BPcontrol

A Mobile App to Monitor Hypertensive Patients

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Summary

Background: Hypertension or high blood pressure is on the rise. Not only does it affect the elderly but is also increasingly spreading to younger sectors of the population. Treating this condition involves exhaustive monitoring of patients. The current mobile health services can be improved to perform this task more effectively.

Objective: To develop a useful, user-friendly, robust and efficient app, to monitor hypertensive patients and adapted to the particular requirements of hypertension.

Methods: This work presents BPcontrol, an Android and iOS app that allows hypertensive patients to communicate with their health-care centers, thus facilitating monitoring and diagnosis. Usability, robustness and efficiency factors for BPcontrol were evaluated for different devices and operating systems (Android, iOS and system-aware). Furthermore, its features were compared with other similar apps in the literature.

Results: BPcontrol is robust and user-friendly. The respective start-up efficiency of the Android and iOS versions of BPcontrol were 2.4 and 8.8 times faster than a system-aware app. Similar values were obtained for the communication efficiency (7.25 and 11.75 times faster for the Android and iOS respectively). When comparing plotting performance, BPcontrol was on average 2.25 times faster in the Android case. Most of the apps in the literature have no communication with a server, thus making it impossible to compare their performance with BPcontrol.

Conclusions: Its optimal design and the good behavior of its facilities make BPcontrol a very promising mobile app for monitoring hypertensive patients.

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1.Background

Hypertension is one of the most important risk factors in cardiovascular diseases, the leading cause of death worldwide [1]. It affects about 20% of the adult population, a percentage that increases with age [2]. Uncontrolled hypertension is an ongoing challenge to health care systems worldwide [3].

Home Blood Pressure (*HBP*) monitoring consists of patients taking readings at home and registering these using a digital device. Then, the patients send the readings to a health professional who is responsible for taking appropriate action [4, 5, 6].

Information and Communication Technology (ICT) applied to *HBP* can play an important role [7, 8]. However, the difficulty of ensuring satisfactory monitoring of blood pressure is still a great challenge [9, 10].

There is a potentially important role for novel techniques to lower blood pressure, especially in primary health care, where the management of hypertension mainly takes place [11]. In a recent scientific article, the American Heart Association concluded that *HBP* monitoring should become a routine component of blood pressure measurement in the majority of patients with known or suspected hypertension [6]. One *HBP* approach is patient self-management, defined as the ability and willingness of a patient to monitor him- or herself. Some studies have shown that self-management blood pressure monitoring is at least as good as, if not better than, office-monitoring of blood pressure [1, 12].

A comparison between 20 web sites (free to try from a total of 60), used to manage and present HBP readings was carried out between June and August 2009 [13]. The results showed that none of these 20 web sites were directly linked to common electronic medical records. Despite web sites having alert values, none of them provided any tools for sending alert messages to patients in any format, i.e. to telemonitor them.

Encouraging results where obtained in a phone-based system for monitoring hypertension in diabetic patients that provided an automatic BP alert to patients [3]. In the pilot study with 33 patients, 24-h ambulatory BP fell by 11/5 (±13/7 SD) mm Hg, more home readings were received by the server than expected, and 42 BP alerts were sent to patients. Medication adherence was measured before and after using a hypertension management app for 4 weeks with 38 patients [14]. The perceived usefulness score was 3.7 out of 5. However, apps that only track and report data may be insufficient, as they often have low reuse rates. BP telemonitoring combined with self-care support reduced the BP of diabetic patients with uncontrolled systolic hypertension and improved hypertension monitoring [15]. Telemonitoring consisted of a BlackBerry smartphone paired with a Bluetooth-enabled home BP monitoring device. BP readings were automatically transmitted by the smartphone to the application servers, alerting patients with a self-care message to their screens. In another study [16], the patients suggested that health care partnerships need to be incorporated to engage and retain users. The state of the art of mobile medical and health apps was recently examined [17]. They concluded that apps may have deficiencies and limits and disparities in health and low health literacy may negatively affect use. Getting users to download and engage with mobile apps is an art [18]. Furthermore, many smartphone apps are not based on behavioural change theories or guidelines (where these could make a significant, positive difference, if implemented) [19]. Recently [20], a study of a wide range of hypertension self-management apps showed that only 3% of the apps were developed by healthcare agencies, such as universities or professional organizations. None of these apps employed the use of a BP cuff or had any documentation of validation against a gold standard.

