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TERRAIN: FETAL GROWTH TELEHEALTH SYSTEM BASED ON 2D FETAL HEAD IMAGE USING RANDOMIZED HOUGH TRANSFORM

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Abstract

Intrauterine growth restriction (IUGR) is one of many fetal abnormalities, which has high contribution on maternal mortality rate and perinatal mortality rate in Indonesia. Apparently, IUGR impact can be reduced if only the symptoms are detected earlier and the correct treatment is applied. However, fetal growth detection and monitoring process in Indonesia is obstructed because the number of physicians is very limited and ultrasonography (USG) devices are expensive. Moreover, both the physicians and USG devices are only available in big cities. To answer those problems, this research proposed an intelligent system that can provide fetal growth telemonitoring in rural areas. This system consists of three components: portable USG device, mobile application which is developed using Android operating system, and server application which is developed using Django. The main feature of this system is automatic fetal head parameter detection and its ability to operate in the limited internet access environment. In this system, automatic fetal head parameter detection uses RHT method to approximate fetal head's ellipse shape. Experiment result shows that RHT detection ability with $\Delta_{ellipse}$ average of 79.564 and running time average of 0.373 second.

Keywords: *Intrauterine growth restriction, ultrasonography, telemonitoring, automatic fetal head parameter*

Abstrak

Intrauterine growth restriction (IUGR) adalah salah satu dari banyak kelainan janin yang memiliki kontribusi tinggi pada angka kematian ibu dan angka kematian perinatal di Indonesia. Ternyata, dampak IUGR dapat dikurangi jika hanya gejala terdeteksi sebelumnya dan pengobatan yang tepat segera diterapkan. Namun, deteksi dan pemantauan proses pertumbuhan janin di Indonesia terhambat karena jumlah dokter sangat terbatas dan perangkat ultrasonografi (USG) yang mahal. Selain itu, dokter dan perangkat USG hanya tersedia di kota-kota besar. Untuk menjawab permasalahan tersebut, penelitian ini mengusulkan sebuah sistem cerdas yang dapat memberikan telemonitoring pertumbuhan janin di daerah pedesaan. Sistem ini terdiri dari tiga komponen: perangkat USG portabel, aplikasi *mobile* yang dikembangkan menggunakan sistem operasi Android dan server aplikasi yang dikembangkan menggunakan Django. Fitur utama dari sistem ini adalah *automatic fetal head parameter detection* dan hal tersebut dapat beroperasi di lingkungan yang memiliki keterbatasan akses internet. Dalam sistem ini *automatic fetal head parameter detection* menggunakan metode RHT untuk mendekati elips bentuk janin kepala tersebut. Hasil eksperimen menunjukkan bahwa kemampuan deteksi RHT dengan Δellipse rata-rata 79,564 dan berjalan dalam waktu rata-rata 0.373 detik.

Kata Kunci: *Intrauterine growth restriction, perangkat ultrasonografi, telemonitoring, automatic fetal head parameter*

1. Introduction

Based on Health Ministry Department of Indonesia, maternal mortality rate (MMR) and fetal mortality rate (FMR) in Indonesia are 30 for every 1,000 babies born and 300 for every 100,000 babies born respectively.[1] These numbers are quite high and become one of the main health aspect to be resolved in 2015 by Indonesia Ministry of Health. Major factors which cause high MMR and FMR are Intrauterine Growth Restriction (IUGR). In fact, some medication methods and treatments to cure IUGR are present nowadays.

However, IUGR detection is often too late and its medication is obstructed by insufficient number of gynecologist and fetal health monitoring devices such as ultrasonography (USG) for most people in rural areas. Moreover, the gynecologists and USG devices are also poorly distributed between each area in Indonesia which makes it nearly inaccessible for most people that lives from big cities to access fetal health service.

Regarding this issue, telehealth technology shows promising benefit and potential. This technology offers wider providence of various health services such as medical prevention, medication, consultation, and monitoring by connecting remote patient and service provider using information technology. Telehealth can be considered as new way to provide health service remotely. By using this method, patients don't need to come to hospital or interact with physician directly. In practice, telehealth have some variants: telecare, telemedicine, and telemonitoring.

