Wireless uterine contractions monitoring system for pregnant women using a low-cost integrated sensor network

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Abstract*-In this article, we propose a wireless uterine contraction monitoring digital solution for pregnant women in the third trimester of pregnancy using low-cost electromyography sensors. The solution is intended to detect abnormalities, reduce premature birth issues and provide a safe and controlled system, especially for first-time pregnant women. The pandemic and remote location have significantly decreased prenatal care. In Peru, for instance, a large population of pregnant women resides in villages and locations where obstetric care is not offered. Transportation and lodging costs as well as the fear of contracting a virus have increased health and pregnancy complications with the proposed solution, we aim to mitigate these issues by proposing a safe, simple, wireless, low-cost and reliable monitoring solution. The solution includes four components: 1. An electromyography sensor that records contractions and sends them to the smartphone via Bluetooth; 2. A mobile application that sends the data to the cloud; 3. The registration of information in the database 4. Alert and notification system. Preliminary results show that the solution was able to meet the crucial obstetric care offerings and the waiting time to have a first contact with an obstetrician.

Keywords - Preterm labor; Internet of Things; electromyography; uterine contractions; primigravida.

I. Introduction

Fetal and neonatal deaths are a serious problem in Peru. According to the Centro Nacional de Epidemiología, Prevención y control de Enfermedades (CDC), 6182 deceased babies were registered in 2019 [1], 75% of them were in the last trimester of gestation. In addition, 42% of deaths are linked to problems in the health of pregnant women during the first 6 months of pregnancy. In addition, the Instituto Nacional Materno Perinatal (INMP) reports that in Lima a large part of pregnant women arrive at childbirth with less than 5 prenatal care [2], which makes it difficult to detect anomalies that may affect the health of the mother and the fetus. This shows many uncontrolled pregnancies and a high probability of premature birth.

Peruvian pregnant women go through difficulties to be cared for by an obstetrician, among these the distance from their homes to obstetric centers, since on average it takes them 31 minutes to travel [3]; low quality of health services, since only 49% of the human and material resources of the establishments are suitable for the care of pregnant women [4]; and delay in emergency care. About this point, the report on the measurement of waiting times in the INMPI emergency service reports that pregnant women wait an average of 1 hour and 18 minutes to be seen by a specialist and use the electronic monitoring service. However, they must wait an additional 2 hours and 21 minutes to be admitted (hospitalization, obstetric center, surgical center) or referred home [5].

The barriers to accessing obstetric services preclude early detection of anomalies that can jeopardize the welfare of pregnant women and fetuses. If these abnormalities are not identified early, they could result in preterm delivery or even death of the fetus and mother [6]. On this, the CDC reports that during 2019 approximately 16 babies died every day and 86% of them due to prematurity [1].

Recent research on the use of electronic devices in the monitoring of pregnant women shows that the detection of irregularities in the frequency and interval of contractile activity allows determining when the pregnant woman presents a complication or is in labor [7]. Therefore, various technological solutions use sensors that implement techniques such as tocodynamometry to measure uterine pressure, and electromyography to record uterine electrical activity (also called electro hysterography). On this, several authors conclude that surface electromyography measurements are 30% more accurate than those obtained by tocodynamometry (60% and 90% respectively), both compared to measurements from an intrauterine pressure catheter [8].

Due to the large number of fetal and neonatal deaths in Peru, the difficult access to obstetric services and the possibility of using portable devices to remotely monitor uterine dynamics in pregnant women during the last trimester, we found the need for implement a technological solution that serves as a tool for diagnosing complications in pregnancy, providing valuable information to obstetric personnel.

This work evaluates mobile technologies and sensors to monitor the contractile activity of the third trimester of pregnancy in primiparous women or pregnant women with an intergenesic period greater than 5 years. This is one of the few solutions that combine electromyography sensors and mobile applications for this purpose. It is expected that this system will periodically monitor pregnancy, allow for the timely identification of complications, provide security for women by

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providing information to specialists for early care, and reduce avoidable fetal and neonatal mortality as far as possible.