A preliminary web-based server, called SHUITE (Simple Health Universal and Integral Treatment Environment), that supported monitoring of hypertensive [8] and tobacco-quitting [21] patients by sending SMS messages was developed by our research group. The ability to perform bidirectional communication between patients and clinicians made the proposal innovative and a very useful tool for hypertension and tobacco-quitting patients. Furthermore, the framework was moved into a real-world cloud environment. Efforts were made to design a scalable framework when increasing the number of hospitals (thus increasing the number of both patients and clinicians).

Further research investigated the addition of new features. The most important one was to provide good response time of the SHUITE-server [22, 23, 24], in other words, ensuring that service requests should be performed in a predetermined time.

In the present work, we go one step further. We provide access to standard medical records and allow physicians to monitor and communicate with patients by means of a mobile app (BPcontrol).

2. Objective

Our aim was to design an HBP app to be used in monitoring hypertensive patients. In this paper, we present BPcontrol, a useful, robust, user-friendly and efficient app for monitoring hypertensive patients. The app named BPcontrol was developed by the Hesoft Group in collaboration with the University of Lleida, and the Android version can be freely downloaded from Google Play. It communicates with a server called SHUITE (Simple Health Universal and Integral Treatment Environment), tasked with hosting patient and clinical information. Patients can send their measurements to their clinicians via BPcontrol. Clinicians thus have electronic medical records for their patients in SHUITE, monitor their blood pressures automatically, can visualize useful data in a user-friendly way and check their statistical evolution in a web-based environment.

BPcontrol extends the SHUITE services, adding the ones most widely used in smartphones, such as instant messaging (chat). Taking advantage of the available technology, a mobile application was developed for use in smart phones and that provides different features to enable patients to participate actively in monitoring their disease. Hence, patients can check different charts, see their evolution and communicate with the medical team in real time. Moreover, the application also implements a notification system to alert patients that they are outside their blood pressure range. This comprehensive and personalized monitoring has the potential to minimize the risk of heart attacks and significantly reduce the costs associated with traveling, while increasing the number of patients with effective and accurate monitoring.

The research challenge of this work is to design and implement an app with enough robustness, usability and efficiency. To succeed, we must provide adequate architecture for BPcontrol and efficient operation and communications with the SHUITE server.

3. Methods

3.1 BPcontrol

BPcontrol is designed to upload pressure readings to a server (SHUITE) and visualize them later, at the user's will. Thus, it is necessary to communicate and synchronize BPcontrol and SHUITE.

Algorithm 1: BPcontrol-SHUITE.

```
do
        BPcontrol:
        Collect MorningPressures
        Send EveningPressures
        Send MorningPressures & EveningPressures to SHUITE
        SHUITE-server:
         PressuresAverage = Average(MorningPressures, EveningPress-
        ures)
        Compute HealthStatus
        Store PressuresAverage & HealthStatus in SHUITE's DB
             Answer=HealthStatus
        if HealthStatus == bad then
        Answer = Answer & Video
        end if
        Send Answer to BPcontrol
        BPcontrol:
        Show BP.HealthStatus
        if BP.HealthStatus == bad then
             Store Video in app's BD
        end if
while !Exit
```

The BPcontrol-SHUITE operation (Algorithm 1) presents the BPcontrol and SHUITE communication protocol. For a graphic explanation, see also ▶Figure 1. Patients add two different sets of readings per day to BPcontrol, three morning readings and three evening readings. The last two morning and evening samples are delivered to the SHUITE by the patient. Then, the SHUITE computes the average of the readings (*PressuresAverage*) for the diastolic and systolic measures and the patient's *HealthSatus* (bad, regular or good) and saves them in the SHUITE's DB. Clinicians can assign different reference blood pressures to each patient, depending on their particular health conditions. The respective default values are 90 for the diastolic and 140 for the systolic pressure. If *PressuresAverage.sistolic* (or *PressuresAverage.diastolic*) minus the systolic (or diastolic) reference of each patient is between [+5,-5], the status (*HealthStatus*) of the patient is considered good (*HealthStatus*=good); between [+10, –10] regular and higher range values, bad. Then, SHUITE responds to the mobile app with another message (*Answer*). If the status obtained is bad, the physician can suggest the patient to make an appointment with a specialist and attach a counseling video. The video will be saved in the app DB (*SQLite*) so that the patient can see it whenever he/she wants. It should be noted that this response does not contain a video when the readings are considered regular or good.

3.1.1 BPcontrol Design

Currently, there are many alternative technologies for developing applications for mobile devices.

The first app developed by our group was called BP. This was implemented using HTML, CSS, Javascript, JQuery Mobile and *PhoneGap*, an open-source tool for creating cross-platform apps. An important design requirement was that the application should be compatible with all the major platforms. So, we decided to use the PhoneGap framework.