Telehealth has several main benefits: lower cost, service equality, wider service providence, and personalized treatment [1]. Dixon et al. [2] also stated that telehealth has more value where the numbers of medical specialist are not enough to fulfill the population's needs. However, not all health services are feasible to be implemented through telehealth. Roine et al. [3] stated that efficiency and efficacy prove of telehealth so far suitable with teleradiology, telepsychiatry, and echocardiographic image. However, in order to implement telehealth some challenges need to be resolved, such as providing related technology infrastructure, training both remote and central medical staff, and telehealth program socialization.

Some research related to the implementation of telehealth has been conducted in the recent years. Kareem et al. [4] designed a virtual telehealth system based on clinical decision support system (CDSS) where patent's disease and its prescription could be predicted. By taking advantage of CDSS, the system knowledge base will grow thus have better accuracy overtime. Zang et al. [5] developed integrated telehealth application called deStress to monitor patient's stress level. When high stress level is detected, deStress will notify the patient and advise solution to relieve the stress. Another example of telehealth implementation is a telehomecare system named Keep In Touch [6]. Keep in Touch was designed to monitor cardiac and diabetic patient daily. Every day, patient submit its health data using certified biomedical devices remotely. The medical expert monitor the patient's health development using web based application.

Motivated by previous researches, implementation of telehealth system for fetal growth development is initiated. This system has bright prospect as fetal growth monitoring suits telehealth characteristic domain, such as image-based analysis and routine check-up.

This research aims to design telehealth system, Terrain, for fetal growth monitoring in Indonesia. The main contribution provided in this research is the architecture and software design for fetal growth parameter detection. The next contribution is development of telehealth applications for fetal growth parameter detection. The applications consist of web server and mobile application. Moreover, this research will also produce an embedding algorithm for fetal growth parameter detection in mobile device.

Another problem that will be solved in this research is to develop and implement a novel method of automatic fetal head detection for this system. The algorithm will be able to extract fetal head parameter automatically from fetal head image. Automatic fetal head parameter detection will lessen medical expert job and provide quick preliminary feedback regarding patient's fetal growth condition. However, the development and integration of portable USG device for Terrain have not included as the work is currently in progress. As substitute, this research used the already available 40 fetal head images for experiment for testing purpose.

This paper is structured as follows: section 2 explains system design that will be implemented in the fetal growth detection telehealth system, describing system requirement along with its architecture and software design. Afterwards, automatic fetal growth detection basics consist of fetal growth, fetal head parameter, and RHT algorithm will be presented in section 3. Section 4 contains experiment results and brief analysis when telehealth system tested on several fetal head images. Finally, the paper concludes with a summary and further work.

2. Methods

System Design

In rural areas, technology infrastructures have not been developed very well. This causes the scarcity and limitation to one of the most vital factor in telehealth with is the internet connection availability. Based on this condition, store-and-forward telehealth is chosen over real-time telehealth [4]. In store-and-forward telehealth, the medical expert and patient generally communicate each other using fax or email. In other hand, real-time telehealth basic communication uses video conference for communication which would require higher bandwidth and architecture requirements. The drawback store-and-forward is high time-factor [7]. Patient may need to wait more than two days to receive feedback from medical expert.

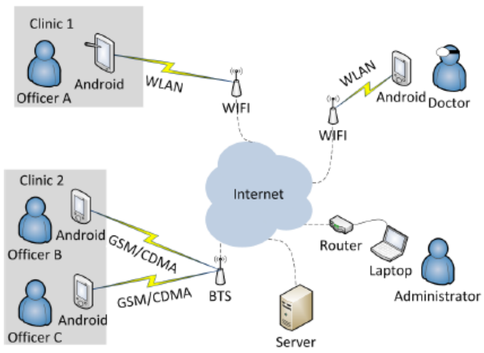

Figure 1. Terrain system architecture diagram.

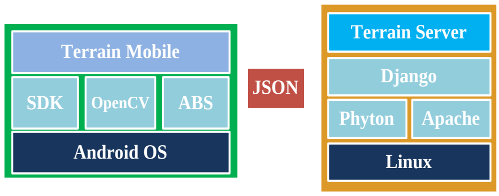

Figure 2. Terrain software architecture diagram.

There are three main actors in Terrain: patient, medical officer in clinic, and gynecologist. Periodically, patient will do fetal growth check up on nearby clinic. Medical officer will record patient's data and USG photo using Terrain mobile device. Terrain application then analyze USG photo to get fetal growth parameter. The corresponding parameter then is plotted on fetal growth graph to detect growth abnormality. Medical officer could also send message to physician using Terrain mobile if needed. When the clinic data is synchronized, patient's data will be available on gynecologist device. At this point, gynecologist could validate fetal growth parameter, give the patient feedback, and respond to messages sent by clinics. The next time synchronization is occurred in clinic device, medical officer will receive gynecologist's validation and feedback. Thus, follow up action can be executed by medical officer on patient based on gynecologist recommendation.

