Combining Automated Image Analysis with Obstetric Sweeps for Prenatal Ultrasound Imaging in Developing Countries

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Abstract. Ultrasound imaging can be used to detect maternal risk factors, but it remains out of reach for most pregnant women in developing countries because there is a severe shortage of well-trained sonographers. In this paper we show the potential of combining the obstetric sweep protocol (OSP) with image analysis to automatically obtain information about the fetus. The OSP can be taught to any health care worker without any prior knowledge of ultrasound within a day, obviating the need for a well-trained sonographer to acquire the ultrasound images. The OSP was acquired from 317 pregnant women using a low-cost ultrasound device in St. Luke's Hospital in Wolisso, Ethiopia. A deep learning network was used to automatically detect the fetal head in the OSP data. The fetal head detection was used to detect twins, determine fetal presentation and estimate gestational age without the need of a well-trained sonographer.

Keywords: Prenatal ultrasound · Obstetric sweep protocol · Image analysis

1 Introduction

Worldwide, 99% of all maternal deaths occur in developing countries [1]. Ultrasound imaging can be used to detect risk factors, but requires a well-trained sonographer to obtain and interpret the images. Unfortunately, there is a severe shortage of well-trained sonographers in developing countries [2]. Therefore, ultrasound imaging remains our of reach for most pregnant women in developing countries. In 2011, DeStigter *et al.* introduced the obstetric sweep protocol (OSP) [3]. The OSP consists of six predefined free-hand ultrasound sweeps over

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the abdomen of the pregnant women, which are visualized in Fig. 1. The main advantage of the OSP is that it can be taught to any health care worker without any prior knowledge of ultrasound within a day, making wide application of this protocol in developing countries feasible. In the paper of DeStiger *et al.* the OSP data was sent via the Internet to radiologists, who interpreted the images and sent back the result to the midwife. In this paper we combine the OSP with image analysis, to automatically detect the fetal head. We show that it is feasible to estimate the gestational age, detect the fetal presentation and detect twin pregnancies with the automated head detection using the OSP data. This would mean that there is no need for a well-trained sonographer to both acquire and interpret the ultrasound images. There is also no need for a technical infrastructure which includes an Internet connection and therefore this represents a next step towards making prenatal ultrasound feasible and accessible to pregnant women in developing countries.

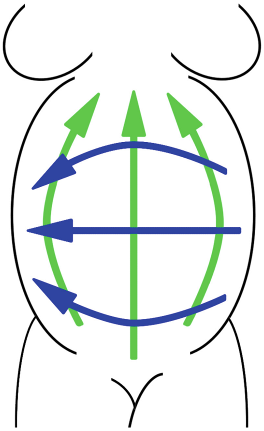

Fig. 1. Visualization of the six free-hand sweeps of the obstetric sweep protocol. The three transverse sweeps are obtained by moving the ultrasound transducer from the pubic bone to the breast bone (green arrows). The three longitudinal sweeps are obtained by moving the ultrasound transducer from the left side of the patient to the right side of the patient (blue arrows). (Color figure online)

2 Methods

2.1 Data

An experienced gynecologist (second author of this paper) acquired both the OSP together with the standard imaging plane, for measuring the reference head circumference (HC), from 317 pregnant women using the MicrUs Ext-1H (Telemed Ultrasound Medical Systems, Lithuania). The MicrUs EXT-1H is a low-cost ultrasound device which was connected to a mid-range Windows based notebook via USB 3.0. The combination of a low-cost probe and a cheap notebook makes this an affordable and portable solution for obtaining prenatal ultrasound images in developing countries. The data was acquired in St. Luke's Catholic Hospital and College of Nursing and Midwifery in Wolisso, Ethiopia. Acquisition of this data was approved by the local ethics committee.

