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System and Method for Measuring Fetal Head Position with IMU Sensor and Ultrasound Probe

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Abstract
Fetal head position is one of the important indicators during labor. Abnormal fetal head position is likely to affect the normal processof childbirth, which may lead to increased risks and costs of childbirth.The monitoring of fetal head position is indispensable for the assessment of the process of labor. The risk of childbirth can be reduced by the timely detection of abnormal fetal head position and the initiation of intervention measures. Aiming at the above problems, this paper proposes a new method for fetal head position measurement by combining both attitude detection and ultrasonic imaging. The proposed method can accurately measure the fetal head position, provide a reliable method for assisting doctors to monitor the process of labor, reduce the threshold of experience needed by doctors to evaluate the fetal head position, and help doctors to timely detect abnormalities in labor and initiate scientific intervention means.
Keywords: *Fetal head position, IMU;Ultrasound probe, attitude detection*

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I. INTRODUCTION

Since 1985, the WHO believes that the cesarean section rate to maintain between 10% and 15% is the most ideal[1]. Because caesarean sections are risky, may affect the health of the mother and fetus, and may reduce the chances of a mother's later pregnancy.The delivery way needs to be reasonably evaluated based on the parameters during delivery, the parameters during delivery have a guiding role for doctors in implementing the necessary interventions[2-4]. Therefore, during labor, accurate delivery parameters need to be obtained for labor assessment.

At present, fetal head position and fetal head location are widely used as important parameters to evaluate the delivery process. Abnormal fetal head position is one of the important causes of dystocia, especially the Occiput Posterior(OP). At the beginning of labor, the probability of the OP is 30%[5, 6], and it is more likely to happen among primiparas[7, 8]. If the fetal position remains OP for a long time, the probability of instrument delivery will be increased[9]. By detecting the fetal head position and making intervention measures, the normal delivery process can be ensured, and the ultrasonic probe is the appropriate detection equipment[10, 11]. Ultrasonic equipment is reliable in detecting the fetal head position, but an experienced operator is needed[7, 12]. In clinic, usually by transvaginal digital examination to detect fetal position. It is found that during the first stage of labor, fetal head position assessed by transvaginal digital examination and intrapatrum sonography have an average recognized percentile of 42%[5, 10, 13-17]. Thus, the use of ultrasonic equipment to detect the fetal position depends on the operator's experience. The operator may be required to have both spatial imagination and experience with ultrasonic equipment.

In this paper, a method that can assist the doctor to complete the measurement of fetal position is proposed, which no longer requires the operator to carry out spatial conversion, and reduces the difficulty of usingultrasonic equipment to detect fetal position.Therefore, this paper will designed a system and propose a method for measuring fetal head position with IMU sensor and ultrasound probe. To assist midwives in the effective monitoring and assessment of fetal head position, promote natural delivery and reduce the occurrence of dystocia.

II. SYSTEM DESIGN AND METHOD

2.1 SYSTEM DESIGN

2.1.1 Overa design

The design of the system is base on STM32L432KBU6 as the main control chip. The voerall composition of the system is as shown in Figure 1. And the Print Circuit Board (PCB) in 3D view is as shown in Figure 2.

