A web-based system for personalized patient education and compliance monitoring

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Abstract—The economic importance of therapy compliance has grown steadily in recent years, not only because of the efficacy of newer therapeutic methods but also because of the increased costs of treating the consequences of poor compliance. Improved compliance can lead to significant savings by preserving or restoring a patient's health, improving quality of life, by reducing the number of medical services required when therapy fails or appears ineffective, and by helping limit the rise in national health care costs. Within the framework of the TEN-Telecom European Commission Programme, C-Monitor project developed an integrated health telematics platform to enhance chronic patient compliance to therapy and interactive communication with their attending physicians. The overall aim of the project was to study the potential benefits, both in clinical and financial aspects, of such innovative systems and services along cost-efficiency of care provision. The platform developed has been validated in controlled small-scale trials in a number of European countries. The Greek pilot involved installation of the system in a private hospital in Athens and the validation scenario dealt with morbid obesity patients that have undergone surgical operation. A number of 30 patients were recruited for the trial. Results of the trial indicated the technological robustness of the proposed system and the potential clinical and economic benefits of running such services. Further trials are required to better address cost-efficiency issues with respects to the service goals.

Keywords— *therapy compliance, patient education, health telematics.*

1. Introduction

Hospitalizations is the largest component of health care costs. Among hospitalized patients, high cost users are mainly those with repeated admissions [1]. In 1998, it has been reported a 22% readmission rate within 60 days of hospital discharge in the medicare population at an estimated cost of 8 billions $, the 24% of all inpatient expenditures [2]. Several studies suggest that 9% of all readmissions and up to 50% of readmissions by high risk patients are preventable [3–5]. Inadequate patient education, unrecognized clinical deterioration and noncompliance have been implicated as causes of preventable admissions [3–5]. Noncompliance with long term medication regimens is more than 50% [6]. The use of multiple prescriptions is closely related to noncompliance. This is particularly important in those with chronic diseases as heart failure and chronic obstructive pulmonary disease who consume a high amount of medications [7, 8]. In those patients noncompliance to drug therapy is approximately 90% and the percentage is probably worse for diet therapy and life style changes [9].

Several other studies have documented the cost of patient noncompliance with therapeutic procedures. According to the national council on patient information and education (NCPIE) (http://www.talkaboutrx.org/compliance.html), the annual cost of non-compliance to therapy is about 100 billions $. Furthermore, NCPIE suggest the following recommendations to be addressed to improve compliance:

- **for physicians** – involve the patient in treatment decisions:
    - monitor compliance with prescribed treatment at every patient visit;
    - document patient compliance using a compliance-monitoring form that can be incorporated into the patient's record;

- **for patients:**
    - become active participants in making treatment decisions and solving problems that could inhibit proper medicine use;
    - talk to health professionals about why and how to use their prescription medicines;
    - recognize, accept, and carry out their responsibilities in the treatment regimen.

The economic importance of therapy compliance has grown steadily in recent years, not only because of the efficacy of newer therapeutic methods but also because of the increased costs of treating the consequences of poor compliance. Improved compliance can lead to significant savings by preserving or restoring a patient's health, improving quality of life, by reducing the number of medical services required when therapy fails or appears ineffective, and by helping limit the rise in national health care costs.

Within the activities of the C-Monitor project, funded by the TEN-Telecom European Commission Programme, an integrated health telematics platform has been developed to enhance chronic patient compliance to therapy and interactive communication with their attending physicians. Overall aim of the project was to study the potential benefits, both in clinical and financial aspects, of such innovative

systems and services along cost-efficiency of care provision.

The C-Monitor system was designed to allow patients to organize daily activities with respect to therapeutic needs in a personalized and friendly manner. It collects patient clinical and non-clinical data and reminds them about therapy needs/plan (drugs, exams, weight control, etc.). In the same time, the responsible doctor is informed not only about the patient's condition but also about patient compliance to therapy and deviations.