2.2 Fetal Head Detection

A previously designed deep learning network was used to classify each frame within the OSP data whether the fetal head was present. The deep learning network uses three labels: present, partially present and not present. Present means that the fetal head falls within the field of view (FOV) of the frame. Partially present means that the fetal head falls partially outside of the FOV of the frame, which makes an accurate head circumference measurement impossible. Not present means that the fetal head is not present in the frame. The deep learning network was trained on a separate dataset acquired from 183 pregnant women using the SonoAce R3 (Samsung Medison, Korea). This dataset only contained the three transverse sweeps of the OSP as explained in previous work [4]. The network architecture was inspired by the VGG-Net of Simonyan and Zisserman [5]. The number of deep learning network parameters was minimized, to only 843 thousand parameters, to make deployment on low-cost hardware possible.

2.3 Estimation of Fetal Head Circumference

The OSP data will most likely not contain the standard plane that is normally used to obtain the fetal HC. But in previous work we have shown that it is possible to manually estimate the HC with the use of the OSP data [4]. In this work we used a previously designed CAD system to automatically estimate the HC in a random subset of thirty fetuses (excluding twins), with a GA ranging from 23 until 40 weeks. The CAD system measures the HC in all frames that were classified as containing the fetal head by the deep learning network. The 75th percentile of all measured HCs was taken as the final HC estimation, since the HC obtained in the standard plane is one of the largest circumferences one can measure from a fetal head. The automatically estimated HC was compared to the reference HC, which was obtained by the experience sonographer in the standard plane. The curve of Hadlock [6] was used to determine the GA from the HC.

2.4 Automated Frame Separation

Since the six free-hand sweeps of the OSP were made in a predefined order, it was possible to automatically separate the six sweeps to be able to determine fetal presentation and detect twin pregnancies. The six sweeps were automatically separated using the mean pixel intensity per frame. A threshold was used to determine for which frames the transducer touches the abdomen of the pregnant woman. The threshold is defined by Eq. 1, where μ is the mean frame intensity for all frames of one patient and σ is the standard deviation of the mean intensity per frame.

$$Threshold = \mu - \sigma \tag{1}$$

The largest six connected components were selected as the six sweeps. Smaller connected components were assigned to the nearest sweep. Figure 2 shows the result of the automated frame separation for one patient. This simple procedure turned out to be sufficient for correctly separating the sweeps in 306 of the 317 ultrasound series at our disposal.

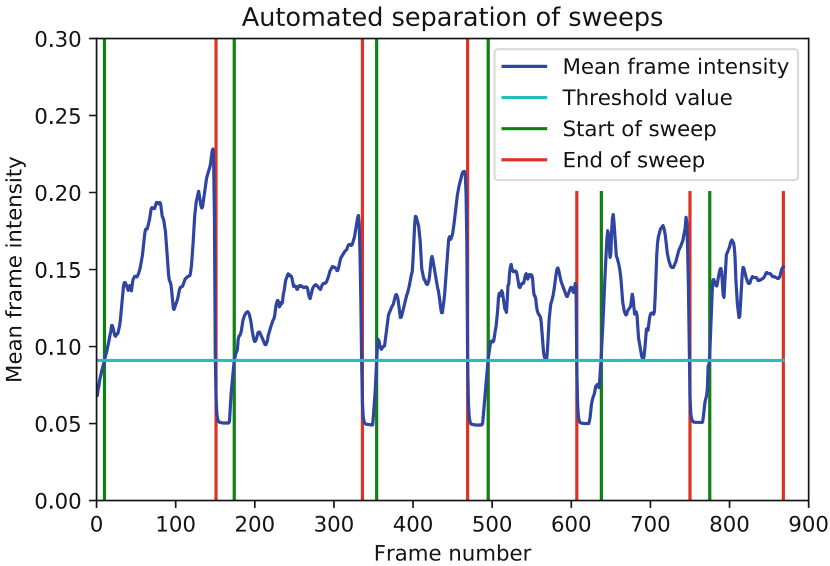

Fig. 2. Visualization of the automated separation of the six sweeps for one patient.

