Wearable Technology Model to Control and Monitor Hypertension during Pregnancy

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Abstract — **In this paper, we proposed a wearable technology model to control and monitor hypertension during pregnancy. We enhanced prior models by adding a series of health parameters that could potentially prevent and correct hypertension disorders in pregnancy. Our proposed model also emphasizes the application of real-time data analysis for the healthcare organization. In this process, we also assessed the current technologies and systems applications offered in the market. The model consists of four phases: 1. The health parameters of the patient are collected through a wearable device; 2. The data is received by a mobile application; 3. The data is stored in a cloud database; 4. The data is analyzed on real-time using a data analytics application. The model was validated and piloted in a public hospital in Lima, Peru. The preliminary results showed an increased-on number of controlled patients by 11% and a reduction of maternal deaths by 7%, among other relevant health factors that allowed healthcare providers to take corrective and preventive actions.**

Keywords – wearable; technology; mobile health application; hypertension; pregnancy; data analytics.

I. INTRODUCTION

Pregnancy complications related to hypertension, also known as a preeclampsia, represents a serious risk to the mother and the baby. Preeclampsia is associated with adverse outcomes such as miscarriage, preterm birth, low birth weight, and stillbirth. Worldwide, the maternal mortality ratio (maternal deaths per 100,000 live births) was 216 in 2015 compared to 436 in least developed countries [1]. Therefore, developing countries are still lagging mechanisms to promote better pregnancies.

Preterm birth due to hypertension is by far the most predominant adverse outcome in pregnancy, with half a million babies born preterm every year in developing countries such as the United States. These births have accounted for about $26 billion per year of direct and indirect costs [2]. In Peru, hypertension is the second cause of maternal death (representing 17 to 21% of total deaths) and preterm births [3]. The common denominator of hypertension during pregnancy is the increase in blood pressure (BP) equal to or greater than 140/90 MmHg and when appropriately controlled could be a preventable risk factors [3]. Hypertensions problems in pregnancy are also expected to rise due to the increased of maternal age and incidence of chronic disease [1].

Recent advances in mobile technologies in healthcare and in particular wearable technologies (m-health), have positively contributed to new possibilities in controlling and monitoring health conditions remotely as well as tracking health factors in daily life environments. Wearable technologies permit people with new tools to engage in healthier lifestyles and habits, monitor their health conditions, therefore reducing their risk of chronic diseases through behavior change and health surveillance [4].

This paper evaluates mobile and wearable technologies to control and monitor hypertension during pregnancy and proposed a technological model that could potentially become a health system to prevent and control hypertension problems in pregnancy. This model is one of the few that combine a group of the patient's own parameters such as blood pressure, heart rate and physical activity with a wearable device. This model is expected to empower patients in engaging in healthier behavior, making them aware of their health condition, provide patients' real-time health information to healthcare providers who can enable healthier pregnancies, and ultimately reduce the indirect and direct costs associated with maternal and child health problems.

This paper is organized as follows. We start by briefly discussing some of the current health controlling and monitoring models for patients with hypertension and then focus on describing the details of the proposed model. We end the paper with a conclusion and discussion of the preliminary results observed in a case study.

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II. Literature review on Controlling and Monitoring Models for Hypertension in Pregnancy.

Hypertension is a silent disease that when diagnosed, treated and controlled could save the lives of a large population, especially pregnant women. Prior studies have attempted to address the consequences of hypertension in pregnancy by developing health systems that could control and prevent these disorders. Most of these studies propose a combination of health parameters and technologies. Hypertension disorders in pregnancy are also known as preeclampsia. Below, we briefly discuss some of relevant risk factors that trigger this health disorder and the technologies used to control and monitor it so far.

A. Preeclampsia variables

Multiple risk factors that allow preeclampsia to unfold have been identified in the literature.

Table I shows 14 of the most significant variables found in the literature. From these variables, certain patient information can be identified that requires urine and blood tests.

