The HOMEY project: a telemedicine service for hypertensive patients

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Abstract. This paper deals with the opportunities and challenges of "intelligent dialogue" technologies in the context of medical applications and, more specifically, home care. The system focuses on an automated, telephone-based home monitoring service for chronic hypertensive patients. A remarkable point in the development of systems that are going to communicate with patients is the promotion of compliant behaviors. In the case of hypertension, we refer to the compliance with the prescribed treatment. To this concern, a number of cognitive theories have been recently proposed to account for the willingness to change our own behavior, that is more and more considered the key issue for disease prevention. In our system, the dialogue is personalized according to these theories, taking into account the patient's actual condition and the clinical practice guidelines on hypertension management. The system has been tested through a clinical trial involving patients from two Italian hospitals. Results show a blood pressure decrease in the group of patients exploiting the Homey service.

1 Introduction

Advances in Information and Communication Technologies open the possibility for widespread use of novel human-computer interfaces. Among them there are interfaces based on automated speech recognition (ASR) [1,2,3]. In general, an automated dialogue system is a complex software installed in a workstation, called “telephony platform", connected to a telephone number (sometime toll-free). When a call comes in, the computer is able to answer and talk to the caller through a natural dialog and a synthesized voice. The machine is also able to comprehend the user's answers, provided in natural language. In this way a conversation takes place on the telephone line between computer and patient. The automatic dialogue, besides the limitation due to the fact that on one side there's merely "a machine” rather than a human, can never-

theless serve and autonomously solve simple and routinely tasks. In fields other than healthcare, such systems are able to provide common services, for example train table information, road conditions, and room reservation. In the healthcare field they can book laboratory tests, or collect clinical information from patients, directly from their home, or wherever a phone can be employed (including mobile phones). Some examples already exist, for smoking cessation [4], physical activity enhancement [5], and severe disease monitoring [6,7]. See also [8] and [9] for interesting reviews.

2 The Homey Project

The European Union, with a funding for research activities within the Health Care for Citizens programme, gave birth to the HOMEY project in year 2001. As mentioned, the project goal is building dialogue systems, which will provide easier and more efficient communication between specialist health centres and patients affected by a chronic disease.

Far from willing to interfere with the direct relationship between physician and patient, or other caregivers, introduction of these technologies aims at improving the flow and availability of information at the point of care. The actual system has been developed in collaboration with specialists in hypertension care from various Italian hospitals (IRCCS Policlinico San Matteo in Pavia, Hospital Careggi in Florence, and Hospital Sacco in Milan).

2.1 Background and Motivation

Several clinical studies pointed out that home monitoring has the potential of increasing health outcomes, granting at the same time cost savings for the national health system. This remarkable feat is especially attractive in western countries, where public investors are pushing towards a more effective use of money in the healthcare services [10]. Prevention of cardiovascular diseases, often caused by hypertension, is one of the means for saving very high future costs. Models for behaviour change highlight the importance of being conscious of the benefit that will be gained by modifying one's own behaviour. The ability to convey messages in a way which is effective and convincing has been taken into consideration by theories of behaviour adoption. The most prominent ones are the Social Cognitive Theory [11], the Health Action Process Approach [12], and the Trans-Theoretical Model [13]. Recently the importance of understanding cardiovascular risk has been strongly stressed in medical literature. British Heart Foundation periodically publishes fact-files, which are compiled with a wide spectrum of doctors to reflect current opinions. Fact-file number 10/2002 [14] reviews evidence about how cardiovascular risk is consistently underestimated by the population. It argues that better risk communication is crucial to the adoption of behaviours which reduce risk: stopping smoking, low-fat diet, increased physical activity and taking medications as prescribed. A patient's feeling of being in control over the potential development of a coronary heart disease is generated by two components: (1) response efficacy, i.e. the knowledge that

the actions taken have the potential to improve health, and (2) self-efficacy, i.e. feeling confident in one's ability to adopt the risk-reducing behaviour. Therefore, risk communication involves imparting information about risk, how to reduce that risk, and ensuring that patients have confidence in their ability to change their behaviour. These are the intentions of the developed dialogue for hypertensive patients.