The proposal is based on the interconnection of a device containing a Spark Fun Myoware Muscle electromyography sensor and a Spark Fun Pro nRF52840 Mini microcontroller with a mobile application. This device is light, easy to adhere to the skin for the comfort of pregnant women, it has an embedded Bluetooth Low Energy antenna for transmitting the readings made and it is inexpensive to manufacture. The mobile application developed with Google's Flutter SDK receives the data from the microcontroller and sends it through the HTTP protocol to a web service hosted in the SAP Cloud Platform, which will be in charge of processing it, persisting it in a SAP High performance Analytic Appliance (HANA) database and issuing alerts to obstetricians, pregnant women and relatives of these, in case abnormal contractions are identified at the gestational week of the pregnant woman so that those interested can take action in a timely manner in the face of the emergency.

This article is organized as follows: We will start with a review of the literature on the use of electronic devices in pregnant women. Then, the section of the proposal with the analysis and development of the contraction system. The following section details the preliminary results of the case study carried out for the validation of the proposed solution, and the last section presents the conclusions of the study.

II. Literature Review

Pregnant women during the second and third trimesters begin to feel uterine contractions progressively. These are called the "motor of childbirth", since they generate the necessary force that drives the fetus through the birth canal. The behavior of the contractions is irregular up to six months of gestation and they are difficult to perceive; however, in the last three months, parameters such as intensity and duration adopt a pattern that indicates the proximity of the baby's birth. Several authors have studied measurement techniques for the mentioned variables to identify the onset of labor. Next, some techniques for measuring the intensity and duration of contractions are briefly appreciated, as well as the technologies used in their recording.

A. *Contraction measurement techniques*

There are external techniques that are applied to the skin of the pregnant woman's belly, whose precision is variable; and others that are invasive, since an object is inserted inside the womb and are usually of high precision, but it represents a risk for the pregnant woman and the fetus if it is carried out in a prolonged and repetitive way. Table I lists the most common techniques when reviewing the literature. Electromyography stands out for its high precision compared to the others.

TABLE I.
Contraction Measurement Techniques

N°	Measurement technique	
	Technique	**Reference**
1	Electromyography / Electro hysterography	[7], [8], [9], [10], [11], [12], [13], [16], [18], [20], [21], [22], [23]
2	External tocodynamometry	[7], [8], [9], [10], [11], [13], [16], [18]. [20], [21], [23]
3	Intern tocodynamometry	[8], [9], [10], [11], [13], [18], [20], [21], [22]
4	Magnetomyography	[22]

According to the researchers, the most used technique in the clinical field is external tocodynamometry. However, compared to other techniques, it has low precision and sensitivity to capture uterine dynamics [8,10]. Furthermore, this technique is uncomfortable, since it requires a specific position that pregnant women must adopt and the pain due to the constant pressure exerted by the transducer on the belly; and it is not effective in women with high body mass index. On the other hand, many researchers define the intrauterine pressure catheter (IUPC for its acronym in English) as the benchmark for monitoring. The downside is that it is invasive and can only be applied after the membranes have ruptured. In addition, cases of infection and damage to the placenta have been reported [13,18].

Given this scenario, electromyography is chosen because it is a non-invasive method, it uses superficial electrodes adhered to the mother's womb, it has an accuracy of approximately 90% compared to IUPC, it can be used antepartum and during labor and delivery. Processing cost is low compared to other techniques.

B. *Evaluation of electromyography sensors*

The market for small sensors aimed at recording body parameters has diversified and specialized significantly in recent years. For this reason, when searching for electromyography sensors, we found several options. Table II shows 4 models of reduced dimensions, light and compatible with different microcontrollers.

TABLE II.
Electromyography Sensors

Model	Myo Ware Muscle Sensor	Gravity Analog EMG Sensor by OYMotion	Grove EMG Detector	EMG click bundle
Dimensions	20.7 mm X 52.3 mm	27 mm X 35 mm	20 mm X 40 mm	57.15 mm X 25.40 mm
Weight	20 g	36 g	44 g	22 g
Price	$ 37.95	$ 37.50	$ 29.90	$ 47.20
Accessories	3 clasp-shaped electrodes	3 dry metal electrodes, auxiliary cable with 3 electrodes Cable 3 pin analogs	6disposable patches auxiliary cable with 3 electrodes	30 disposable patches. Auxiliary cable with 3 electrodes
Integration	Other development boards (Arduino, Raspberry, etc.)	Other development boards (Arduino, Raspberry, etc.)	Other development boards (Arduino and LinkIt ONE only)	Other development boards (Arduino, Raspberry, etc.)