TABLE I. PRIMARY PREEMCLAMPSIA RISK FACTORS

N°	Primary preemclampsia risk factors	
	Risk factor	***Reference***
1	Physical activity, Hypertension	[6], [7], [8], [9], [10], [11]
2	Feeding, Maternal anemia, Glucose in the blood, Hemoglobin	[6], [8], [9], [10]
3	Family history of preeclampsia, History of other cardiovascular diseases	[6], [8], [9]
4	Waist circumference	[6]
5	Consumption of alcohol, Consumption of cigarettes	[6], [9], [10]
6	Depression or stress in pregnancy, Pregestational diabetes mellitus	[6], [8], [9], [11]
7	Age, Gestational age Weight. Talla	[6], [7], [8], [9], [10], [11]
8	Pretibial edema that left fovea	[8]
9	Pulmonary edema, Renal insufficiency	[7], [9], [10], [11]
10	Hepatic transaminase enzymes	[7], [9], [11]
11	Increased body mass index	[6], [7], [8], [9], [10]
12	Medicine for pressure, Glucose, Insulin level	[6], [8]
13	Liquid level administered and eliminated	[7], [8]
14	Proteinuria, Thromboembolism	[7], [8], [9], [10], [11]

B. Assessment of Blood pressure measuring devices

Table II shows the different devices that measure blood pressure.

Wearable devices have been found to be the most effective way to measure blood pressure remotely because of their higher usability. Patients can wear the device practically all day long. Some of these devices also have the capability of measuring other health parameters such as heart rate.

TABLE II. BLOOD PRESSURE MEASURING DEVICES

Characteristics	Device		
	Manual blood pressure monitor	***Digital blood pressure monitor***	***Wearable***
Comfort	0.11 KG	0.46 KG	0.09 KG
Measuring Parameters	* Blood Pressure	* Blood Pressure	*Blood Pressure *Heart Rate *Steps
Health Validation	[12],[13],[14],[15],[16]	[12],[13],[14],[15]	[17],[18]
Measuring accuracy	±2MMHG	±3MMHG	±5MMHG
Accessibility	100 soles	300 soles	115 soles

We decided to use the "V07" wearable device. This device has the following characteristics. An important factor of this device is its high compatibility with Android and IOS operating systems.

N°	V07 Smart Wristband Features	
	Characteristics	***Description***
1	Compatible OS:	Android,IOS
2	Compatability:	Android 4.4 / iOS 8.0 and above systems
3	Bluetooth Version:	Bluetooth 4.0
4	Health tracker:	Heart rate monitor,Pedometer,Sedentary reminder,Sleep monitor
5	Charging Time:	About 90mins
6	Battery Capacity:	70mAh

C. Assessment of Cloud Platforms

Cloud platforms have largely used in healthcare applications because besides being highly scalable, these platforms also provide infrastructure for development, deployment and application management [19]. The cloud model not only provides storage services, but also offers integrating tools for orchestrating different services like analytics, predictive, gamification, among other applications.

Table III shows the main cloud providers in the market of M-mobile health.

We decided to use the SAP cloud platform (SAP HANA) for several reasons. First, the University where the model was developed is part of the University Alliance Program that SAP offers and as such it provides free resources to pilot these times of studies. Also, this platform provides 10GB of free data for testing, piloting and development. This platform also has the capability of providing real-time data analytics on large volume of data if needed.

D. Assessment of Mobile operating systems

At present, there are 3 leading operating systems in the market.

Table IV shows performed analysis on mobile operating systems based on 4 characteristics: market, language knowledge, flexibility and deployment [23] [24].

We decided to use the Android operating system because it has a larger market of people and we can connect a wearable device without problems compared to an IOS which just connect devices who has the same system operations.