2.2 The Clinical Problem

Hypertension is a chronic disease whose care requires, among other factors, attention to healthy life habits and care in monitoring of blood pressure values, weight and heart rate. Numerous clinical tests, in fact, proved that long-term elevated blood pressure values remarkably increase the probability of serious damage of important body organs, mainly heart and brain, causing illnesses such as stroke and myocardial infarction. Hypertension affects a large fraction of European adult population: according to recent estimates, as high as 40%. Luckily, drugs available to reduce blood pressure are numerous and effective. Unluckily, there is low compliance to both drug prescription by general practitioners (GPs) and assumption by patients.

Specialist centres have an outstanding role in the care process of the disease. In these centres, physicians are able to apply the latest best-practice care procedures (according to internationally accepted guidelines), adapting them to the specific patient. An effective care, however, requires that doctors are timely informed of the health status of their patients: for example, they should know the blood pressure values, whether side effects occurred, and also whether patients were compliant with the prescribed therapy and life style. Therapy, in fact, often comprises of both, drugs and life style modifications, such as doing more physical exercise, following a diet and ceasing to smoke.

Higher quality of interaction between physician and patient, and the information exchange between the two, are therefore essential for the effective care of hypertension and other chronic diseases. Unfortunately, organizational and economic constraints lead to few patient encounters, normally once or twice every year. In these encounters, a blood pressure Holter test should be prescribed, i.e. the automatic collection of blood pressure values for 24 hours, through a simple, non invasive device.

The low frequency of control visits has some bad consequences: these patients in general take one or more drugs, and early detection of side effects may be impaired; patients feel "abandoned" by the healthcare system, and this affect their therapy compliance; some of them stop the pharmacological treatment without advising medical experts; with no close monitoring, they are also less willing to maintain a good life style.

The dialogue system which Homey partners have developed serves this purpose: to enable doctors and patients to continuously exchange information on health conditions, and to have this information flow happening in a simple and timely way, even during the time gap between their physical encounters.

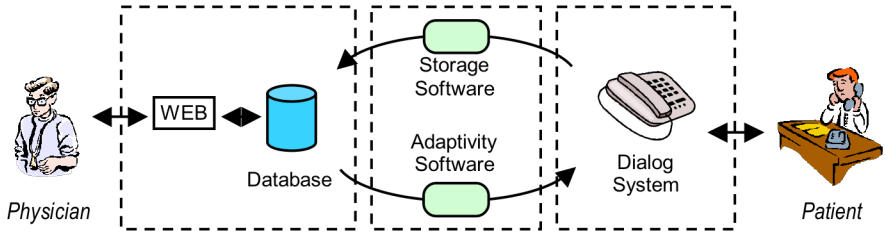

Figure 1: The Architecture of the Homey system

3 The Technological Solution

The above mentioned functionality is illustrated in Figure 1. Since patients are in general over 60, simplicity is assured by the use of the telephone, which is easy to use and highly diffused (the service is accessible from the mobile too). The use of a dialogue system replaces the need of using specialized computer-based tools, sometimes complicated for patients to use, and at the same time grants that the precious information collected is organized and stored, and not lost, for example, in loose notes. Thanks to the use of a common telephone, information is immediately transferred to the care centre, where doctors are able to evaluate it and decide, when necessary, suitable changes to make the therapy more effective. To be useful, a data collection system must also organize the data acquired and present it in order to be easily interpreted, and therefore support the physician's decision process. In our case, this simplicity hides the adoption of innovative technologies, gathered not only from research on human speech recognition and automatic creation of natural language dialogues, but also on the intelligent use of electronic patient records (EPR). In the Homey system the technologies are integrated with an EPR system, able to store demographic data, disease history, outcomes of previous visits and laboratory tests, and, above all, blood pressure values and side effects possibly reported by patients. Such data are recorded and stored, for each patient, both whether it comes from the physician's visit, or self-reported by the patient via the dialogue system by telephone. As shown in Figure 2, the physician looking at the patients' data can see whether information comes from telephone or from direct encounters: in fact, the latter case is indicated by an icon with a person writing on the PC, while in the former the telephone icon appears. Moreover, the icon represents either a flawless or a broken telephone, meaning that the call has been closed in the correct way, or some exceptions occurred leading an unexpected call closure, respectively. This is very important to give data the correct reliability.