After analyzing the information presented in table 2, it was determined that the MyoWare Muscle Sensor is the one that has the adequate performance for the project, since it is the lightest of all, it has 3 embedded electrodes and high sensitivity. In addition, this sensor is used by researchers for the construction of robotic arms and hands. The documentation is freely downloadable and the source code of other projects that integrate this device in their solutions is even provided.

C. Evaluation of cloud platforms

Mandeep, Reecha, Jagjit [27] refer to Paas as a service that provides the platform through the web to develop, initialize and administer applications. A base operating system with some build tools is shipped with the platform. In this way, developers can assemble and remake applications. In addition, it allows organizations to plan and build applications that are incorporated into the platform with unique programming segments. These applications are versatile and exceptionally accessible, as they select certain attributes from the cloud. According to Pierloi, Concetti, Belly and Palma [26] indicated that their research should be a tool for developers to make an informed choice of a platform depending on the use case. Similarly, Mandeep et al. [27] indicated that their study provides the new cloud customer with knowledge of various platforms so that they can choose the most convenient one.

TABLE III.
COMPARATIVE CHART OF CLOUD SERVICE PROVIDERS

Provider / Characteristics	Scalability	Languages Compatibles	Security	Domain name	Trial Period
Microsoft Azure	Manual and Automatic	C# F# Node.js Python JavaScript PHP C++	TLS/SSL	Yes	1 month
Google Cloud	Manual and Automatic	Go Java C# JavaScript Python PHP Ruby	TLS/SSL	Yes	12 months
Amazon Web Services	Manual and Automatic	C# F# Node.js Python JavaScript PHP C++	TLS/SSL	Yes	1 month
SAP Cloud Platform	Manual and Automatic	Java Note.js Python ABAP JavaScript PHP	TLS/SSL	Yes	12 months
Heroku	Manual and Automatic	JavaScript Java PHP Ruby Go Python Scala Clojure	TLS/SSL	Yes	Not available

We decided to use the SAP cloud platform for several reasons. First, the university where the technological solution was developed is part of the SAP University Alliance program offered by SAP and as such provides free resources to pilot these study times. In addition, this platform provides 120GB of free database storage for testing, piloting, and development. This platform also could provide real-time data analytics on a large volume of data if required.

D. Comparative technological solutions for fetal monitoring

Currently there are various technological solutions that use sensors to measure contractile activity and other variables of pregnant women. Table IV presents 4 solutions that allow monitoring a pregnancy [14,15,17,19].

TABLE IV.
TECHNOLOGICAL SOLUTIONS FOR FETAL MONITORING

Characteristics	Solutions			
	Fetal Master Caution	Sense4Baby	Bloomlife	Novii
Period	All pregnancy	Third trimester	Third trimester	Week 37
Location	Torso	Belly	Belly	Belly
Parameters	Bodily	FHR and contractions	Contractions	FHR, MHR, and Contractions
Country	Israel	E.E.U.U.	E.E.U.U / Belgium	E.E.U.U.
Cost	Not available	Not available	$ 360	$ 6 561
Measurement	ECG	CTG	Electrophysiology	EMG y ECG

As can be seen in the previous table, a large part of the solutions is used in the last weeks of gestation [19,28], this period being where contractions occur with greater frequency and intensity. Another important characteristic and common point are the location of the device on the belly to measure pregnancy parameters with various techniques such as electrocardiography, cardiotocography, electrophysiology, and electromyography [14,17,19,29]. Finally, some of these solutions are not yet available on the market because they do not have a sale price and others such as Blooomlife and Novii have a price that is not very accessible [30,31] for many Peruvian pregnant women.

III. UTERINE CONTRACTIONS SYSTEM: PROPOSED SOLUTION

A. Description of the proposal

Based on the literature reviewed, we propose a technological solution capable of recording the intensity of uterine contractions through a low-cost electromyography sensor and notifying the obstetrician and family members of a risk situation. The selected reference system is aimed at monitoring blood pressure in pregnant women with hypertensive diseases using a wearable [24]. Although the physiological variable is different from that of our solution, there are similarities such as the SAP Cloud Platform deployment platform, the use of sensors and the end users. Next, the operation of the solution divided into 4 components is explained as shown in figure 1 and the integration architecture of hardware and software components.