3 Results

Figures 3, 4, and 5 show the result of the fetal head detection by the deep learning network for a fetus in cephalic presentation, a fetus in breech presentation and a twin pregnancy, respectively. The color bar shows the three labels of the network classification. All frames classified as fetal head present (shown in red) were used to automatically estimate the HC. Table 1 shows the mean difference (MD), mean absolute deviation (MAD) and 1.96 standard deviations (SD), between the automatically estimated HC, obtained from the OSP data, and the reference HC, obtained by the experienced gynecologist from the standard imaging plane for the thirty randomly selected cases. The GA could not be computed for six fetuses, because the HC of these fetuses were larger than the largest reported

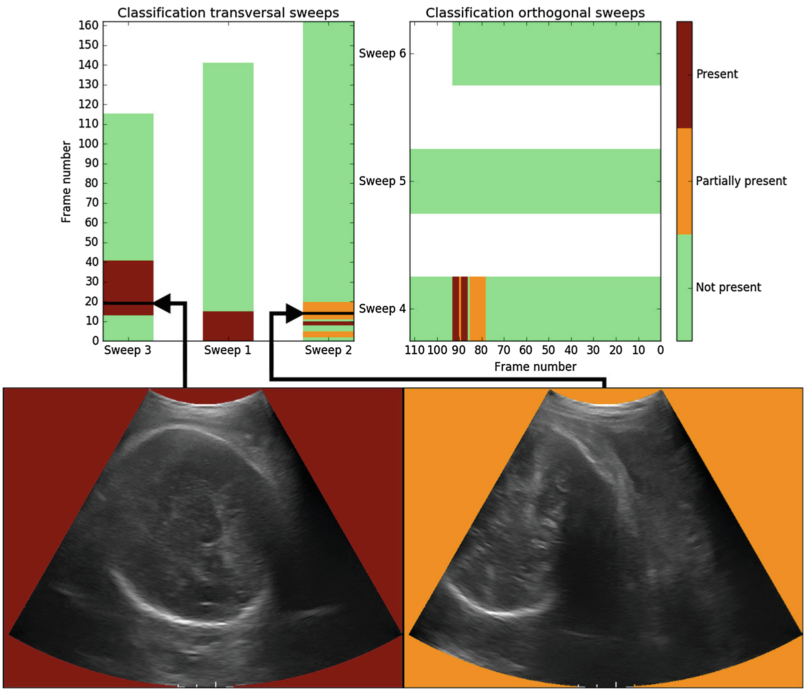

Fig. 3. Visualization of the head detection output by the deep learning network of a fetus in cephalic presentation. The bottom two images show two example frames from the sweep data. The left frame was classified as fetal head present. The right frame was classified as fetal head partially present.

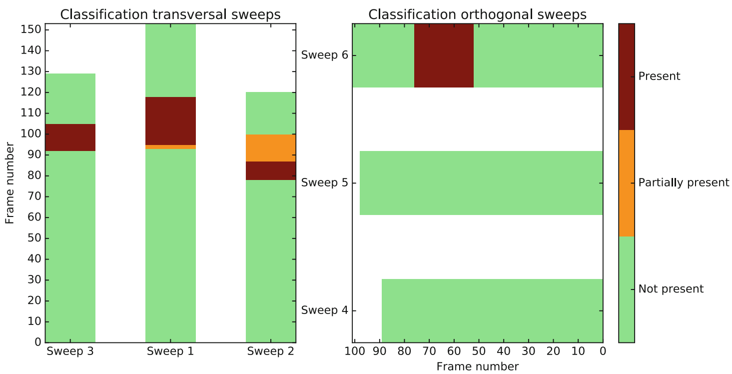

Fig. 4. Visualization of the head detection output by the deep learning network of a fetus in breech presentation.

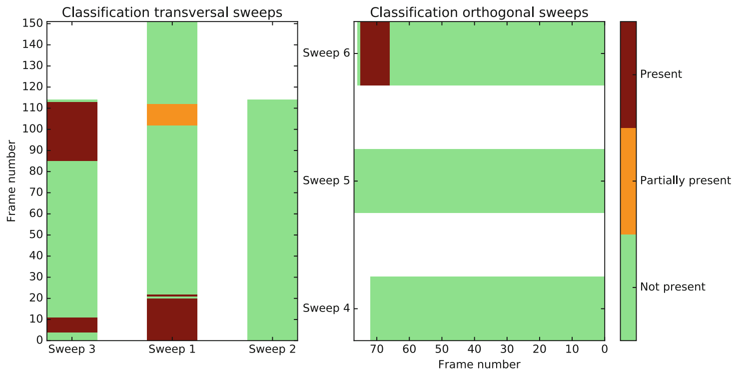

Fig. 5. Visualization of the head detection output by the deep learning network of a twin pregnancy.