As internet connection is not always available and limited, synchronization process will only take place every one week or so. Therefore, Terrain application on mobile device should be able to be operated on offline mode. The process of capturing fetal image and automatic fetal growth parameter detection expected to be available even though internet connection does not exist.

There are several other aspects we should consider to fulfill the medical requirement of the hospital, scientific community researching on telehealth implementation [5]:

First, the Terminal Versality. It is important that the system have high system flexibility and reduce practical cost. To fulfill this requirement, Terrain will be developed using Android mobile operation system which is flexible, rich of feature, and highly extensible. Android also provide interface for developer to integrate various devices and peripherals.

Second is Data Transmission and Storage. We should consider data transmission rate and reliability for each transmission. There are two kind of data transmission in Terrain: the channel between USG and Terrain mobile where image retrieved, and the channel between Terrain mobile and server where synchronization occurs. As for storage, there are local storage which reside in the Terrain mobile and server/central storage. Both storage should have sufficient capacity to hold USG telehealth data. In the case of multiple synchronization, server will receive massive data transmission and processing thus cloud-based service need to be considered.

Third, Sensor Data Quality and Validation. Unlike normal fetal growth monitoring on hospital, we are designing a telehealth system where there is no medical expert validate and giving guidance. Thus, the system should be able to detect various fetal biometric parameters remotely. Also, the system should provide remote validation feature by medical expert as the system have fault possibility.

Fourth, the Algorithm Efficiency And Computational Cost. Since the most activity of this system resides on the mobile device, the employed methods should have reasonable complexity and responsivity. This aspect includes fast fetal biometric parameter detection, high quality of interaction and user experience.

Architecture

Terrain consists of three main hardware components: mobile device, PC, and server. The components are physically separated and communicating each other using internet. Terrain mobile device is Android device with portable USG probe integrated on it. This device will be used by remote clinic and physician. PC will be used by administrator to access web application in server where the doctor, clinic, and clinic officer data are managed. Server will provide synchronization service among all android user and act as central data storage. The hardware architecture is shown in Figure 1.

Terrain has two applications: android mobile application and web server application. HTTP Protocol and JSON are used by both applications to communicate between each other. In addition of Android SDK, Terrain mobile application also

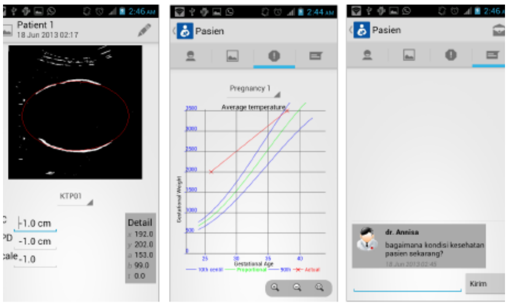

Figure 3. Terrain Android application user interface.

uses Open CV and Action Bar Sherlock library. Open CV library has essential image processing capability for fetal image parameter detection. Action Bar Sherlock library was used to provide uniform GUI among different version Android operating system. On the other hand, web server application was developed using Django, Python based -web framework. The web server application runs on Apache with no additional library. The software architecture is shown in Figure 2.

Terrain Android application is embedded in Terrain mobile device which will be used by gynecologists and clinics. This application has several features: patient data management, USG image management, automatic fetal growth parameter detection, plot fetal growth chart to detect abnormality, and gynecologist-clinic messaging service. Additional features like validation and correction of automatic fetal growth parameter are added on gynecologist side. However, addition and deletion of patient data only available on the clinic side.

Terrain web application is designed for system administrator to manage gynecologists, clinics, and medical officer's data. By using this application, those data can be added, deleted, or modified.

Both allocation and data access permission between doctors and clinic can be managed through this application. In addition, Terrain web application also responsible to handle synchronization process of all Terrain mobile device.

GUI Design

GUI is implemented at both Terrain mobile and web server. At the Terrain mobile, the GUI is designed for clinic officer and physician to view patient's profile, USG image overview, fetal growth analysis, and message history. The GUI on the web server is designed for administrator to manage clinic, clinic officer, and physician data. Figure 3 and Figure 4 shows GUI design for mobile application and web application respectively.

