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Survey on IoT solutions applied to Healthcare

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Abstract
The Internet of Things (IoT) is a new technological paradigm that allows any object or thing to be connected to other things, services or people through the Internet. IoT brings tools for empowering working areas such as health, logistics, industry, security, agriculture and environment. In this paper, we introduce a comprehensive survey of IoT technologies, methods, statistics and success cases applied to healthcare. In the last section its talked about the work done in this subject on the Colombian context, including successful applications and current projects.

Keywords: Internet of things; e-Health; healthcare.

Revisión del estado del arte de soluciones IoT en salud

Resumen
El internet de las cosas, también conocido como IoT por sus siglas en inglés (Internet of Things), es un nuevo paradigma tecnológico que permite la interconexión de objetos (las cosas), servicios y/o personas por medio de internet. IoT introduce nuevas herramientas que enriquecen el trabajo en diferentes sectores industriales. Este artículo presenta un estudio del trabajo desarrollado en todo el mundo en tecnologías con base en el concepto de IoT en el marco de la industria del cuidado de la salud, incluyendo métodos, estadísticas y casos de éxito. En la última sección, se discute sobre el trabajo realizado en este ámbito en el contexto colombiano, incluyendo aplicaciones exitosas y proyectos que se encuentran en desarrollo.

Palabras clave: Internet de las cosas; e Health; cuidado en la salud.

1. Introduction

This survey focuses on applications regarding the health-care industry and *IoT*. Here, our goal is to highlight applications, studies, statistics and products that are derived from the healthcare *IoT* technological sector. To this purpose, we have followed the methodology presented by [1] and [2], in which the entire *IoT* sector applied to healthcare has been arranged into five categories and three sub-categories that allow us to identify potential trends. The results of this survey give to the reader a broader view of the state-of-the-art applications and methods used within the healthcare *IoT* industrial sector and future opportunities of growth.

The structure of this survey is composed by the sections shown in Fig. 1. Firstly, we start by providing a simple definition and ground work on *IoT* and eHealth concepts relevant to the subsequent sections. Secondly, we carry out an in-depth review of the main categories found in the literature.

This article is organized as follows: in chapter 3 *Personalized Care*, presents cases that are related to the trend called *Internet of Me*, this are applications such as the user can have a virtual doctor, its own health information available 24 hours. In chapter 4 *Health-wearables*, are studies that revolve around wearables devices that focus on gather health information. This can be either as commercial products or prototypes. In chapter 5 *eHealth and Colombian Applications*, we cover some cases where eHealth solutions have been implemented in Colombia and the impact of those solutions on the target community. Finally, in chapter 6 *IoT and health: Tomorrow*, we conclude this survey by presenting some tendencies and key factors on the future of eHealth.

2. Health-care and internet of things

We will start the discussion on the Internet of things with a brief description of *IoT* and some examples of past projects in that area.

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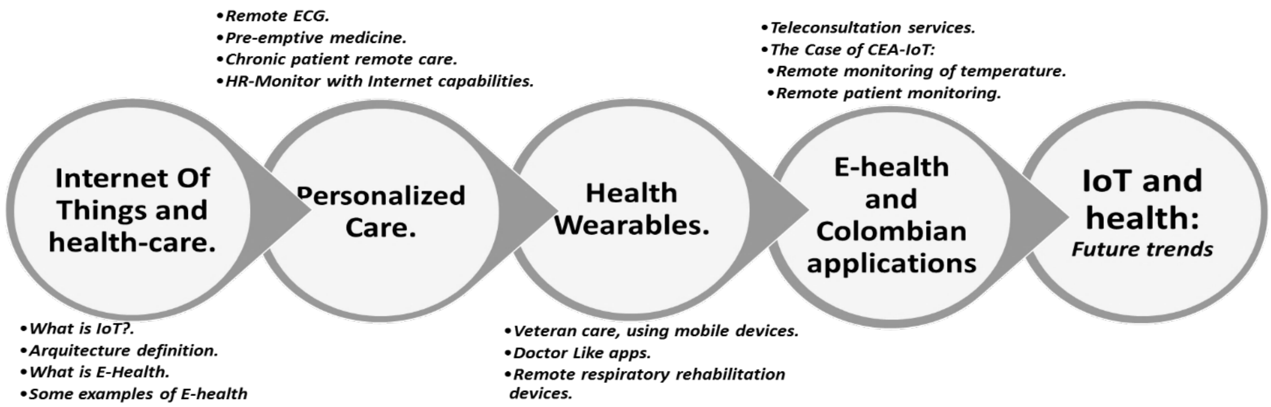

Figure 1. Survey chart.
Source: The authors.