Important design decisions were adopted, and these are still unchanged in newer implementations. The possibility of including push notifications to the application, required to register in any of the companies that offer it as a free service (Push Woosh, Urban Airship, Push Bots, AeroGear, etc.), was ruled out. These free services usually have restrictions on their use and we do not wish to depend on third-party servers to implement the notification system. It was therefore decided to use the local notification system provided by PhoneGap. However, the poor response time provided by BP was an important drawback. Native mobile apps provide fast performance and a high degree of reliability. So, BPcontrol, a newer version of BP, was developed as a native Android and iOS app. The

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Android app was implemented using the principal language for Android: Java. XML was also used for the user interface. In the case of the iOS version, the languages used were Objective-C and C. BPcontrol uses an internal notification system that does not depend (as in the BP case) on any third-party notification system.

The main drawback of native apps is their expense compared with hybrid apps (i.e. made with PhoneGap), because they need to be developed for each native platform.

Various design patterns, such as Model-View-Controller, were used to implement BPcontrol. The SQLite database (DB) was used to store readings and video links, and the framework used for network connectivity was *Google Volley* in Android and *AFNetworking* for iOS.

Information is retrieved from the SHUITE through connections established by web services from the BPcontrol. This ensures low data capacity requirements and avoids legal problems regarding the privacy of medical data. For example, the patients' records are only stored in the SHUITE server, and not in each individual smartphone. However, this introduces a low penalty in obtaining the required information remotely, although it does not significantly affect the user interactivity. We created ad-hoc web services, which are used to exchange data in the *JSON* format between the clients (BPcontrol instances) and the server (SHUITE).

3.1.2 BPcontrol Features

There is no need to register to access the main BPcontrol window (▶Figure 2a). The start button at the bottom enters the patients into the private area (▶Figure 2b). If the patient is registered on the SHUITE server, he/she can then register the application with their phone number. Additional buttons provide information about BPcontrol, collaborating hospitals (i.e. with SHUITE and BPcontrol support) and contact details.

To access the private area, new users must first register in the BPcontrol by providing the country prefix and phone number, which is then verified on the SHUITE DB. Once registered, the patients are allowed to access the patients' area.

The first time the user enters the application, the reference time is set. Regular notifications to the patient start from then. If the patient has weekly monitoring, notifications are sent every Wednesday at 8:00 and 21:00. For biweekly monitoring, notifications are sent on the 1 and 15 of each month at 8:00 and 21:00.

The main features provided by BPcontrol are explained in ▶Table 1. The main features of BPcontrol (uploading and consulting readings, geolocation, as well as the chat) are explained separately below.

3.1.3 Uploading Readings

Two readings (taken with the patient's own device in the morning and evening) can be introduced (▶Fig. 5b). Pressing any of the three boxes displays a selector for the measurements to be introduced, these being the systolic and diastolic pressures and pulse. The readings are sent if the pressures and pulse are within a specified range[1]. Users then send the two readings to the SHUITE server. The application also helps the patients with useful advice.

Once the blood pressures and the pulse have been sent, the app immediately shows the results of the analysis (processed on the SHUITE server and returned to the app) through a traffic light indicating the status of the patient. In addition, a short message (and occasionally videos) with medical advice is sent.

There are three possible status (light colors) and three associated messages:
1. Good (green). Everything was fine. Remember to keep measuring and sending your pressures.
2. Regular (yellow). Do not forget, salt-free diet. Remember to take the medication and do some physical activity.
3. Bad (red). We have seen your records. Do not worry. We will contact you to bring your next clinical appointment forward.

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[1] Systolic pressure must be in the range [50-250] mm/Hg, diastolic pressure between [30-130] mm/Hg and pulse between 10-200 bpm [25].

All previous lights (and messages) are easily accessible from the main menu, as are the explanatory videos.

3.1.4 Consulting Readings

BPcontrol can show a graphic evolution of the patients' measurements. Different types of visualization can be chosen. By clicking *global*, the plot of the blood pressures (▶Fig. 3a) appears. The *morning* and *evening* buttons separate the samples by these periods of the day. Start and finish dates can be selected. Alternatively 1, 3 and 6 months selectors are available and patients can also select custom dates. It is also possible to access a numerical list containing the overall pressures and pulse rates (▶Fig. 3b). The *MPAndroidChart* library has been used to implement the graphic-evolution charts in the Android version.

3.1.5 Geolocation

BPcontrol shows the distance from the patient's current position (i.e. smartphone with BPcontrol installed) to any of the centers associated with the application. The health centers are displayed by order of distance (▶Figure 4a). This way, the user can choose the nearest center.

