Han-Chang Wu, Chao-Hung Lin, Shuenn-Tsong Young, and Te-Son Kuo

Monitoring Long-Term UTERINE CONTRACTIONS

In this article, we discuss an apparatus that can monitor long-term uterine contractions and detect the onset of preterm labor that the mother may not even be aware of. This apparatus includes a portable monitor for data storage. Built-in memory enables the monitor to record up to two days of signals. Filtering and algorithms for detecting abnormal symptoms are programmed in a microcontroller. It includes a friendly user interface for setting thresholds. We also present a novel pressure sensor that can transfer the pressure signal of uterine contractions into frequency variations via a ferrite core and a self-oscillating circuit. The pressure sensor has the advantages of simplicity, stability, and reliability, as well as low power consumption and low cost, which is highly desirable for portable devices in long-term ambulatory monitoring applications.

Early diagnosis is necessary to prevent preterm labor that results in the birth of an infant between 20 and 37 weeks of gestation. Preterm labor is the cause of high perinatal morbidity and mortality. It results in huge expenditures for premature infant care [10]. Statistical data shows that the rate of preterm birth is between 8% and 10% and costs over $3 billion each year in the United States alone [13]. The risk of preterm birth could be reduced significantly with prompt treatment of tocolytic medication. However, it is difficult and confusing for the mother-to-be to sense the contractions of preterm labor. Claudia et al. [1] showed that only 17% of uterine contractions are accurately perceived. Contractions occur normally throughout pregnancy, however, they can occur at any time, and they are usually painless. The pattern of contractions in a preterm labor may occur every 15 minutes or less. Each contraction may last from 40 s to 120 s. The uterus tightens and becomes hard during a uterine contraction.

Uterine contractions can be monitored by both direct and indirect methods. Contractions increase the hydrostatic pressure of the amniotic fluid within the pregnant uterus. A catheter can directly measure intrauterine pressure. This method is usually employed in clinical fetal monitoring; however, applying a catheter is an invasive act and cannot be considered for ambulatory monitoring or preterm labor detection. Examination of the cervix and self-palpating of uterine contractions can also be used to make a diagnosis [5].

An indirect, or noninvasive, method for measuring uterine contractions is the use of tocodynamometers, which are pressure sensors. This is a noninvasive method in which an instrument is placed against the abdomen to detect uterine electromyography (EMG); these are electric signals generated by the muscles. The tocodynamometer can sense the tension of the abdomen walls when a uterine contraction occurs and, hence, can measure uterine contractions in a noninvasive and safe way. Nevertheless, it has serious limitations in quantitative measurements of contractions. The output is only qualitative with proportion to the pressure of contractions. The pressure of the abdomen may also change as the body moves, so that baseline pressure is not static and can change frequently.

In recent studies, uterine EMG has also enabled another methodology to detect uterine contractions [4], [7]. Contractions can be determined according to frequency variations of the uterine EMG signals. Several analysis methods for time-frequency have been proposed to extract the frequency variation. Although the signals are electrically acquired like electrocardiography (ECG), the detecting algorithms are still undergoing research and need huge computational power. This method is, therefore, not suitable for implementing ambulatory uterine contraction monitors.

Ambulatory monitoring of uterine contractions at home, or at work, is essential to avoid preterm labor. In the mid 1980s, a new methodology, known as home uterine activity monitoring (HUAM), was proposed to automatically detect uterine contractions [8]. These contractions were monitored by an external tocodynamometer strapped on the maternal upper abdomen. The uterine contractions were then recorded and transmitted to practitioners (by telephones and modems)

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for advice on treatment. The practitioner evaluated the received magnitude and frequency of the uterine contractions. If the contraction frequency exceeded a threshold, the woman was asked to take the HUAM one more time or to see a doctor immediately. Many clinical studies have been conducted, and it was concluded that the HUAM, or ambulatory method, provided positive results in detecting and preventing preterm labor [2], [3], [8], [12] for high-risk women.