2. Design considerations

2.1. Platform description

The C-Monitor platform comprises of the following subsystems:

- The web server hosting the ASP.NET web pages that expose the C-Monitor functionality over the Internet to the web clients (browsers) of both physicians and patients.

- The application server exposing web services that are consumed by the ASP.NET web pages on the web server and are responsible for the communication with the database server.

- The database server built on a MS SQL Server 2000.

- The C-Monitor desktop applications that enable the customization/maintenance of each clinical scenario and the definition of treatment plans.

- The notification services module that is responsible for notifying physicians or other subscribers whenever an event that a subscriber is interested in occurs (by distributing e-mail notifications to an SMTP server).

The overall system architecture is depicted in Fig. 1. As shown in figure, the C-Monitor platform supports a four-tiered distribution of the software modules exposing functionality over the Internet and a two-tiered distribution (client/server) for the C-Monitor desktop applications running inside the boundaries of the hospital/clinic intranet. In case that hardware limitations exist, the C-Monitor platform can also be implemented easily as a three-tiered solution, with the web and application server hosted on the same computer. The physician and patient web client tier uses the web browser environment for the interaction with the users, so that minimal configuration and tuning is required, other than adjusting network connectivity (dial-up) parameters and browser settings. The ASP.NET web pages on the C-Monitor web server communicate with an ASP.NET web services façade hosted on the application server. The application server is responsible for the communication with the database containing all medical data. The notification services modules interact with the SQL server engine and

allow the distribution of e-mail alerts to the various subscribers through any available SMTP server (hosted within the healthcare institution or provided by an external ISP).

The C-Monitor desktop applications are entirely built on the .NET framework platform and support two-tiered (client/server) architecture. These applications run within the boundaries of the health care institution intranet and are responsible for the definition and maintenance of each clinical scenario and for performing the main tasks requiring rich client capabilities in terms of user interface and advanced security environment. There are four main desktop applications available:

1. The scenario management application enables the customization of the platform for different scenarios. This application allows the users to define and maintain each clinical scenario. The main elements of a clinical scenario are: risk factors, which are questions that help the physician identify the patient's needs for on-going treatment, define medical guidelines and retrieve relevant information regarding his/her medical problem, the parameters of the scenario, such as medical measurements, medication, measurement units, etc., the medical staff and the patients participating in the scenario.

2. The therapeutic schema application allows physicians to create the personalized patient therapeutic schema including information regarding diagnosis, medication plan, examination plan (including in-house controls such as blood-pressure measurement, weight control, etc.), dietary plan, exercise and lifestyle guidelines, and any other information or direction to the patient that forms part of the therapeutic schema. This application allows physicians to define a personalized therapeutic schema by taking into account the values of risk factors that are relevant to the specific patient. After completing the review of the developed therapy plan, the physician forwards the plan to the patient, which will then allow the patient to register data and keep track of therapeutic steps to follow.

3. The document management application allows the physician to store and characterize documents intended to be published for patients. These documents can be later automatically retrieved according to their relevance to the patient's medical problems.

4. The translator utility enables the easy translation of the user interface for both web and desktop applications into any language.

