CareBox: A Complete TV-Based Solution for Remote Patient Monitoring and Care

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Abstract. Influent voices from different areas like government and insurance companies already realized the savings that could be done with remote health monitoring and assistance systems. The TV is still the technology that older adults feel more comfortable with, and therefore we present *CareBox*, a new prototype that perfectly integrates with TV viewing experience and uses this almost ubiquitous mean to provide some features that they really feel the need in their daily lives: health agenda, medication intake and vital sign measurement scheduling and alerts, vital sign monitoring, videoconference with doctors and other features that may be also useful for doctors like support for medical questionnaires and health videos.

Keywords: Ambient Assisted Living, Telemedicine, Homecare, eHealth, Remote monitoring, TV, Set-top box.

1 Introduction

The majority of older adults are affected with chronic conditions and acute illnesses. Isolation (either physical or social) has been a social weapon that is covertly lowering the results of any care service.

Remote patient monitoring systems have been around for many years and are seen as a solution to reduce the costs for health care, which are still raising due to the increasing of life expectancy [1], but only few had been effectively working in the real world. Lack of interoperability is one of the main reasons for this. The creation of health information standards like ASTM-CCR or HL7 came to promote the interoperability and the adoption of this kind of technology.

CareBox is one of the main results from the EU-funded research projects eCAALYX [2] and CAALYX-MV [3] and was thought-out and designed with all these issues in mind. It aims at using well-known and standard technology to provide a full-featured and easy-to-use remote patient monitoring service, focusing on interoperability standards to allow its adoption by many stakeholders. Apart from the aforementioned features, it was completely designed to be adaptable to any environment and electronic medical record. This will certainly open many doors for the development and integration of new and innovative features.

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2 State of the art

Fortunately, there are a lot of projects under the telemonitoring and homecare topics but few provide TV-based interfaces for the patient. There are essentially two main alternatives to provide them to the final user: either through an expansion (widget, plugin, etc.) to the official STB firmware of a DTV service provider or through a dedicated STB. Both have benefits and drawbacks. The former alternative allows the software to be easily distributed and maintained, being the costs significantly reduced due to the fact of not needing a dedicated hardware for the service. However, there are major drawbacks like the fact of having rather limited hardware support and little to no control over the operating system. Also, the homecare service can only reach population that holds a subscription to the DTV service. There are several examples of projects that use this approach like KeepInTouch [4], HERA [5], DIGA [6] and Panaceia-ITV [7].

The other alternative to provide TV-based patient monitoring and care services is through a dedicated STB. This approach allows having full control over the system and better hardware support, therefore not depending on any DTV service provider. On the other hand, the costs can be significantly higher. IN-HOME [8], OLDES [9], Avicena [10] and the work in [11] are example of projects that followed this approach.

CareBox fits in this latest category of care services using a dedicated STB. However, it stands out for its open and modular design, adjustable to any needs and focusing on interoperability, the integrated support for several vital sign sensors, the special care on the user interface and the drive for a smooth and intuitive integration with the TV viewing experience.

3 System Design

Providing a modular architecture to *CareBox* means not only there was the care to decouple the presentation layer from the logical layer, but also to decouple the communications layer from the logical layer. Also, there was the focus on using free, open and standardized technologies and protocols to promote the use of the system in every use case. *CareBox* was developed to be running on a *Nvidia ION*-based Mini-PC (Intel Atom 1.6GHz CPU, 2GB RAM) (Fig. 1). The operating system runs on an internal USB pen and is a modified version of the *OpenELEC* distribution, which targets at providing a complete XBMC media center with minimum software requirements, complemented by a *Firefox* web browser for generic use. Having complete control over the *Linux* operating system allows us to provide support for several hardware components, namely peripherals used in the system: dongles for vital-sign sensors, webcams, remote controls, etc.

Most of the implementation was done using the scripting and skinning capabilities that XBMC media center provides to develop plugins using the *Python* programming language.

