Framework for Monitoring Peruvian Patients with Hypertension using a Smartwatch and GPT

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***Abstract*. Hypertension has been a silent disease that has affected a large part of the world population; in 2022, 5.5 million cases were registered in Peru. Current treatments show an inadequate control of this disease. Therefore, a framework is proposed to build an application for remote monitoring of hypertensive patients using technologies such as smartwatches and artificial intelligence of GPT, considering the diagnostic methodologies of hypertension used in the world, physiological variables and the implementation of GPT-4 as an assistant for the correct treatment of hypertension. The methodology was followed: selection of measurement techniques, selection of physiological variables, selection of the smartwatch model, implementation of GPT-4 and construction of a mobile application. The experimentation had two scenarios: (a) use of the traditional model and (b) using the proposed method. The results of the experimentation showed that the time to measure and record blood pressure and heart rate (TMR) was 44.44% faster with the app. The medical diagnosis time (TMD) was 80% more efficient than the traditional method. In addition, in the expert judgment evaluation, patients and cardiologists rated the solution with 4.2 and 4.1 points respectively, valuing it as "agree" in use of the proposed solution.**

Keywords — Hypertension, Framework, Blood pressure; Smartwatch, GPT, Blood pressure monitoring

I. INTRODUCTION

Hypertension is a public health problem that currently affects about 1.28 billion adults between 30 and 79 years of age worldwide, with two thirds of cases concentrated in low- and middle-income countries, where only 1 in 5 individuals achieve effective control [1]. In Peru, it is estimated that in 2022 there were around 5.5 million people over 15 years of age with hypertension [1]. Specialists mention the importance for regular monitoring of blood pressure (BP) and heart rate (HR) to achieve more effective control of hypertension and prevent possible future complications [1].

The high prevalence of hypertension, especially in resource-limited regions [2], in addition to the 5.5 million cases in Peru [1] demonstrates the magnitude of the problem. Inadequate control can lead to serious cardiovascular and cerebrovascular complications, which not only has an impact on the health of individuals, but also on the medical systems and the economy of countries [3], [4]. Therefore, there is a compelling rationale for the implementation of effective solutions to facilitate continuous BP and HR monitoring in hypertensive patients.

To address the challenge of hypertension management, there are mainly two categories of technological solutions. On the one hand, predictive solutions for hypertension risk using machine learning algorithms, such as those presented in [5], [6], [7], which focus on predicting hypertension and cardiovascular risks. On the other hand, mobile solutions [8], [9] focused on the management and monitoring of hypertension through the use of smartphones. However, to date, in Perú none have specifically addressed real-time physician-patient management using mobile devices and the Internet of Things (IoT) within a mobile application downloadable by any adult. This omission represents an opportunity to optimize consultation processes in this field and becomes the focus of our research.

This study proposes to elaborate a framework to develop a technological solution that allows cardiologists to efficiently and conveniently monitor their hypertensive patients. The BP and HR measurement technology of smartwatches will be employed, and GPT's Artificial Intelligence (AI) will be used to provide monitoring alternatives to the physician and patient, facilitating and optimizing the consultation process.

II. RELATED WORKS

A. *Risk Factors*

Among the various risk factors identified, it was found that "alcohol and smoking" represent an increased risk of developing hypertension [5], [6]. There is a causal relationship between smoking, excessive alcohol consumption and increased risk of cardiovascular disease, being significant factors in the development of heart disease. “Diabetes and cholesterol" also predispose to hypertension since type 2 diabetes is characterized by high blood sugar levels, and elevated HDL-C cholesterol levels that are associated with increased risk [5], [7]. In addition, studies such as [7], [8] point out that "demographic and genetic" characteristics increase the risk of hypertension. In [7], significant differences in diagnosis and risk factors for heart failure are identified according to sex, socioeconomic level and ethnicity. In [8], the influence of "genetics" in the development of hypertension is mentioned, mentioning that polygenic risk scores (PRS) based on genomic studies can effectively predict the probability of early hypertension. Thus, genetics emerges as a fundamental pillar in the understanding and approach to hypertension, contributing to a more holistic and tailored approach in the promotion of cardiovascular health.

