

# A Tele-home Care System Exploiting the DVB-T Technology and MHP

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## Summary

**Objectives:** The aim of this research work is the development of a low-cost system for telemedicine based on the DVB-T technology. The diffusion of DVB-T standard and the low cost of DVB-T set-top boxes bring the vision of a capillary distribution of tele-home care monitoring systems with easy-to-use patient's interface.

**Methods:** Exploiting the potentiality of the DVB-T set-top box, we transformed it into an "on-demand tele-home care interface". The Xlet we developed is able to govern the functionality of an external microcontroller-based unit for the acquisition of the bio-signals of interest. The uplink connection is used to send the exam results to a remote care center.

**Results:** The Xlet providing the patient interface on the set-top box is uploaded by a DVB-T broadcaster without any intervention in the patient's home. A prototypal low-cost base station for the acquisition of the patient's signals (1-lead ECG) has been developed. It is able to be connected to the set-top box via an infrared link. A smart-card-based system is in charge for the customization of the Xlet for every patient.

**Conclusions:** The proposed system, based on a currently widespread infrastructure, is able to allow the patients monitoring from home without any installation procedure. Even untrained (or elderly) people can easily use such system due to their practice with the basic DVB-T home-entertainment equipments.

## Keywords

Telemedicine, tele-home care, remote monitoring, DVB-T, MHP

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## 1. Introduction

Telemedicine is an interesting example of pervasive healthcare system, aimed to enable patients with chronic diseases to be assisted remotely by the care staff without the need for frequent visits to the hospital. Beyond the advantages for the patients, the costs for the public administration can be reduced exploiting low-cost equipments to create the infrastructure. Until now, the largest part of such systems was based on a PC with an internet connection (e.g. [1]) or on expensive dedicated devices (e.g. [2-4]). Often, they are not intuitive for untrained people (or not conceived with this aim [5]) and then their use is intended only for young people, more accustomed to digital equipments but at the same time not representing the main telemedicine target. Furthermore, if a PC is not present in the patient's home, the cost to set-up the platform could be high.

After 2012, Digital Video Broadcast Terrestrial (DVB-T) will be the only terrestrial television system. Any TV set can be used with DVB-T providing that an external set-top box is properly connected. Taking into account the wide diffusion of TV sets and the very low cost of DVB-T set-top boxes, the development of a telemedicine system based on such technology could represent the answer to the problems raised by the other solutions.

In this paper, a prototypal device and the whole system framework for a DVB-T-based telemedicine system are presented. In such a system, the patient is able to interact with the health-monitor device through the TV screen and the remote controller of the set-top box. The application running on the set-top box is provided by a digital video broadcaster, so that the soft-

ware maintenance and upgrade can be easily accomplished without any direct user intervention. The adoption of the interactive set-top box, which embeds a modem for a data uplink connection, allows the transmission to a remote care center (RCC) of the examination results over the telephone network without a personal computer or any dedicated device. A personal smart card enables the patient to configure the application for his/her needs without any direct intervention. Beyond the standard home entertainment equipments, the system uses a low-cost prototypal base station to perform the acquisition of the patient's signals. This unit is completely controlled by the application running on the set-top box that provides also the interface for the patient. To validate the system we developed a prototypal base station (BS) limited to the acquisition of a 1-lead electrocardiogram (ECG).

The remainder of this paper is organized as follows. In Section 2 a brief analysis about related works is presented. In Section 3 the whole system is introduced; in Section 4 the application on the set-top box with the user interface is presented, whereas some details on the hardware base station are given in Section 5. In Section 6 a short description of the application broadcasting technique is given. Section 7 concludes this work.

## 2. Related Works

The primary activity of telemedicine systems was the transmission of diagnostic medical images using television for medical consultation from physician to physician in

remote places. Recently, telemedicine systems through the Internet via satellite have become a reality by means of high throughput mixed satellite-web communication channels. This section presents some home-oriented telemedicine projects making use of DVB and Internet, without the claim to be exhaustive.