Fig. 1. *CareBox*

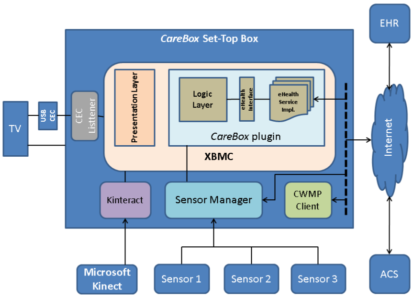

Fig. 2. *CareBox* architecture

One of the strongest points in *CareBox* is its focus on interoperability. The modular design regarding the communications layer allows the system to support different protocols and communication schemas and technologies, being quite easy to switch from one module to another and to implement new ones. Currently, and since the system was developed under the support of the eCAALYX project, only the implementation for the protocol used by the care server developed in the project is available, as well as an early, but quite usable, implementation for the *eHealthCom* [12] server. Nevertheless, implementations for subsets of the ASTM-CCR and HL7-CCD specifications are underway. These implementations will explore all the possibilities of using the standards for every feature available. In case that is not possible, extensions to the standards will be used.

The management of the system can be done remotely since *CareBox* provides an expandable CWMP (TR-069) client that allows not only remote configuration but also remote firmware upgrade through the use of an Auto-Configuration Server (ACS).

4 Technical Details

4.1 General Considerations

CareBox firmware image features a small footprint (slightly more than 120 MB, plus 100 MB if compiled with support for Microsoft *Kinect*) and a quite short cold boot time (nearly 20-30 seconds on a USB pen), although it supports a standby mode.

The system was properly set up in order to include several libraries and frameworks needed for some *CareBox* features. It can use either Ethernet or Wi-Fi to access the Internet and comes with an RF remote control that allows a simple operation of the set-top box. This remote is also programmable so that it can also control the TV set through InfraRed.

Fig. 3. *Reminders interface (Google TV)*

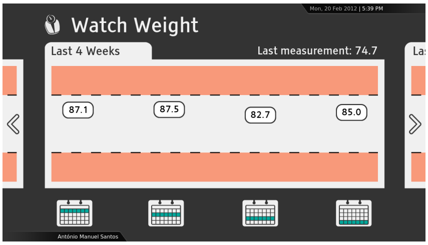

Fig. 4. *Weight graphics*

4.2 Multi-User Support

CareBox was also designed to have multi-user support. Depending on the protocol and caretaker server, the configuration can hold data for more than one user, to be used in scenarios where *CareBox* is shared by multiple users in the same location.

Two login mechanisms are available: one is having a simple user selection interface, without any authentication method. This is the simpler to deploy, although it may raise privacy issues. The second mechanism came to address these issues and uses a fingerprint sensor connected to the STB (via USB) (Fig. 1). Right after validating a fingerprint, the user is automatically logged in and may be logged out manually or by idle timeout.

4.3 User Interface

Regarding the graphical user interface, a lot of care was taken in this matter. It must be emphasized that the system was primarily designed to be used by elderly people, as it was a main requirement of the eCAALYX project, and the current minimalist design is based on the work made by [13] and [14]. The output of this work came from some tests made with real people using low-fidelity prototypes and mock-ups.

4.4 Agenda and Reminders

In order to help the patients in their schedules, a useful medical agenda was developed to ease the tracking of their medication, vital sign measurements and appointments. To raise the usefulness of the system, a reminders system was developed and uses the TV to warn the patient for upcoming events (Fig. 3). It uses time frames based on patient's daily routine: *Wake-up time*, *Breakfast*, *Lunch*, *Dinner* and *Bed time*. This information, alongside last intake time, allows for a quite effective reminders system, alerting the patient for medication at the right time. *CareBox* holds medication information based on common parameters used in standards like ASTM-CCR or HL7. Specifically, medication frequency is based on what SNOMED CT defines.

4.5 Vital Sign Monitoring

Another main feature of *CareBox* is the ability to read vital sign measurements from some sensors (using Bluetooth) and provide the patient with easy reading graphics that represent their evolution. The TV acts as a wizard providing all the guided steps for taking measurements. There is no local storage, although a retry system may be triggered in case of a sporadic network failure. The patient also has the ability to select from within different time frames for each vital sign when viewing the graphics. All the measurements are grouped in time blocks and all the measurements taken within that time block are processed in order to have a mean value that will be shown on the graphic (Fig. 4). While this is straightforward regarding weight, things are a bit trickier in what it takes to blood pressure, since there's no explicit separation of systolic and diastolic graphics. In this case, the mean arterial pressure calculation (MAP) is used, based on the values of the diastolic pressure (DP) and systolic pressure (SP) (1).

$$MAP \simeq \frac{2}{3}(DP) + \frac{1}{3}(SP) \tag{1}$$

CareBox also supports vital sign thresholds per patient, represented as red areas at the top and at the bottom of the graphics.