B. *Monitoring Devices*

Four devices have been found to measure BP: wearables, conventional devices, smartphones and ultrasound machines. As for wearables in [9] an OMRON HeartGuide smartwatch was used comparing its accuracy with an A&D TM-2441 clinical device. In [10], a Samsung Galaxy Watch 3 and a blood pressure monitor were used, concluding in both studies that the differences between devices were not very significant and are acceptable versus sphygmomanometers. In addition, in [11], [12] smartphones and ultrasound were used. Using smartphones, BP is monitored by means of the oscillometric finger pressure technique. [11], where the user gradually presses while the phone measures the photoplethysmographic waveform (PPG) and the applied pressure, and then calculates the values. In addition, in [11] mentions that ultrasound is used to measure area and blood velocity in arteries such as the carotid artery to calculate BP.

C. Contribution of AI

Several AIs have been found that can contribute greatly to medicine. The most widely used are ChatGPT in all its generations in [13], [14], [15]; followed by GPT-4 in [15], [16], [17] and Google Bard in [17]. We are in an emerging generation of AI with great potential in all areas. Studies such as [13], [14], [15] mention that GPT can have a great impact on medicine if used correctly, demonstrating ability to provide information on a wide range of health topics, answer questions about prevention strategies and recommendations. As a result, more specific AIs focused on public health, such as Med-PaLM, are emerging. [15], integrated with Google Bard and oriented to excel in this field, although still under development.

D. Technological Solutions

There are several technological solutions to address this problem, the most widely used being "mobile applications" [18], [19], [20] and "smartwatch applications." [21]. Studies such as [22], [19] separated patients into two groups, one that used mobile apps to monitor BP and another with traditional follow-up. From this it is concluded that the use of mobile apps generated greater BP reduction, better medication adherence and moderate physical activity. In [20] the BP Journal app was used for medication monitoring and reminders in 11 patients between 43 and 74 years of age, who felt empowered by using it to control their BP. In [21], they developed a smartwatch app where the device was shown to be able to monitor patients' vital signs accurately, detect falls and other events reliably.

III. PROPOSED FRAMEWORK

In this section, we present the Framework for monitoring patients with hypertension, making use of IoT devices such as Smartwatches and artificial intelligence represented by GPT. This approach targets two key user groups: cardiologists and patients with hypertension. The process is divided into five phases (see Fig. 1).

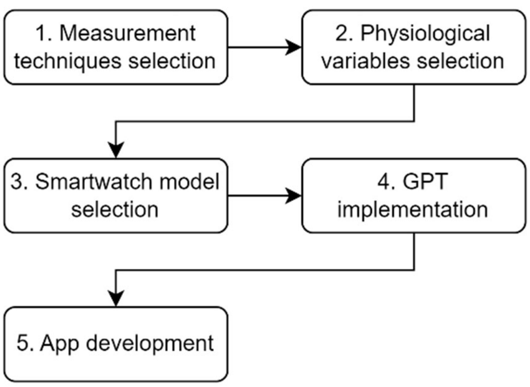


Fig. 1. Proposed framework

A. Selection of measurement techniques

In studies conducted to monitor hypertension, two types of measurements are often considered standard for medical centers around the world.

a) American Measurement: The American guidelines for the diagnosis of hypertension, published by the American College of Cardiology (ACC) and the American Heart Association (AHA), state that hypertension is diagnosed when a patient's systolic BP is greater than 130 mmHg and diastolic BP is greater than 80 mmHg. This is based on the average measurement from at least two different visits to the physician's office *[23]*.

b) European Measurement: The European guideline, developed by the European Society of Cardiology (ESC) and the European Society of Hypertension (ESH), states that hypertension is diagnosed when the patient has a systolic BP greater than 140 mmHg and/or a diastolic BP greater than 90 mmHg, as the American guideline is based on the average of several measurements taken on different occasions *[23]*.

In conclusion, these differences in measurements between the guidelines highlight the different findings and treatments of hypertension for each patient as appropriate. In Peru, the European guideline predominates as the most important, which is why it will be used as a reference in this study.

B. Selection of physiological variables

For the deployment of the mobile application, key variables relevant to the measurement of hypertension will be used. As part of the development process, the expertise of a cardiologist has been called upon to verify and determine the most used variables within the primary filter for the diagnosis of hypertension. The variables used in the study have also been considered. [5], [7], [8] and the classification of the variables: primary, secondary and tertiary. Table I shows the 16 selected variables grouped by type.

