

A SMART MEDICINE MANAGER DELIVERING HEALTH CARE TO THE NETWORKED HOME AND BEYOND

An Overview of the iCabiNET System

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Abstract: Misuse of prescription and over-the-counter drugs is a growing problem that impinges heavily on the well-being of people and the economics of public health systems. Most commonly, misuses arise from forgetfulness or lack of information about drugs and their interactions, hence there is much place for solutions to automatically monitor medicine intake, issue reminders and deliver medical advice. This paper presents a system that accomplishes these tasks by harnessing recent advances in smart medicine packaging, residential networks and semantic reasoning. Such a combination yields a medicine manager featuring great precision in drug monitoring, plus unprecedented capabilities to reach the users and provide them with valuable information.

1 INTRODUCTION

Recent statistics reveal that the misuse of prescription and over-the-counter drugs is becoming a major problem as life expectancy increases and the range of medications grows, to the point of being as dangerous and costly as many illnesses (Sullivan et al., 1990; Downey et al., 2000). To ground this significance in numbers, consider the following USA facts, retrieved from (American Heart Association, 2007; Akram, 2000; Office of Applied Studies, 2005):

- 50% of filled prescriptions are taken incorrectly. In the worst extreme, 65% of the elderly fail to comply with their medication regimens, with 26% of those errors being potentially serious.
- 23% of nursing home admissions are due to abuse or non-compliance, costing \$31.3 billion per year and affecting 380,000 people. The same happens with 10% of hospital admissions, costing \$15.2 billion and affecting 3.5 million people.
- \$75 billion are annually spent on preventable hospitalizations due to medication misuse, plus other \$30 billion on additional medications prescribed after non-compliance.
- 125,000 deaths occur annually due to drug interactions.

As noted in (Hughes et al., 2001; MedPrompt, 2007), misuses typically arise from forgetfulness or lack of information about the different drugs available. This has raised enormous interest in developing solutions to automatically monitor medicine intake, issue reminders and deliver medical advice (Bricon-Souf and Newman, 2007). Some precedents for this idea can be found in (Wan, 1999; Ho et al., 2005), with embedded systems that employed RFID¹ devices to recognize medicaments and weighing scales to guess the doses available. However, those systems are impractical due to the following drawbacks:

- The weighing scales require the users to pick one medicament at a time and put it back before picking another. This is a cumbersome discipline to follow in many cases, entailing a clear risk of monitoring imprecision.
- The means available to reach the users are very limited, merely consisting of embedded screens, lights or alarms. Thus, it is not possible to prevent forgetfulness if the user happens to be out of home, or simply in a room where he/she cannot see the lights or hear the alarms.
- Finally, the previous systems rely on the assumption that people use a medicine cabinet as the

¹RFID: Radio Frequency Identification.

only place for medication keeping. Nevertheless, polling data reveals that this may not be true in as many as 90% of the cases, as people tend to store their medicines in various places around the house (Fishkin and Consolvo, 2003).

With these problems in mind, we introduce in this paper a system, called the iCabiNET, that tackles the aforementioned issues by integrating recent advances in various areas of research. The basic ideas behind this system are explained in the overview of Section 2. After that, Section 3 describes two usage scenarios to illustrate the benefits and the potential uses of our approach. Section 4 provides technical details of an implementation capable of realizing those scenarios. Finally, Section 5 includes a summary of conclusions and motivates future work.

2 SYSTEM OVERVIEW

As shown in Fig. 1, we have conceived the iCabiNET as a new element of a residential network, ready to communicate directly with other appliances installed in a house, and with the outside world through a residential gateway. Within this setting, the operation of the system consists of two major steps, to be detailed in the following subsections:

- Gathering information about available drugs and doses.
- Processing that information to identify and react to actual or potential misuses.

2.1 Gathering Information

In what concerns the gathering of information about available medicines and doses, the iCabiNET can coexist with any of the previous monitoring solutions (Wan, 1999; Floerkemeier and Siegemund, 2003; Ho et al., 2005), given that they propagate data over the residential network. Furthermore, we have introduced support for the *smart packaging technologies* currently promoted by stakeholders of the pharmaceutical industry. As explained in (Goodrich, 2006; Harrop, 2006), the idea is to integrate RFID devices and different types of sensors with the packaging of the medicines, to allow tracking not only medicine names, but also the doses available with no additional equipment. A common example is that of *smart blister packs*, which record the removal of a tablet simply by breaking an electric flow into the RFID's integrated circuit; other possibilities exist for liquid medicines, ointments and so on.