4.6 Questionnaires

Medical questionnaires are a useful tool for the doctors to retrieve medical data from the patients. Functional Impairment (Barthel Index) or Geriatric Depression Scale questionnaires are common examples in the context of treatments of elderly people with chronic conditions. Although most of them are designed in order to have questions of dichotomous nature, the system supports any number of questions with any number of possible answers.

4.7 Health Videos

Another topic that isn't being vastly explored by this kind of systems is the possibility of using them also for pedagogic purposes. Allowing the patient to watch videos related to their condition, or just providing generic health-related videos (daily exercises, how to use a sensor, etc.) is of utmost importance. Therefore, and exploring the fact of having the system developed on top of a media center framework, *CareBox* easily provides this feature, supporting almost every video and audio format (Fig. 5).

4.8 Videoconference and Emergency Call

A patient will feel much more safe and confident if he knows that he can establish a visual communication with his doctor (or even with his own family) in a quite easy way, anywhere, anytime. As for the doctor, he will certainly be pleased to be able to video-call his patients anywhere, using common technology like, for

Fig. 5. *Health video playing*

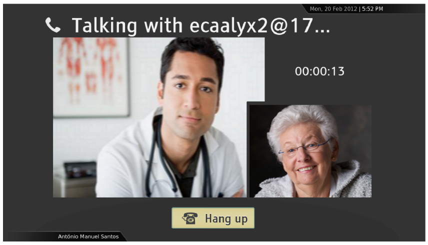

Fig. 6. *A running video call*

instance, his own smartphone. Therefore, *CareBox* provides an integrated VoIP client that can be used to start or receive audio/video calls with/from doctors, as long as the needed configuration parameters are provided (Fig. 6). Following the care of using standard technology, this client uses the SIP standard (used by most of existing VoIP services) and currently supports H.263, H.263+ and H264 video codecs (MP4 and VP8 are currently being worked on) and PCMU, PCMA, Speex and Siren audio codecs (GSM and G.726 are also currently being worked on).

The whole client is developed on top of a stack of open-source libraries and frameworks, namely *GStreamer*, *Telepathy*, *Farstream* and *Sofia-SIP*. *CareBox* is provided with a webcam (it includes the microphone) but it should support any webcam compliant with the UVC specification and supported by the *Video4Linux* 2 drivers. *CareBox* also offers an Emergency Call service, which basically uses the VoIP client to make an audio call to a pre-defined contact.

4.9 TV Integration

CareBox is provided as a set-top box that simply connects to an available input on the TV. Although it supports analog connection through VGA output (it provides an adapter for SCART/S-Video connection), *CareBox* also provides a digital HDMI output (for both video and audio) and explores some unused capabilities of this type of connection.

The HDMI-CEC standard allows a device to be able to control others through an HDMI connection. The standard defines several messages and commands that can be used by a device to achieve optimal integration and ease some common operations by the users. *CareBox* supports the HDMI-CEC standard, at least a subset that allows it to be perfectly integrated within the patient's TV viewing experience. Most of the times, the patient will of course be watching his favourite TV shows so if, for instance, a medication reminder is fired or *CareBox* is receiving a call from a doctor, there should be a way for the patient to be instantly notified. *CareBox* can do it through the use of an USB-CEC adapter [15] and a carefully designed and developed daemon for this purpose. When such a scenario happens, *CareBox* will immediately switch the TV input to the one used by itself and the user is asked to follow up the event. When it finishes, *CareBox* will do the reverse and will switch the TV back to the previous input.

Another interesting thing is that the support for the HDMI-CEC standard allows the user to use the TV remote to control the *CareBox*. So there's no need to be always switching the remotes to control either the TV or the *CareBox*. This is a really important feature given the usual resistance by the elderly people to learn to use new input devices.

Currently, most TV manufacturers do support this standard (or at least a subset), although sometimes published under commercial sounding names like *Simplink* (LG), *Anynet+* (Samsung), *Bravia Link* (Sony), *EasyLink* (Philips), etc.