Table 1.
Most relevant works on IoT architectures.

Layers	In [4]	In [5]	In [6]	In [7]	In [8]
Sensing Component	Sensors	Perception Layer	Perception Layer	Node level	Sensor management
In-site data processing	Acquisition system	-	Translator	-	Identification management
Communication management	Data transition	Network layer	Network layer	Link level	Network Access management
User/machine interface	Big Data	Application layer	Application layer	-	Intelligent Application
Error management	-	-	-	Network level	-
Power and security	-	-	-	-	Power and security management

Source: Summary of the authors of [4-8].

1.1. IoT

Brendan O'Brien, Chief Architect & Co-Founder, Aria Systems says: *'If you think that the Internet has changed your life, think again. The IoT is about to change it all over again*!'. We see it as a revolutionary, visionary and new technological paradigm that connect, gather information and react accordingly to events on the world.

The *IoT* is a concept of a world-wide network that is composed of any object (thing) that can be embedded into any environment with the aim of measuring variables (either physical, electrical, etc.) and sending this information through the internet to some other location for storage and/or analysis. This is a huge definition; accordingly to the Forbes magazine [3], in 2014 there were 16 billions of Internet connected devices and for 2020 estimations goes as high as 40.9 billion devices, all capable of internet connection and inter-device communication.

Some examples of previous works, [4-8], present in some measure the definition of how a basic IoT architecture should be composed. We took those definitions and in Table 1, we compare and summarize them as base for the upcoming work on this section and some of the prototypes on projects ahead.

With a basic architecture defined, next we need to see what have been done in IoT. There are several surveys that include a recompilation of applications, history, protocols and technologies according to the *IoT* paradigm [9-15]. In these studies, there are clear explanations on every aspect of the concept by presenting and explaining some of the latest protocols related to *IoT*. Lastly from a business perspective, [16], focus in an analysis of the transitions times between the conventional work flow process into the enterprises, when there is an inclusion of any *IoT* and/or Big Data solutions.

1.2. eHealth

This work will focus on the *IoT* solutions applied to the health care industry, or most commonly known as eHealth. EHealth is one of topics involving *IoT* with the most potential, being one of the main sectors where *IoT* can have the most relevant economic and social impact [9,14].

This is further discussed in [17], which present an analysis of the economic impact for *IoT* applications including eHealth solutions. This study concludes that eHealth has the highest percentage of investment with 40% of the total expenses done in *IoT*-related subjects. The approximate market share is presented on more detail in Fig. 2.

As any topic as broad and complex as *IoT*, or even the smaller eHealth, is needed to organize the information on a few selected categories. We start by selecting 3 key fields that will be the main trends to change and improve with *IoT*-based innovations following the analysis made by [1]. These three fields are:

1) Personalized service and product in healthcare.
2) Wearables revolving around healthcare.
3) Cases, products or experiences on Colombia.

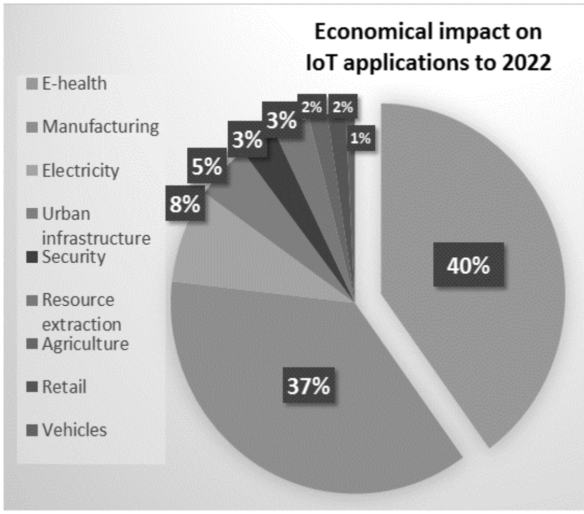

Figure 2. Economic Impact of IoT for 2022.
Source: [3].

