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ORIGINAL PAPER

VISIGNET: a wireless body area network with cloud data storage for the telemonitoring of vital signs

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Abstract Telemonitoring systems, including Wireless Body Area Networks (WBAN), are an important support for the monitoring of patients with chronic diseases. This article shows the development and evaluation process of VISIGNET, a prototype open hardware interoperable vital signs monitoring system that captures data of clinical variables from a patient and sends them to a cloud-based service for their remote visualization. The article first presents a synthesis of the system design, which consists of a WBAN that captures data from three sensors, namely heart rate, body temperature, and blood pressure. Then, it explains the WBAN operation and the data transmission process to Xively, a cloud service. Finally, this article shows the findings of the evaluation of the system, analyzing parameters like coverage, the Frame Error Rate (FER), end-to-end delay, and the battery life of the sensors. It also shows the implementation of a case study with 100 patients from two health centers.

Keywords Wireless body area networks (WBAN) · Cloud service · Telemonitoring · Performance

1 Introduction

Enormous efforts in research and development of portable electronic systems have been made in order to monitor the health of human beings. These endeavors have been largely motivated by the high costs of health care and the technological advances in micro and nanotechnology [1]. The miniaturization of sensors and intelligent materials are influencing the continuous advances in this research field. Hence, they are changing the current health view, allowing the individual management and continuous supervision of patients' health.

The monitoring and remote control of illnesses has become an important alternative to improve the quality of life and welfare of people. There are many individuals who, due to incurable diseases which demand specific control throughout the individuals' lives (chronic diseases), have to be continuously monitored by their doctor for regular medical check-ups [2, 3]. These types of diseases represent high costs for both, health systems and patients. When these diseases do not have strict and periodic controls, they can cause other much more serious problems that can lead to either surgical procedures or the prescription of more expensive medications for their treatment. These kinds of situations have given birth to health telemonitoring systems, among which include WBAN [4] that are intended to capture data from measurements of clinical variables and to send them to remote systems for specialized medical personnel to review. This type of solution has the advantage of minimizing costs associated with the patients' personalized attention, lessening the discomforts of moving to health centers that patients have to face.

Nowadays, there are several projects associated with health telemonitoring systems based on WBAN, as shown in the systematic review published by Min Chen et al [5]. Works cited in this article use data gathered by a network of sensors that send signals to a main system in which data are stored. The main problem of this approach is its limited interoperability with other platforms in regard to the storage

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of clinical data, since its architecture works only for storage systems already developed.

A review on mobile based health monitoring systems is presented in [6]. Only one of the projects cited in this article is based on WBAN. The work presented by Jovanov et al. [7] called ActiS is used to monitor heart activity, but ActiS is composed by only one sensor, therefore nor practically providing a complete WBAN. In [8, 9] a WBAN was developed based on ActiS sensors which is able to monitor physical activity and heart or muscle activity and implemented in conjunction with a medical server, however this system can only send information to that specific server in one single location. A system with a cloud-based service as VISIGNET for remote visualization is more interoperable.

Considering the above mentioned situation, there is a need to design and implement a telemonitoring system that allows the open interconnection of medical devices provided with wireless interfaces. They must also define information processing procedures in order to gather data from the sensors and transfer them to a cloud service so that the data can be remotely visualized and thus, be able to monitor the health of the patients who might require a constant monitoring of vital signs.

This article describes the implementation process of the telemonitoring system VISIGNET that makes use of Bluetooth technology which ensures technical interoperability to capture data, which are then sent to a cloud service that should in turn allow health professionals to remotely manage their patients' health information. VISIGNET also supports interoperability at the technical and syntactic levels, allowing interconnections among the BCU and open hardware wireless medical devices with Bluetooth technology, that specify an Application Programming Interface (API), in which the data transmission format is defined. It has been divided into four sections. The first section shows a synthesis of the process for the design of VISIGNET to capture data about heart rate, body temperature, and blood pressure. The second section describes the telemonitoring system operation that includes the capture of clinical variables and their linkage with a cloud service called Xively [10]. The third section reveals the findings of the system's evaluation of technical parameters such as coverage, FER, battery life of devices, and end-to-end delay of VISIGNET; as well as the evaluation with patients. The fourth section presents the discussion of the results and the conclusions of the study.

2 VISIGNET design

A WBAN allows the monitoring of activities and physiological actions of the human body by using sensors located in different parts of the body. In a WBAN, two types of nodes can be identified: one is the Body Central Unit (BCU) that collects data from sensors and reports to the users through an external link such as a watch or a web platform. The other type is the Body Sensor Unit (BSU) that receives, processes, and transmits signals from the human body.

IEEE 802.15.6 is the first international standard that specifies Wireless Body Area Networks (WBAN). This standard defines the Media Access Control (MAC) and Physical (PHY) layers.

To meet the design criteria of a WBAN (IEEE 802.15.6), it is necessary to use efficient MACs, which allow to coordinate the transmission of information among network nodes. VISIGNET operates under the Polling technique, where the BCU sends polling messages to all nodes which respond by transmitting a message with sensor's information.

Due to the industry's rising interest in short-reach wireless connectivity technologies, the Bluetooth technology is commonly used for the development of WBAN [11]. VISIGNET uses Bluetooth technology (IEEE 802.15.1) which is a wireless communication technology based on Frequency Hopping Spread Spectrum (FHSS) on the 2.4 GHz Industrial-Scientific-Medical (ISM) band. When two or more devices are interconnected, a piconet is created. It is worth mentioning that a piconet is characterized by the interconnection of a maximum of 8 Bluetooth devices, one acting as the master node that regulates the traffic of the others called slave nodes [11]. Linking these two concepts, the basic model of VISIGNET can be defined, assigning the BCU to the master node and the BSU to the slave nodes.

VISIGNET has been designed to especially for patients with chronic diseases that require a constant monitoring of vital signs in order to reduce patient's visits to his healthcare facility. The system is able to monitor vital signs such us body temperature, heart rate, and blood pressure.