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The system for ambulatory uterine contraction monitoring is usually comprised of a tocodynamometer and a monitor for data storage and retrieval. Although several systems have been designed for uterine activity monitoring, they have limitations for long-term monitoring because of their weight and power consumption. The tocodynamometer, which senses the pressure variation of the uterus, also plays an important role. Conventional pressure sensors use strain gauges, linear variable differential transformers (LVDT), or piezoelectric materials [6], [11]. These kinds of sensors are expensive, complicated, and require system calibration. They also have complex interfacing and operational circuits.

System Block Diagram

The proposed system for long-term uterine contraction monitoring includes a pressure sensor and a portable monitor. As illustrated in Fig.1, the pressure sensor converts uterine activities into frequency variations from 1 to 2 MHz. The portable monitor is a microcontroller-based embedded system. We chose the 89c52 microcontroller because of its intelligence and functionality. A CMOS counter serves as a frequency down-converter for scaling down the frequency variation from 50 to 100 KHz. There are two timers in an 89c52 microcontroller. One is the system timer, which interrupts every 10 ms. The other is a 16-bit counter. The value of the counter is acquired, and then it refreshes as the system timer starts. A low-power static random access memory (SRAM) of 128 K bytes provides long-term data storage. The system can store about two days of uterine contraction signals. Three keypads are used to provide several system functions: manual setting of threshold and baseline values, checking system conditions, and transmitting data to personal computers via an embedded universal asynchronous receiver and transmitter (UART) module. Digital output ports control a 122*32 dots liquid crystal display (LCD) for better user interface. The LCD can display real-time uterine contractions. The power management module regulates a 9 V alkaline battery into stable 5 V and –5 V power signals. It also provides retention power to the SRAM when the system switch is off. For long-term monitoring, the power signal of the uterine contraction pressure sensor can be controlled by the microcontroller through the power management circuit.

Design of the Uterine Contraction Pressure Sensor

The structure of the pressure sensor is illustrated in Fig. 2. Uterine contractions are transduced to vertical displacements of a ferrite core equipped with four springs. A self-oscillating Colpitts circuit then converts the displacements into frequency variations. As the schematic illustrates in Fig. 3, the frequency of the oscillator is determined by a transistor, Q_1, two capacitors, C_1 and C_2, and a coil, L_1, from the following expression:

$$f = \frac{1}{2\sqrt{L_1\left(\frac{C_1 C_2}{C_1 + C_2}\right)}}. \tag{1}$$

The displacement of the ferrite core determines the inductance of the coil and thus alternates the frequency of the Colpitts oscillator. A buffer circuit, Q_2, isolates the Colpitts oscillator from unwanted capacitance from connectors and cables. The left side of the schematic shows the interfacing

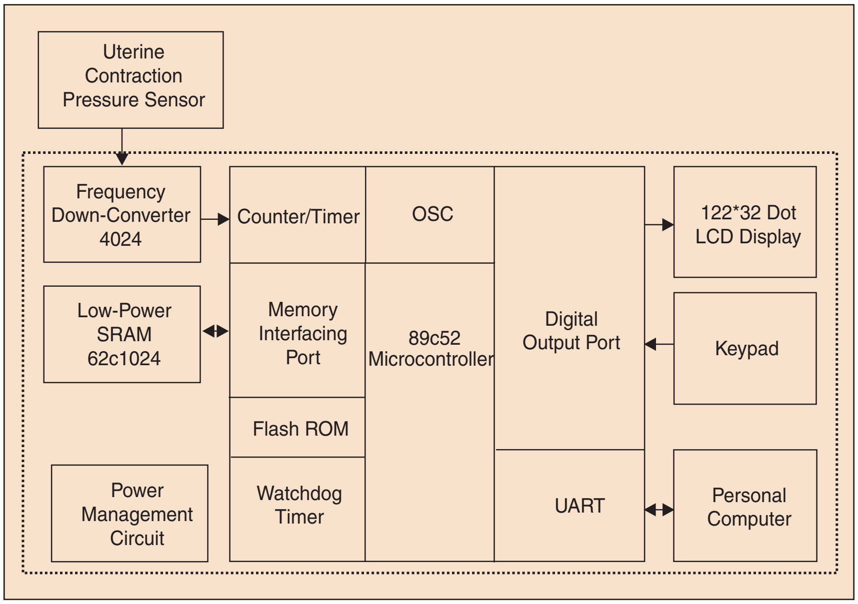

Fig. 1. Block diagram of the monitor hardware.