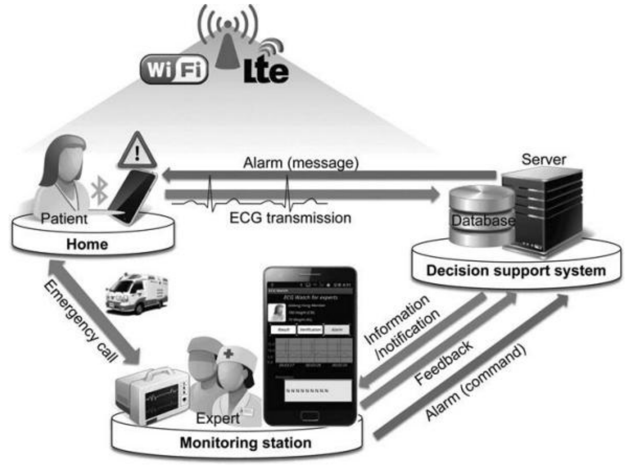

Figure 3. Monitoring system implemented in [19].
Source: [19].

3. Personalized care

The first trend we will discuss is the Internet of Me, or personalized care. This trend focus on products or services in which the patient can have a 24/7 doctor on his care and can access multiple diagnostics, etc. In the forthcoming sections, we explore the research behind this area, products on the market, statistics and impact on the health sector.

3.1. Research

In this subsection, we will talk about 2 studies of cases where the medic-patient gap was meant to be decreased, both on deceases where constant medical supervision was required.

According to the first case report, [18], in 2013 there were 9 million patients living with a chronic health condition in Canada, and 75% of the seniors have one or two chronic conditions. This program was implemented on the Stanford Chronic Disease Self-Management Program via telehealth (tele-CDSMP) with the purpose of the education on chronic condition management. This aimed those communities that live on rural areas, especially on those in Northern Ontario.

This is a 6-week health education program that helps people develop effective self-management skills to handle with the physical and emotional challenges of living with a chronic disease. Through the development of the research was evidenced an improvement on health-related attitudes. This lead to a positive change on the life styles of those patients.

The second study case, [19], present a preemptive approach to hearth disease management. This is based on the thought that any heart condition has multiple symptoms that can go from arrhythmia, pain, fainting or straight a heart attack. Being the case that some of these symptoms do not result on a consultation. And worst of all, there is a high chance that these symptoms won't manifest during the medical appointment.

A constant monitoring device that uses remote electrocardiography (ECG) and a cloud-based system was implemented to inform the patient about a possible heart condition. This kind of implementation generated a massive amount of data, bringing a new issue: assigning personnel to do a constant monitoring job will be expensive and inefficient. The solution presented was a trained a system to constantly analyze the data and notify the expert to generate an emergency call to the patient. This scheme is shown in Fig. 3.

The assessment of this system had 234 test footage, taken from the MIT-BIH Arrhythmia Database, with a final sensitivity of 97.22%, specificity of 96.89% and 97.06% accuracy.

3.2. Products

The first product, [20], is a model to perform the 6-Min Walk Test without the use of expensive and numerous devices. This is accomplished by performing an estimator based on a correlation between walking patterns and SpO2 levels of the patient. An estimation of the SpO2 levels is performed using real-time data of the integrated accelerometer, and embedded sensors on a smart-device. The data gathered from these sensors are the input of a support vector machine (SVN) trained to evaluate the SpO2 levels from the movement information of a patient. This method was tested on patients with an obstructive respiratory pathology to predict the SpO2 levels during the test. The results made a prediction with an accuracy of 87.96% to 92.99%, compared to results of conventional test protocols.

Another example of *IoT* solutions to improve the patient-medic relationship, are those which monitor the patient at home. Although is a great approach, these implementations have some challenges, especially on hardware required to setup a homecare system. It tends to be expensive, not very user-friendly and not open source to build custom-made solutions. In [21] was proposed and implemented a hybrid system with local and cloud data analysis of several environmental and physiological variables of the patient.