Finally, both the patient and the medical personnel have to be able to view the gathered information. That is why VISIGNET has been provided with a visualization watch by means of which the measurements gathered by the sensors are displayed. In addition, these measurements are uploaded to Xively by using an Internet connection in the BCU, enabling the medical personnel to remotely and in real time, view and monitor the patient's health condition.

For the communication with the Xively Platform, VISIGNET uses an Ethernet (IEEE 802.3) connection. When the BCU detects that an Internet connection has been established, it creates an array with heart rate, body temperature, and blood pressure and sends it to Xively.

Figure 1 shows the whole VISIGNET model, specifying the medical sensors, the visualization watch, and the Internet connection to the web platform.

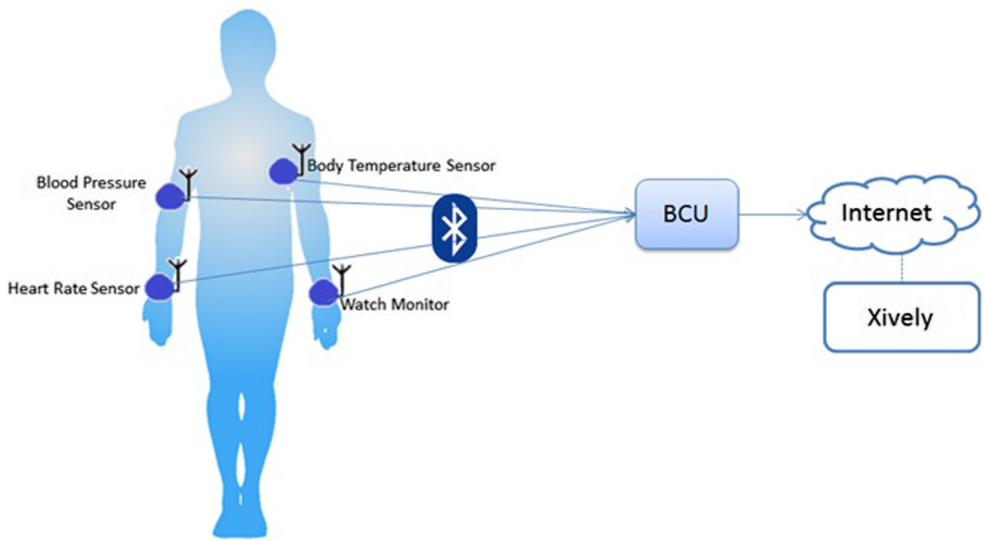


Fig. 1 VISIGNET Model

2.1 Sensor units

The BSU generally consists of [12–14]:

- A sensor that receives the signals from the human body.
- A processing unit that receives and digitizes the information gathered by the sensors and transmits it to the BCU.
- A radio frequency module that establishes the wireless communication between the BSU and the BCU for the exchange of information.

The device Kodea v2.0 was chosen as the sensor for blood pressure. Although this device does not have integrated Bluetooth communication, it has a serial interface through a USB port for the transmission of data. Then, an external module with Bluetooth technology was adapted to this device allowing the wireless exchange of information with the BCU.

The Lilypad Temperature Sensor was the body temperature sensor used. This sensor has an integrated chip MCP9700 that supports a range of measurements from 0° C to 70° C, and has been specified for medical applications, specifically for digital thermometers [15].

The heart rate sensor is built with open-hardware technologies and it basically combines a heart rate optical sensor with a circuitry of amplification and noise cancellation, which makes it faster to capture reliable measurements.

The processing units of VISIGNET are based on Arduino, a platform of open hardware that allows a fast development of prototypes. The Arduino Pro Mini (3.3V, 8Mhz) was used as the processing unit for the BSU of blood pressure and heart rate. Thanks to its low energy consumption, the battery lasts longer. In addition, due to the battery's small size, it is ideal to be adapted to the BSU without causing any inconvenience. The Arduino Lilypad Main Board was used for the body temperature BSU since it easily adapts to textiles.

This Bluetooth module has reduced size and low power consumption, about 20 mA during transmission and 3 mA when connected. The HC-05 module has a point-to-point connection compatible with the Serial Port Protocol (SPP) profile, therefore compatible with any BCU that uses this profile for system communication.

2.2 Central unit

The BCU consists mainly of a radio frequency module and a processing module responsible for the control and storage of information sent by the BSU. The Arduino Mega 2560 was adopted as the processing unit for the BCU since its low energy consumption might allow it to maintain active for longer periods of time, in case a battery is used.

The OBS421 was the module chosen for the Bluetooth wireless communication. The main characteristic taken into account for the selection of this device was its point - to - multipoint connection with classic Bluetooth modules as well as with Bluetooth 4.0 modules, which makes it highly

Table 1 BSU measurements classification

BSU	Classification	Meaning
Body Temperature and Heart Rate	B	Low
	N	Normal
	A	High
Blood Pressure	N	Normal
	PH	Pre-Hypertension
	H1	Hypertension state 1
	H2	Hypertension state 2