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TABLE III. CLOUD PLATFORMS

Cloud Platforms	Description
SCP - SAP CLOUD PLATFORM	SAP Cloud Platform is the agile as a service platform (PaaS) for digital transformation, with capabilities and comprehensive application development services that allow companies to collect, manage, analyze and take advantage of information of all kinds, to extend and connect to commercial systems and innovate new cutting-edge scenarios to allow the company to adapt and advance continuously. It allows customers to obtain business agility, create a truly integrated and optimized company, and accelerate digital transformation throughout the business, all without the requirement to maintain or invest in local infrastructure. SCP has the following services: integration, user experience, analytics, development and operations, collaboration, security, business, storage, mobile and internet of things. Unlike other platforms, it provides 10 GB of free storage in development mode and the development, operation and testing time is indefinite [20].
IBM - BLUEMIX	BLUEMIX supports several programming languages and services, as well as the development methodology DevOps in an integrated way to create, execute, deploy and manage applications in the cloud. Bluemix is based on the open technology of Cloud Foundry and it runs on the infrastructure of SoftLayer. The services offered by this platform are: storage, mobile, Watson, data and analytics, internet of things, security, application service and integration. The development and testing is for a period of 30 days and provides 2 GB of memory for user use [21
GOOGLE CLOUD PLATFORM	Google Cloud Platform is a set of public cloud computing services offered by Google. The platform includes a range of hosted services for the development of applications, storage and applications that run on Google's hardware. Software developers, cloud administrators and other IT professionals in the company can access platform services through the public Internet or through a dedicated network connection. The services offered by this platform are: storage, mobile, big data, internet of things, security, application service and integration. Google offers us a trial time of 12 months, also provides 1GB of memory and grants $ 300 for development because some services are not completely free [22]

TABLA IV. MOBILE OPERATING SYSTEMS

Characteristics	*Mobile operating systems*		
	Android	*IOS*	*WindowsPhone*
Market	59%	23%	2.2%
Language knowledge	81%	13%	4%
Flexibility	Multi team	Apple machine	Microsoft team
Deployment	30$	90$	Free

E. Wearable Models to Control and monitor hypertension

A standard communication model has been proposed for controlling and monitoring hypertension [26, 27]. One model considers one health parameter, blood pressure [26]. In this model, a blood pressure measure device is given to the patient to take home. This device communicates with the health providers via an online terminal and sends data to be synchronized in a cloud environment. The messages are sent by text and emails to healthcare providers. The technological architecture of this model suggests the use of scalable infrastructure supported by service providers, see Figure 1.

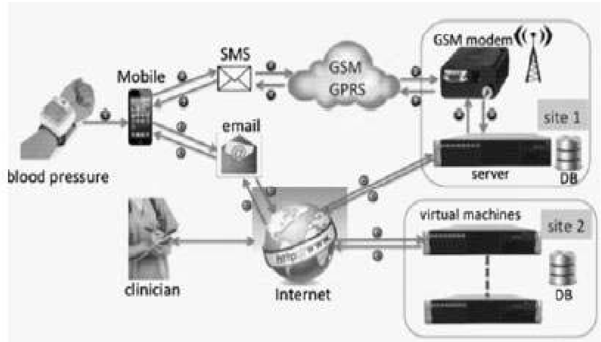

Figura 1. MHealth application deployment architecture for telemonitoring blood pressure

Another proposed model has used an additional parameter, weight [27]. In this model, old adults can measure their blood pressure and weight themselves. Their data gets linked to their health providers. Differently from the previous model, this model suggests a system where the data is sent to the health center where a healthcare provider analyses the data and pairs patients' cases with previous solved cases (e.g., a decision support system). In this model, the measurement devices are connected to the health institution server through the Internet. The deployment of this model is divided in 3 domains: User domain (e.g., health parameters), data domain (e.g., database servers and algorithms to interpret and store data that will be displayed to the doctors), and service domain (e.g., health providers' services that use systems data to provide feedback to the patient). See Fig. 2.

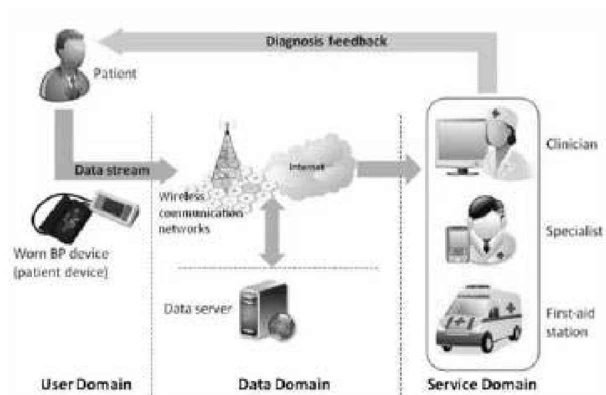

Figura 2. Health system model for blood pressure monitoring

III. CONTROL AND MONITOR HYPERTENSION DURING PREGNANCY: PROPOSSED WEARABLE MODEL

A. Description of the Model

Following the standard model found in the literature, we propose an enhanced model to control and monitor hypertension during pregnancy. This model focused on 3 users: patient, healthcare provider and the healthcare organization.