TABLE I. PHYSIOLOGICAL VARIABLES OF THE PATIENT

Variable type	Variables
Primary	Gender (F01), age (F02), weight (F03), height (F04), nationality (F05), systolic BP (F06), diastolic BP (F07) and HR (F08).
Secondary	Body mass index (F09), alcohol consumption (F10), tobacco consumption (F11), sedentary lifestyle (F12)
Tertiary	Diabetes (F13), Arrhythmia (F14), Asthma (F15)

C. Smartwatch Model Selection

For the selection of the smartwatch models applicable in the project, a Benchmarking of Smartwatches that can be purchased in Peruvian stores has been elaborated (see Table II). In order to know which devices are suitable, 8 main characteristics have been defined and by means of the Likert Scale have been evaluated (1 = "totally disagree", 2 = "disagree", 3 = "neutral", 4 = "agree", 5 = "totally agree").

According to the benchmark results, the "Samsung Galaxy Watch 5" and "Huawei Watch D" smartwatch models are the most accurate devices for calculating patient physiological data. Therefore, in this study, the "Huawei Watch D" will be used to integrate with the proposed mobile application.

TABLE II. BENCHMARKING DE SMARTWATCH

Features	**Apple Watch Series 7** [24]	**Huawei Watch D** **[25]**	**Huawei Fit 2** **[26]**	**Samsung Galaxy Watch 5** **[31]**
Usability	5	4	3	5
Practicality	5	4	3	5
BP measurement	4	5	1	5
HR measurement	4	5	3	5
Reliability	5	5	3	4
Comfort	5	3	4	3
Compatibility	2	5	5	3
Price	2	4	3	5
Total	4	4.38	3.13	4.38

D. Implementation of GPT

With the goal of achieving medical excellence and empowering patients, OpenAI's cutting-edge GPT technology has been incorporated in its latest version through an API [27]. This artificial intelligence, trained with large data sets, can individually analyze each patient's information and offer personalized recommendations according to their circumstances, to support medical diagnosis. In this way, a dual purpose is sought: to provide the patient with accurate and relevant information, while equipping medical specialists with data-informed diagnostic alternatives, enabling them to make informed decisions and prescribe the most appropriate treatments (see Fig. 2).

Fig. 2 shows the flowchart on how the use of the GPT API is applied in Smartbeat, which follows the following steps: (i) it starts with the application of a brief triage questionnaire to the patient and the collection of their physiological data in order to obtain relevant information prior to the medical consultation, (ii) through the use of an API, this data is sent along with a "prompt" specifically designed to facilitate the interaction with the GPT assistant, (iii) GPT is configured in the role of medical assistant and, by means of an OpenAI API key, queries and instructions inserted in the prompt are generated, (iv) in this way, GPT analyzes the information and provides an answer adjusted to the required variables and protocols, (v) in case the answer is directed to the patient, it presents recommendations to improve his health and treatment. If it is directed to the physician, it uses professional language to suggest possible symptoms, tests and measures to be taken for proper care.

Finally, the answers generated by GPT are sent to patients and physicians through the mobile application.

E. Application development

A mobile application was built that can record the medical history of the patient's blood pressure; this application is designed so that each BP recorded by the patient can be viewed by the patient's physician in the shortest possible time. The physical architecture of the system presents Bluetooth connectivity between the patient's mobile device and the smartwatch (see Fig. 3). Both patient and physician interact in the mobile application developed in flutter and with a microservices architecture coded in Node.js. These have an additional layer of protection (Gateway Layer) and individual PostgreSQL databases, reinforcing the robustness and responsiveness of the application.

In addition, regarding the flow, the practicality of the application has been considered so that patients of different ages can interact without difficulties. The flow of the application is as follows: (i) the patient performs a BP measurement assisted by his physician, (ii) the results are displayed including the hypertension classification, (iii) the physician can receive support from the assistant bot in case professional information is needed, (iv) the physician registers the medical prescription depending on the patient and (v) the physician follows up his patient.