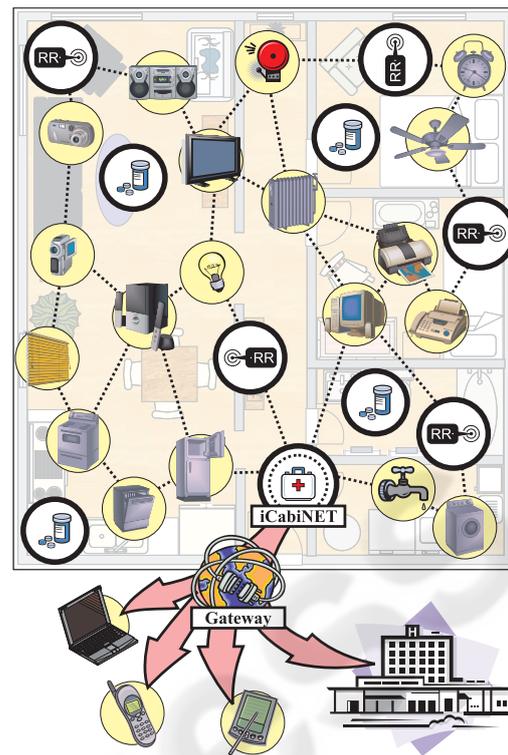


Figure 1: The iCabiNET system in a residential network.

Smart packaging enables the iCabinet to monitor the intake of drugs from anywhere, with the highest precision, with no need to keep all drugs in a unique place, and with no risk of mistaking one drug for another. The system simply gathers information by polling RFID readers deployed around the house (the RR devices in Fig. 1) or connected to the residential network from other places (e.g. from the office).

2.2 Reacting to Misuses

Primarily, the iCabiNET is intended to enforce some *medication guidelines*, such as “*the user should take one of these tablets every 4 to 6 hours*”. Accordingly, in the operational scheme of the system (see Fig. 2), there is a ‘Watchdog’ module devoted to continually supervising the information gathered about available medicines and doses, to check that the former remain in good condition and the latter decrease correctly with time. This module detects odd circumstances driven by *rules* that may involve user conditions (like age, gender or previous diseases), and notifies those circumstances by triggering different types of *events*.

The events are the input for a second module, the ‘Actuator’, to decide what *actions* will be performed to issue warnings or deliver health care information to the user. This module firstly considers generic state-

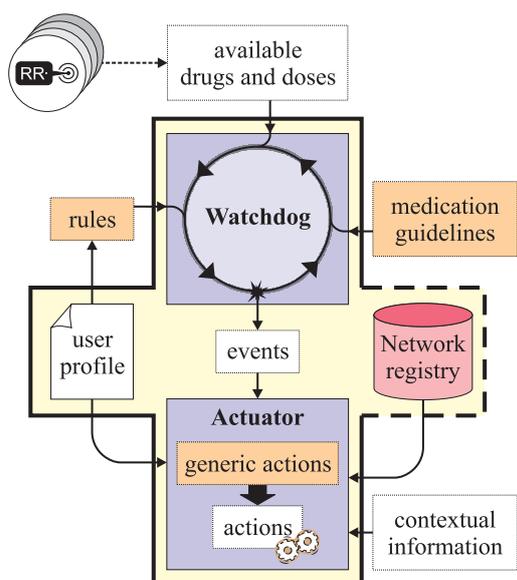


Figure 2: The operational scheme of the iCabiNET.

ments with no liaison to specific appliances, such as those of Table 1. Then, it instantiates those statements on demand, using the appliances it finds most convenient. In doing so, the ‘Actuator’ takes into account data from the user’s profile, contextual information provided by external devices (e.g. about whether the user is sleeping, watching TV or out of home) and descriptions stored in a *network registry* of the appliances connected to the residential network and the operations they can do.² Thus, for example, a “warn the user” action can be automatically made to trigger an alarm clock, to interrupt a TV program and display some message on screen, or to make a telephone call. The enormous range of possibilities enabled by the residential network to reach the user is precisely the point that makes the iCabiNET most advantageous with regard to previous systems.

Orchestrating appliances as explained above requires the iCabiNET to take a great number of decisions that cannot be determined beforehand. Noticeably, this *intelligence* is not catered for by the current residential network standards (Baxter, 2005), because they merely provide for executing pre-compiled programs (usually referred to as *bundles*). Thus, it would be necessary to write different versions of the same behavior for all the possible configurations of devices in and out of home, even considering the different ways to invoke the same operations for appliances assembled by different manufacturers. Such an approach would obviously exhibit limited flexibility

²The registry can reside in the iCabiNET or in any other device permanently connected to the residential network, most typically the residential gateway.

Table 1: Some events types and actions they might trigger.