The Interactive Satellite Multimedia Information System (ISIS) project [2] realized a telemedicine system based on satellite communication for furnishing interactive services for residential users together with the traditional TV distribution, porting typical applications developed for terrestrial network (Internet) to the satellite digital video broadcasting technology (DVB-S). By a dual-band terminal, connected in uplink via Eutelsat satellite and in downlink via the Italsat satellite, the ISIS system provides a small and low-cost transceiver for sites not connected to the Internet or connected only in dial-up low-speed mode. Through his Java application for the DVB-S transceiver, called Medical Environment for Diagnostic Images (MEDI), the project can manage a medical image database for remote expert consultation and so it demonstrated the feasibility of satellite-based interactive multimedia services for telemedicine purposes.

In 2001, a multipurpose health care telemedicine system with a base unit and a mobile unit was developed in Greece too [3]. At patient's home, the mobile unit allows the transmission of vital bio-signals and static images of the patient to the base unit at the physician site (office or hospital). The mobile unit device is compliant with some of the commercial main vital signs monitor and it is able to transmit ECGs, non-invasive blood pressure (NIBP), body temperature, percentage of arterial oxygen saturation (SpO<sub>2</sub>) and heart rate. Based on the TCP/IP protocol, the communication between the two parts ensures safe data transmission and the possibility to use different telecommunication means (GSM or satellite links).

Launched in January 2001, the Universal Remote Signal Acquisition For hEalth (U-R-Safe) tele-home care project [4] created a mobile telemedicine system for home monitoring to be used by elderly

people and disabled patients in Europe. Via short range Wireless Personal Area Network (WPAN), wearable ECG and SpO<sub>2</sub> sensors are connected to a portable electronic device, able to send the recorded data to a remote central through the TCP/IP protocol and the wireless public network (GPRS, UMTS and GEO satellites). The portable unit is also capable of sending an alarm when patient fell sick, falls or pushes a button.

The Standard and Interoperable Satellite Solution to Deploy Health Care Services Over Wide Area (HEALTHWARE) project [5] is an integrated project of the Aeronautics and Space thematic priority of the 6th Framework Program (FP6) for satellite telecommunication systems and telemedicine applications. Thanks to the digital video broadcasting-return channel by satellite (DVB-RCS) technology, that offers satellite reception and transmission capabilities from anywhere, the project aims at developing and validating DVB-RCS-based telemedicine solutions. It will focus on the areas of chronic respiratory disease, cardiology and oncology, through four main applications: medical training, tele-consultation, second opinions and monitoring and remote assistance at home.

The PANACEIA-iTV project [6] is a personalized home care system enabling the citizens to monitor their health and at the same time to access health information and guidance. Through the DVB-S technology, patients suffering from Adult Congenital Heart Disease (ACHD) at the Royal Brompton Hospital can be monitored from their home. The system aims to evaluate the attitude at use of new technologies such as interactive TV in remote health care for disease management.

Even if these systems are very interesting, none of them owns the characteristics presented in Section 1, primarily the possibility to be used by untrained people to perform single exams rather than continuous monitoring, with an immediate visual confirmation of the quality of the signal measurement. None of them could be used by the patient to control his/her health state through simple measurements even without sending the exam to a RCC.

### 3. System Overview

The system presented in this paper was conceived to keep as low as possible the costs of the extra-hardware with respect to a minimum setup composed of a TV and a DVB-T set-top box connected to the telephone line. This way the usability by untrained people not accustomed to digital equipments but the TV set one is also preserved. The system is depicted in Figure 1. It is composed of two main parts hosted respectively in the RCC and at the patient's home.

In the RCC there is only a simple PC acting as TCP/IP server. The server receives the data stream and saves some files on a database directory: a patient identification file, providing all the information needed to identify the patient, and some exam data files. For exams such as ECGs, requiring a graphical visualization on the RCC, such data files are accompanied by a header file specifying the information useful for the correct visualization (e.g. sample rate). The same does not hold for exams such as arterial blood pressure, temperature, etc.

On the patient side, beyond the TV set there is only a local microcontroller-based BS connected to the set-top box through its RS-232 serial port. The BS directly provides some examination features (in this prototypal version only a 1-lead ECG), and can be expanded to embed both other examination hardware and interfaces to connect some commercial devices (such as glucose meters, coagulometers, etc.). It is connected to the set-top box for data visualization and transmission, and it is controlled by it and then indirectly by the user only through the remote control. A personal smartcard (the largest part of DVB-T set-top box provides the smartcard slot for pay-per-view services) has a twofold role: identification and configuration, as we will see in Section 4.1.