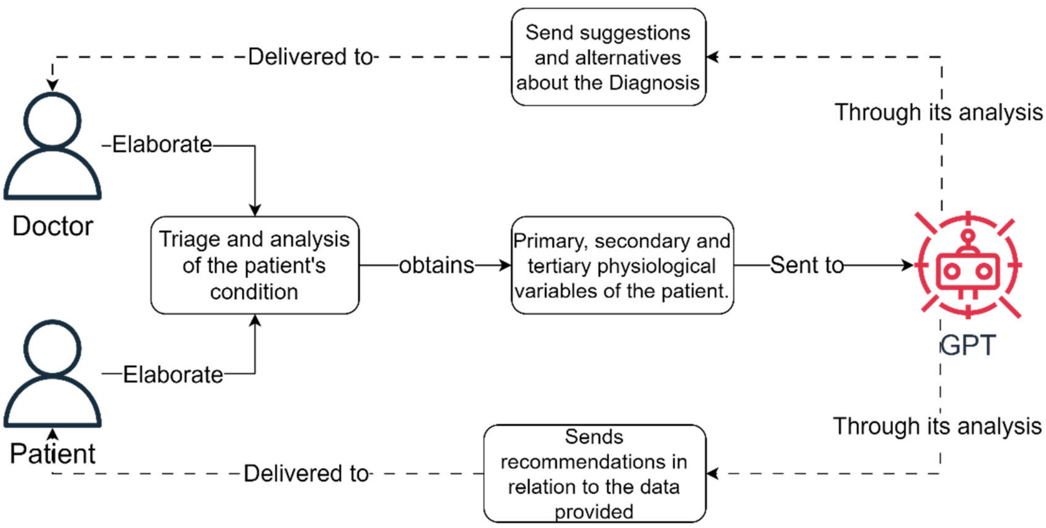


Fig. 2. Flowchart on the application of GPT in medical care

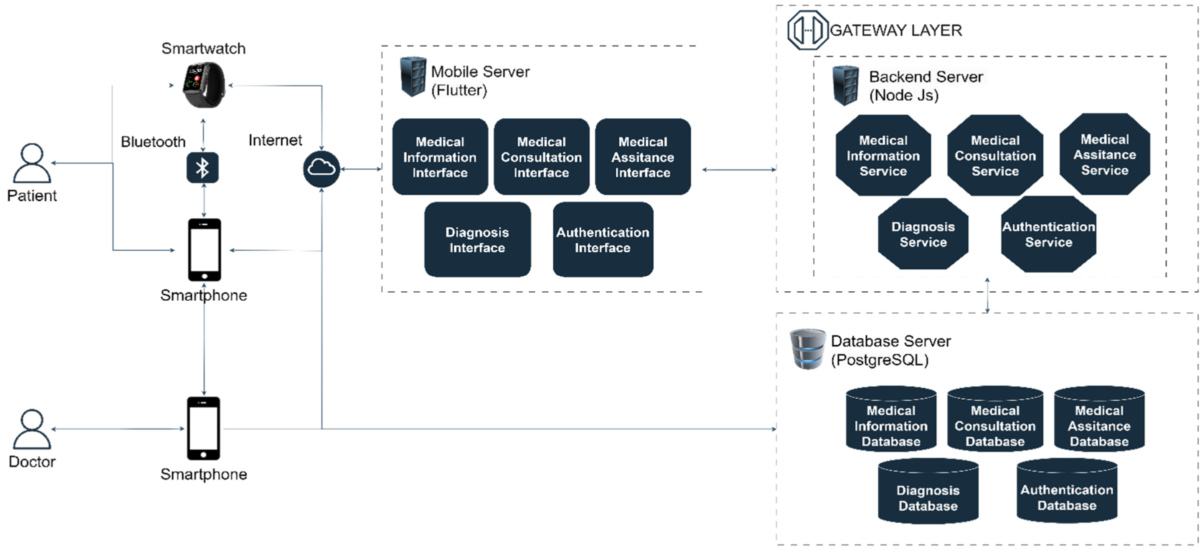


Fig. 3. Architecture physical

IV. VALIDATION

The validation of the study was performed in 3 private medical offices, located in the district of Lima, Lima province, Peru, with the participation of 3 cardiologists and 12 patients with arterial hypertension. The control experiment consisted of monitoring patients in the traditional way and the test experiment consisted of monitoring with the proposed SmartBeat application. Each experiment was performed in parallel with a duration of 2 weeks (see Table III). In addition, cardiologists and patients were surveyed to determine their perceptions of the quality of the mobile application.