This hybrid method of data analysis reduces the hardware requirements, time to access the information and facilitates to access to the platform. The system architecture can be seen in Fig. 4.

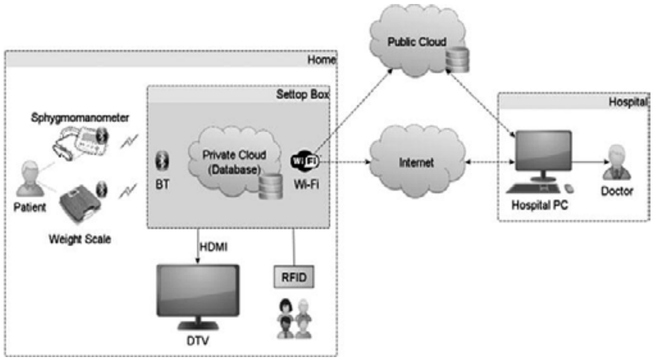

Figure 4. Homecare system implemented in [21].
Source: [21].

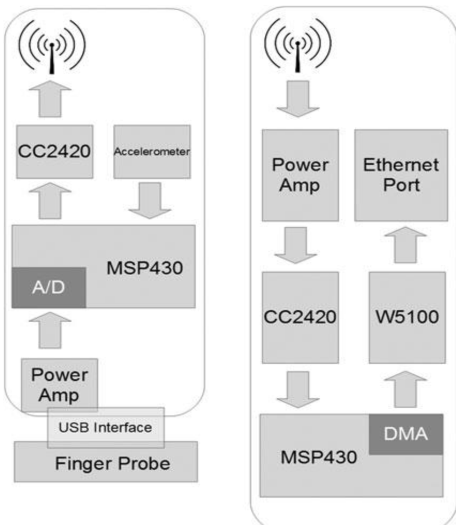

Figure 5. System topology for the Internet-enabled heart rate monitor implemented in [22].
Source: [22].

Figure 6. Heart rate monitor prototype implemented in [22].
Source: [22].

The next study is another approach, to change the current device status, with a special interest on increase the patient comfort of an Internet-enabled heart rate monitor, [22]. This monitor was implemented on a finger probe reducing its size and weight. Fig. 5 shows the topology and the reference of the parts used to build the working prototype (Fig. 6 shown the prototype).

This system was compared to a high-end commercial electrocardiogram sensor (Nellcor NPB-4020), for simulated heart rates from 30 to 240 BPM, with astonishing results of 100% accuracy. Later was performed a year-long trial, with a total, 32 seniors are wearing the sensors, 24 of whom have suffered from a stroke or have Parkinson's disease, resulting on an average of availability 99.48%.

3.3. Statistics and impact

The previous cases were products or services that were tested on a focus group that agreed on the usage of the technology. But one of the biggest issues that face *IoT* and eHealth is the access to the solutions by the patients. The study in [23] presents the acceptance percentage of the use of eHealth services by patients suffering from bronchial asthma and other chronic respiratory conditions via a questionnaire, consisting of 73 different questions distributed among 200 patients remaining under the care of a tertiary-care pneumology centers in Krakow, Poland.

Similar to the previous work, in [24] is presented a case of study to assess the willingness to use information systems among 286 patients over 60 years register in southwest Poland's Lower Silesia Province. This questionnaire asks about the current usage of information technologies by the patients, and their willingness of usage of services based on this kind of technologies. These studies resulted on a low reception of the technologies, 41%, and discourages the implementation of this kind of services on elderly population.

The access and acceptance of a service is a consumer point of view statistic, on the next case we presented a case of the viability of a specialized test performed using tele consultations. The test performed was a diabetic retinopathy examination, a test that must be performed regular on diabetic patients to avoid eyesight lost, usually performed by a trained professional, but in this case performed by tele-medicine with a non-mydriatic camera, [25].

This study resulted that only 20 % of the cases studied by the tele-consultation service needed a follow up checkup, with 86% of these cases being redirected because mad image quality, proving that in this kind of examination can be time and money saver to the health provider and patient. Not only specialized test can be replaced using *IoT*-enabled technologies, in Arizona, United States, [26], was made a study to evaluate the effects of constant remote monitoring to patients suffering from a heart condition from December 12, 2011 to December 12, 2012. The results of this study can be seen in Fig. 7, where the comparison between the start of the program and the end clearly indicate better results of the patients using the *IoT* system, with decrease of the evaluated factors of at least 40%.