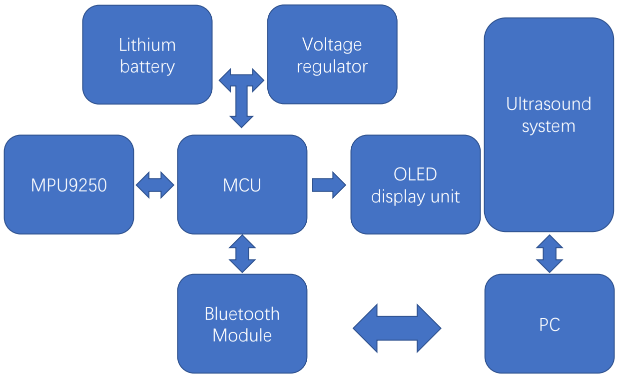

Figure 1 system composition block diagram

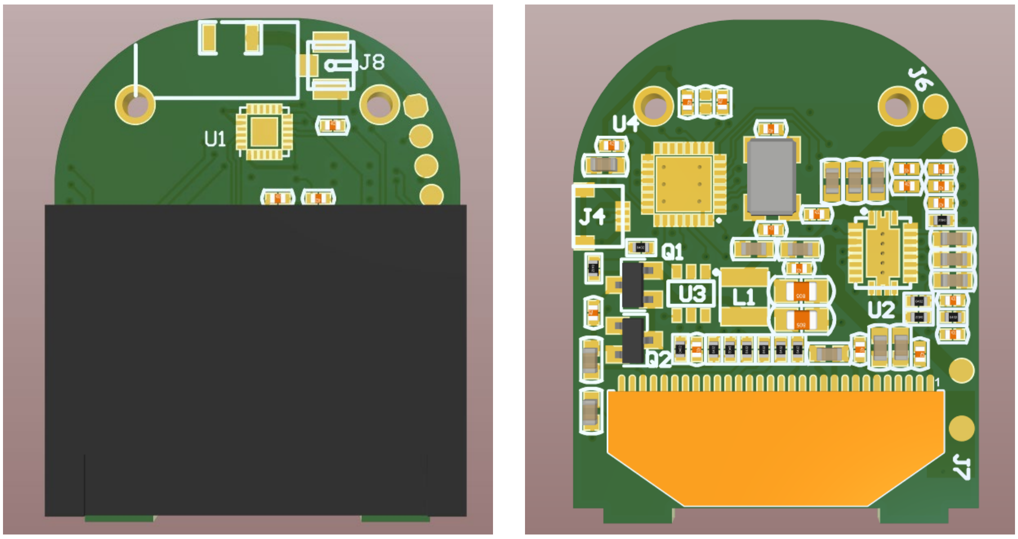

Figure 2 Print Circuit Board in 3D view

2.1.2 Master chip unit

STM32L432KBU6 with low power and high performance is chosen as the processor.The STM32L432KBU6 is the ultra-low-power microcontroller based on the highperformance ARM Cortex -M4 32-bit RISC core operating at a frequency of up to 80 MHz. The Cortex-M4 core features a Floating point unit (FPU) single precision which supports all ARM single-precision data-processing instructions and data types. It also implements a full set of DSP instructions and a memory protection unit (MPU) which enhances application security.

2.1.3 IMU sensor

This design chooses to use MPU9250 as attitude detection sensor. The MPU9250 is internally integrated with a 3-axis gyroscope, a 3-axis accelerometer and a 3-axis magnetometer, and the output is a 16-bit digital quantity.Data can be exchanged between integrated circuit bus (IIC) interface and single chip microcomputer, and the transmission rate can reach 400 kHz /s. The angular velocity measurement of gyroscope has good dynamic response.The static measurement precision of accelerometer is high.The measuring range of magnetic induction intensity of magnetometer is ±4800 T, which can be used for auxiliary measurement of yaw Angle. The MPU9250 comes with a DMP: Digital Motion Processor (DMP) hardware acceleration engine that integrates nine-axis sensor data and outputs a complete nine-axis fusion algorithm to the application side.With DMP, we can use the MPL (Motion Process Library) provided by InvenSense to realize attitude calculation conveniently, which reduces the load of Motion processing operation on the operating system and greatly reduces the difficulty of development.

2.1.4 Power supply module

The voltage regulator Tps79330 is used on the system.Reduce the 7.2v battery voltage to 3.0v and supply it to MCU, sensor, etc

2.1.5 OLED display screen

In this paper, the 0.96 inch OLED screen is used as the human-machine interaction interface, which can more intuitively observe the attitude data and debugging data of the system.The OLED screen has a resolution of 128*64, and USES SSD1306 as the driver chip.

2.1.6 Bluetooth module

In the early stage of design and debugging, the hc-05 bluetooth module is used to transmit data to the computer to save and display.Because the sensor needs to be calibrated before use, the use of wireless transmission can make the calibration operation more flexible.