Once a center has been chosen, an inbuilt Google Maps API shows the shortest way from the patient's current position (▶Figure 4b) to the center by car. There are two buttons with direct access to Google Maps and Navigation apps.

3.1.6 Chat

The application also has a chat window (▶Figure 5a) that enables patients to contact the medical team that monitors their blood pressure. Whenever required, a patient can easily ask the doctor a question and, in return, the doctor's response will appear in the same application window (i.e. the chat one).

3.2 Analysis

The robustness of BPcontrol was firstly measured. The usability and efficiency of BPcontrol and BP apps was tested. BP is a previously implemented platform-aware app. BP was implemented using PhoneGap, which allows it to be executed in Android and iOS.

To make a rigorous evaluation of the application **robustness**, we used a tool that allows control of the crashes that occur when using the application. This tool is called *Crashlytics*. This tool lets you control the users who are active in real time, sending customer betas and providing exhaustive information about crashes when they occur, among other things.

To measure the **usability**, a BPcontrol test was performed with 20 randomly chosen users (students, teachers and clinicians). Changes performed following to their observations made BPcontrol a great user-friendly app. People had to perform various actions within the app, such as introducing pressures, looking up directions to a hospital with no prior experience with BPcontrol. They also rated the user experience of BPcontrol and BP between 1 and 5.

The **efficiency** of BP was compared with that of the native one presented in this article, BPcontrol (implemented in the Android and iOS operating systems). The devices (and their operating systems and versions) used were Samsung Galaxy S2 (Android v. 4.2.2), Samsung Galaxy S3 (Android v. 4.3), Nexus 5 (Android v. 5.1.1), Ipad 2 (iOS v. 8.4) and Iphone 6 (iOS v. 8.4).

The efficiency parameters measured were **start-up**, **communication** and **plotting**. The **start-up** is defined as the elapsed time for an app to start. The **communication** between an app and SHUITE is defined as the mean response times from clicking the send button when delivering the measurements from the app to SHUITE to obtaining its response. This operation ends when control over the video included in the response is obtained. The **plotting** is defined as the elapsed time for drawing a chart on the mobile screen. These times were the average of 3 different measurements. Times below one second guarantee that the user's train of thought remains uninterrupted [26].

4. Results

4.1 Robustness

Crashlytics detected a total of 106 crashes during the debugging period of BPcontrol (2 months). Most of them were produced when loading data (30%), locating centers (14%) and drawing charts (35%). Today, the app is almost crash-free.

4.2 Usability

The first 10 users who evaluated the BPcontrol app introduced an average of 2 suggestions each, the next 5 only 1 and the remaining ones did not recommended any changes. The user experience of BPcontrol was, on average, 4.5 and 3 for BP.

4.3 Efficiency

Firstly, we evaluated the **start-up** efficiency (▶ Table 2). In the Android case, BPcontrol was, on average, 2.4 times faster than BP. In absolute time, this represents a difference of 5 secs. The iOS version was 8.5 times faster. In this case, the time difference reached 8 seconds. The cross-reference APIs used by PhoneGap introduced a considerable penalisation in the BP execution time. iOS behaved better than Android basically because its processors are much faster. The devices and operating systems used to evaluate the start-up of BP and BPcontrol are listed in ▶ Table 2.

▶ Table 3 shows an analogous to the one above measuring the **communication** between BPcontrol and SHUITE. For the Android case, BPcontrol was, on average, 7.25 times faster than BP. In absolute time, this represents a difference of 8 secs. The iOS version was even faster, specifically 11.75 times. In this case, the time difference reached 11 seconds. These results emphasized the usefulness of native apps.

▶ Table 4 shows the same experiments as before in obtaining the times by **plotting** the 6-month graphic. For the Android case, BPcontrol was on average 2.25 times faster than BP. In absolute time, it represents a difference of 3 secs. On this occasion, iOS was not applied due to the difficulty of finding an iOS library with similar performance to that used with Android. These results emphasized the usefulness of Android apps.

4.4 Feature Comparison

BPcontrol provides logging, charting, reports, tips and advice, as do such existing hypertension apps as *BP Lite*, *iBP*, *IBPTouch*, *BPMonitor*, etc (all can be purchased at the app Store). In the Google Play Store, one can also find Android apps like *iCare BP Monitor*, *BP Watch*, *Finger BP Prank*. All the apps for both operating systems offer the self-monitoring features, reading sampling, alerts, charts and so on. However, none of them provides support of a physician, chat between physician and patient or broadcasting communication among a group of patients. ▶ Table 5 shows a comparison of the main features provided by these apps.