4. Health wearables

The next trend we will discuss is the Health wearables (H-wearables). On this trend, it will be a special focus on all systems, prototypes or studies that involves a wearable or change the value creation of a certain system, program or procedure. In the forthcoming sections, we explore the research behind this area, products on the market, statistics and impact on the health sector.

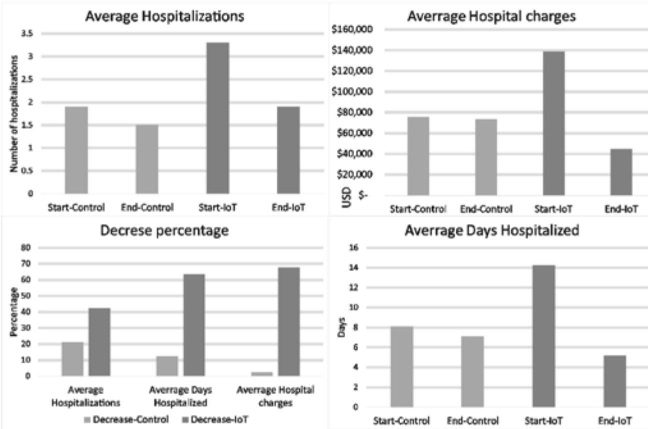

Figure 7. Results of the implementation on [26].
Source: [26].

4.1. Research

The first case of study presented on this section is a study of the acceptance of a tele intensive care unit (Tele-*ICU*), [27]. This study made a survey to gather the usage perceptions of this kind of systems across several health institutions. This kind of system employs several *IoT*-enabled sensors to be on the patient location. The results presented that the average feels comfortable using the system and had positive feedback about it. Among other responses, highlighted that this kind of systems increasing quality of service and decrease response times in case of emergency.

Finally, is concluded that the use of this kind of services help to decrease the personnel required and the amount of work needed at an Intensive Care Unit (*ICU).*

Another medical service that could use a solution on *IoT*, is the pharmacy section. Implementations aimed to improve in one aspect or other are presented in [28-30]. The first one developed a temperature and humidity *IoT* registry with cloud access, the second is inventory centered, how to establish a better inventory management system.

The last one is a system to aimed to decrease the number of medication error due to the lack in staffs, with a special consideration on those entities that have an inability to follow procedures designed to avoid this kind of errors but are for large hospitals. It was prototype implemented between the University of California Davis Health System and six rural hospitals. After this implementation, it was reduced 30% the errors of medication delivery with only a 19% of errors reported across the medication orders received during the trial.

Finally, a study of the viability of establishing any tele consultation service on third world countries from the connection stability is the focus in [31]. This was a study made on health clinics in rural KwaZulu-Natal, South Africa. The tele services that were tested were: database access, e-mail, and tele-clinics. After several tests, quality of service examination and package loss analysis, the study conclude that it was not possible to provide this kind of clinical services in a reliable way with the Internet access available at that location.

4.2. Products

From a hardware point of view, in [32] is presented a development of a low-cost body inertial-sensing network, composed by a base station, three wearable inertial measurement nodes, and a wireless communication protocol. Every node contains one three-axis accelerometer, one three-axis magnetometer, and one three-axis gyroscope. This study proved that the body inertial sensing network can provide a viable approach for a wearable system to capture biomotion statistics.

Other application are solutions to improve the life quality, [33], especially those patients with chronic obstructive pulmonary disease (*COPD*). This solution was a tele-platform that increase the information access to the patients with this condition and more so to those in areas where access to a specialist is relatively hard. But all solutions that are implemented must consider the interaction between the service, product or platform and the final user. Finally, was performed an analysis from an expert point-of-view on how accessible, reliable and friendly was the platform for *COPD* patients in rural areas.

To improve the quality of life from the perspective of the improvement the subjects eating patterns and the quality and size of the food ingest, as well as changing the exercise routines, [34]. To fulfil this, there was implemented a web page to control the dietary intake information. By photo upload into the platform the users of the app received professional feedback on the dietary intake and could log all their meals, either by a new upload or selecting from a previous entry.