2.2 Method

2.2.1 Fetal head position assessment method via IMU sensor and ultrasound probe

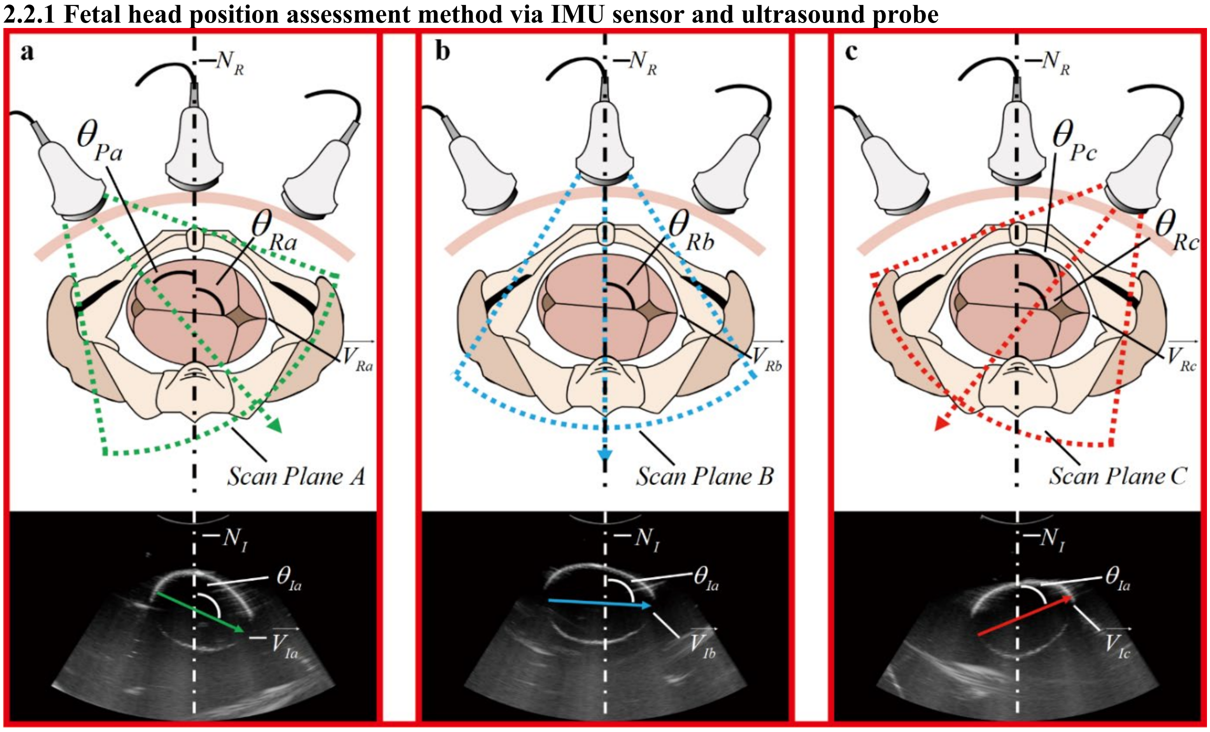

Figure 3 Description of method for measuring the fetal head position via ultrasonic prode and IMU sensor. (a)Place the probe at the left side of the abdomen will get Scan Plane A. (b)Place the probe at the midle the abdomen to get referenced attitude. (c)Place the probe at the right side of the abdomen will get Scan Plane C.

The probe attached with IMU sensor was placed in the middle position of the abdomen and scanned perpendicular to the abdomen plane, which was recorded as Scan Plane B. The fetal head is assumed to be in the right occipitoposterior, consistent with the schematic diagram of the model shown in the Figure 3.b. Let the perpendicular line N_R divide the pelvis. The vector $\overrightarrow{V_R}$ indicating direction of the occipital frontal diameter(OFD), Indicating the direction from the occipital position of the fetal head to the frontal position. θ_R is defined as the Angle at which the vector $\overrightarrow{V_R}$ rotates clockwise relative to the line N_R ($0° \leq \theta_R < 360°$). Therefore, clinically defined fetal head position can be converted into Table 1. If the probe scan at position B can obtain clearly visible and clinically available ultrasound images, the obtained ultrasound images will be similar to US Image in Figure 3.b. The difference of acoustic impedance between fetal head and amniotic fluid is large, so that strong ultrasonic echo reflection occurs at the interface, the ultrasonic image presents a bright ellipsoid boundary contour. We consider the major axis of the highlighted ellipse to be the occipital frontal diameter(OFD), and let the vector indicating the occipital frontal diameter in the US image be $\overrightarrow{V_I}$. The Angle between $\overrightarrow{V_I}$ and the centerline N_I in the image is θ_I ($0° \leq \theta_I < 360°$), which can be calculated by the endpoint coordinates of the the major axis of the ellipse. When scanning at position