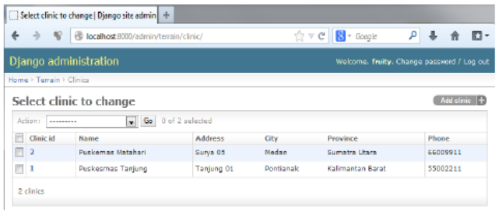

Figure 4. Terrain web application user interface.

Algorithm Design

Fetal Biometric Detection

There two main biometric parameter in fetal head USG image which are often used to detect IUGR: head circumference (HC) and biparietal diameter (BPD) [8]. These biometric parameters can be obtained by calculating ellipse approximation on fetal head image. HC and BPD the can be derived from the ellipse approximation and image's scale. In Terrain, modified RHT [9] is used to approximate ellipse on fetal head image. Before RHT is applied, thresholding technique is used on fetal head image to obtain binary image. The binary image then serves as input of RHT method.

RHT works by transforming image information into ellipse parametric space in a certain number of times. Ellipse parametric space is five dimensional space which represents five ellipse parameter: x, y, a, b, and θ. For ellipse detection, the transformation is done by choosing five random white pixels from input image and uses those points to solve ellipse equation.

The transformation result is then noted in five 1Daccumulator where each accumulator holds an ellipse parameter vote. This research used equation(1) up to equation(12) stated below to get ellipse parameter [10].

At the end of transformation process, the highest vote or occurrence in each accumulator is the result of RHT. In Terrain, RHT is implemented using C++ language and integrated in Android using JNI and Open CV library. The example results of ellipse detection on fetal head image are shown in Figure 5.

$$\boldsymbol{U} = x^2 + y^2 - U(x^2 - y^2) - V\,2_{xy} - R_x - S_y - T = 0 \quad (1)$$

$$e = \frac{b}{a} \quad (2)$$

$$U = cos\,(2\theta)\,\frac{1-e^2}{1+e^2} \quad (3)$$

$$V = sin\,(2\theta)\,\frac{1-e^2}{1+e^2} \quad (4)$$

$$R = 2x_0(1-U) - 2y_0V \quad (5)$$

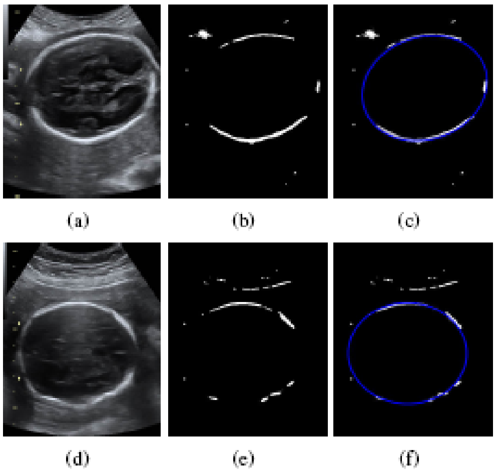

Figure 5. Ellipse detection result on two sample images. (a) and (d) are initial images, (b) and (d) are binary images, (c) and (f) are fetal head approximation result using RHT.

$$S = 2y_0(1 + U) - 2x_0V \tag{6}$$

$$T = \frac{2a^2b^2}{a^2+b^2} - \frac{x_0R}{2} - \frac{y_0R}{2} \tag{7}$$

$$x = \frac{SV+R+RU}{2(1-U^2-V^2)} \tag{8}$$

$$y = \frac{RV+S-SU}{2(1-U^2-V^2)} \tag{9}$$

$$a = \sqrt{\frac{2T+x_0R+\ y_0S}{2(1-\sqrt{U^2-V^2})}} \tag{10}$$

$$b = \sqrt{\frac{2T+x_0R+\ y_0S}{2(1+\sqrt{U^2-V^2})}} \tag{11}$$

$$\theta = \frac{1}{2}\ arctan\frac{V}{U} \tag{12}$$

Fetal Growth Anomalies Detection

Fetal growths anomalies can be detected by using existing HC and BPD growth chart.3 as the potential in accuracies of BPD measurement are higher than HC, it is more recommended to use head circumference for fetal growth evaluation. The growth chart shows ideal size, 5th centile, and 95th centile of HC from gestational age of weeks 13 until 42. The HC and BPD approximation of images obtained from automatic detection or physician's validation then plotted on the charts overtime. Any anomalies related to IUGR then easily detected by analyzing the fetal growth chart.