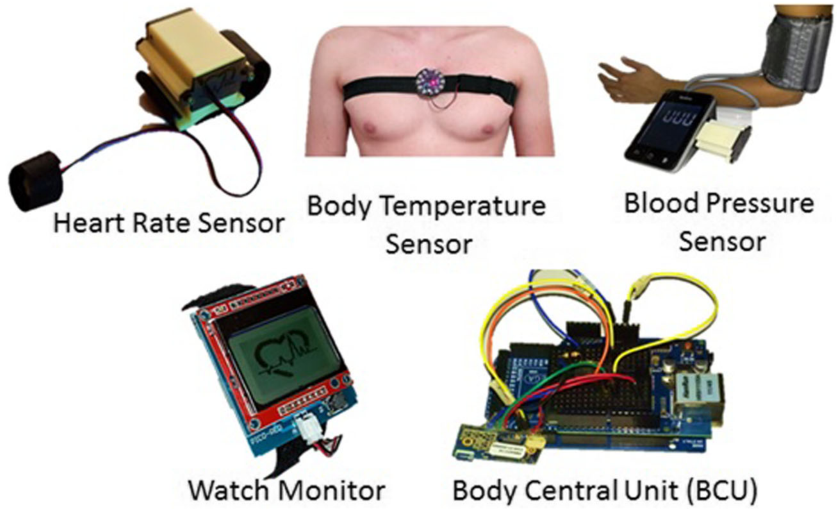


Fig. 2 VISIGNET components

operational. In fact, this module has the Wireless Multidrop technology that enables it to simultaneously send information to all the devices connected to it, facilitating the use of the polling protocol. In addition, it is able to connect to up to seven (7) classic Bluetooth devices. This scalability characteristic is enough for VISIGNET because its provides VISIGNET with the ability to handle three more new BSUs, considering that the system already has three (3) established devices (heart rate, body temperature, and blood pressure) plus the visualization watch. An Ethernet module for Arduino was used to connect VISIGNET to Xively.

2.3 Visualization watch

A Liquid Crystal Display (LCD) from a Nokia 5110 cellphone was used to locally display the vital signs measured by VISIGNET. Similarly, the board Arduino Pro Mini as the processing unit, and the Bluetooth HC-05 were used.

Visualization watch show each vital sign and classify those according to the criteria show in Table 1 [18–20].

Figure 2 shows the VISIGNET developed components. Figure 3 reveals the information displayed in the visualization Watch that has a section where the measurements gathered by the BSU are displayed, another section where the measurements are classified, and a third section where the heart rate is graphed.

3 Communication frames in VISIGNET

To ensure VISIGNET allows reliable transmission of information among the nodes of the system, two communication frames were defined as presented in Fig. 4. The first communication frame corresponds to the transmission of information from one BSU to the BCU. The second communication frame corresponds to the information transmitted from the BCU to the visualizing watch.

4 Operation of VISIGNET

The Polling protocol was established as the means of access to the operation of the VISIGNET system. This method allows the configuration of programed transmissions through inquiring messages, avoiding conflicts among the BSU.

In order to establish the wireless connection between the BCU and the BSU, the Bluetooth of the BCU has to be set up as the master. Based on the polling technique, the BCU is simultaneously connected to each BSU so that they can transmit the information. The BCU establishes the order in which each sensor node starts the transmission, using a parameter called ID that identifies them.

To start a data gathering cycle, the BCU sends an ID which is received by all the nodes connected to VISIGNET. However, only the BSU identified by this ID can be allowed to transmit the information monitored by its sensor. The BCU receives and verifies the integrity of the data by means

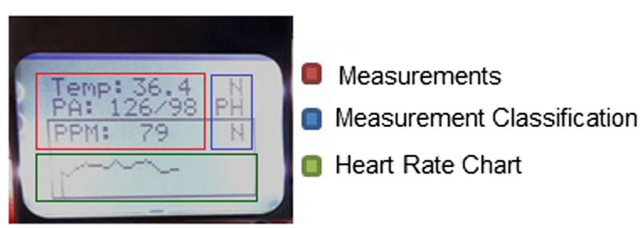
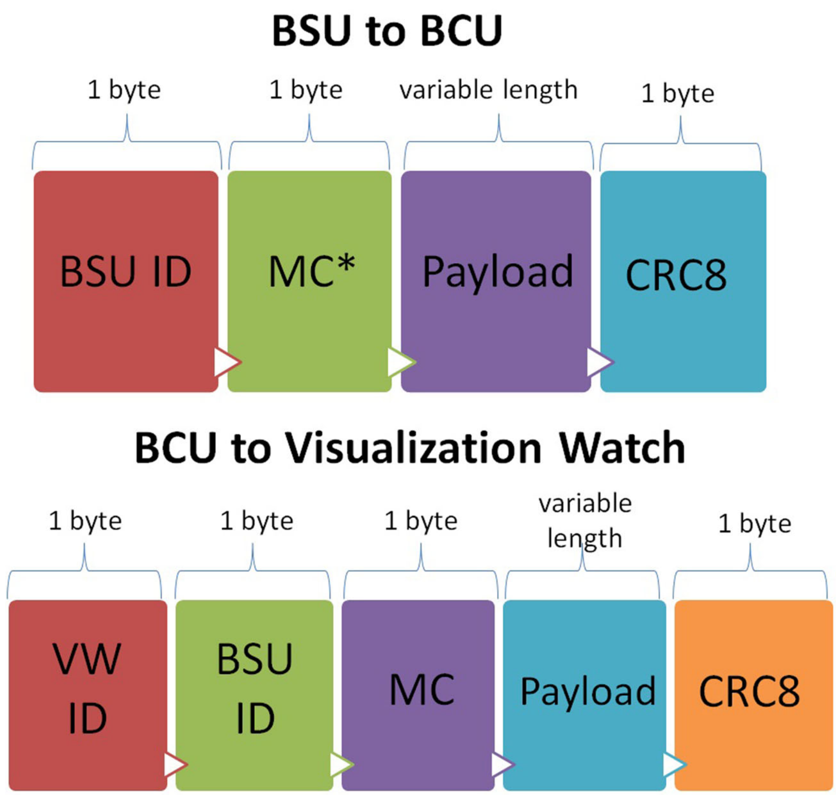