For this work, we used the Telesystem TS7.4DT set-top box, with the version 21p1 of the producer's software, and implementing the MHP 1.02 profile with some enhancements, primarily the addition of Java packages for both the smart card and the serial RS-232 port management. The real-time OS is Osmosys. The MHP set-top box acts as a (slow) PC, having user I/O devices

(remote control and TV screen), communication ports (RS-232) and an internal modem beyond the traditional audio/video connectors.

## 4. The Software: MHPHomecare

Since the proposed telemedicine system is based on a DVB-T platform, it is worth to analyze at first our application running on the patient set-top box, *MHPHomecare*, which manages the whole system. It is an Xlet, i.e. a JavaTV application model following a well defined lifecycle [7]. The Xlet is loaded into the set-top box by means of a broadcast transmission provided by a broadcaster (Section 6). Once *MHPHomecare* has been loaded, if the patient activates it by means of the remote control as for any other MHP application, the graphic interface is launched providing interactivity with the patient.

### 4.1 MHPHomecare Patient Interface

The patient interacts with the application providing control commands through the remote control and analyzing their effects through the TV screen, where the different Full-Screen Frames (FSF) of the application are shown.

At first, a *primary* FSF is shown (Fig. 2), waiting for the insertion of a valid identification smart card into the appropriate set-top box slot. Without any valid identification card the application cannot proceed. For this research work we used the ACOS2 microprocessor card by Advanced Card Systems Ltd. The application reads from the card the user data file, which stores the patient's name and its personal identification code, the treating physician's name and its identification number, a permission exam code, some information about the ISP (user ID, password, telephone number) and the RCC server IP address. This way the patient does not have to remember any code, number, password, etc. The RCC must program the smart card for a patient personaliz-