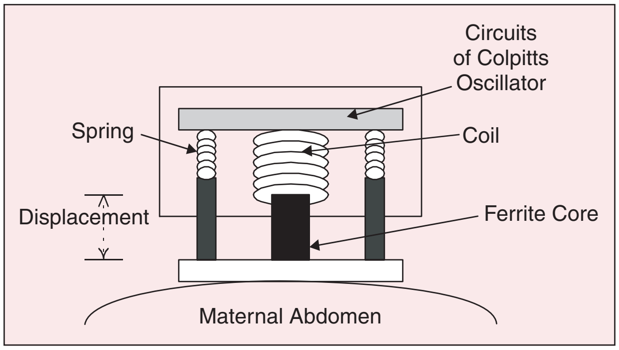

Fig. 2. Sensor structure.

circuit designed in the monitor. The output signal of the oscillator is linked to the monitor and transistor Q_3, and shapes the oscillating signals to TTL levels. The output frequency is counted by a microcontroller. A switch circuit, Q_4, controls the power of the sensor, so that the sensor is activated when the microcontroller needs to acquire uterine contractions.

System Software Design

The software flow chart is illustrated in Fig. 4. When monitoring the pressure variations, the sensor may acquire uterine contractions as well as respiration signals. Because the frequency spectrum of respiration signals ranges from 0.06 to 0.3 Hz, the frequency value is sampled every second. The microcontroller resolves the frequencies to 100 units for further processing. The conversion from displacement to frequency output is nonlinear in (1), as shown in Fig. 5. The microcontroller then maps the nonlinear frequencies to linear outputs. To eliminate unwanted respiration signals, we apply a finite inpulse response (FIR) low-pass filter of 0.05 Hz cut-off frequency to the linear outputs. Baseline value is set manually by the keypads with gesture changes. Then the filtered signals are deduced by the baseline value. The microcontroller stores the signals into the SRAM.

The uterine contraction monitor determines abnormality by comparing the signals to a threshold, which is also set manually, according to the doctor's instructions. There are three abnormality symptoms designed in the system:

- The abnormality is continuous and prolonged for more than two hours;
- The abnormality accumulates more than 30 minutes every hour, and continues for several hours; and

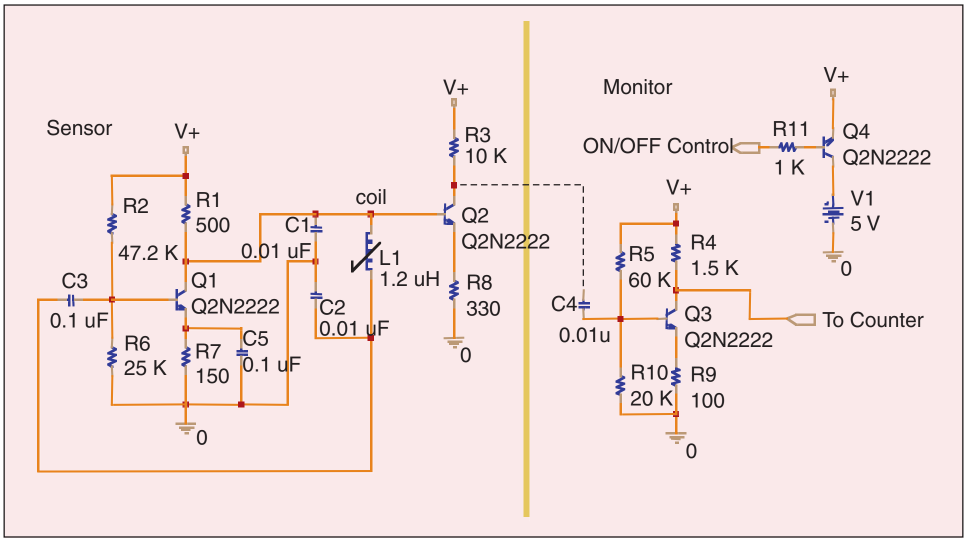

Fig. 3. Schematic of the sensor.