Fig. 3 Visualization Watch sections

Fig. 4 Communication Frames in VISIGNET



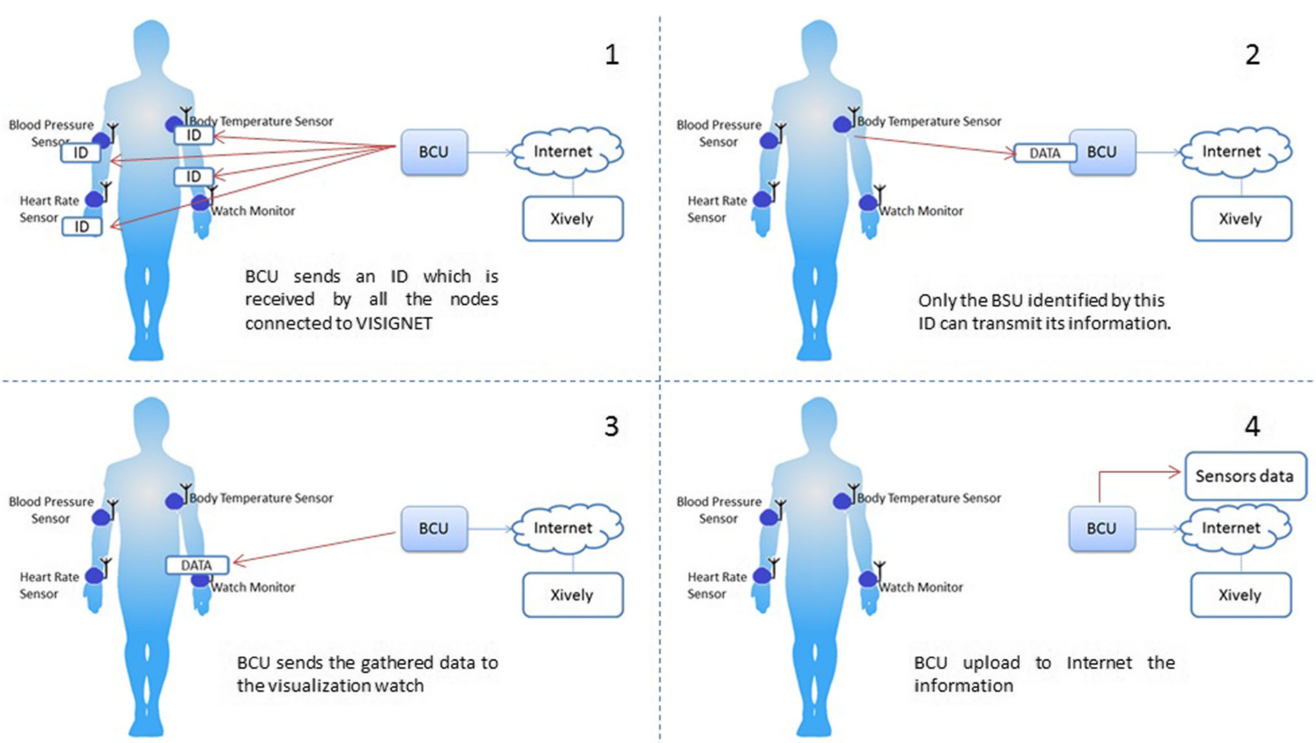


Fig. 5 VISIGNET operation

of a Cyclic Redundancy Check (CRC). CRC ensures that the information received was not corrupted during transmission. CRC was implemented as an additional field of the communication frame, therefore stored and sent to the BCU. When the communication frame is received by the BCU, this unit calculates a CRC of the received information, and compares it with the CRC received in the frame. If the CRC calculated is equal, the information is accepted; on the contrary the data is discarded.

After the BCU has concluded the processing of the data gathered, it continues with the process of collecting data, sending the following sensor node ID until a cycle of data collection of the three sensors has finished. Once the BCU has finished a poll cycle, it sends the gathered data to the visualization watch and then to Internet in order to be displayed in the web platform.

Figure 5 shows the operation of VISIGNET described above.

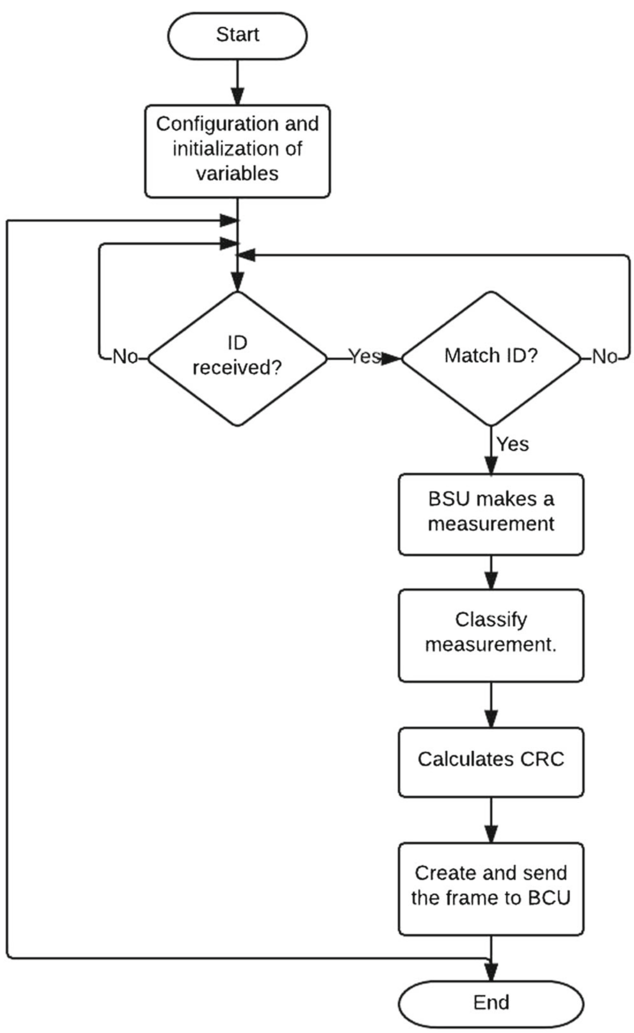


Fig. 6 Information processing in the BCU

5 VISIGNET information processing

Figure 6 describes the information processing in the BCU. In general, the BCU has five basic steps represented by turns. The first three turns correspond to the communication of each sensor with the BSU (blood pressure, body temperature and heart rate). Turns 4 and 5 are for the visualization systems of VISIGNET, i.e., the Visualization watch and the Xively Platform.