B, we have scan plane B. Obviously, the angle of the fetal head $\theta_R = \theta_I$. However, there is no guarantee that scaning at position B will yield clinically clear and usable images. The operator will scan at the left side of the abdomen (as show in Figure 3.a) or the right side (as show inFigure 3.c) to obtain a clear view of the fetal head outline and landmarks to determine the direction of the occipital frontal diameter (OFD). During the actual scan, the probe position and angle are adjusted to obtain a clear image. While move the probe to position A for cross-sectional scanning, The attitude of the probe changes $\Delta\theta_p = \theta_{Pa}$ relative to the previous position. Assuming that the attitude of the probe in position B is the reference attitude, the angle θ_{Pa} $(-180° \le \theta_{Pa} < 180°)$ from position B to position A can be measured by the IMU MEMS sensor attached on the probe. Since these are cross-sectional scans of the abdomen, θ_P can be approximated by the rotation of the probe around an axis. It can be understood as the angle of rotation of the probe from position B to position A. When the probe is in position C, $\Delta\theta_p = \theta_{Pc}$. θ_R is restricted to 0-360 °, so that the calculated θ_R corresponds to table 1. We use the following formula to calculate the fetal head angle:

$$\theta_R = \theta_I \pm \Delta\theta_P \pm 360^{\circ} (0° \le \theta_R < 360°)$$

Table 1 Angle θ_R relative to Clinically defined fetal orientation

Occipitoposterior(OP)	$337.5° < \theta_R < 360°$，$0° \le \theta_R \le 22.5°$
Right occipitoposterior(ROP)	$22.5° < \theta_R \le 67.5°$
Right occipitotransverse(ROT)	$67.5° < \theta_R \le 112.5°$
Right occipitoanterior(ROA)	$112.5° < \theta_R \le 157.5°$
Occipitoanterior(OA)	$157.5° < \theta_R \le 202.5°$
Left occipitoanterior(LOA)	$202.5° < \theta_R \le 247.5°$
Left occipitotransverse(LOT)	$247.5° < \theta_R \le 292.5°$
Left occipitoposterior(LOP)	$292.5° < \theta_R \le 337.5°$

III. EXPERIMENTAL RESULT

Using the fetal head phantomand pelvis phantomshown in theFigure 4, the experimental apparatus was designed to verify the reliability of the designed system and the proposed method.

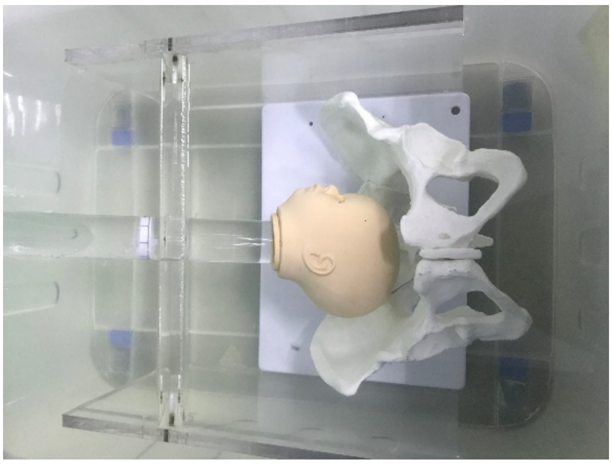

Figure 4model of fetal head and pelvis

Forty experiments were conducted, and each section was measured five times and averaged.The measurement results and the angle marked on the model are analyzed by Bland–Altmanmethod, and the results are shown in theFigure 5.The average error of the measurement results is within the proper range, and the proposed method is feasible and effective.

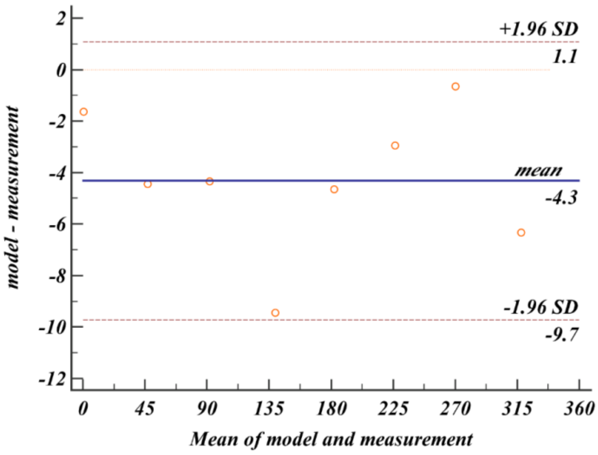

Figure 5 Bland–Altman plot for comparison of fetal head anglemarked on the model with those measured vie imu sensor and ultrasound probe.

IV. CONCLUSION

This paper presents a method to measure the fetal position based on ultrasonic probe and IMU. IMU was added to the probe for attitude detection and a feasible fetal head position measurement scheme was designed.The experimental results show that the measurement method is reliable and can provide accurate evaluation parameters for the delivery process.

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