Such features, however, are not all of the functions of the dialogue system: technology innovation in this telemedicine project led us to realize a system that generates a dialogue tailored to every single patient. Data stored in the EPR, together with the history of calls made by a patient, are accounted for by the system. Reasoning on that, it is able to formulate a different dialogue on a case-by-case basis; the dialogue is generated run time, depending on the specific condition of the patient, prescribed

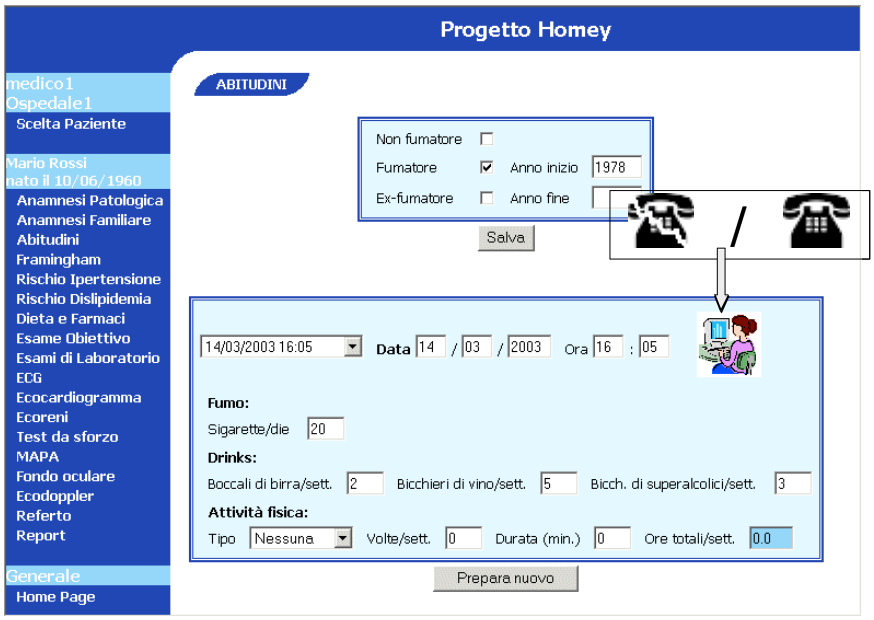

Figure 2: The Electronic Patient Record interface. Possible icons, namely a person, a telephone, a broken telephone, indicate modality of data entering (see text for details).

drugs, side effects, and his/her life style. Suggestions are generated in agreement with international guidelines about hypertension management [15]. The dialogue, however automatic, is therefore adaptive: its internal workings takes into account both the information contained in the clinical records, the data coming from the ongoing conversation, and the medical knowledge coded in the guidelines.

3.1 The Dialogue Generation

The system interprets a dialogue description written in a high language level, which specifies the spoken interaction: which steps to take, what questions are to be asked to the user and what possible utterances are allow in reply. The user is first authenticated with a numeric password. Then, the dialog engine interprets a state vector which represents the patient's health state and other associated information. The system presents the caller with a series of questions (also known as *prompts*), dealing with specific aspects of the patient's health state and behaviour. The questions are organised by topic in "contexts". The contexts implemented in the current version (of course they can be increased to improve the extent of the conversation) are:

- Service identification,
- Patient identification,
- Patient compliance assessment,
- Patient health status understanding,

- Educational advices
- Quantitative data acquisition,
- Possible side effects investigation,
- Life style investigation,
- Planning of next patient actions,
- dialogue conclusion

It is worthwhile noting that not all the contexts and questions are necessarily activated at each call. In fact, the adaptivity features modify the flow of the call depending on the specific patient.

Speech recognition and dialogue interpretation technologies we used in our application are provided by SPINET system (Speech Into Enriched Text). The system, developed by ITC-Irst research Institute, provides both the engine which performs the actual recognition on the sampled audio signal, and the dialogue manager [16]. The system speaks to the caller via a synthetic voice, which does not suffer the limitation of prerecorded prompts, restricted to fixed sentences. The voice is created at run time by a commercial text-to-speech software (we used "Silvana", from the Actor system, licensed by Loquendo). The telephony platform used was ContaCT, licensed by Reitek SpA.

3.1.1 Examples of dialogue

The dialogue system we developed leverages two advances in dialog technology, as it is not only adaptive but also *mixed initiative*. Such a dialogue try to mimic the behaviour of a telephone answerer, whose counterpart may anticipate answers to questions that have not been formulated yet. For example:

...
System: Please tell me your heart rate
Patient: I don't know it, I know my pressure: systolic is 130 and diastolic is 92
System: So, you did not measure heart rate, but you have 130 over 92 as blood pressure, can you confirm?
Patient: Yes
...