During the BSU turns, the BCU sends an ID to each sensor, in order to request information. Then, the BSU which identifies with that ID, sends the frame. The BCU receives it and calculates the CRC. The BCU compares the CRC received with the one calculated. If CRC matches, the information is stored in a temporary variable.

In turn 4, when the BCU has completed the data collection cycle (blood pressure, body temperature and heart rate), the BCU sends three frames (one for each BSU) to the visualization watch.

Finally, in turn 5, the BCU checks if an Iinternet connection is available. If the connection is available, the BCU arranges the three measurements in an array and sent it to the Xively Platform and the cycle is finished. If no Internet connection is available, the cycle is finished.

6 Communication of VISIGNET with Xively

Xively was chosen as the wireless monitoring platform because it supports wide combinations of software and hardware that enable systems to create solutions with official libraries for multiple languages and platforms such as Arduino, Python, Java, among others. Besides, it offers end-to-end security in the whole platform in order to ensure the integrity of the data, allowing it to determine who can have or cannot have access to the data [16]. When the BCU detects connections to Internet, it creates an arrangement with heart rate, body temperature, and blood pressure and sends it to Xively.

Figure 7 shows the results of visualizing the measurements of the vital signs monitored by VISEGET in Xively. The figure shows the graphs corresponding to the body temperature, systolic pressure, diastolic pressure, and heart rate.

7 Evaluation of VISIGNET

For the evaluation of VISIGNET, two studies were carried out:

- A technical evaluation.
- A functional evaluation with a group of patients.

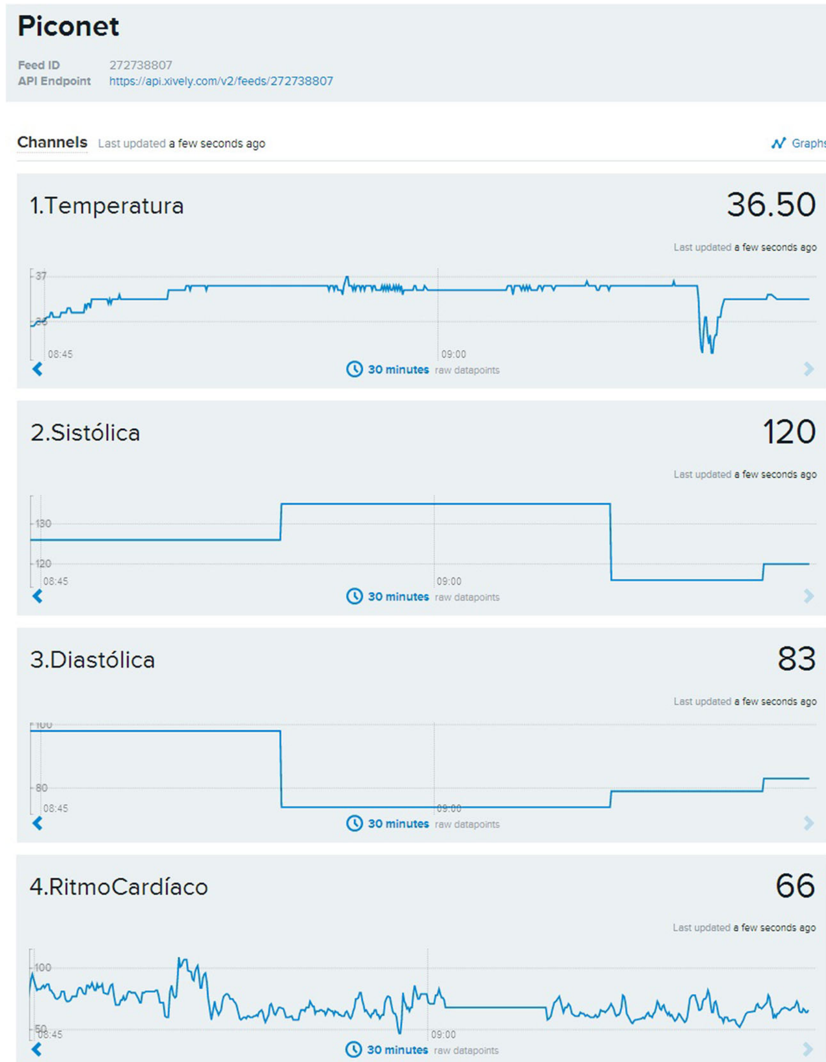


Fig. 7 Vital signs visualized in Xively

For the technical evaluation, the following parameters were analyzed:

– Coverage: the main purpose of this test was to obtain the maximum range of reach between the central unit and the sensor devices when indoors with and without line of sight.
– Frame Error Rate (FER): this test was aimed at determining the number of frames incorrectly gathered in regard to the frames that were sent.
– End-to-end delay: this test provided the average time VISIGNET spends in collecting data and sending them to Xively.
– BSU Functioning Time: in order to determine the maximum time of functioning of each BSU by using fully charged polymer lithium batteries of 3.7V at 850mAh, all the nodes of the system were used continuously simulating a real environment of the application.

The functional evaluation of the system was performed through a case study of primary care in two health institutions: the Integral Health Division and the Health Unit of the University of Cauca. It compared, throughout a statistical analysis, the measurements gathered by the sensor devices of VISIGNET with the measurements gathered by conventional medical devices. In addition, a survey was given to those patients that participated in the test that aimed at determining the grade of acceptance to the system under implementation.

7.1 Technical evaluation

This test evaluated the most relevant parameters that verify the correct functioning of VISIGNET, i.e., coverage, FER, end-to-end delay, and functioning time of the BSU. A fully charged 850mAh batteries were used.