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The phases below describe the process in which the model operates. First, a wearable device obtains patient health parameters, this data gets sent to a mobile device through an application, the data gets stored in a database in the cloud and finally the data is processed and analyzed through a data analytics application offered by the cloud provider. Figure 3 shows the phases of the proposed model.

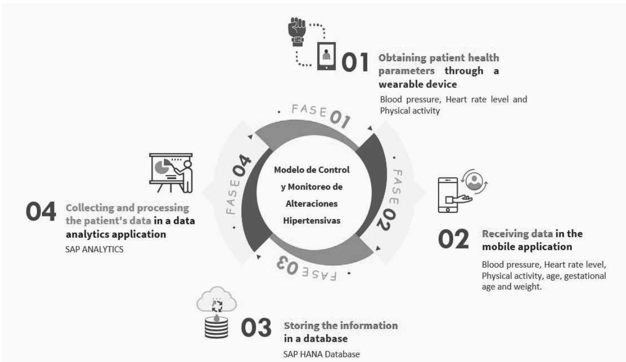

Figura 3. Wearable Technology Model to Control and Monitor Hypertension During Pregnancy

In this model, we propose the use of a multiple risk factor system. As earlier discussed, the literature has identified major risks that develop preeclampsia, some of these significant variables of preeclampsia require a medic exam to determine their value. For that reason, we will use 6 variables listed in table V.

TABLA V. SIX MAJOR RISK FACTORS FOR HYPERTENSION IN PREGNANT PATIENT

N°	Main risk factors of hypertension	
	Risk factor	***Reference***
1	Hypertension	[6], [7], [8], [9], [10], [11]
2	Heart rate level	[4]
3	Physical activity	[6], [10]
4	Age	[6], [8], [9]
5	Gestational age	[6], [7], [8], [9], [10], [11]
6	Weight	[6], [7], [8], [9], [10]

Among these factors, gestational age, hypertension measurement, increased body mass index (BMI), weight, proteinuria, smoking, and thromboembolism seem to be the highly cited risk factors accounted for preeclampsia. Niveles of hypertension greater than 140/90 mmhg, a BMI about 30 or more, and weight have to be relative weight to the patient's height, are considered levels of high risks when it comes to flag a high risk pregnant patient.

A. Model phases

1. *Obtaining health parameters through wearable devices*

For the data acquisition phase, the patient wears a wearable sensor device on her wrist. The device captures her blood pressure, heart rate and patient steps. The method of colleting these data would be set in agreement with the healthcare provider. For our case study, the data was collected every 30 minutes.

2. *Data reception in the mobile application*

The wearable device is connected via Bluetooth with the mobile application all the data captured by the wearable will pass immediately to the cell phone and the memory of the wearable will be cleaned to obtain new data. This case occurs when the cell phone is not connected to the wearable, otherwise the data will be stored directly in the cell phone memory. The patient will be able to monitor his health anytime through the statistics shown in the application, besides this, he will be able to visualize the medicines that s/he must take, appointments and her/his treatment. The application is also developed to alert the health organization and the patient when an incident of high blood pressure is present, this alert also shows the location on google maps in which the patient is located. The variables such as weight, age and gestational age must be entered by the user manually in the application, each modification made will be recorded.

3. *Information storage*

The stored data automatically transferred to the SAP HANNA database and the data will be deleted from the phone memory.

4. *Collecting and processing data*

A data that is stored in the database is useful for the statistics to provide greater accuracy of patient's status to the doctor and health organization. Data processing on SAP Analytics will allow the organization to make strategic decisions in real time more elaborated.

B. Integration Architecture

The proposed architecture will support the control and monitoring model of hypertensive alterations in pregnancy. This model represents the 3 users: patient, doctor and health organization. This architecture shows how our model is supported with technology. It is important to highlight that the deployment of the application, although it is being done in SAP Cloud Platform, this can also be deployed in other platform that meets necessary services of database, web and applications servers "Fig. 4".