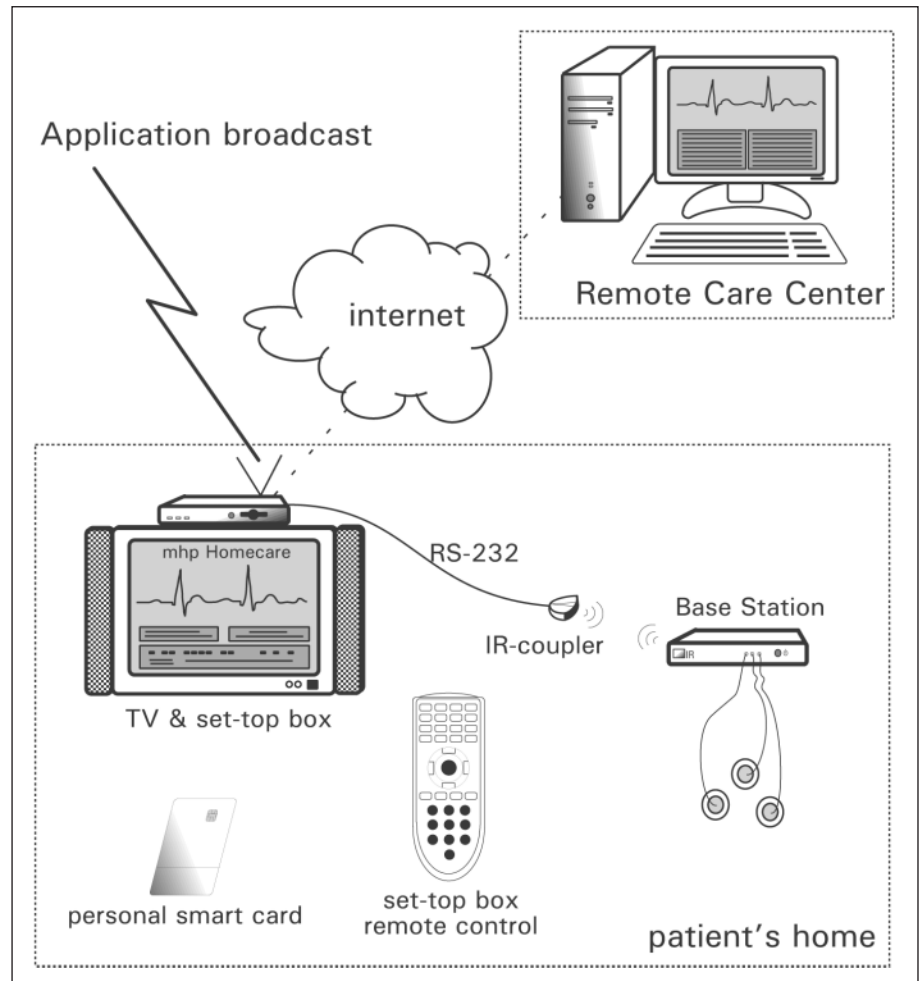


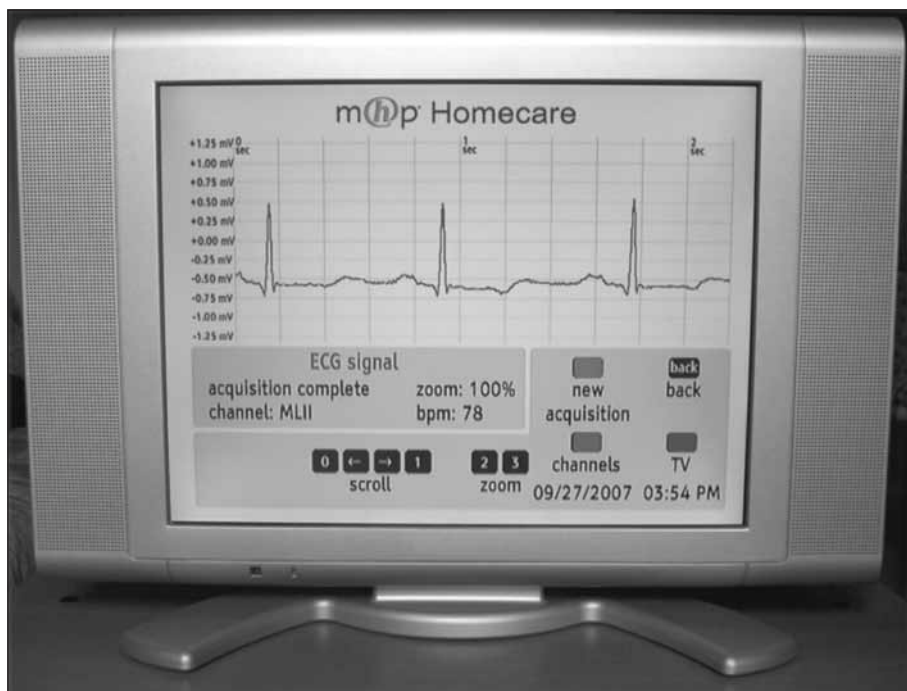
Fig. 1 The main parts of the proposed telemedicine system

ing such information, so that different patients can share the same hardware platform simply inserting their personal smart card. For instance, the permission exam code is used to allow the patient to perform only some specific exams among those available, hence disabling all the other ones. The smart card must be still in place until all the examination procedures are concluded. A small area on the top-right corner of this FSF is devoted to the background TV program streaming (Fig. 2). From the primary FSF, the patient can choose the exam to perform (a new FSF for that exam will be loaded), send the results of all the performed exams to the RCC (if any), review the performed exams. A pop-up window alerts the patient if he/she is exiting the primary FSF without sending the results to the RCC (the exam results will be lost).

At the moment the application supports only one exam, i.e. a single lead ECG or a 3-lead ECG. A screenshot of this FSF for a 1-lead ECG is depicted in Figure 3. Hereafter we'll describe the ECG exam FSF in the more complex case (3-lead). This FSF enables the ECG acquisition and shows in real-time the samples acquired from the BS and all the other information sent by it about the current exam, such as the heart rate and warning messages on signal quality. Before starting the signal acquisition, the user can choose to see in real time a single lead or all the acquired lead. As in any commercial ECG device, the actually sampled main leads are only 2 (I and II) whereas the other one (III) is computed as  $III = II - I$ . Once the exam has been saved, from the same FSF it is possible to review it on the TV, with a scroll feature, and to zoom on a single lead.



**Fig. 2** A shot of the main screen of the *MHPHomecare* application (primary FSF) on an LCD TV



**Fig. 3** A shot of the ECG exam screen of the *MHPHomecare* application (ECG Exam FSF) on an LCD TV

The patient can also redo the same exam: a pop-up alerts the patient that the previous record will be overwritten. Pressing the *Back* key on the remote control, the appli-

cation returns to the primary FSF with the possibility to send the record to the RCC via the internal modem, simply pressing a key. Every FSF can be reduced to allow the

patient to watch a TV program while the application is running in background.