Table 2 Results of the VISIGNET coverage

		Coverage [m]
Line of sight indoors		$\tilde{5}2$
With obstacles	1 wall	$\tilde{1}2,4$
	2 walls	$\tilde{5},81$
	BCU y BSU on different floors	$\tilde{4},56$

For the coverage analysis, scenes that simulated the commonest places for the use of VISIGNET were defined. They included a house, a hospital, and a doctor's office, among others.

Table 2 shows a summary of the results obtained in the tests of maximum reach carried out to the system in the different scenarios. In the first scenario, the BCU and BSUs were located in a corridor on condition of line of sight, varying the spacing between them, reaching a maximum distance of approximately 52 meters. This distance was achieved considering that the hallway acts as a waveguide. For the second scenario, the BCU was located on the corridor and the patient with BSU entered a room, in order to determine the maximum distance range having walls as an obstacle. The result obtained was of 12.4 meters in the case of a wall (20 cms wide) and 5.81 meters with two walls. Finally, in the third scenario, the BCU is located on a different floor to the one that the patient with BSU is located; the maximum range obtained was 4.56 meters.

The reception rate of incorrect frames of the system was determined with the analysis of the FER. In order to do this test, a series of counters were implemented in the code of information processing of the BCU. These counters increased when incorrect or correct frames were received.

Table 3 shows the results obtained when exchanging 2000 frames of information between BCU with each BSU at a gap distance of approximately 6 meters. This result was displayed thanks to window of the serial monitor of Arduino IDE.

In order to calculate the FER, the following expression was used:

$$\%FER = (Fr/Fs) * 100 \tag{1}$$

Where

Table 3 Results of BSU FER

BSU	Correct frames	Incorrect frames	FER(%)
Body Temperature	1997	3	0,15%
Blood Pressure	2000	0	0,00%
Heart Rate	2000	0	0,00%

– Fr: Incorrect frames received.
– Fs: Total frames sent.

According to the results obtained, it was found that the FER of the sensor devices is optimum. There was only a different value of 0% for the body temperature sensor although it is a result that shows a correct functioning of this BSU.

When the test was carried out, VISIGNET exchanged a total of 6000 information frames (2000 for each BSU), receiving only 3 wrong frames. This leads to the conclusion that the total FER of the system is of 0.05%, indicating that for each 10000 frames, 5 wrong frames were received. In general, a maximum FER value allowed for wireless connections in medical applications is not specified. However, the FER obtained for the system guarantees a continuous functioning considering that in case an information frame is lost, the system does a new cycle of information collection in a short period of time.

The end-to-end delay corresponds to the time spent by the BCU to complete a processing cycle that includes the collection of the data from the three BSUs and sending them to the visualization systems which include the watch and the web platform Xively. With the aim of obtaining the times between each cycle, the API of Xively was used. This enables the system to acquire all the parameters of each load of information to the platform, including the time when the load was carried out, specified in hours, minutes, seconds, and thousands of seconds.Using the above mentioned method, 100 registers of load were obtained, allowing it to calculate the different times spent by the system to complete a processing cycle. Calculating the average of these values, it was found that the average time is 3,32 seconds. The main reason for the appearance of variations in the total time of a processing cycle lies in the fact that the connection speed to Internet is constantly fluctuating. The time obtained is extremely low if compared to the time that could be spent by a patient or a physician to move to a health center or his/her house in order to monitor his/her vital signs. Thus, the prototype piconet manages the health information of the patient efficiently and in real time, avoiding the movement of patients or medical personnel.

Finally, the functioning time of the BSUs is a parameter aimed at determining the number of functioning hours of each BSU by using a fully charged battery of 850mAh at 3.7V. To that end, the BSUs were started up and after each hour, a register of the voltage of the batteries was taken. The results of these measurements are shown in Table 4.

At the end of the test different functioning hours were found for each sensor device. However, the functioning of the prototype piconet is guaranteed for a minimum of 24 hours with each BSU fully charged.

Table 4 Results of the functioning time of the BSU

BSU	Total Functioning Time
Body Temperature	~25 hours
Heart Rate	~29 hours
Visualization	~34 hours
Blood Pressure	~36 hours

7.2 Functional evaluation

The methodology to perform the functional evaluation consisted of using the VISIGNET sensors to take the vital signs of 100 patients that attended a general medical appointment, and then taking their vital signs by using the conventional devices that medical personnel use. With the purpose of confirming that the VISIGNET sensor devices obtain measures similar to those gathered by traditional devices, a statistical analysis was carried out by using a T-Student test that allows the determination of whether both groups of data are significantly different. In order to use this test, two hypotheses have to be posted: the research hypothesis (H1) suggests that the two groups differ significantly, and the null hypothesis (H0) suggests that the two groups do not differ significantly.

According to what was previously established, the following hypotheses were defined for this study:

- H0: There is no significant difference between the measurements gathered by the VISIGNET devices and those gathered by conventional devices.
- H1: There is a significant difference between the measurements gathered by the VISIGNET devices and those gathered by conventional devices.

Table 5 shows the results obtained after the statistical analysis was carried out.

For the heart rate and body temperature BSU, a significance of 0,363 and 0,070 was obtained respectively, being larger than 0,05. In this case, the H0 is accepted and it can be concluded that the difference between these measurements with conventional devices and the BSU for heart rate and body temperature is not significant. Hence, the result is an optimum performance of the sensors.

