with integrated pressure sensors.

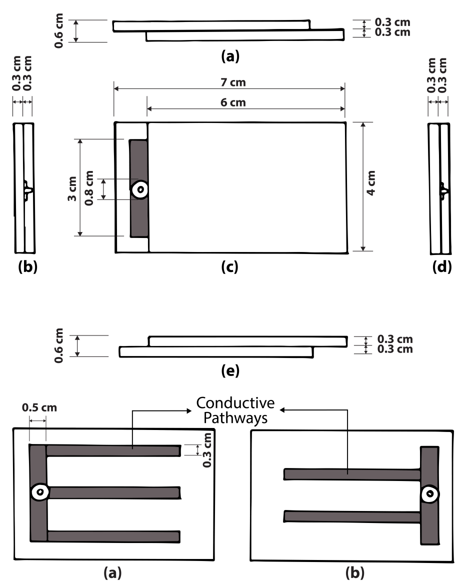

Fig. 3. *Top image:* (a) top view (b) left view (c) front view (d) right view (e) bottom view of the isolated Velostat sensor, *Bottom image:* Complementary conductive path built inside the sensor: (a) Lower insulation layer, (b) Upper insulation layer

2) Circuit Design: The circuit design [Fig. 4] is for a single sensor. To integrate three sensors, three identical circuits are required. The circuit operates such that when the sensor is contracted, elongated, or subjected to pressure, the voltage across it changes as Velostat is a piezoresistive material whose resistance varies with pressure. This alters one branch of the Wheatstone bridge, producing a measurable output voltage. When there is no pressure change, the load resistance produces a baseline voltage that may vary between patients. A potentiometer is used to fix this baseline voltage, which can

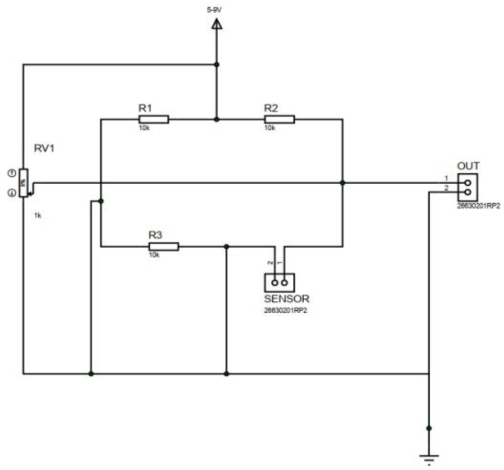

Fig. 4. Voltage acquisition circuit design for individual sensor.

be adjusted as needed. It also helps minimize undershooting of the sensor value due to recoil.

C. Calibration Method

The UC intensity range of standard CTG machines is 0 to 100 mmHg. Sensor calibration can be performed using a CTG machine as a reference. To this end, an inflating ball with uniform pressure distribution was used as the controlled pressure system in which 0 to 100 mmHg pressure was generated using an automated pump. By simultaneously acquiring both sensor voltage outputs and CTG UC pressure readings from the same setup, a voltage (V) to pressure (mmHg) mapping was obtained for each individual sensor [Fig. 5]. The 'Bionet Fetal Monitor FC-700' CTG machine was used in this study. The calibration equation from the mapping can be used during clinical data acquisition. These data also allow for a comparison between the sensor readings and CTG outputs, providing an initial estimation of the feasibility of using the sensors as an alternative to CTG.

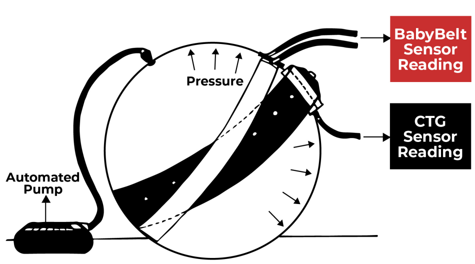

Fig. 5. Setup for calibration of sensors using standard CTG machine sensor as reference.

D. Prototype and Feasibility Analysis

The constructed prototype is shown in Fig. 6. The constructed sensors respond to pressure changes at resting positions; however, their suitability for UC monitoring requires further evaluation. For this initial feasibility analysis, we constructed a physical phantom designed to mimic a pregnant abdomen [Fig. 6]. A flexible PVC inflator was integrated into a mannequin mimicking a pregnant abdomen, enabling simulation of the pressure generated during contractions. Pressure within the PVC inflator was generated using an automated pump. The purpose of this phantom testing was to evaluate whether the sensors could detect internal pressure changes when attached externally to a structure similar in shape to a pregnant abdomen. For data acquisition, MATLAB R2025a was used with its Arduino Hardware Support Package.

Fig. 6. BabyBelt Prototype. *Top image:* **Left:** Front view, **Middle:** Back view, **Right:** Circuit integration. *Bottom image:* **Left:** Conduction pathway in sensor, **Middle:** Velostat sheets, **Right:** Individual Sensor.

IV. Results & Evaluation

A. Comparison with Standard Clinical Device

Three sensors are used in the wearable device, and all of the three sensor voltage readings were acquired simultaneously with the CTG machine on the same setup [Fig. 5]. The pressure is initially increased from the baseline up to 100 mmHg on the CTG, and then gradually decreased back to zero. The acquired readings are plotted in Fig. 7. The correlation values and calibration equations are listed in Tab. I.