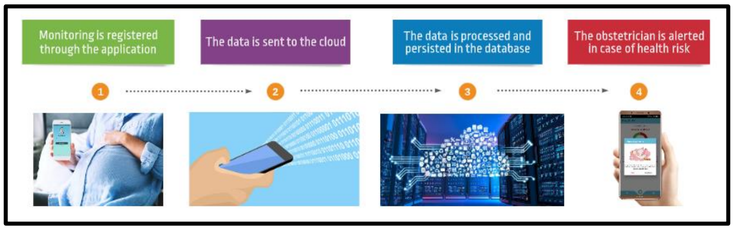

Fig. 1. Operation of the mobile application.

B. *Phases of the solution*

1) *Registration of the intensity of contractions through the electromyography sensor*

The pregnant woman will lie on the bed in a comfortable position. The lower abdomen will be cleaned with a little alcohol and then the surface electrodes will be attached. The next step is to press the power button on the device and pair it with the smartphone. For this, the pregnant woman enters the mobile application and activates the bluetooth icon to establish the connection. Then, she goes to the new monitoring interface and the intensity of the contractions will be automatically recorded at the same time, the pregnant woman can press a button each time she feels her baby move. This procedure usually takes between 10 and 30 minutes.

2) *Sending the data*

The data stored in the smartphone is sent through the HTTP protocol to a web service hosted in the Cloud Foundry environment of SAP Cloud Platform, which will oversee processing it according to the gestational week of the pregnant woman and the intensity ranges of the contractions.

3) *Data persistence*

Subsequently, the data is persisted in a HANA Cloud database so that pregnant women and obstetricians can consult the monitoring history at any place and time of day.

4) *Return of information and sending alerts*

This phase contemplates the return of information about the contractions such as the frequency, the average intensity and interval and the number of fetal movements during a monitoring. In addition, alerts are issued to obstetricians, pregnant women, and relatives of these, in case abnormal contractions are identified so that the interested parties can act in a timely manner in the face of the emergency. There are 2 types of alerts that are generated at the end of a monitoring and another that is sent before a sign of risk.

First, emergency alerts occur when the number of contractions or their intensity does not correspond to the current gestational age of the pregnant woman. Both the pregnant woman and the obstetrician can see a pop-up message if the application is running or if not, a notification is sent, in both cases the application shows the data of the last monitoring. Second, labor-type alerts are generated when the pregnant woman is between weeks 38 and 40 of gestation; and that in the last monitoring of her they registered more than 3 contractions and of high intensity. Third, an emergency button has been considered in the main interface of the application to notify the obstetrician in the event of a risk sign such as persistent headache, high fever, absence of fetal movements and vaginal bleeding. These factors have been considered because they are the main signs of a premature birth that can compromise the life of the pregnant woman and the fetus if they are not treated in time.

C. *Integration architecture*

The integration architecture is a high-level representation of the various components that make up the uterine contraction monitoring system. The goal of this architecture is to detail the relationships that exist between the components and how they depend on each other. In Figure 2 the solution proposal and its operation at a general level can be graphically demonstrated. The proposed solution is a tool that will help the obstetrician so that she can detect irregularities in the mother's contractions according to her gestational period.

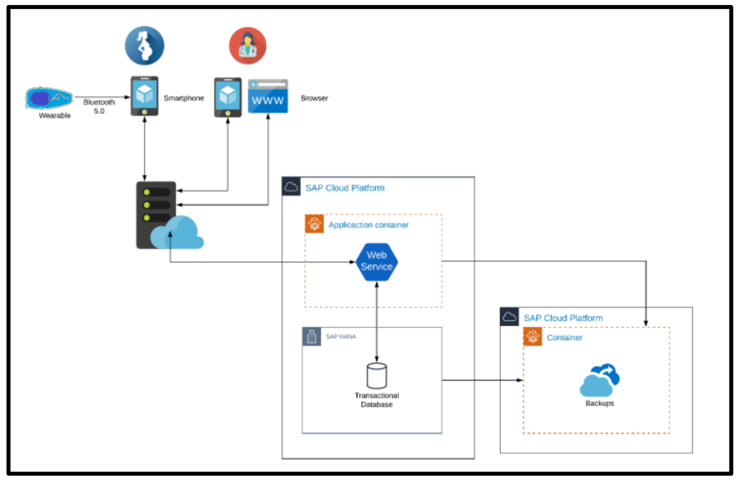

Fig. 2. Integration architecture of the proposed technological solution.