As an example of adaptation, we consider a 65 years old patient that shows high blood pressure values in spite of a prescribed treatment. In this case there is the suspect of low compliance, thus the patient is reminded to take the prescribed drugs and follow the suggestion for a healthier life style.

....
System: Please tell me your blood pressure values
Patient: I have a systolic pressure of 160 and diastolic is 100
System: So, you have 160 over 100, it's high, can you confirm?
Patient: Yes
System: Are you still swimming two times a week?
Patient: Yes., I do
System: Are you still smoking?
Patient: Yes., 5 cigarettes per day
System: You should stop smoking.

System: I remind you that you have to take your BetaBlocker pill in the morning, after the blood pressure measurement
Patient: Yes
System: I want to inform you about a risk that you have: considering next 10 years, you have a certain risk of suffering from stroke or myocardial infarction; this probability is more than double, with respect to other people. But if you try complying more with your drug therapy and healthy habits, keeping your blood pressure levels above 140/90, you can reduce this risk, and you are expected to live without problems much more than 10 years!.
...

Another facility that the system embeds is that a physician, after looking at the patient's data entered by telephone, can write a text through the EPR interface, and this text will be voice-synthesised to the patient during his/her next call. In this way, the patient may receive a much tailored suggestion by his physician and in the same time he will feel reassured, because he has the evidence that "someone on the other side" is periodically monitoring his data.

4 System Validation

A motivation for the adoption of the system is that its use will prove economically viable and beneficial to the collaborating parties. Clinical evidence suggests that careful monitoring and self-monitoring of hypertensive patients can have a beneficial impact not only on the allocation of resources in hospitals , but also on the actual health condition of subjects, and their motivation to change behaviours in favour of healthier habits [17].

To verify this hypothesis for our proposed system, we collaborated with the caregivers to design a randomized controlled clinical trial. About 300 patients, after being informed of the scope of the study, have been enrolled. They were randomly assigned to either a control group (patients treated conventionally) or a treatment group (patients using the telephone-based system). The groups size ratio was 1:1, stratified by sex. Full details for this study, including considerations on the clinical perspective, are given in reference [18], while results are shown in Table 1. As a guide to read Table 1, medical experts agree that the Holter measurement (i.e. the average values over the 24 hours) is more reliable than the single, ambulatory measurement, because the latter is affected by some biases: first, it is well known that blood pressure is highly variable during the day; second, there is the "white uniform" effect, that in many patients causes a temporary increase of blood pressure.

About the absolute value of blood pressure difference, the reader must be aware that, according to the most recent clinical evidence, also a few decrease (5-7 mmHg) is highly effective in reducing cardiovascular risk.

Table 1. Results of the controlled randomised clinical trial

	Traditional treatment group (Systolic/Dyastolic, mmHg)		Homey service group (Systolic/Dyastolic, mmHg)	
	Ambulatory measurement	Holter measurement	Ambulatory measurement	Holter measurement
Enrollment	141/91	139/91	141/90	141/85
Follow-up	130/87	128/83	128/86	125/75
Blood pressure decrease	11/4	11/8	13/4	16/10

Values under the column “Ambulatory” are blood pressure values measured by physicians in a clinical settings, those under “Holter” show average values of 24-hour monitoring (the latter are considered by physicians the most reliable measures). For each measurement type, figures at trial start (Enrolment) and end (Follow-up) are quoted. Patients using the spoken dialog system (treatment group) on the average show a slightly better control of their ambulatory blood pressure values with respect to the control group. The decrease of Holter measure is much more evident. Both groups exibit a statistically significant decrease in blood pressure with respect to enrolment. All figures quote systolic/diastolic blood pressures.

5 Conclusion

The present work illustrates an automatic dialogue system, with particular reference to the reasons why these systems are especially relevant for individualized patient monitoring. We applied this technology in the medical domain of hypertension, but it is worth stressing that it can be adapted to the most part of chronic disorders, when patients' treatment develops at home. The acceptance of our dialogue system among patients was very satisfactory, as it is confirmed by the fact that, months after the trial's conclusion, a remarkable fraction of the patients originally enrolled is still using it to periodically report their data. Up to now only the effectiveness of the system on the health outcome has been estimated. Future direction of the study will include an economic evaluation, considering the fraction of patients requiring hospitalisation and additional treatment to cure side effects.

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