Database Synchronization

Synchronization is one of the main implementtation challenges as internet connection is not always available. To fulfill this requirement, the same basic database schema is implemented in both mobile and server application. Some database modification then applied to both applications.

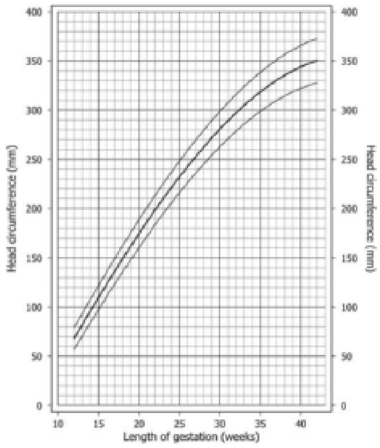

Figure 6. Normal fetal growth graph based on HC in SEA region (http://www.gestation.net/).

In Terrain mobile, three additional attri-butes are added in every database table: active, create timestamp, and modify timestamp. Active attribute shows that whether an entry is "deleted" from system. Create timestamp and modify timestamp shows when an entry is first created and last modified. On the other side, five additional attributes are added in every server database table: active, create timestamp, modify timestamp, arrival timestamp, and modify arrival timestamp. The first three attributes is identical to Terrain mobile while the later shows when an entry is created and modified in server.

Synchronization process is always started by mobile application. When the process initiated, all entries of every table in mobile application which were created and modified between current time and previous synchronization timestamp are collected. The collected entries then sent over internet to server by presenting the entries in a certain JSON structure. When the data reached server, JSON structure then converted to Python object, validated, and applied to server database. Afterwards, all the entries of every table in server database which were created and modified between current timestamp and previous synchronization timestamp are collected, converted to JSON structure, and delivered back to mobile applications. These server changes are then validated and applied on mobile application.

3. Results and Analysis

The experiment conducted by running RHT on 40 fetal head images which is obtained from Ciptomangunkusumo Hospital. Gynecologists already give ellipse approximation, HC, and BPD of every

TABLE 1
EXPERIMENT RESULT FOR FETAL HEAD MEASUREMENT USING RHT

Parameter	μ	σ
Δ_x	9.225	8.725
Δy	40.575	18.082
$\Delta\alpha$	10.861	10.831
Δb	6.233	6.615
$\Delta\theta$	12.668	9.031
$\Delta ellipse$	79.563	34.083
$\Delta center$	42.806	17.306
ΔHC	1.29	1.387
ΔBPD	0.25	0.394
t	0.373	0.406

fetal head image. Android device used in the experiment has 512 MB of RAM and 1.4 GHz Scorpion single core processor. The parameters that will be measured in this experiment is RHT ellipse approximation, running time, and its derived value: HC and BPD. The result of experiment is shown in table I. Δx, Δy, Δa, Δb, and Δθ are the difference of related ellipse parameter attributes; Δ_{ellipse} is sum of ellipse parameter difference; and Δ_{center} is ellipse's center point distance between physician annotations with RHT ellipse approximation result in pixel unit. ΔHC and ΔBPD is represented in cm unit and running time t is in second unit.

In this experiment, RHT's running time has reasonable result with average of 0.373 second. The HC approximation is also quite good with ΔHC of 1.29 cm. Based on graph, the average HC growth every week is 9.65 mm. It means that HC approximation has average of Δ1.33 week difference with physicians' annotation. However, Δ_{ellipse} and Δ_{center} are still high which indicates RHT's ellipse approximations are often misaligned.

4. Conclusion

This paper introduces the implementation of Terrain, fetal growth telehealth system based on 2D fetal head image using RHT. Terrain uses store and forward method is chosen as telehealth concept to broaden fetal health service availability and reduce infrastructure cost. This system is consisting of two main software components: Terrain mobile and web server application.

Terrain mobile is implemented in Android device while web server is implemented using Django framework. Terrain mobile has four features: patient data management, automatic fetal head parameter detection, fetal growth analysis, and messaging system. In the other hand, web server acts as central data storage, provides synchronization services, provides interface to manage doctor, clinic, and clinic officer data.

There are a lot of aspects in Terrain that needed to be improved in the future: USG sensor integration, implement better fetal head parameter detection method, and implement cloud-based server to handle bigger data access and transmission. It is also important to include the other fetal images to get more biometric fetal parameter like abdominal circumference, femur length, and crown rump length. More biometric parameter information will increase the accuracy of fetal growth anomaly detection.

Acknowledgment

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