The study lasted for 12 weeks from September to November 2011. This study compared that method of logging of the dietary intake information and classic ones, in which the best results are seen on the system developed, in fat reduction, waist ratio and weight loss.

4.3. Statistics and impact

One of the main benefits of a telehealth service is the reduction of travel associated expenses. For the Veterans Affairs (VA) offices was performed a study, [35], to analyze the travel expenses during the 2005 and 2013-time frame. The study calculated the travel distance and time saved because of tele-medicine, which resulted in an average travel savings of 145 miles and 142 min per visit. Which led to an average travel payment savings of $18,555 per institution per year.

In a similar problematic but under the secondary care expenses on an established telehealth program at the NHS Birmingham East and North, the Birmingham Own-Health [36]. The results of a comparative study between a control and a focus group concluded that was present a reduction of 27% of the expenses on the focus group, equivalent in a reduction from $1,678 to $1,305.

Another kind of patients that beneficiate from reduction on travel expenses are maternal, newborn, and child health (MNCH), [37] . This study was performed in Malawi, during 2013 to 2015. The implemented system of tele-consultations and remote assistance concluded on a decrease of the cost associated of $29.33 per patient and $4.33 per successful use, with an average cost for each patient being expected from $67 to $355, meaning a minimum expense decrease of 19%.

Lastly is a study of the impact of 12 apps running on a clinic environment. This study ([38]), made analytics over the time on the application, discrimination between users, interaction with the data services, interaction between medical staff and patients, and data demand from these users. On average the medical staff apps (administrative, nurses and doctor apps), were accesses 452 times per day, especially on the inter-communication departments. On the patient point the average access was 222 times per day, being appointments and test results being the main categories.

5. Colombian cases of ehealth applications

On the local context, there are 2 main examples of eHealth developments. The first case is presented as a 2-part study of the impact of a consultation service called *Doctor Chat*. This tool was created with the aim of improving access to health care services in Colombia, especially in rural areas. The purpose of the first part of this study was to analyze the different queries that were submitted between May 2007 and June 2009. This analysis was focused on three parameters: trend issues, demographics and the scope of the service. There were 1624 consultations within this time frame, with a tendency of the users asking about information on sexual and reproductive health issues. With these results a more specialized research can be done to accurately measure the impact of this kind of services. The second part [39], focused the sexual risk behaviors associated with poor or miss-information on sexuality asked through the usage of the app and the impact of its continuous use.

To evaluate the effectiveness of the app a comparative and well recognized survey was implemented prior the use. After a 6-month period, the same survey was made. The results prove an increase of 22 % in the correct answers and moreover, 4 behaviors were pin pointed as major sexual risks in the population. These were:

- Homosexual intercourse.
- Non-use of condoms.
- Sexual intercourse with non-regular and commercial partners.
- Use of psychoactive substances.
- Lack of knowledge on symptoms of sexually transmitted diseases and HIV transmission.

The second example of eHealth developments on Colombia, is the work done by a novel research center founded on 2016, The Excellence and Adoption Center in Internet of Things (Centro de Excelencia y Apropiación en Internet de las Cosas [CEA-IoT]) [40,41].

The CEA-IoT it's a governmental initiative with the collaborative efforts of top notch technological enterprises, Intel, Microsoft and HP enterprise as well as local and well established enterprises such as Hospital Universitario San Ignacio, Logika, Totto, among others and finally several of the top-notch universities of the country including, Pontificia Universidad Javeriana, Universidad Autónoma de Bucaramanga, Universidad Santo Tomas and the Universidad Tecnológica de Bolivar.

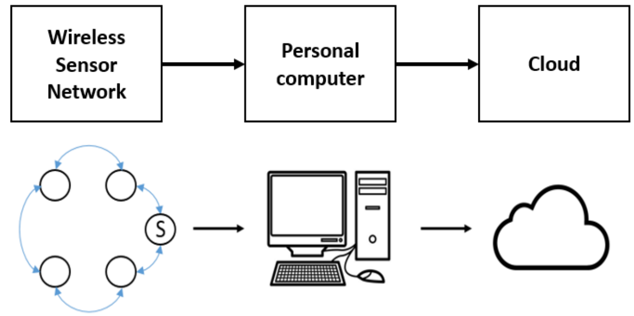

Figure 8. Architecture of the first project at CEA-IoT
Source: The Authors

The aim of the center is to motivate the creation, transference and appropriation of knowledge in IoT related subjects, this is accomplished by designing different projects for enterprises by work teams created on an educational environment and with the guidance and assistance of the of top notch technological enterprises.