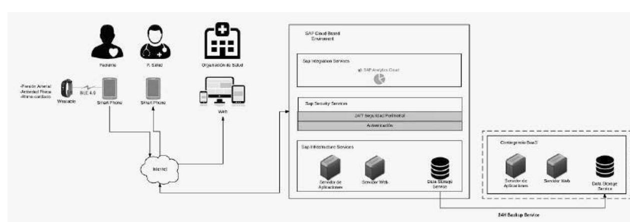

Figura 4. Architecture for the control and monitoring of hypertensive alterations during pregnancy

IV. CASE STUDY

A. Organization

The Social Health Insurance Hospital also called EsSalud was the healthcare organization where the model was validated.

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This Peruvian institution's mission is to be a social security health institution that provides comprehensive care with quality and efficiency to improve the well-being of insured Peruvians. The general institution consists of 400 establishments among general hospitals and specialized health establishments. Prior to the implementation of the model, there were no records of controlling and monitoring cases of hypertension among pregnant women. Therefore, the institution was receptive to try the pilot implementation of this project in one location. We work with 20 pregnant patients who live in Lima and their gestational were between 3 months and 9 months. The study was conducted between October and December 2017. The study received Ethics clearance by the Peruvian University of Applied Sciences and EsSalud.

B. Implementation

1. Obtaining health parameters through a wearable device

A wearable device and instructions of use wares given to each pregnant patient. The main recommendation was to not remove except when bathing or having to charge it. The charge of the device lasts approximately 90 minutes.

2. Data reception in mobile application

The wearable device sends all health parameters values obtained in a 30 minutes range (heart rate and blood pressure) to the mobile application, which is used as a mean to store data in SAP HANA database. It is important that mobile application is connected to internet and paired with wearable via Bluetooth.

3. Information storage

We did not use all the storage provided by the Cloud platform for the preliminary results. But, we are expecting to collect more data and thus conduct more analyses.

4. Collecting and processing data

Aggregated analysis was performed. We showed the healthcare providers how the data could be potentially analyzed and displayed. For example, one graphs showed all patients who had their blood pressure and heart rate controlled. A second graph indicated the analysis of the patients based on the healthcare parameters, and a third graph showed the month of gestation where higher alerts by pressure or high heart rate occurred. This preliminary information helped the healthcare providers to start developing new strategies to control and monitor these patients more efficiently and effectively.

C. Results

Based on the data collected, we could observe how an information management is important for health decision making either for the patient or the healthcare provider. The wearable device and data transfer facilitated the control and monitoring of blood pressure to about 75% of the patient's time daily. Out of the total subject pool, we found that 70% of the subjects (14 pregnant women) had abnormal health parameters during the study. This number was alarming since most of these women were not profile as a high-risk group when the study started. Even though, the sample size was very small, it provided the healthcare institution with relevant information to start taking action on developing better strategies to control and take care of their pregnant population.

Another interesting finding was to observe and confirm health guidelines. For example, we found that in their thirtieth month, pregnant patients had a greater number of alerts for high blood pressure and high heart rate compared during their twentieth month of gestation. Although, this finding was not surprising, it helped healthcare providers develop preventive and corrective actions starting from week 28th of pregnancy. Prior this data, high blood pressure and heart rates alerts were thought to start on week 34 or 36 of gestation among health pregnant women. Even though, our goal was to increase the number of healthcare parameters to monitor and control preeclampsia in pregnancy, future studies should aim to have a more comprehensive measure of healthcare parameter to monitor and control not only preeclampsia but other alterations in pregnancy.

V. CONCLUSIONS

In this work, we proposed a wearable technology model to control and monitor hypertension during pregnancy. In this model, the level of care for pregnant patients is monitored and controlled based on alerts provided by a group of health parameters.

The model was piloted in a healthcare center in Lima, Peru. The number of controlled patients was increased by 11% and the rate of maternal deaths was reduced by 7%. These percentages were calculated based on verbal a baseline data given by the administrators of the healthcare center because there was not an established system to control and monitor hypertension in pregnancy. The pregnant patients expressed satisfaction with the model because they felt empowered by checking and monitoring their own health. They also found the technology non-invasive and easy to use. They also commented on the friendliness of the graphics and alerts. The doctors could treat their patients on time based on the values of their blood pressure and heart rate and start developing strategies to improve the care of this population. Finally, the organization verified the great impact that such a model could have on their business process as well as their final mission of improving health conditions.

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