5. Discussion

BPcontrol offers the main services the physicians of a medical center require from a hypertension app. As shown in the Results section, BPcontrol is robust and user-friendly. In general, user experience was better when using the native development. Regarding start-up efficiency, Android and iOS were respectively 2.4 and 8.8 times faster than BP. In addition, good efficiency when communicating with the SHUITE server and requesting a response from it, was obtained in the native apps. BPcontrol response time were 7.25 times faster in Android and 11.75 in iOS than the system-aware BP App. When comparing plotting performance, BPcontrol was on average 2.25 times faster than BP in the Android case. Native apps take advantage of the features and services the operating system offers apps, such as efficient access to GPS, quick loading, fast screen refreshing and so on. In general, the

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native versions were between 2.25 and 11.75 times faster than the PhoneGap ones for both smartphones and tablets. As a concluding remark, PhoneGap operation is smooth with high response times, while in native apps, the sense of navigation is very reactive, fluid and the response time to user interaction is very fast. According to the results, it can be seen that the performance difference between native apps and PhoneGap is very significant.

On the other hand, it is difficult to compare performance with other apps in the literature because each offers different features. Most of them have no connections with a server. BPcontrol is characterized by having a local database, but it is constantly synchronized with the server. Thus, BPcontrol never losses data due to malfunctions in the mobile because new data is constantly stored in the SHUITE-server DB. However, higher performance can be reached by the apps that do not communicate with any server. BPcontrol downloads and uploads data for at most 5 seconds. In addition, synchronization is performed asynchronously during BPcontrol operation. The other apps have no connection to servers and therefore do not communicate with any server, so the user can use the apps immediately without time penalties. However, these penalties in BPcontrol are imperceptible to the final users and we can assure that will never lose information, at the expense of somewhat lower performance.

The usability evaluations were very subjective, depending heavily on the people who carried out the test. The tool evaluation was carried out with users who may be potential patients. Adherence should be measured in a further study.

6. Conclusions

This article presents a mobile App, called BPcontrol, to monitor hypertensive patients. The study analyzes the different technologies and provides an overview of the possible architectures for use in this area. In addition, the mobile App integrates with other services provided by the SHUITE server through web services, increasing its flexibility and functionality. BPcontrol was implemented using Android in a native development framework. We can assure that BPcontrol is a robust app. This native version was compared with another implementation, called BP, implemented previously with a very suitable framework for cross-platform applications, PhoneGap. We tested the efficiency of the native and PhoneGap versions with the Android operating system for both smartphones and tablets. In general, the native versions were between 2.25 and 11.75 timesfaster than the PhoneGap ones for both smartphones and tablets. The user experience was also better when using the native development. Developers must use native APIs instead of Phonegap, unless multiplatform is a hard restriction. Overall, the robustness, usability and efficiency of BPcontrol are very good. It was shown that it can be successfully deployed in medical centers to keep track of hypertensive patients.

Conflicts of Interest
The authors declare no conflict of interest.