In the case of blood pressure sensor (systolic and diastolic), the condition of significance was not reached, implying that there is a variation between the measurements of pressure with conventional devices and the ones taken with VISIGNET, even if the error percentage was very low. This could happen due to the following reasons:

- The conventional sphygmometers can lead to mistakes because they depend on the hearing and visual conditions of the patient that uses the sensor. In addition, it is necessary to take into account that the readings of pressure are approximate.
- The positioning of the patients for measurement were not the same since the medical doctors took the measurements in their offices and once the appointment had concluded, the measurements of the vital signs with the BSU were taken in another office.
- The patients arrived to the medical appointment after doing some exercise (walking, for example) and they did not take the recommended relaxation time before having the blood pressure measurement, creating a condition that could cause higher levels in the first measurements.
- Doing any movement implies an increase in the blood pressure between 6 mmHg (systolic) and 5 mmHg (diastolic) approximately.
- Speaking during the blood pressure measurement implies an increase of 6-7 mmHg, approximately.
- Having any physiological necessity could increase the blood pressure up to 10 mmHg.

In order to get deeper into the analysis of the results for blood pressure, the sample was broken down by range of ages and a specific T test for systolic and diastolic pressure

Table 5 Statistical Results of Clinic Variables

			95% CI	
Vital Sign	Error percentage	Sig.	Lower	Upper
Systolic Pressure	2,00%	0,00	1,431	3,509
Diastolic Pressure	2,68%	0,00	0,955	3,285
Body Temperature	0,15%	0,070	-0,1125	-0,0045
Heart Rate	0,39%	0,363	-0,340	-0,920

CI Confidence Interval of difference

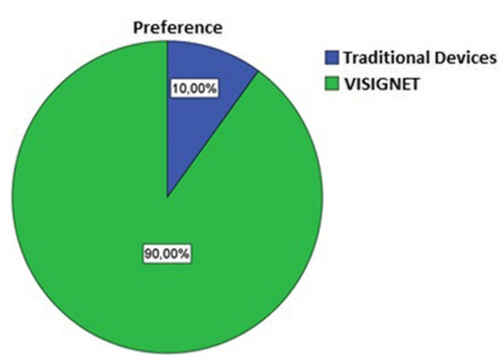


Fig. 8 Results of the survey: Preference

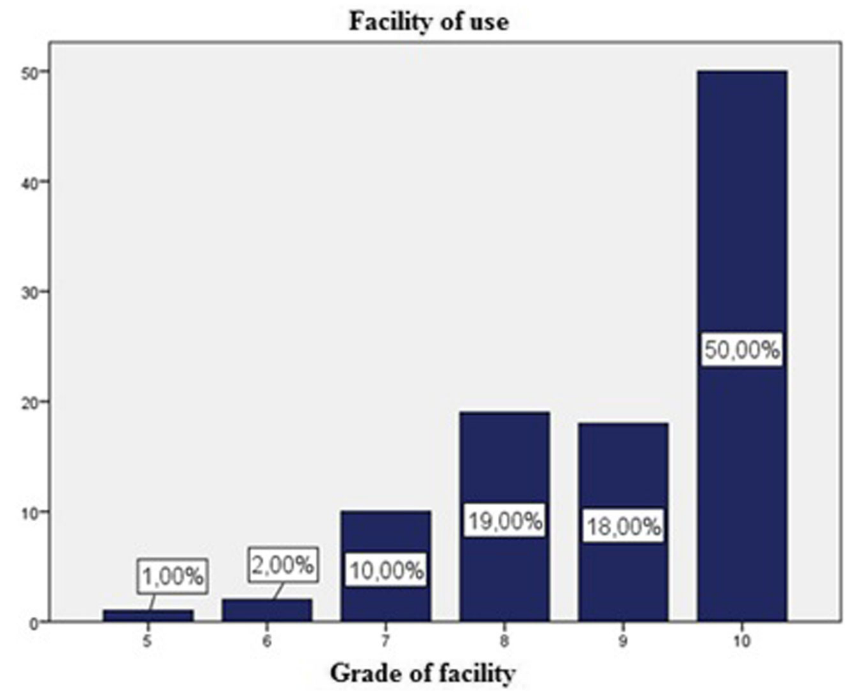


Fig. 9 Results of the survey: Facility of use

was done. It was found that the difference of the blood pressure between the measurements taken by using VISIGNET and the ones taken by conventional devices were significant (smaller than 0,05 and thus, H1 is accepted) only for the range between 20 and 29 years old. This could happen due to the following reasons:

– It was very common to find that young people did not follow the requirement of keeping quiet during the measurement of the blood pressure.
– Studies and research have shown that young people are the population who are most affected by the syndrome of the White Coat Hypertension effect [17].