Event	Action
Oblivion	“Wait up to 90 minutes before reminding the user”
Expiration	“Deliver increasingly serious warnings day after day”
Depletion	“Arrange an appointment with the doctor to get a new prescription”
Interaction	“Recommend an innocuous combination of drugs with the same effects”
Discontinuation	“Restart the medication at a lower dose”
Abuse	“Warn the local authorities”

and severe scalability problems. The iCabiNET’s solution to these questions builds upon two main ideas:

- The first idea is to deliver *virtual bundles* containing no implementation, but rather process flows that arrange medication guidelines, user conditions, rules, events and generic actions in semi-formal constructs.
- The second idea is to enhance the network registry with mechanisms from the Semantic Web (Antoniou and van Harmelen, 2004), using *ontologies* as unique conceptualizations of what the different appliances can do and how: operations, input and output parameters, quality attributes, etc.

As shown in Fig. 3, when a virtual bundle appears in the system, the iCabiNET creates one *implementation bundle* to supervise the occurrence of events in the corresponding process flow. Then, when it is time to perform some actions, the implementation bundle uses matching techniques like those of (Paolucci et al., 2002; Fujii and Suda, 2005) to find the most suitable appliances at the moment (A, B, D and E in Fig. 3) and start invoking their operations in the specified order. This approach promotes openness and interoperability, making it possible to deliver the same virtual bundles to everybody, regardless of the particular appliances owned by each user. Furthermore, nothing has to be re-programmed when any element changes, and it is even possible to incorporate newly-invented devices and functionalities with a simple update of the ontologies.

Following the commented scheme, several virtual bundles are preloaded in the iCabiNET to deal with common tasks, such as checking interactions between available drugs by accessing remote data bases, or downloading process flows to drive the monitoring of new drugs acquired by the user. Other virtual bundles

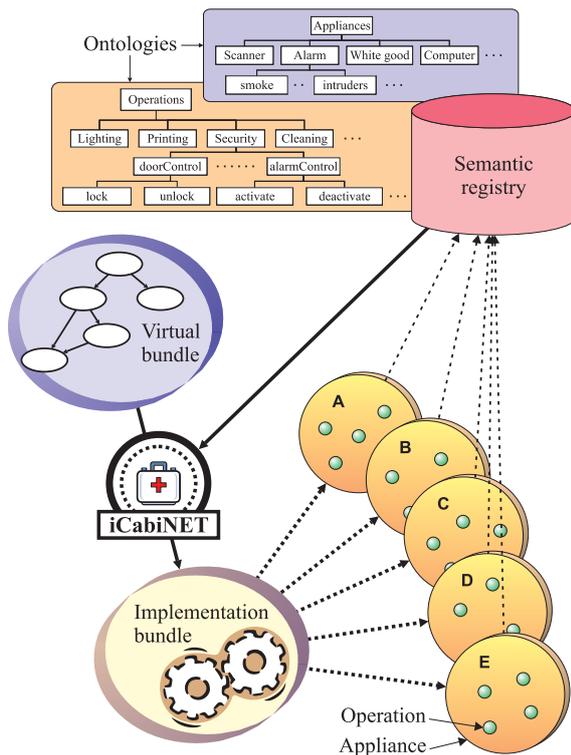


Figure 3: Activating appliances from virtual bundles.

can be entered by the user or by authorized external entities, like health institutions (they know what the user needs) or pharmaceutical companies (they know the best way to take their products).

3 USAGE SCENARIOS

Having explained the essentials of the iCabiNET, we now describe two usage scenarios to illustrate the range of functionalities it can deliver. The technologies employed to make these scenarios possible are described in Section 4.

3.1 Scenario #1

Ann is having breakfast before going to work, and switches on the radio to hear the first news of the day. When she is about to turn off the apparatus, the iCabiNET reminds her of the medicines she should carry, playing a pre-recorded message. Later, following the prescription issued by the doctor (loaded into the iCabiNET directly from the health center), Ann receives an SMS message in her mobile phone every three hours to remember taking her drugs. At the end of the day, when Ann is back in her house, the iCabiNET attempts to check that the available doses have

decreased as expected, but it turns out that Ann has left them behind. In this case, the iCabiNET rings the in-home telephone to ask Ann whether she has taken the medicines correctly; she replies affirmatively by pressing the asterisk key. During the night, the alarm clock in Ann's bedroom will be responsible for waking her up when it is time for new doses.

3.2 Scenario #2

While having a walk outside, Bob decides to buy an over-the-counter drug to treat his allergy to pollen. Afterwards, when he enters his house, the iCabiNET records the tablets he has bought, and automatically downloads medication guidelines for adults from the manufacturer. A few days later, Bob is watching TV in the living room. When it is time to take a pill, the iCabiNET pops up a reminder on the screen, indicating the drug's commercial name, a photograph of its packaging and the recommended dose. For the best comfort, the system starts flashing the lights of the room where Bob had left the tablets the last time he took one. As Bob takes a new dose, the iCabiNET finds that the pills are running out; so, when he sits back in the sofa, he is faced with an interactive TV application that he can use to buy new supplies from an online drugstore. Bob uses the remote control to enter shipping and payment details, and takes the opportunity to buy some throat lozenges he likes.