## 4.2 Set-top Box to BS Interface

The control of the BS from *MHPHomecare* takes place by means of an RS-232 serial port connection. To avoid direct coupling with the AC mains, the serial connection is infrared (IR)-coupled.

*MHPHomecare* stops the signal acquisition if:

- the user presses the appropriate key on its remote control;
- the signal quality is too poor (e.g.: misplaced electrodes), displaying a message on the exam FSF;
- the default exam time (10 seconds for the ECG) has been reached.

After the exam stops, the BS sends to the set-top box a last word with the value of the heart rate expressed in bpm so that the proper FSF can be updated.

## 5. Hardware: the Base Station

We developed a simple BS with a serial interface. According to the international recommendations about the patient's safety, the physical connection between the BS and the set-top box is represented by an IR link. The BS embeds a module for the IR transmission of the serial stream, whereas the set-top box exploits an external IR coupler connected to the RS-232 serial port. From the patient's point of view, the BS is a black box without any own user interface: it is controlled by the patient through the remote control of the set-top box. The BS is battery-powered, for simpler use and improved patient safety. At this moment, it implements a single-lead ECG (lead I) and consists in a classical ECG amplifier coupled with a very simple and low-cost Digital Signal Controller (DSC), i.e. the Microchip<sup>TM</sup> dsPIC30F4013.

The ECG amplifier is a low-pass system with a variable gain up to 2000 and a cut-off frequency of 100 Hz. It consists of an optically isolated instrumentation amplifier

with high CMRR connected to the wrists of the patient and an inverting operational amplifier connected to the right ankle for electromagnetic coupling noise rejection purpose, so that only three disposable electrodes can be used. The DSC is programmed to sample the ECG signal at 250 Hz. The sampled signal is digitally filtered to remove the mains interference and the baseline drift. We also implemented a simple QRS detector for heart rate calculation and visualization on the TV screen. The heart rate is calculated on the overall signal but the QRS detector works on-line sample by sample. The QRS detector is based on both the signal and its first derivative amplitudes, and is a modified version of the algorithm presented in [8]. It was chosen for its simplicity, since the indication to be provided is only for a qualitative analysis (it can be performed again on the RCC). The RR interval measurement is performed sample by sample, and if it is too far from the standards a warning code is sent to the set-top box to ask the user to control the correct connection of the electrodes. The average heart rate is sent when the acquisition stops and is referred to the average RR during the acquisition window. All these computations are performed in real-time on the BS, since the set-top box is quite slow in processing due to the Java VM and to the applications running on it.

## 6. Broadcasting MPHomecare

The application is loaded on the patient's set-top box through an ether broadcast DVB-T transmission, while the user is watching the broadcaster's channels. In general, a DVB-T broadcast system is designed to transmit a compressed digital audio/video/data MPEG-2 stream, using Orthogonal Frequency Divisional Multiplexing and a modulation technique compatible with the traditional 8 MHz bandwidth of the analog transmission channel (i.e. QPSK, 16QAM and 64QAM). The compressed video, audio, and data streams of one TV channel are multiplexed together to form a Programme Elementary Stream (PES). The