Protection of Human and Animal Subjects
Due to the non-hazardous and voluntary nature of the study, no protocols were set in place to protect human subjects. Participation was anonymous, voluntary, and non-remunerated. Withdrawal of their data from the study by the volunteers was possible at any stage of the process, up to 15 days after they concluded the survey.
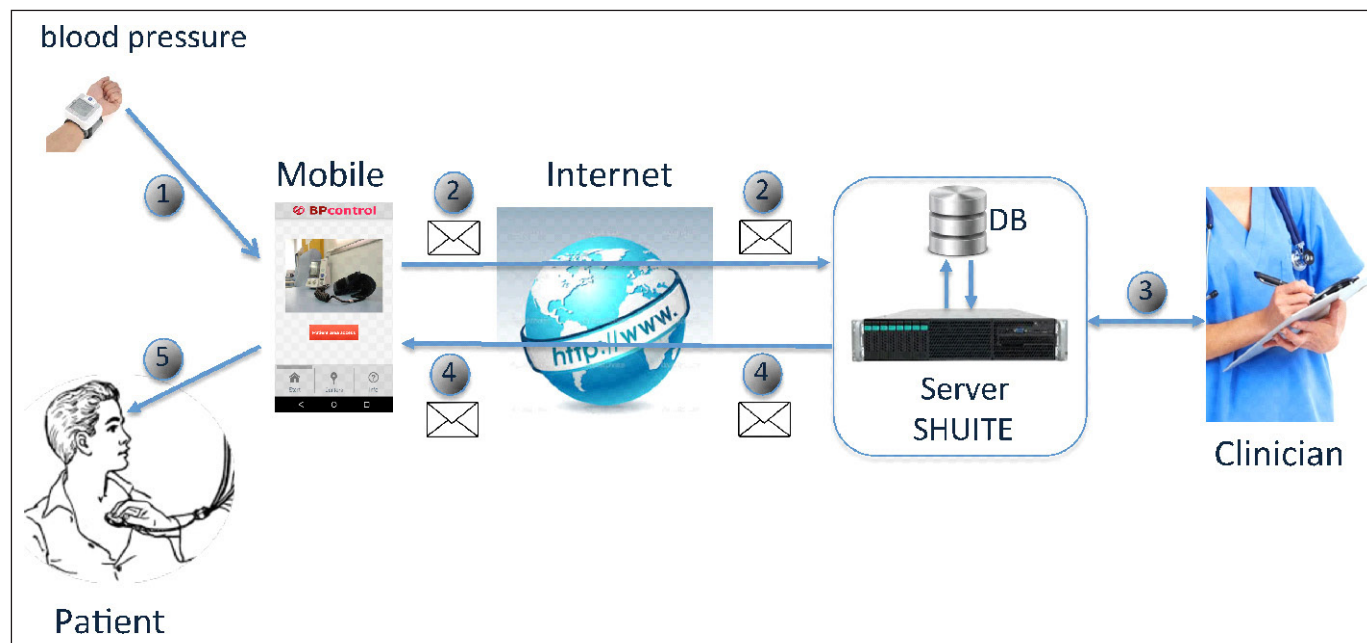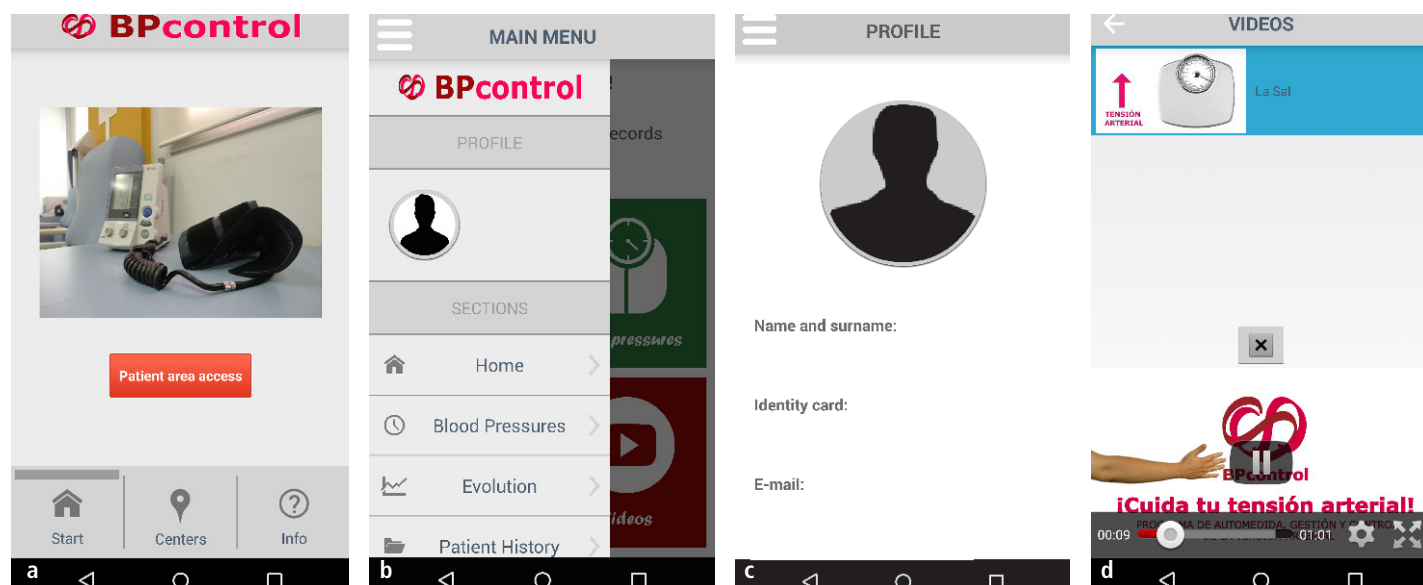
Fig. 1 BPcontrol operation