2.2. Security issues

It is conceivable that a system handling medical data should be compliant to directives for protection of data and other security requirements. As discussed earlier, the C-Monitor platform comprises of an Internet part, which exposes functionality over the Internet to web browsers and an intranet
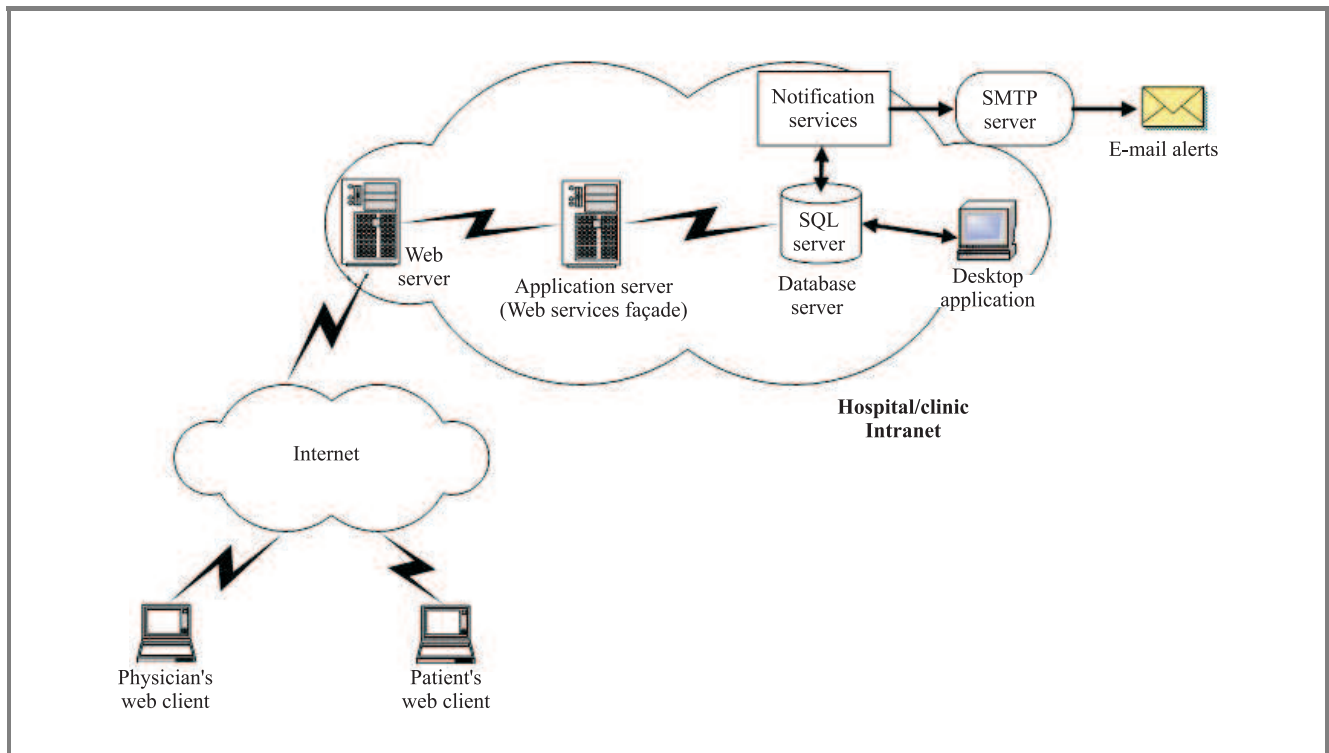
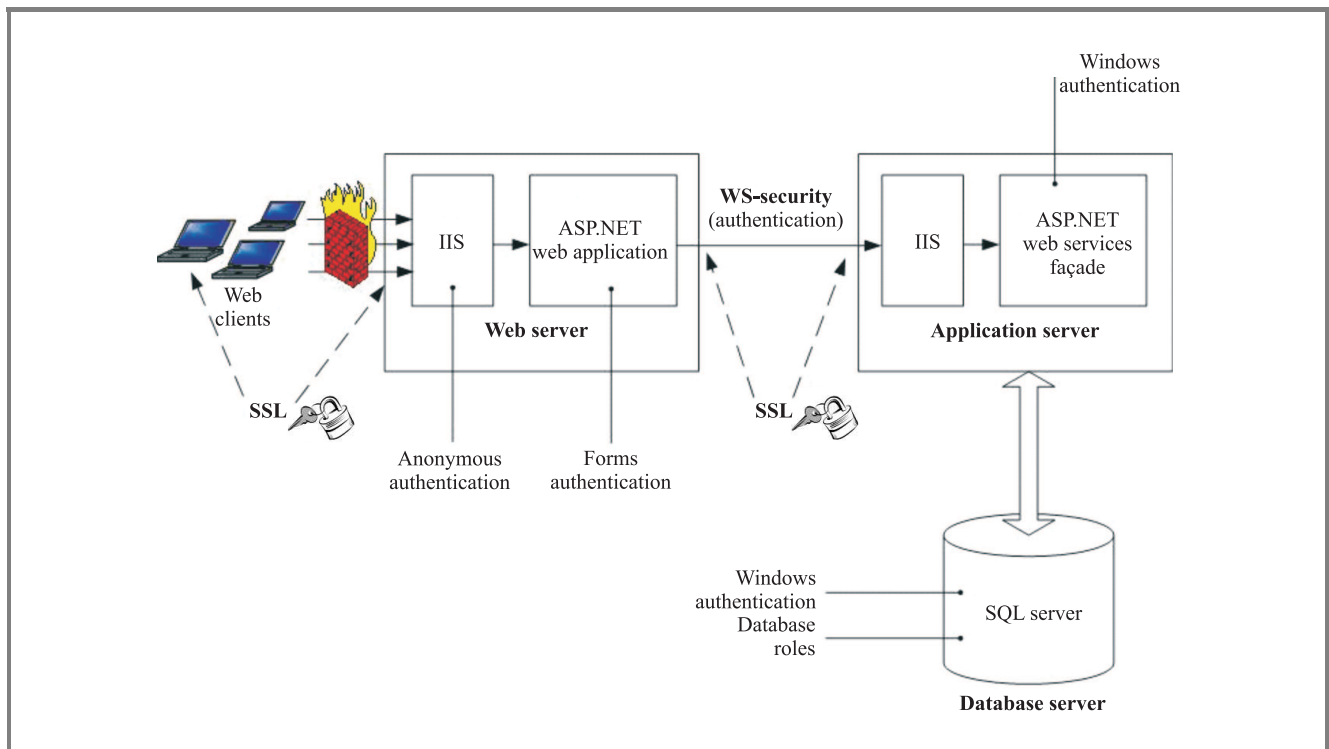***Fig. 1.*** Overall C-Monitor system architecture.