During the first year, the CEA-IoT on eHealth have been developed 2 projects, both associated with the Hospital Universitario San Ignacio; and a stand-alone prototype. Following we present and summarize these projects.

5.1. An IoT approach for wireless sensor networks applied to eHealth environmental monitoring

The first project, is the development and implementation of a wireless sensor network (WSN) of temperature and relative humidity for hospital infrastructure. This project had an 9-month development time, in which a WSN was implemented on 11 locations for continuous remote monitoring. Using the architecture of Fig. 8, we implemented a cloud-based monitoring system on which we have an easy-to-read graphic system accessible by any web browser and an internet connection.

Each node composing the WSN is an embedded hardware of reference MTM-CM5000-MSP of Advanticsys. This node has an embedded temperature and relative humidity sensor, wireless connectivity on the 2.4 GHz band and is powered by 2 AA batteries. Likewise, the node supports the 6LoWPAN protocol and it has embedded the Contiki Operating System.

The WSN is composed by 3 types of node software configuration, maintaining a single hardware standard. These configurations are:

1) Sink node: Is the node connected to the computer to receive all the data for the network.
2) Sensing node: Is a node located on the site of interest in which is needed to sense temperature and/or humidity.
3) Link node: Is a node located to ensure the point-to-point communication across the whole network. Does not sent data of its own sensor.

The system uses a local computer to create a local log report of the data gathered by the sink node, and upload any new data to the cloud service. The system is set-up to measure temperature and humidity once every hour.

After a trial period of 9 months after to the project implementation a reliability metric was extracted by analyzing

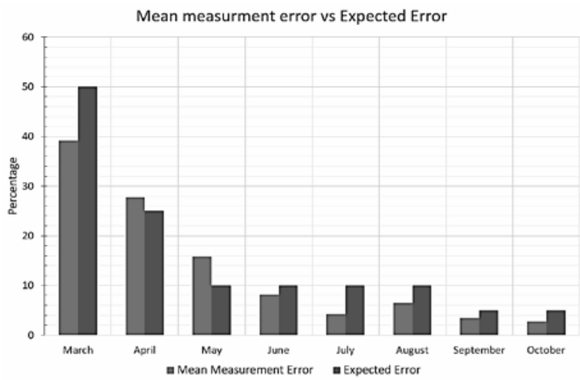

Figure 9. Mean error percentage vs the expected error each month.
Source: The Authors

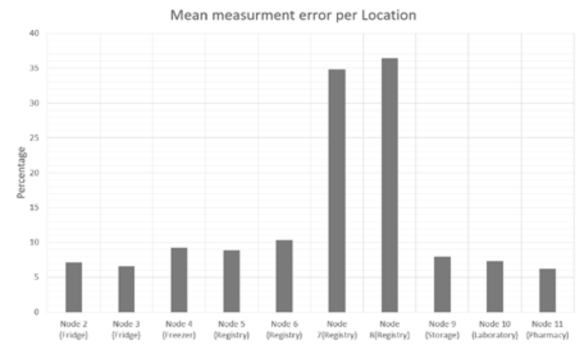

Figure 10. Mean error percentage by location.
Source: The Authors

missing messages from local log and from the cloud service. This metric was calculated for each node location evaluating the whole trial period and each month for the whole system.

The Fig. 9, resumes the mean error of the whole system (light grey) and the expected error for each month (dark grey). For most of the months the expected error was less compared to the error presented. On the first 3 months of the trial, we expected a high error due to the non-familiarity between the staff and the system, causing disconnections that where left unattended for long periods of time (4-7 days). The Fig. 10, present the mean error of the messages that arrive either on the log reports on the computer or the cloud platform. The larger error presented where on nodes 7 and 8, which was an expected result. This greater error was due to the late inclusion of theses nodes, almost 2 months after the start of the trial. The system remains presenting a mean error during the whole trial around 10%, meaning less than 140 messages (from a total of 1400 messages) lost each month.