Table 1. Mean difference (MD), mean absolute difference (MAD) and 1.96 standard deviations (SD) between the automatic estimation and the manual reference.

	HC (mm)	HC (%)	GA (days)
MD	-6.6^{a}	-2.1^{a}	-3.6^{b}
MAD	11.3^{a}	3.7^{a}	9.4^{b}
1.96 SD	23.9^{a}	7.4^{a}	16.8^{b}

$^{a}N = 30$, $^{b}N = 24$

value of the curve of Hadlock. This rather high number is associated with the fact that most pregnant women visit the hospital in Ethiopia at a late stage in their pregnancy.

4 Discussion

In this paper we show a system that can automatically extract information about the fetus with the use of the OSP. The OSP can be taught to any health care worker without any prior knowledge of ultrasound within a day. All data for this study were acquired with a low-cost ultrasound device in Ethiopia and the design of the automated image analysis system makes deployment on low-cost hardware possible.

Fetal head detection: The results show that it is possible to automatically detect the fetal head in the OSP frames with the use of the deep learning network. Separation between the head present and partially present was performed to make automated estimation of the HC possible, since the HC can only be measured when the fetal head falls within the FOV of the frame.

Estimation of fetal head circumference: Table 1 shows the MD, MAD and SD between the reference, obtained in the standard plane, and the automated estimation, obtained from the OSP data, for both the HC and GA for thirty randomly selected cases. The literature shows different inter-observer variabilities for the HC measurements. Napolitano *et al.* reported in 2016 an inter-observer variability with a 95% limits of agreement of 4.9% [7], which is only one and a half times smaller compared to our 1.96 SD of 7.4%. Sarris *et al.* reported in 2012 an inter-observer variability with a 1.96 SD of 12.1 mm [8], which is twice as small compared to our 1.96 SD of 23.9 mm, but Sarris *et al.* reported in 2013 a 97th percentile SD of 24.2 mm [9], which very similar to our reported 1.96 SD of 23.9 mm. This comparison shows that the automated system estimates the HC close to the reported inter-observer variability in literature and does this without obtaining the standard imaging plane. The resulting MAD in GA of 9.4 days is very promising for automatic estimation of the GA using the OSP. Future research has to show how this GA estimation can be used in practice.

Determine fetal presentation: Figures 3 and 4 shows that it could be feasible to determine the fetal presentation from the OSP data, making it possible to plan a caesarean section in case of breech presentation. At this moment, the deep learning network only detects the fetal head. Retrain the network to detect both the fetal head and the fetal abdomen could make this method more robust. To the authors knowledge, only Maraci *et al.* have tried to automatically determine fetal presentation with a single free-hand sweep, but this single sweep missed either the fetal head or abdomen in 31% of the 129 test cases [10]. This problem could be solved with the six sweeps of the OSP data, but future work is required to show performance of our approach on the full dataset.

Detecting twin pregnancies: Figure 5 shows the deep learning classification result for a twin pregnancy. Two fetal heads can be discriminated in sweep 1 and 3 of the OSP, so it could be feasible to automatically detect twin pregnancies with the OSP. Future research is required to determine if all 35 twins present in the study data can be detected using the OSP data.

5 Conclusion

This paper shows the feasibility of using prenatal ultrasound in developing countries by combining the obstetric sweep protocol (OSP) with automated image analysis. The OSP can be taught to any health care worker without any prior knowledge of ultrasound within a day, so there is no need for a well-trained sonographer to obtain the ultrasound images. We show that it is feasible to automatically detect basic information about the fetus like: estimation of the gestational age, determine fetal presentation and detect twin pregnancies.

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