Fig. 2. C-Monitor overall system security.

part, which offers services within the boundaries of the hospital/clinic intranet. The overall system security model is depicted in Fig. 2.

The security model for the Internet part includes the use of secure sockets layer (SSL) for privacy and integrity and forms authentication where users' credentials are forwarded to a web service that authenticates them against a user list stored in the C-Monitor database. The web clients communicate with the C-Monitor web server over a secured SSL connection. Secure sockets layer is a set of cryptographic technologies that provides authentication, confidentiality, and data integrity. The use of server certificates has been chosen for simplicity, as a main objective of the platform is to require minimal configuration and tuning on the client side. For enhanced security the web administrator can use client certificates as well. However, the use of client certificates requires issuing client certificates for each web client and installing them on the client's computers. The intranet security model includes:

- WS-security to prevent unauthorized users from accessing the web service functionality. WS-security describes enhancements to SOAP messaging to provide quality of protection through message integrity, message confidentiality, and single message authentication. These mechanisms can be used to accommodate a wide variety of security models and encryption technologies. The web service functionality is exposed only to authorized users of the platform because each web service method request must also provide a valid usernametoken, which is authenticated against the C-Monitor database.

- SSL connection between the web and application server. The communication channel between the web and application server can be secured using SSL connection. The configuration steps are already described in the Internet security section. The web service method calls use the HTTPS protocol.

- Windows authentication for the web service façade. The web service's virtual directory is configured for integrated Windows authentication. Web services authenticate the web-based application's process identity.

- Windows authentication for the SQL server connection. The recommended authentication mode for the SQL server database is Windows authentication. Windows authentication is more secure than SQL authentication for the following reasons:

    - credentials are managed for every user and the credentials are not transmitted over the network;

    - embedding user names and passwords in connection strings is avoided;

    - logon security improves through password expiration periods, minimum lengths, and account lockout after multiple invalid logon requests; this mitigates the threat from dictionary attacks.

    However, if the SQL server database is not configured for Windows authentication mode or is protected behind a firewall, the C-Monitor platform offers encryption/decryption for the secure storage of the connection string.