During and after the system deployment there was positive feedback form the staffs in-charge of the system, whom previously had to do this record manually. This kind of system frees up to 60-minute each day to those in-charge of the records, recovering 1.25 days per month and 15 days every year. Also, the remote visualization make the process more accurate and faster.

5.2. Remote monitoring of patients

The second, and still undergoing, project, is for remote

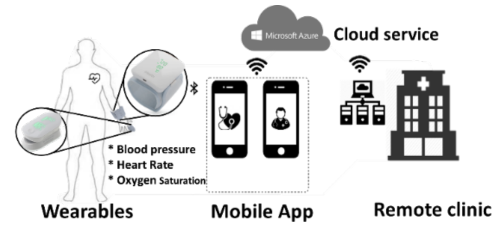

Figure 11. System Architecture.
Source: The Authors.

monitoring of non-critical patients with a heart failure. This project aims to reduce or avoid the expense of time consumed by the medical staff when they visit the patient at home for a medical consultation. During this consultation, the medical staff register the current state of the patient while gathering information of vital signs such as heart rate, respiration rate, temperature, weight, blood pressure and oxygen saturation levels. This information later (next day) must be manually logged to a clinical information service. Likewise, and due to the delay reporting the information gathered from the patient, the medical staff will never know the current state of the patient avoiding to carry out a preventive medicine.

For this project, we developed a cloud-based system, using Microsoft Azure suite, and a mobile application to integrate 3 wearables to remote measure the vital signs from the patient on designated hours. This improves the time management, increases the amount of measurements done and decreases the expenses associated to the measurement procedures. Also, this kind of system allow to increase the capacity of the health program without needing to invest on recurring expenses and decreases de amount of work associated to each professional.

The developed app is meant to have multiple purposes, it serves as a gathering point of all the data, is a tool to communicate the medical staff with the patient. This app also, gather quantitative and qualitative information on the well-being of the patients and have important information about their treatments, such as therapies and indications of well-being changes that could mean an alarm.

This project is being developed from 3 fronts (Fig. 11), the first one takes care of the identification and connection of the wearables, the app development and cloud back-end. The second one the patient management and ethics approval to deal with the well-being of any patients, guaranteeing that the system won't generate any risk to the patients. The last front is the patient trail to validate the system integrity and applicability on a real test.

In this project, we have 3 wearables (all approved by the FDA and tested in real patients), that measure hearth rate, respiration rate, skin temperature, blood pressure and oxygen saturation. The ethics committee from a Hospital (Hospital Universitario San Ignacio) had approved the patient and information management protocol. The next step is to start the trial, that at the moment of this work remains under preparation stage.

6. Iot and ehealth: future trends and upcoming work

IoT and the health care system today are getting more and more interest, on the previous sections was a clear tendency on surveys and studies of feasibility of these technologies with positive results on all cases, and the success cases impact over a 30-60% the economy associated with the services it's related.

Today the technology is still undergoing the development phase, with large gaps between the leading countries and those with similar conditions of Colombia. Although this gap exists, Colombia is starting the process of education and public acceptance towards this new paradigm.

One of the biggest issues that the eHealth is facing is the acceptance of the most relevant users, the elderly, the technological shift this population faces it's a challenge that the technology struggle with, and reduces the times and resources invested on these services; but this challenge will disappear as a new generation emerge, giving the opportunity to be massive implemented and developed. Likewise, a clear future on each of the trends discussed on this article.

1. The Internet of Me or personalized care: The future points to a common and shared database where all the medical information from the patients will be cloud-storage, with unique identifications for each doctor, nurse or any health professional.
2. Outcome Economy or H-wearables: We will have the today's equivalent of health sensors on us the whole time, without these to interfere with our day-to-day activities, sending, analyzing and anticipating with all the data.

As single trends these are the futures that accordingly to the today we can expect, but in a near future might appear a ground-breaking technology that changes these perceptions. The tendency is to close gaps, in training, in technology, in time, in space, even on people.

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