4.10 Google TV Port

With the recent developments on *Google TV*, a clear window of opportunity has opened in what it takes to developing applications for the TV. The video overlaying ability is clearly an added value in this system, allowing notifications on top of the TV image (Fig. 3). Therefore, *CareBox* also has a port for *Google TV*, which can be later distributed as an application through *Google Play*. This port is almost fully functional, when compared with the current features of the standalone version, only missing the support for taking measurements and a VoIP client due to limitations on the support to USB peripherals, including webcams.

4.11 Microsoft Kinect support

Foreseeing the need to promote body activity, *CareBox* has provided the support for Microsoft *Kinect* (support for other similar devices like Asus *Xtion Pro* can be easily added) through the integration of the OpenNI/NITE middleware stack and the development of a natural interaction driver, *Kinteract* [16], that detects some common hand movements (directions, wave, push, backward, etc.) and maps them into pre-configured standard keyboard events, which are then sent into the Linux user level input subsystem (*uinput*). XBMC will then react normally like being controlled by the remote control, allowing the user to easily navigate through the *CareBox* user interface. Taking into account that *CareBox* is primarily designed to be used by older people, some subjects with ages between 60 and 75 were asked to do some movements they feel as appropriate to control the user interface in what it relates to the common actions (up, down, left, right, select, back, etc.). The idea is to improve *Kinteract* so that it can accurately detect some common gesture patterns applied by these users, thus reducing the learn curve, improving the results and therefore motivating the user to select this interaction method more often.

5 Results

Up until now, the only trustful results are the ones that are coming out from the field trials that took place in Germany with 10 patients. All the features were tested except for the *Videoconference/Emergency Call*. The field trials were divided in two phases. The first phase took place in January 2012 and focused more on the usability and stability of the system, with a limited set of features being tested. In what it takes to the home system, namely the STB, it was tested with just the *Health Status* (vital signs) and *Health Agenda* (and *Reminders*) features enabled. Also, the user interface was still in a draft mode and not as stylish as the one presented in this document. The results were not as positive as expected [17]. The patients found the navigation confusing, mainly due to the fact of having the main menu showing all the options, even if some of them were still not available for testing. To worsen things up, the remote control was not working properly due to a manufacturing error and the patients also found the keys too small. Also, the long waiting periods on every request to the Caretaker server (which were due to major issues on the implementation of the server) lowered the rating of the system. Nevertheless, the patients were able to work with the STB after minor training and all the implementation, including all under the hood and system-level applications, was found to be working properly, without major issues being detected. The second phase of the field trials took place in March and April 2012 and already included a larger set of features, except again for the *Videoconference/Emergency Call*. The patients immediately noticed an increase on the usability and the overall results were more positive, even taking into account the learning effect inherent to these second trials. Apart from some minor issues, the overall impression included some considerations and recommendations like: the remote control should be more tailored for this scenario, with only the necessary buttons; long loading times (due to severe connection issues to the Caretaker Server); no immediate visualization of the measurement value on the TV after using a sensor (not an issue anymore since the STB can now act as sensor gateway); learning curve still too steep. Massive field trials will be taken in different countries in the already running CAALYX-MV project, which basically runs a market validation of all the prototypes that came out from the eCAALYX project. These field trials will comprise about 80-100 patients over three different countries.

Also, Fraunhofer Portugal AICOS has recently made another round of internal tests with ten older adults in order to validate the implementation of the user interface and collect feedback in order to improve it. The results of the tests [18] showed that the overall user interface layout is now appropriate, although some interesting findings and recommendations were provided and are already implemented.

6 Conclusions and Future Work

CareBox tries to gather all import features into a single product that can be easily distributed and managed. Currently, and despite still being under heavy development, there are already some foreseen features being implemented like expanding the support to medical information standards (HL7 and ASTM-CCR) and extending the support to sensors using technologies like *ANT+*, *Zigbee* or

Z-Wave. New features are also in the pipeline: promote user mobility with movement games using Kinect, support for the visualization of more vital signs, including physical activity data, and adding new services like, for instance, home automation using recent standards like *OpenURC*. Last but not least, the development of a simplified interface for smartphones could also be of major importance, allowing the user to interact with the system (for instance, acknowledging medication reminders, making/receiving calls, etc.).

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