Fig. 2 BPcontrol Features. a) Main window b) Menu c) Patient's Profile d) Videos
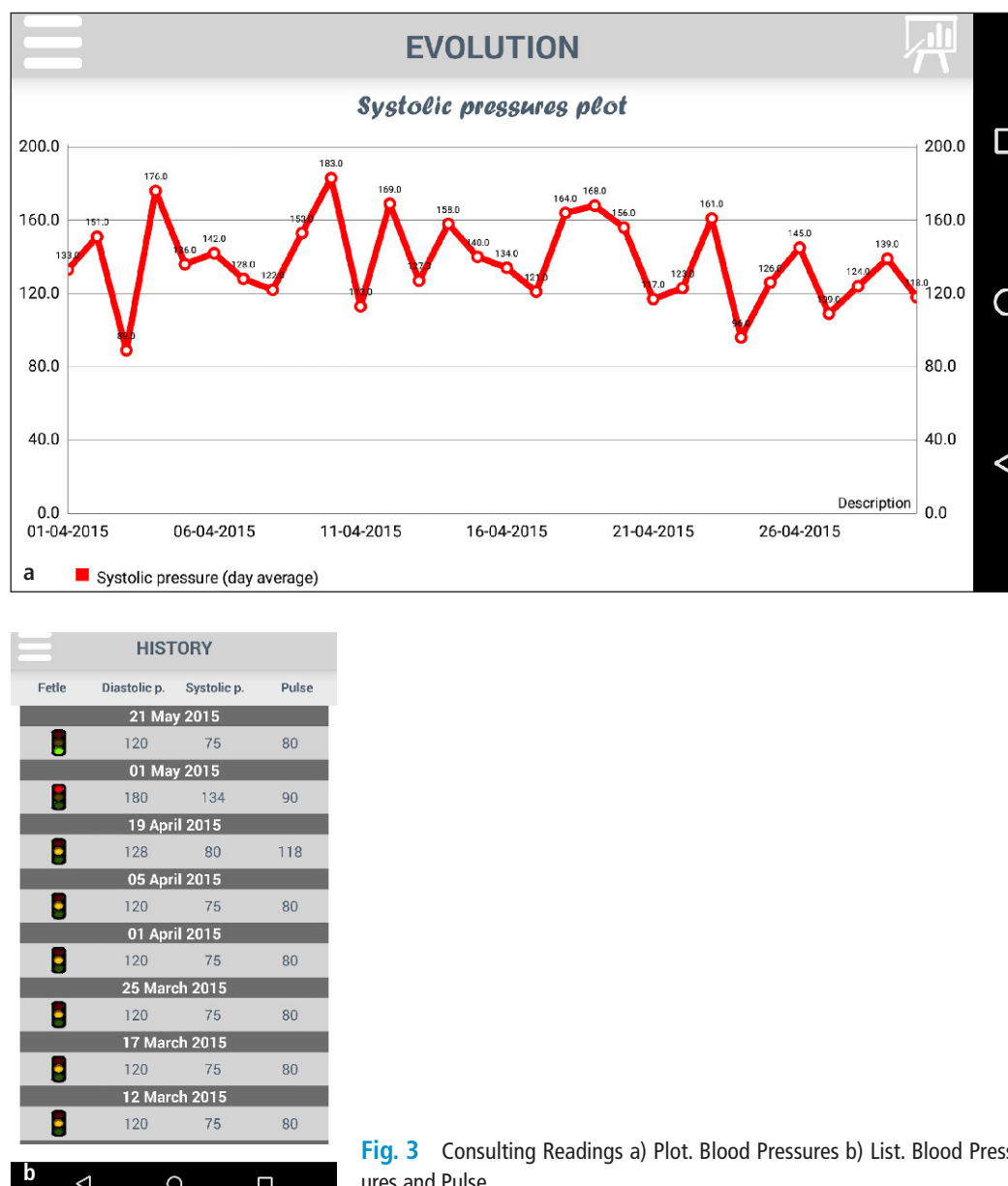
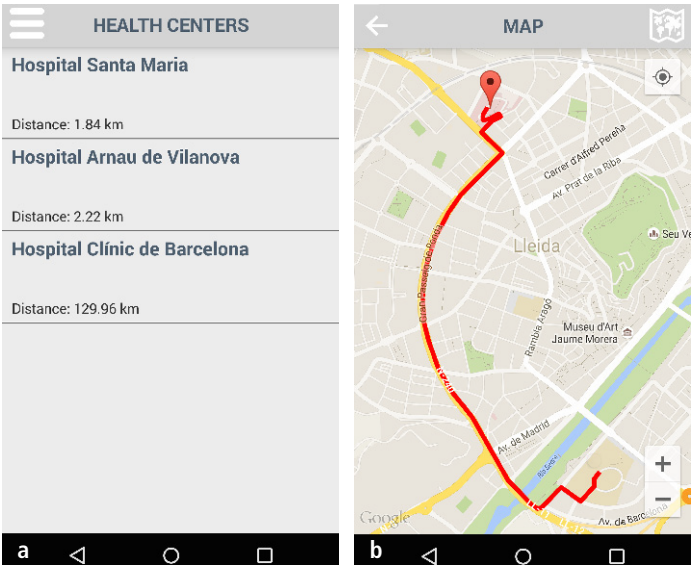Fig. 3 Consulting Readings a) Plot. Blood Pressures b) List. Blood Pressures and Pulse