IV. CASE STUDY

A. *Organization*

To carry out the case study we coordinated with a registered obstetrician and a primiparous woman from the last trimester of pregnancy. The study was carried out during the month of October 2020 and the participants gave us their consent for the processing of their personal and sensitive data for academic research purposes.

B. *Business process*

In based on the care flow chart for the pregnant woman contained in the technical health standard for comprehensive maternal health care published in 2013 by the Ministry of Health (MINSA) [32], it was modeled, with the help of obstetricians who work at hospitals in Lima, the current process of obstetric emergency care shown in figure 3 and the electronic fetal monitoring sub-process in figure 4 using the BPMN notation.

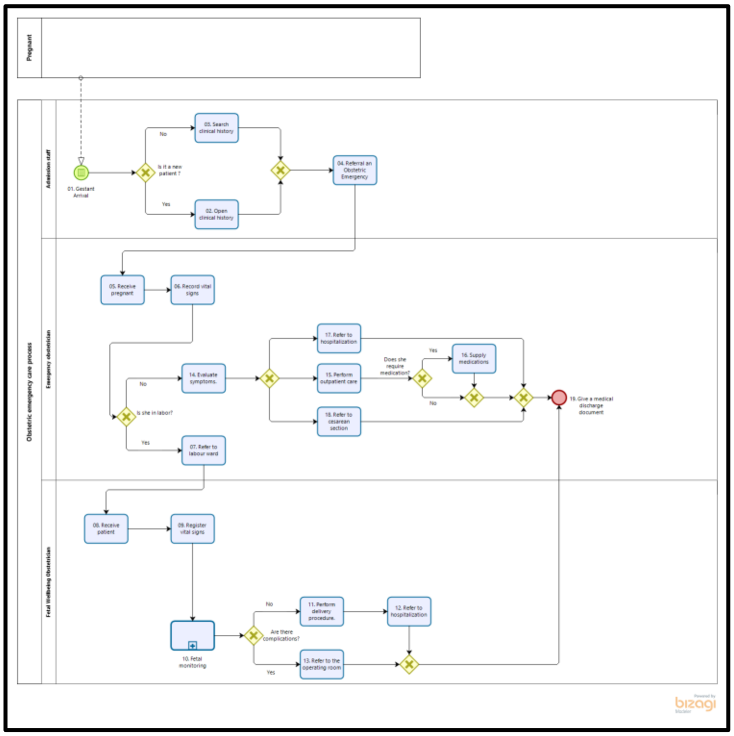

Fig. 3. AS-IS obstetric emergency care.

The critical activities that were identified for improvement with our proposal relate to the reception of patients when they enter the emergency service and the measurement of pregnancy parameters during electronic monitoring.

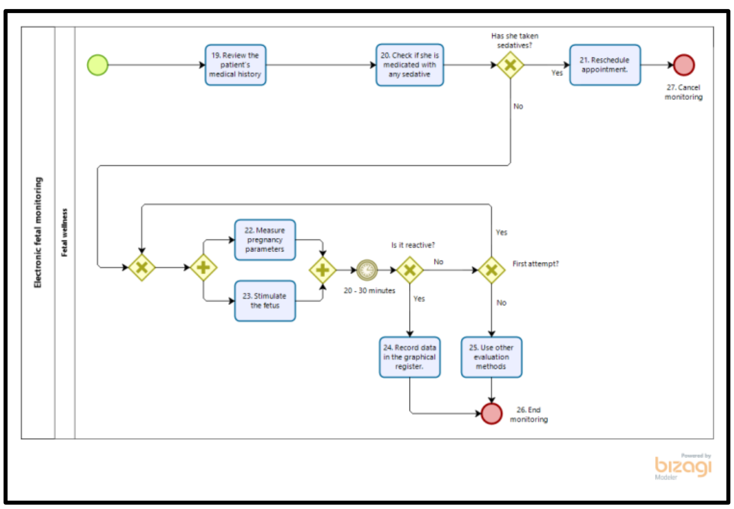

Fig. 4. Electronic fetal monitoring sub-process.

C. Implementation

Validation process consists of 5 stages arranged as follows:

1) Functional tests

This stage consists of the black box testing of the application. To achieve this, a request was sent to a virtual company of our university for the assignment of a certifier. At the end of the execution of the tests, the virtual company granted us a certificate that guarantees the correct functioning of the mobile application.