TABLE I
Sensor correlation and calibration with corresponding CTG readings

Sensor No.	Pearson Correlation Coefficient with CTG	Calibration Method	Calibration Equation	R^2	RMSE	MAE
Sensor 1	0.9327	Cubic Polynomial Regression	P = -0.12 V^3 - 0.1579 V^2 + 1.119 V + 0.1095	0.8802	0.1132	0.0912
Sensor 2	0.9766		P = 0.05815 V^3 - 0.1919 V^2 + 0.821 V + 0.3042	0.9562	0.0708	0.0528
Sensor 3	0.9810		P = 0.1041 V^3 - 0.3644 V^2 + 0.9902 V + 0.2624	0.9696	0.0554	0.0330

B. Feasibility Analysis with Physical Phantom

Feasibility analysis with physical phantom was conducted using the method described in Section III-D. Inflating the PVC inflator with an automated pump increases the pressure,

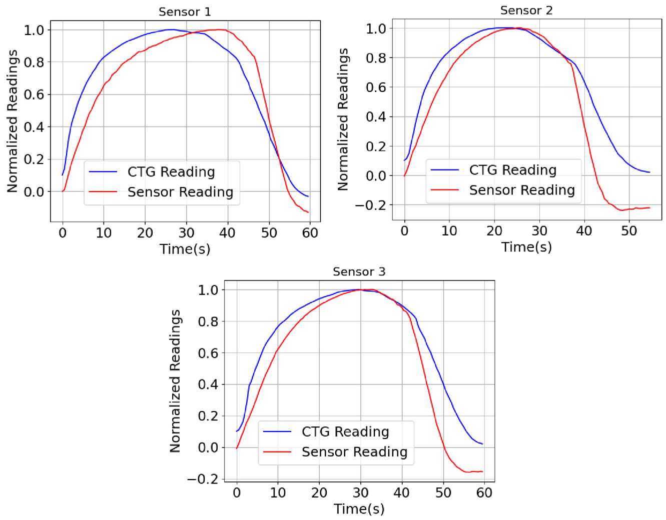

Fig. 7. Comparison of normalized CTG and individual sensor readings simultaneously taken on the same controlled pressure setup. [Fig.5]

while deflating it reduces the pressure. The resulting sensor responses are shown in Fig. 8.

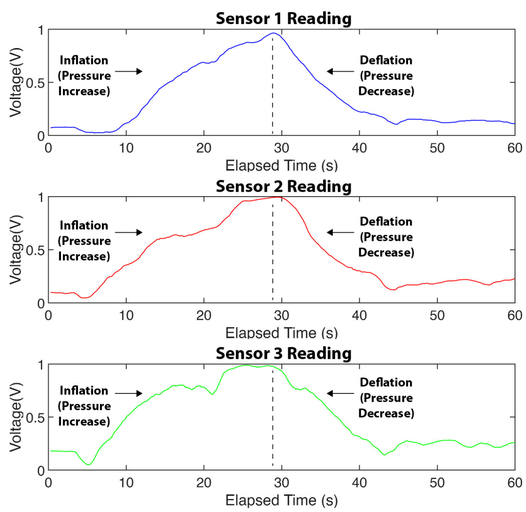

Fig. 8. Sensor response on physical maternal abdomen phantom.

C. Volunteer Data Acquisition Findings

Sensor readings were acquired from a pregnant volunteer with proper consent during contractions for feasibility check. In real-life use, the data showed more movement noise. High-frequency muscle breathing patterns were also detected but effectively reduced using a moving average filter. The spatial pressure propagation is evident, with a decreasing gradient downwards. [Fig. 9]

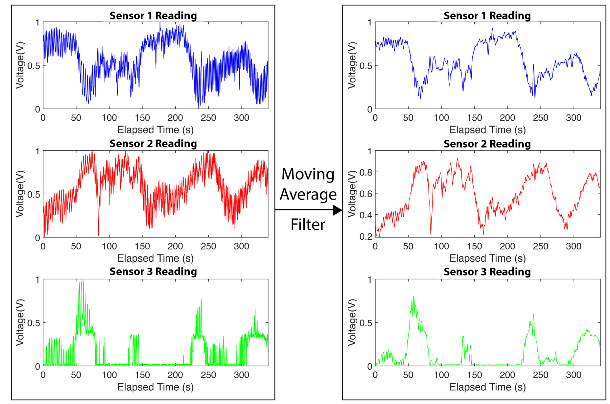

Fig. 9. Sensor response on pregnant volunteer undergoing contraction.

V. Conclusion

This work presents a wearable, low-cost belt-based system for non-invasive monitoring of uterine contractions using piezoresistive Velostat sensors. The device demonstrated feasibility through controlled pressure tests and evaluations with pregnant volunteers, capturing contraction waveforms with morphology and temporal resolution comparable to those of CTG. The analog front-end, built around a passive Wheatstone bridge, ensured stable relative pressure detection while maintaining a compact and low-power architecture. Further evaluation across varied abdominal anatomies and gestational conditions is needed to characterize signal robustness under physiological variability. While the system reliably captured contraction peaks, baseline drift and motion sensitivity remain areas for refinement. In particular, pressure readings are influenced by belt tension and respiration, warranting enhancements in mechanical design and signal conditioning. Broader deployment studies could support integration into unsupervised monitoring workflows, offering an accessible alternative for maternal care in low-resource settings. These findings support the potential of soft, fabric-integrated sensors for expanding access to maternal monitoring, particularly in low-resource settings.

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