4 PROTOTYPE IMPLEMENTATION

In order to assess the feasibility of the approach described in Section 2, we have developed and tested a prototype of the iCabiNET taking the scenarios of Section 3 as a reference of the functionalities it should provide. It is worth noting that the system needs not be a standalone device, hence we built it as a software package to run on any device that is permanently connected to a residential network. Within this perspective, we strove to employ standard technologies and open-source software packages.

As the basis for our implementation, we chose the framework proposed by OSGi (OSGi Alliance, 2005), which is nowadays the most popular standard for residential networks. This platform is advantageous for various reasons: (i) it supports different widespread protocols for secure and non-secure communication among appliances in home and outside, (ii) it defines a cooperative model where appliances can dynamically discover and invoke the operations provided by others, and (iii) it enables remote management of the

appliances and the operations they provide. From among other possibilities, we implemented the iCabiNET as an OSGi bundle using the open software packages from the OSCAR³ project, because they are particularly well documented.

Just like the other residential network standards, OSGi provides no support for orchestrating appliances according to virtual bundles as described in Section 2.2. To this aim, inspired by the work of (Slomiski, 2006), we opted to borrow solutions from the most mature related field of research: Web Services. Therefore, we express the process flows using the BPEL language (Juric, 2006), which provides constructs to describe arbitrarily complex processes, focusing on the invocation of operations and the flow of control between them. There are many tools supporting this language, offering plenty of facilities to create, edit and execute process flows. We have developed the core of the iCabiNET over the ActiveBPEL⁴ engine, introducing the following enhancements:

- The BPEL flows can include declarative rules written in Jess⁵ to drive the generation of events related to the intake of medicines. Accordingly, the ‘Watchdog’ module of Fig. 2 incorporates a Jess execution environment, which is the only protected part of our implementation—it is only free for academic purposes.
- The actions in the BPEL flows include concepts of the SOUPA and GUMO ontologies presented in (Chen et al., 2004; Heckmann et al., 2005), which are also used in a semantic registry maintained by the iCabiNET itself. With those bases, plus the context-aware features of (Gu et al., 2004; Zhang et al., 2005), the ‘Actuator’ module of Fig. 2 uses the Protégé OWL API⁶ to apply the same semantic matching mechanisms we designed for (Díaz-Redondo et al., 2005)—the reasoning abilities are not linked to any specific domain of application.

As regards the interactive applications presented to the user to realize actions in the virtual bundles (e.g. the online drugstore of Scenario #2), the authors of (Ramos-Cabrer et al., 2006) proposed a way to merge OSGi with the MHP standard of applications for Digital TV (Digital Video Broadcasting, 2003). We have extended those mechanisms to support applications for PCs and mobile devices as well, and to handle descriptions of those applications also in terms of the SOUPA and GUMO ontologies.

³<http://oscar.objectweb.org>

⁴<http://www.activebpel.org>

⁵<http://herzberg.ca.sandia.gov/jess>

⁶<http://protege.stanford.edu>

All the code aforementioned pieces of the iCabiNET are written in Java, and so we used this language for the code to glue those elements together. That code was executed by a J2ME virtual machine running on a residential gateway. Out of the iCabiNET itself, in what concerns the gathering of information about the availability and intake of medicines, we completed the settings for our trials with purpose-built smart blister packs, because smart packaging technology is not yet available in retail drugs (only in clinical trials). Besides, we developed our own RFID readers for those blister packs, since we did not find suitable alternatives in the market ready to work within an OSGi network.

5 CONCLUSIONS

Technology may be an important aid to fight the worrisome health problems and the increasing economic costs due to the misuse of prescription and over-the-counter drugs. With this vision in mind, we have designed and implemented the iCabiNET system, which is the first outcome of a multidisciplinary research effort to put technology to the service of better medication monitoring and management.

The iCabiNET can be regarded as a powerful extension of previously-existing solutions to monitor medicine intake (e.g. the embedded systems of (Wan, 1999; Floerkemeier and Siegemund, 2003; Ho et al., 2005)), introducing the ability to issue warnings and deliver medical advice using any appliance connected to a residential network. Eventually, when the smart packaging technologies finally take up the market, the iCabiNET approach will actually replace that of previous systems, providing the greatest flexibility and precision in monitoring, limitless possibilities to reach the user using whichever technological means, and unprecedented capabilities to interact with health institutions, drug manufacturers and retailers.

Also, the iCabiNET can be seen as introducing support to monitor the intake of drugs in previously-existing platforms to provide health care information through Internet-enabled personal computers (Roine et al., 2001), Digital TV (Simonov et al., 2007) or mobile devices (Komminos and Stamou, 2006). In this regard, we can emphasize the integrated and technology-neutral solution achieved with the semantic reasoning features, which render an open environment with feasible and scalable exploitation models.

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