2) Acceptance tests

We met with the participants to explain how the application works, user manuals were sent according to the role each one plays (pregnant or obstetrician). At the end of the meeting, the consent documents for the use of their personal and sensitive data for academic research purposes so they could provide us the respective agreement were sent to the end users, via email. The application testing time lasted one week. In this period the data has been persisted in the HANA CLOUD database hosted in SAP CLOUD PLATFORM.

3) Survey application

A 10-question survey was applied based on the System Usability Scale (SUS) standard that allows us to identify general problems about design, navigability and the user experience when interacting with the application. The first survey was applied at the first day concluded. Later, on the third day, the survey was applied again to know if the score increased or decreased. Finally, at the end of the application trial period, users were invited to complete the questionnaire again.

4) Information analysis

Two sources of information were defined for the measurements. The first source is the database that supports the mobile application. The measurement that is made is the time elapsed from the end of the monitoring until the obstetrician visualizes it. For this, a notification is sent to the obstetrician's smartphone each time the pregnant woman completes a monitoring or sends an alert. Ideally, the time difference should be close to 0 minutes and this will provide the information in a timely manner for the specialist to formulate a pre-diagnostic and indicate whether it is necessary to go to the hospital.

The other source of information is the survey based on the System Usability Scale standard. The maximum score that can be obtained in this survey is 100. There are certain ranges that indicate if our application has a good design. For example, if our score is between 0 and 50 points, it means that our application has serious operating problems, or it is very difficult TO understand the different functionalities. If we obtained from 50 to 70 points, then the application is correctly functional, but the navigation is confusing, and the general design of the application is regular. The last range is from 70 to 100 points, which means correct functionality and easy navigation between the application options [25].

TABLE V.
METRICS FOR VALIDATION RESULTS

N°	Metrics	Formula
1	Waiting time for attention	TE = FVM - FFM
2	Usability Score	$P = \left(\left(\sum PI - 5\right) + \left(25 - \sum PP\right)\right) \times 2.5$

Where:

- TE: Waiting time for attention.
- FLM: Obstetrician monitoring display date.
- FFM: Date of completion of monitoring by the pregnant woman.
- P: Usability score.
- PI: Odd question score.
- PP: Even question score.

5) Results

At the beginning of the validation process, it was expected that the reduction in waiting time for attention would be within 20 to 30%. After processing the data and making the measurements of this indicator, the following results were obtained.

The average waiting time for medical care was 30 minutes, which indicates a reduction of 62% compared to the current average waiting time of 78 minutes.

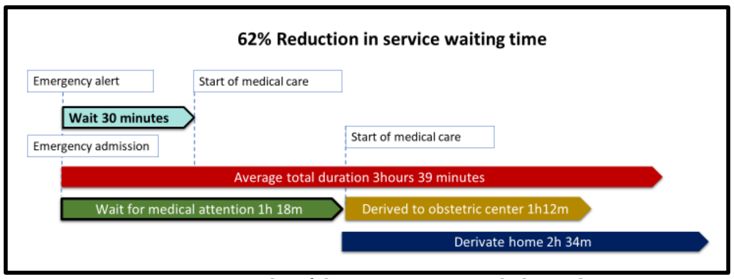

Fig. 5. Results of the attention time with the application..

This shows that with the use of the application the pregnant woman in emergency has a first contact with the obstetrician in less time than if she did approach the medical center.

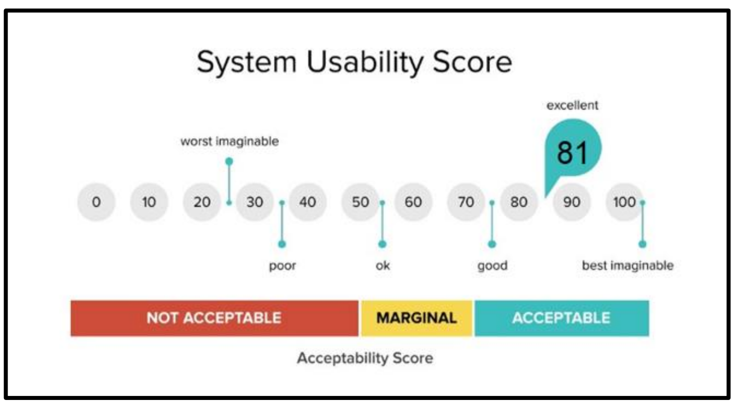

Fig. 6. Score obtained from the S.U.S. based on the graph prepared by 10up.com.