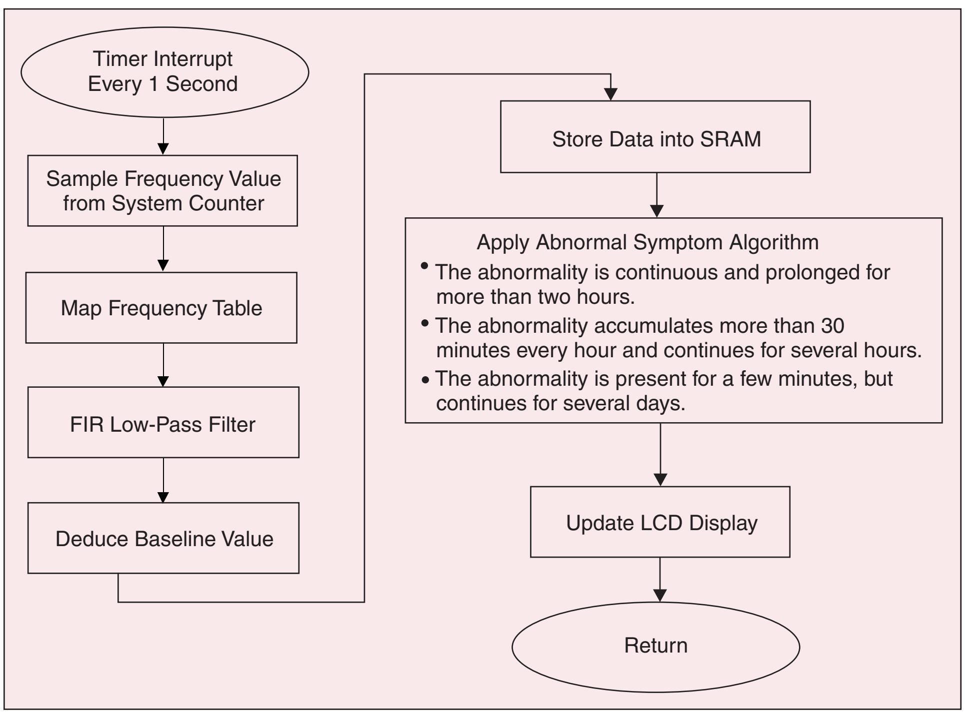

Fig. 4. Program flow chart of the monitor.

- The abnormality is present for a few minutes, but continues for several days.

The uterine contraction monitor determines abnormality by comparing the signals to a threshold, which is also set manually, according to the doctor's instructions.

Results and Discussions

Table 1 summarizes the specifications of the uterine contraction monitoring system. Fig. 6 illustrates the outline of the system. The monitor is slightly thicker than a cigarette box and weighs 205 g. When the microcontroller is in the active mode, its power consumption is 30 mA. Because it is activated every second with about 200 ms duration, the average power consumption of the monitor is 6 mA. The pressure sensor can operate on a voltage supply that varies from 3 to 10 V. The oscillator becomes stable within 500 μs after turning on the power. With a 1 Hz sampling rate, the pressure sensor needs to be turned once per second for 10 ms. Therefore, the average total power consumption is thus about 6.1 mA, and a single 9 V alkaline battery is sufficient to support 24-hour monitoring. The stored data can be retrieved by RS-232 cable in 19200 bps to a personal computer for further evaluation.