TABLE III. EXPERIMENTAL SCENARIOS

Experiment	Scenario	Participants	Metrics
1 (Control)	Monitoring with the traditional method	3 cardiologists 6 patients	*TMR*: Time it takes for the physician to measure and record BP and HR *TMD*: Time it takes for the physician to make a diagnosis during the session.
2 (Test)	Monitoring with SmartBeat	3 cardiologists 6 patients	

A. Experiment 1: Traditional method

The methodology used consisted of 4 steps: (a) taking BP and HR measurements 3 consecutive times and averaging the results to obtain a diagnosis, (b) recording patient symptoms and pathologies, (c) providing recommendations according to the results obtained, and (d) determining medication (if necessary) and next appointment according to patient severity (from 2 weeks to 1 month for mild cases or once a week for severe cases). At the end of the experiment, a meeting was held with the participants through a videoconference on Google Meet to learn about the experience throughout the whole process of experiment 1.

B. Experiment 2: Proposed SmartBeat application

In this experiment, hypertension monitoring was performed using SmartBeat. For this, the following activities were followed: (a) contextualization of the solution, (b) installation and configuration of SmartBeat in the cardiologist and patient devices, (c) synchronization of the specialist and patient accounts, and (d) training and use of the application.

a) Contextualization of the solution: This process begins with the introduction of the application and high-level explanation of each of the processes that users can perform with SmartBeat.

b) Installation and configuration of SmartBeat on physician and patient devices: The beta version of SmartBeat was shared with each of the participants along with the installation guide of the application on a smartphone. Then, the creation of user accounts and the configuration of personal data within the application were carried out.

c) Synchronization of specialist and patient accounts: With the accounts already created, cardiologist were taught how they could synchronize their patients' accounts with their own. This is so that each patient has an assigned physician who will be in charge of the follow-up during the experimentation stage.

d) Training and use of the application: This process began with the explanation of the flow of the application to perform a medical consultation. Then, each of SmartBeat's functionalities was described step by step. Up to this point, the patient could already record his own HR and BP measurements (Fig. 4(a)), and make use of the assistant bot to know his current status (Fig. 4(c)). The cardiologist continuously monitors the report of the events recorded by his patients (Fig. 4(f)), as well as the summary graphs of the measurements of their physiological variables: HR, BP and hypertension level. Also, physicians could already make a diagnosis in the application (Fig. 4(d)). Finally, for patients on medication, they could now locate their diagnosis along with their medical prescription with data such as medication, form of consumption and frequency of intake (Fig. 4(e)).

C. *Expert judgment*

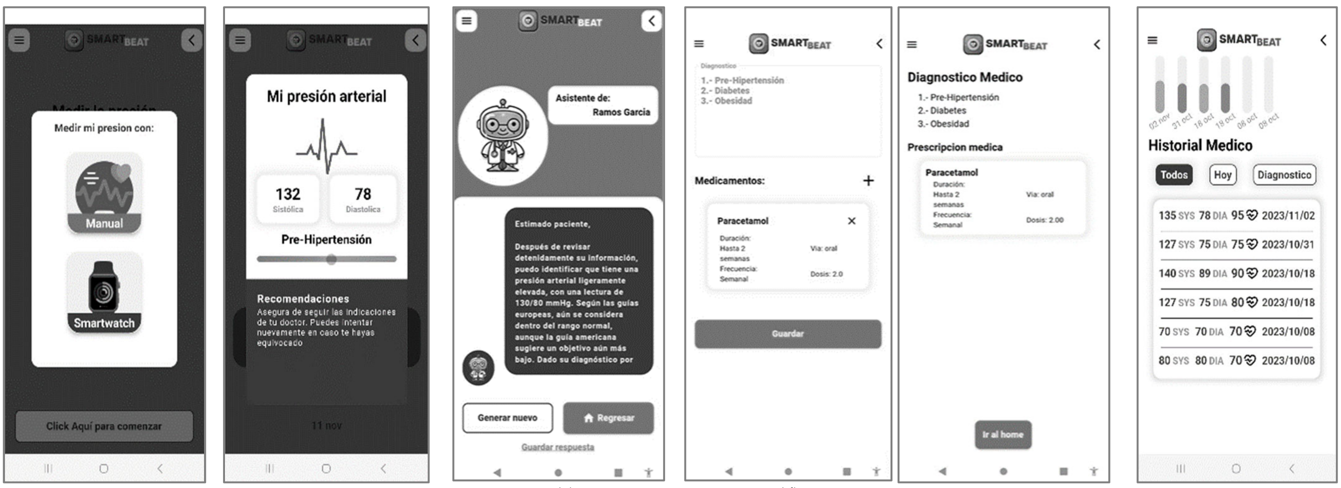
At this stage, 3 activities were carried out with the same participants: (a) explanation of the validation dynamics, (b) development of a survey for cardiologists, and (c) a survey for patients. Through a Google Meet videoconference, the dynamics were explained, and the questionnaires were shared via Google Forms. The survey for specialists consisted of 13 closed questions (see Table IV), while the patient survey had the same structure (see Table V). A Likert scale from 1 to 5 was used (1= "strongly disagree", 2= "disagree", 3= "neutral", 4= "agree", 5= "strongly agree").