On the other hand, the score obtained by averaging the 6 surveys based on SUS was 81 points, which places us in an acceptable range and concludes that at a general level the design of the application manages to satisfy the expectations of the end users.

V. Conclusions

In this article, we propose a technology-focused contraction monitoring system to measure the intensity of uterine contractions through a low-cost electromyography sensor and mobile app. This system made it possible to optimize the care time of an obstetric office so that the doctor can manage the operating rooms of each pregnant woman in a timely manner. Which was implemented as a pilot plan in the city of Lima with the collaboration of a collegiate obstetrician and a primigravida who was in the 35th week of gestation. The proposal contributes to reducing the waiting time for care by 62% from when pregnant women enter the emergency service and have the first contact with a specialist, optimizing the use of obstetric resources at the health facility, and prioritizing pregnant women requiring immediate medical attention. In addition, it can serve as the basis for the development of research on mobile health issues focused on electrodiagnosis and consequently improve the quality of life of women and their babies during pregnancy.

For future research, the authors should ensure that the sample of pregnant women and obstetricians who use and test the solution is extended to a more representative number.

The implementation of our proposal on a large scale requires the development of a distribution plan for the delivery and collection of the electromyography sensors. Likewise, internet coverage must be guaranteed in the places where users reside and the use of smartphones. Finally, the choice of the On Premise or Cloud solution must be aligned with the legal framework for handling sensitive data.

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References

[1] Centro Nacional de Epidemiología, Prevención y control de Enfermedades. (2019). Boletín epidemiológico del perú. Available: https://www.dge.gob.pe/portal/docs/vigilancia/boletines/2019/52.pdf

[2] Instituto Nacional Materno Perinatal. (2020). Boletín estadístico 2019. Available: https://www.inmp.gob.pe/descargar_repositorio?archivo=boletin_estadistico_2019_inmp_oei.pdf&nombre=boletin_estadistico_2019_inmp_oei.pdf

[3] Instituto Nacional de Estadística e Informática. (2020). Condiciones de vida en el perú. Available: https://www1.inei.gob.pe/media/MenuRecursivo/boletines/03-informe-tecnico-condiciones-de-vida-abr-may-jun-2020.pdf

[4] Instituto Nacional de Estadística e Informática. (2016). Establecimientos de salud con funciones obstétricas y neonatales, 2013 y 2015. Available: https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1484/Libro.pdf

[5] Instituto Nacional Materno Perinatal. (2017). Medición de tiempos de espera en el servicio de emergencia del instituto nacional materno perinatal -2016. Available: http://www.inmp.gob.pe/descargar_repositorio?archivo=medici%c3%b3n_tiempos_espera_de_emergencia_inmp_-_dic_2016.pdf

[6] M. C. Cruz, G. Lastre-Amell, and N. I. Lastra, “Revisión de conceptos: embarazo en adolescentes y la experiencia en el control prenatal,” Ciencia E Innovación En Salud, e62:1-21, December 2018.