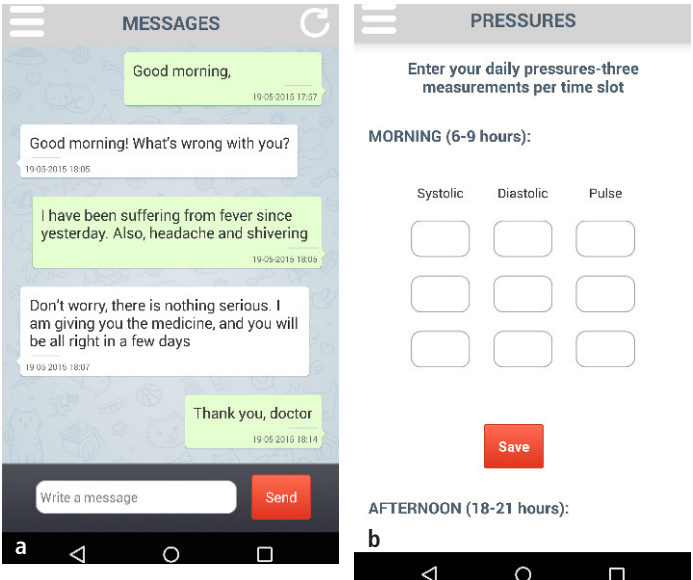**Fig. 4** Geolocation a) Distance to the health centers b) Way between patient and center

Fig. 5 Chat and Inserting Readings a) Chat b) Inserting Readings

Table 1 BPcontrol features

Feature	Description
Registering	Registering patients
Edition	Edit the patient's profile (Figure 2c)
Uploading	Uploading readings to the SHUITE server
Consultating	Plotting and listing the evolution of the patient's readings
Geolocation	Mark the way to an hospital in a Google Maps window
Chat	Instant messaging between patients and clinicians
Videos	Visualize informative videos (Figure 2d)
Advertising	Remind patients to submit blood pressure readings periodically
Installation	Easy downloading and installation
Scalability	Large number of users and hospitals are supported
Language	Spanish and English languages
Help	Support with the use of BPcontrol

Table 2 Start up efficiency (in ms)

Device	Operating System	BPcontrol	BP
Samsung Galaxy S2	Android v. 4.2.2	4,558	10,583
Samsung Galaxy S3	Android v. 4.3	4,321	10,121
Nexus 5	Android v. 5.1.1	3,832	9,638
Ipad 2	iOS v. 8.4	1,378	10,346
Iphone 6	iOS v. 8.4	1,173	9,949

	BPcontrol	BP
Samsung Galaxy S2	1,678	11,468
Samsung Galaxy S3	1,602	11,393
Ipad 2	1,291	14,632
Nexus 5	1,209	9,459
Iphone 6	1,056	12,427

Table 3 Communication efficiency (in ms)

	BPcontrol	BP
Samsung Galaxy S2	**4,669**	**7,892**
Samsung Galaxy S3	3,108	7,683
Nexus 5	2,900	7,506

Table 4 Plotting efficiency (in ms)

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Table 5   Comparison between BPcontrol with other similar hypertension apps. app: Application name. DC: Doctor Chat (direct chatting with the physician). NC: Nearby centers (provides information about the distance to specialized centers). Charts: graphical evolution Charts. RH: Readings' History. AB: Automatic sampling of the Blood Pressure by means of an external device. AP: Automatic sampling of the pulse rates by means of an external device.

app	DC	NC	Charts	RH	AB	AP
BP Lite	No	No	Yes	Yes	No	No
iBP	No	No	Yes	Yes	No	No
IBPTouch	No	No	Yes	Yes	No	No
BPMonitor	No	No	Yes	Yes	No	No
BPcontrol	**Yes**	**Yes**	**Yes**	**Yes**	**No**	**No**
iCare BPMonitor	No	No	Yes	Yes	No	Yes
BP Watch	No	No	Yes	Yes	No	No
Finger BP Prank	No	No	No	No	No	Yes

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