TABLE IV. QUESTIONS FOR CARDIOLOGISTS

Category	ID	Question
Usability	Q01	What aspects of the application did you find most helpful in treating your hypertension?
	Q02	Was it easy to navigate the app and access the features relevant to hypertension monitoring?
	Q03	Was there any aspect of the application that you found difficult to use or understand?
Efficiency	Q04	Did you notice increased efficiency in medical consultation due to the information collected and presented by the application?
	Q05	Did you feel that the application helped you make more informed and efficient decisions during your consultation?
User experience	Q06	How would you describe the convenience and ease of use of the continuous hypertension monitoring process in the app?
	Q07	Did you feel that the continuous hypertension monitoring provided by the app was more convenient than the traditional method?
Integration in medical care	Q08	How do you perceive that the application has influenced your hypertension management and adherence to treatment?
	Q09	Do you feel that the application has provided you with useful information to better understand your condition and make decisions about your health?
Communication with patients	Q10	How do you perceive that the application has influenced your hypertension management and adherence to treatment?
	Q11	Have you felt that the application facilitates communication with your physician and allows you to address your concerns more effectively during consultations?
Satisfaction and recommendation	Q12	How would you rate your level of satisfaction with the hypertension management application?
	Q13	Would you recommend this application to other cardiologists treating patients with hypertension? Why?

TABLE V. QUESTION FOR PATIENTS

Category	ID	Question
Usability	Q01	What aspects of the application did you find most helpful in treating your hypertension?
	Q02	Was it easy to navigate the application and access the functions relevant to hypertension monitoring? Why?
	Q03	Was there any aspect of the application that you found difficult to use or understand?
Efficiency	Q04	Did you notice increased efficiency in the medical consultation due to the information collected and presented by the application?
	Q05	Did you feel that the application helped you make more informed and efficient decisions during your consultation?
User experience	Q06	How would you describe the convenience and ease of use of the continuous hypertension monitoring process in the app?
	Q07	Did you feel that the continuous hypertension monitoring provided by the app was more convenient than the traditional method?
Integration in medical care	Q08	How do you perceive that the application has influenced your hypertension management and adherence to treatment?
	Q09	Do you feel that the application has provided you with useful information to better understand your condition and make decisions about your health?
Communication with cardiologists	Q10	How has the information provided by the app impacted your hypertension-related medical consultations?
	Q11	Have you felt that the application facilitates communication with your cardiologist and allows you to address your concerns more effectively during consultations?
Satisfaction and recommendation	Q12	How would you rate your level of satisfaction with the hypertension management application?
	Q13	Would you recommend this application to other patients with hypertension?



(a) (b) (c) (d) (e) (f)

Fig. 4. Graphical interface of the application

V. Results

A. Experimentation

Table VI and VII show the details and summary of the metrics calculated in both experiments.

TABLE VI. DETAILS OF EXPERIMENTS 1 Y 2

Experiments	Patients	TMR (minutes)	TMD (minutes)
1	1	1.5	8
	2	1.4	10
	3	1.5	10.5
	4	1.3	7
	4	1.5	8.5
	5	1.4	10.5
	6	1.4	8
2	1	0.9	1.8
	2	0.8	2.2
	3	0.9	1.9
	4	0.8	1.6
	5	0.8	1.8
	6	0.9	2.5

TABLE VII. SUMMARY OF EXPERIMENTS 1 Y 2

Experiments	*TMR*	*TMD*
Without the System	1.5 minutes using a sphygmomanometer and a medical chart	10.4 minutes to collect information from different sources
With the System	0.9 minutes using a smartwatch	1.9 minutes using the AI assistant bot

Evaluating both experiments, it is evident that the TMR without the system lasted approximately 1.5 minutes, while with the solution it was reduced to 0.9 minutes. Likewise, the TMD without the system took 10.4 minutes, with the system the same result was achieved in 1.9 minutes, optimizing the time by 80%. In conclusion, the solution substantially reduced the time to measure and record physiological signs and medical diagnosis, improving the efficiency of the consultation for physicians and the patient experience.