[7] M. Altini, et al., “Combining electrohysterography and heart rate data to detect labour,” 2017 IEEE EMBS International Conference on Biomedical & Health Informatics (BHI), pp 149-152, February 2017.
[8] J. Escalante-Gaytán, et al., “Utilidad de la electrohisterografía como técnica de monitorización uterina en el ámbito clínico: revisión bibliográfica,” Ginecología y Obstetricia de México, vol. 87, no. 1, pp. 46-59, January 2019.
[9] R. E. Garfield, and W. L. Maner, “Physiology and electrical activity of uterine contractions,” Seminars in Cell & Developmental Biology, vol. 18, no. 3, pp. 289-295, June 2007
[10] D. Schlembach, W. L. Maner, R. E. Garfield and H. Maul, “Monitoring the progress of pregnancy and labor using electromyography,” European Journal of Obstetrics & Gynecology and Reproductive Biology, vol. 144, no. 1, pp. 33-39, March 2009.
[11] T. Y. Euliano, et al., “Monitoring uterine activity during labor: a comparison of 3 methods,” American Journal of Obstetrics & Gynecology, vol. 208, no. 1, pp. 66.e1-66.e6, January 2013
[12] J. Mas-Cabo, et al., “Uterine contractile efficiency indexes for labor prediction: a bivariate approach from multichannel electrohysterographic records,” Biomedical Signal Processing and Control, vol. 46, pp. 238-248, September 2018.
[13] E. Hadar, T. Biron-Shental, O. Gavish, O. Raban, and Y. Yogev, “A comparison between electrical uterine monitor, tocodynamometer and intra uterine pressure catheter for uterine activity in labor,” The Journal of Maternal-Fetal & Neonatal Medicine, vol. 28, no. 12, pp. 1367-1374, 2015.
[14] Fetal master caution homepage, HealthWatch Ltd. https://healthwatchtech.com/fetal/, Accessed October 24 2020.
[15] Bloomlife homepage, Bloomlife, Inc. https://bloomlife.com/, Accessed October 24 2020.
[16] M. Lucovnik, et al., “Use of uterine electromyography to diagnose term and preterm labor,” Acta Obstetricia et Gynecologica Scandinavica, vol. 90, no. 2, pp. 150-157, February 2011
[17] Sense4Baby homepage, Advanced Maternity Innovations, LP. https://www.advancedmaternityinnovations.com/sense4baby/, Accessed October 24 2020.
[18] M. W. C. Vlemminx, C. Rabotti, M. B. van der Hout–van der Jagt and S. G. Oei, “Clinical use of electrohysterography during term labor: a systematic review on diagnostic value, advantages, and limitations,” Obstetrical & Gynecological Survey, vol. 73, no. 5, pp. 303-324, May 2018.
[19] Novii homepage, General Electric Healthcare. https://www.womens-health.net/novii, Accessed October 24 2020.
[20] J. Jezewski, K. Horoba, A. Matonia, and J. Wrobel, “Quantitative analysis of contraction patterns in electrical activity signal of pregnant uterus as an alternative to mechanical approach,” Physiological Measurement, vol. 26, no. 5, pp. 753-767, July 2005.
[21] T. Y. Euliano, et al., “Monitoring uterine activity during labor: clinician interpretation of electrohysterography versus intrauterine pressure catheter and tocodynamometry,” American Journal of Perinatology, vol. 33, no. 09, pp. 831-838, March 2016.
[22] M. Zhang, P. S. La Rosa, H. Eswaran and A. Nehorai, “Estimating uterine source current during contractions using magnetomyography measurements,” PLOS ONE, vol. 13, no. 8, pp 1-29, August 2018.
[23] R. Parameshwari and S. Shenbaga Devi, “Acquisition and analysis of electrohysterogram signal,” Journal of Medical Systems, vol 44, no. 3, pp. 1-11, February 2020.
[24] B. D. B. Lopez, J. A. A. Aguirre, D. A. R. Coronado and P. A. Gonzalez, “Wearable technology model to control and monitor hypertension during pregnancy,” 2018 13th Iberian Conference on Information Systems and Technologies (CISTI), pp. 1-6, 2018.
[25] A. Smyk. (2020). The system usability scale & how it’s used in ux - thinking design. Available: https://medium.com/thinking-design/the-system-usability-scale-how-its-used-in-ux-b823045270b7.
[26] P. Pierleoni, R. Concetti, A. Belli, and L. Palma, “Amazon, google and microsoft solutions for iot: architectures and a performance comparison,” IEEE Access, vol. 8, pp. 5455-5470, 2020.
[27] M. Kaur,R. Sood, J. Kaur, “Comparative study to understand and analyze cloud computing,” International Journal of Advanced Science and Technology, vol 28, no. 19, pp. 827-833. December 2019.
[28] J. F. M. van den Heuvel, et al., “Hospital care versus telemonitoring in high-risk pregnancy (hotel): study protocol for a multicentre non-inferiority randomised controlled trial.” BMJ Open, vol. 9, no. 10, pp. 1-6, Octobor 2019.
[29] Bloomlife preg-u, Bloomlife, Inc. https://bloomlife.com/preg-u/how_does_bloomlife_work_uterine__muscle_contractions, Accessed October 24 2020.
[30] Ideaning e-commerce, Idea Centric LLC. https://ideaing.com/product/bloomlife-contractions-tracker, Accessed October 24 2020.
[31] NICE homepage, National Institute for Health and Care Excellence. https://www.nice.org.uk/advice/mib228/chapter/Summary, Accessed October 24 2020.
[32] Ministerio de Salud. (2013). Norma técnica de salud para la atención integral de salud materna (105). Available: http://docs.bvsalud.org/biblioref/2019/04/964549/rm_827-2013-minsa.pdf.