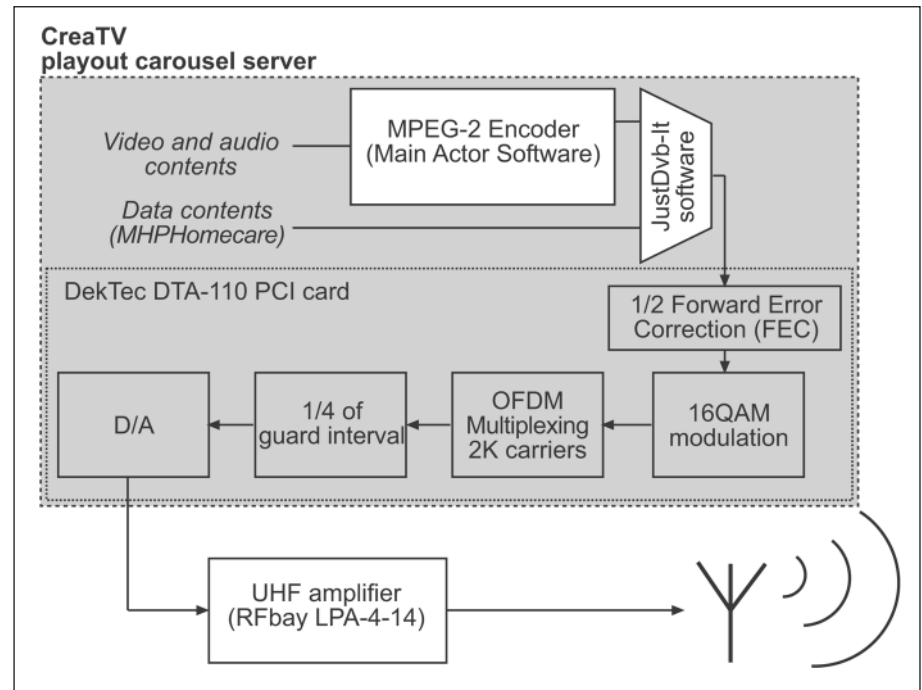


Fig. 4 The block diagram of our broadcast transmission system

basic digital stream that a set-top box can receive is an MPEG-2 Transport Stream (TS), which is formed joining together one or more PES. From the receiver's point of view, all the TV channel and services are received at once but it only demultiplexes and then decodes the selected content, one at a time, from the received TS.

Our DVB-T broadcast system is depicted in Figure 4 and it is based on the *CreaTV* MiniLab by Media Solution. Through the JustDvb-It 2.0 software [9], video and audio MPEG-2-encoded contents are multiplexed together with the Xlet application to build the Single Program Transport Stream (SPTS) to broadcast. A PCI card DekTec DTA-110, a multistandard modulator with UHF Upconverter, is coupled with a 20 dBm RF amplifier (RFbay LPA-4-14) for the ether transmission of the SPTS. To establish the bit rate needed to encode audio, video and multimedia contents in the MPEG-2 format, it is necessary to know the coding and modulation parameters used to transmit the SPTS. We have chosen 1/2 for the convolutional rate, 16QAM for the modulation type and 1/4 of the original block length for the guard interval. The resulting bit rate is 9953 Kbps.

## 7. Conclusions

In this paper we presented a DVB-T-based telemedicine system. The widespread diffusion of the TV sets and the relatively low cost of the DVB-T set-top boxes create the perfect scenario for the introduction of such a technology for the remote non-continuous monitoring of young and elderly people. Compared to traditional dedicated systems, the presence of a visual environment on the TV screen allows a more friendly approach providing also detailed information and feedbacks about the signal quality, and guiding the user through all the exam procedure without any required printed manual. We successfully implemented a broadcasting system to load the Xlet application on the set-top boxes inserting it in a broadcaster TS. This way any software upgrade can be also accomplished without the patient involvement. A simple and powerful smart-card identification and customization system has been proven to be effective in reducing the patient's interaction with the application. A prototypal low-cost base station for the actual bio-signal acquisition and processing has been also presented. We

are continuously improving its functionalities providing interfaces for commercial devices too (e.g. glucose meters).

The next step will be a clinical trial at the patient's home. We are actually selecting a representative set of elderly patients with cardiac diseases with a common experience in the use of the DVB-T entertainment equipment. They will use the prototypal BS, with some additional improvements, sending the results of the exams to the RCC. From the patient side, the procedure is very simple. The patient will have access to the system simply switching on the DVB-T broadcaster's channel and waiting for the Xlet loading (the Xlet will be loaded on the patient's set-top box by a local broadcaster). Then, inserting the smart card programmed by the care staff into the set-top box, the Xlet will automatically configure itself for that specific user. The patient can then switch on the BS, and through red button of the set-top box remote control, he/she will start the acquisition of the exam. Pushing the yellow button on the remote control, the transmission towards the RCC will be performed, and a warning message will inform about the correct outcome.

From this trial we will evaluate the impact of such a solution on the quality of ser-

vice perceived by the patients. The main aspects of interest are: easiness of use of the whole system, satisfaction level due to a more frequent monitoring, improvement of the service perceived by the patients in terms of time saved and reduced number of visits at the RCC ambulatories.

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