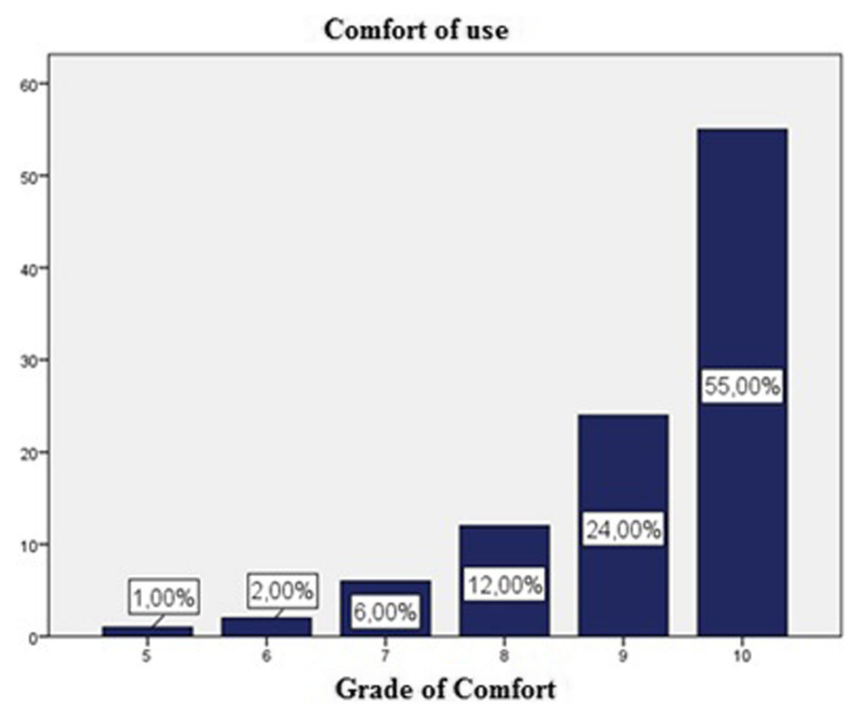


Fig. 10 Results of the survey: Comfort of use

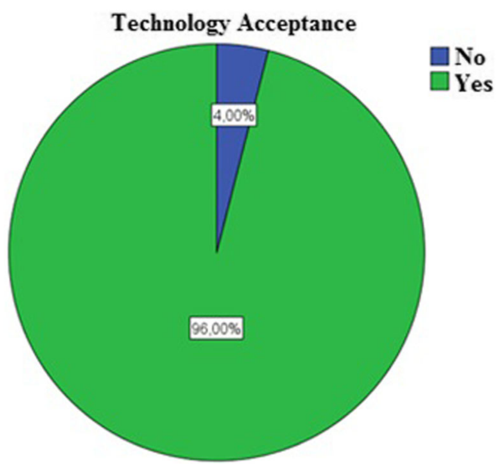


Fig. 11 Results of the survey: Technology Acceptance

7.2.1 Survey

A survey was conducted with each one of the 100 patients in order to qualify the acceptability of VISIGNET. The following variables were evaluated:

- Preference: Determine if the patient prefers that the doctor uses traditional devices or VISIGNET. VISIGNET was preferred by 90% of the users (Fig. 8).
- Facility: Qualify grade of facility (1-10) to use VISIGNET to measure their vital signs. In the scale, 10 is very easy and 1 is very difficult. 50% of the patient consider the system very easy and only 1% consider the system partially difficult to use (Fig. 9).
- Comfort: Qualify grade of comfort (1-10) when the patient uses VISIGNET. 55% of the patients consider that the system very comfortable and only 1% consider the system partially uncomfortable (Fig. 10).
- Technology Acceptance: Evaluate if the patient agrees to use this new technology in care settings. 96% of the patients agree that this new technology should be used in care settings (Fig. 11).

8 Conclusions and further research

From the development and implementation of VISIGNET and all the experiences gained, the following conclusions are stated:

The feasibility of using the piconet topology of Bluetooth for the design and implementation of an interoperable WBAN that allows the interconnection of open hardware medical devices for the exchange of clinical data was demonstrated.

Although there is no literature related to the connection of model OBS421 and the development boards Arduino, these two components were integrated to make connections point-to-multipoint controlled by the BCU. It was possible to connect them simultaneously with the BSU and the visualization watch. Furthermore, the delays caused by the use of a Bluetooth module without this characteristic were avoided. In addition, the module OBS421 allowed the implementation of an access technique called polling, thanks to its compatibility with Wireless Multidrop technology.

By using the development boards Arduino and thanks to the different sources of information, support, libraries, and related hardware available for these platforms, the sensor devices were implemented to monitor the heart rate, body temperature, and blood pressure, and the visualization watch and the BCU with an Internet connection. By using the web Xively platform, the vital signs were uploaded in the cloud in real time in order to remotely monitor the health of patients who use VISIGNET.

With the technical tests of the prototype piconet, parameters such as system coverage, FER, end-to-end delay and the functioning time of the BSU were determined.

According to the Bluetooth technology used, results of the coverage (12,4m and 5,81m with 1 and 2 walls as obstacles respectively) were obtained. These results were in accordance with the ranges of distance specified in those types of Bluetooth modules used. Thus it can be concluded that the prototype piconet is functionally made to operate with all its nodes on one floor, allowing the patient to have a wide mobility.

According to the total functioning time of the BCU, it was established that the lapse between each remote visualization of the vital signs by using the Xively platform is considerably low (3,32 seconds) in comparison to the time that a patient could spend to go to his/her health center or to his/her house in order to monitor his/her vital signs and therefore the health of the patient.

According to the FER obtained, it can be concluded that the prototype piconet shows low error rate or frame loss, which guarantees a great reliability of the system use. In case of loss of an information frame, the system does a new cycle of information collection in a period of time of about 3 seconds.

Finally, the total functioning time obtained for the BSU with a single charge allows the patient to constantly monitor his/her health 24 hours a day and without changing the batteries. Adding the coverage results obtained enables the patient to perform his/her daily activities and manages his/her health at the same time.

By means of the VISIGNET tests done in two health institutions, the precision of the measurements of the system BSU was verified, comparing the measurements obtained with conventional devices currently used in health centers and hospitals. The results showed that error percentages were lower to 3% and in the case of blood pressure and body temperature devices, the significance level were of 0,363 and 0,070 respectively. These results demonstrated that the devices work properly.

For further studies it is suggested to automatically integrate the vital signs monitored by VISIGNET to a Personal Health Record system (PHR) such as Indivo and/or to an Electronic Health Record System (EHR-S) such as OpenMRS, OpenEMR, or OpenVista. This work was previously developed by the authors and reported in [21]. In this work, only a first prototype of VISIGNET was presented, but no evaluation was provided. Furthermore, this first prototype included only two BSU (Heart Rate Monitor and Blood Pressure). The Bluetooth technology in VISIGNET was improved using the module OBS-421 that allows point-to-multipoint connection and simultaneous connection with all BSU.

It is also suggested to implement Low Energy Bluetooth modules for all the VISIGNET units in order to reduce the energy consumption and thus extend the functioning time with just one charge. This team is also interested in studying the use of sensors compatible with the ISO/IEEE 11073 for the communication between personal health devices.

9 Compliance with ethical statement

The authors declare that they have no conflict of interest. All procedures performed with the participants were in accordance with the ethical standards of Bienestar Universitario at University Cauca. Informed consent was obtained from all individual participants included in the study.

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Conflict of interests The authors declare that they have no conflict of interest

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