B. Expert judgment

Fig. 5 shows the results obtained from the questions asked to the three cardiologists (E1, E2, E3), grouped into six categories (usability, effectiveness, user experience, integration into medical care, communication with patients, satisfaction and recommendation).

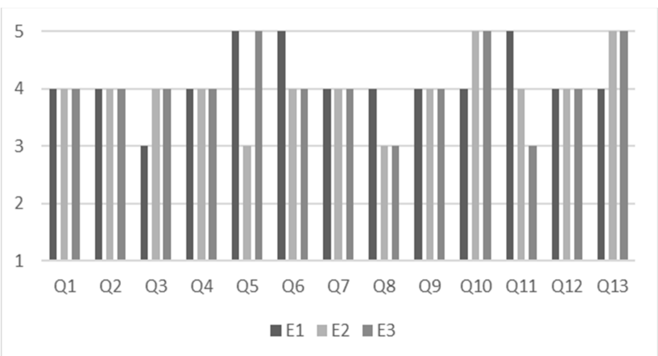


Fig. 5. Summary of experts responses

The results show that on average "usability" has a value of 4.0, "efficiency" a value of 4.2, "user experience" 4.2, "integration into medical care" 3.7, "communication with patients" a value of 4.3 and "satisfaction and recommendation" a value of 4.3.

On the other hand, Fig. 6 shows the results obtained from the questions asked to the six patients (P1, P2, P3, P4, P5, P6), grouped into six categories (usability, effectiveness, user experience, integration in medical care, communication with physicians, satisfaction and recommendation).

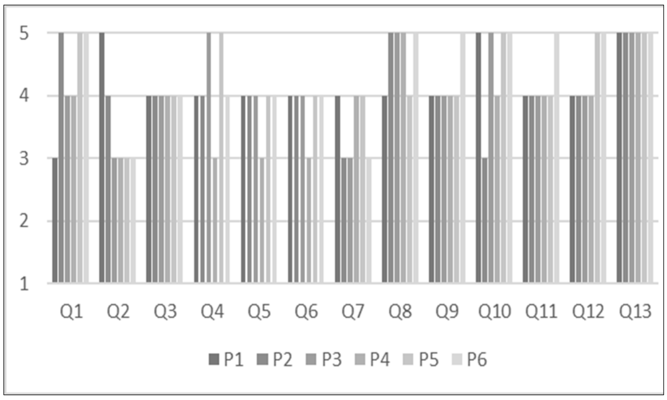


Fig. 6. Summary of patient responses

The results show that on average "usability" has a value of 3.9, "efficiency" a value of 4.0, "user experience" 3.7, "integration into medical care" 4.4, "communication with physicians" a value of 4.3 and "satisfaction and recommendation" a value of 4.7.

VI. Conclusion and Future Works

In the present study, we proposed a framework for the construction of a mobile application (SmartBeat) that helped physicians to manage their hypertensive patients more efficiently using a smartwatch and GPT AI by centralizing all the information needed during the medical consultation in a single application. To this end, five phases were defined: (1) selection of measurement techniques, (2) selection of physiological variables, (3) selection of the smartwatch model, (4) implementation of GPT and (5) development of the mobile application. Sixteen physiological variables were defined based on cardiologists' experience.

To validate the study, two experiments were carried out in three private practices in Lima, Peru, with the participation of three cardiologists and twelve patients. In the control experiment, hypertension was monitored in the traditional way by the physicians. For the test experiment, SmartBeat was used in the following steps: (1) contextualization of the solution, (2) installation and configuration of SmartBeat in the physician and patient devices, (3) synchronization of the specialist and patient accounts, and (4) training and use of the application.

The results showed that SmartBeat obtained positive results for each of the indicators: TMR was 44.44% faster and TMD 80% more efficient compared to the traditional method.

The survey results showed that patients rated SmartBeat with usability, effectiveness, user experience, integration into medical care, physician communication, satisfaction, and recommendation characteristics with a mean of 4.2 ("agree"). And cardiologists with a mean of 4.1 ("agree”).

For future work, we plan to use technologies with greater and updated capabilities such as new IoT devices and Artificial Intelligence that can have greater capabilities than GPT-4. Also, through the same surveys, all our users have been asked for new features that can improve SmartBeat to better meet the hypertension treatments and generate a positive change in society.

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