Compared to existing systems, this pressure sensor for detecting uterine contractions is smaller; it is also lighter and, therefore, reduces the maternal load for the person wearing the sensor. The sensor is highly stable and has reliable output in variable environments; it is simple to use, and it is low cost. Furthermore, the algorithms for automatically detecting the presence of abnormal symptoms are also programmed in the monitor. This capability can alert the pregnant woman to any possible problems, so that she can get to the hospital for more detailed medical care. It also lessens the burden on the hospital, and keeps the pregnant woman living and working under normal conditions for as long as possible.

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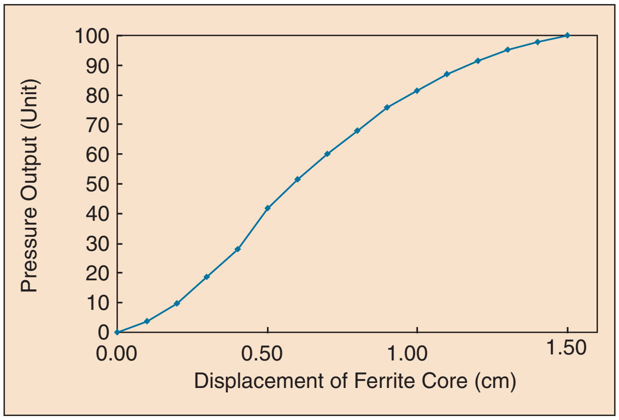

Fig. 5. The relation of the displacement and the output pressure units.

Table 1. System Specifications.	
Portable Monitor	
Monitor Size	90 mm*80 mm*44 mm
Monitor Weight	205 g (with a 9 V battery)
Power Consumption	30 mA @ active mode
Pressure Sensor	
Size	70 mm*40 mm*33 mm
Weight	34 g
Power Consumption	8.2 mA @ 5 V input
Stable Time	<500 μs
Frequency Variation	<0.1%
Output Range	0~100 Units

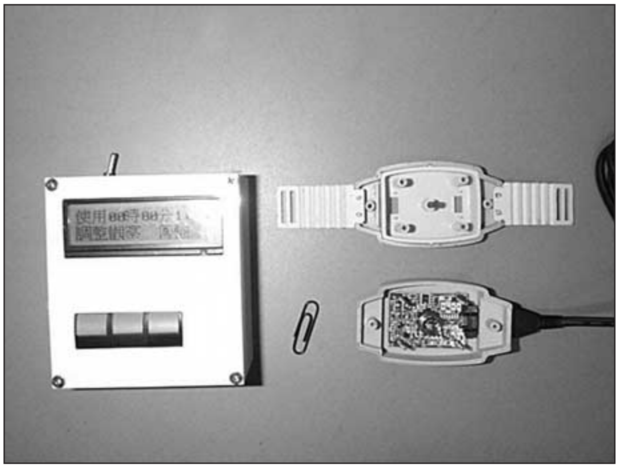

Fig. 6. Photograph of the sensor and the monitor. (Used with permission by Han-Chang Wu.)

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Han-Chang Wu was born in Taipei, Taiwan, in 1974. He received his B.S. degree in 1996 and is working toward a Ph.D. degree from the department of electrical engineering, National Taiwan University. His research interests are biomedical signal processing and medical instrumentation.

Chao-Hung Lin was born in Taipei, Taiwan, in 1976. He received his B.S. degree in 1998, and is working toward a Ph.D. degree from the department of electrical engineering, National Taiwan University. His research interests are medical instrumentation and information technology.

Shuenn-Tsong Young was born in Taiwan, the Republic of China, in 1959. He received his M.S. and Ph.D. degrees from the department of electrical engineering, National Taiwan University, in 1989. Since 1997, he has been a full professor at the Institute of Biomedical Engineering, National Yang-Ming University. His research interests are medical instrumentation, medical imaging, and medical electronics.

Te-Son Kuo was born in Taiwan, Republic of China, in 1938. He received a B.S. degree in electrical engineering from National Taiwan University, Taipei, Taiwan, in 1960, and the M.S. and Ph.D. degrees in electrical engineering from Georgia Institute of Technology, Atlanta, Georgia, in 1967 and 1970, respectively. His fields of interest are computer-aided design, control systems, and biomedical engineering.