- Secure storage of the SQL connection strings. If desktop applications or the web services façade need to use SQL authentication for the connection with the database server, an encrypted connection string is generated and stored in a "config.xml" file. Each time a connection to the database is initialized the connection string is read and decrypted by the desktop applications or the called web services.

3. System validation results

For a health telematics infrastructure to be applicable extended clinical validation and testing is required. In order to validate the C-Monitor platform, trials were set-up in different European countries including Spain, the UK and Greece. In this paper the system validation results of the Greek pilot are presented. The system has been installed in a private hospital in Athens and the validation scenario dealt with morbid obesity patients. In particular the C-Monitor platform was used to assist medical professionals monitor morbid obesity patients following surgical operation. The C-Monitor platform has been used to assist medical professionals monitoring the following parameters:

- body weight (daily),

- nutrition (daily),

- quantity of urine (daily),

- blood pressure (daily),

- body temperature,

- urine kerones-glucose,

- blood glucose, cholesterol, triglycerides.

The criteria for patient inclusion to the trial were:

- poor operative state after gastric by-pass and laparoscopic adjustable gastric bandage,

- obesity according to BMT criteria (BMI > 29),

- biochemical markers indicative of metabolic syndrome related to obesity,

- high blood pressure,

- patients being computer literate and having internet access at home,

- patients able to manage medical device use at home.

Table 1

Platform validation results

Criterion	Very friendly	Friendly	Somehow friendly	Less friendly	Not friendly
User interface	13.8%	41.4%	34.5%	6.9%	3.4%
Navigation	17.9%	39.3%	28.6%	10.7%	3.6%
	Yes		No		
Access problems	17.2%		82.8%		
	Very easy	Easy	Somehow easy	Less easy	Difficult
Ease of service	10.3%	58.6%	31.1%	0	0
	High	Good	Average	Below average	Poor
Fault tolerance	44.8%	34.5%	20.7%	0	0
	Very easy	Easy	Average	Somehow difficult	Very difficult
Ease on training	4.2%	33.3%	20.8%	29.2%	4.2%
	Very high	High	Medium	Low	Very low
Overall performance	0	60%	40%	0	0

For the purposes of the trial, 30 patients have been recruited. The performance of the platform has been evaluated using structured questionnaires with respect to the following parameters:

- friendliness/operability: measure how well the patients like to use the system and their ability to navigate around the system;

- access control: measure the ability to restrict access to certain sections of data from particular users;

- fault tolerance: measure of bugs existence within the system;

- learning requirements: measure of time required for user training and measure of ease in data entry to the system;

- responsiveness and overall system performance: measure of the overall opinion of users on the system performance both from the technical side and from the clinical side.

Table 1 summarizes the system validation results. From the data provided it is clear that without any doubts the majority of participating users ($> 89\%$) agreed that the platform is easy-to-use and to navigate around the information provided without serious problems in accessing the needed information. Furthermore, users were satisfied with system fault tolerance (around 80% rated it above average) and no major bugs were identified during the validation phase. Overall system performance was rated high (60%) and the remaining 40% as medium, thus indicating the potential benefits of the use of the system. The second part of the validation dealt with assessment of cost-efficiency issues. From the initial validation phase it is apparent that the estimated cost-saving from the use of the system is estimated to be more than 30 € at least in 75% of the cases

considered. Furthermore, half of the patients involved in the study expressed their willingness to pay a 10 € fee for using the C-Monitor platform although traditional healthcare services are for free in Greece. Of course, within the framework of the project, validation of the system was only to a limited depth and width, and it is clear that a more detailed cost-efficiency analysis is needed to estimate the economic benefits of using such a system.

4. Conclusions

The increasing development of informatics around the world as well as the recent explosion of the world networking and communication technologies (Internet, mobile communication) could significantly improve quality of care and the health standards leading to a level of health that would permit all individual citizens to participate in a satisfactory manner in every aspect of family, social or financial life. Important attention should be given to the reduction of the inequalities among European countries in order to achieve a common minimum level of health care restricting risks and proving assistance not only at country level but also to the different social or ethnic groups within each member state.

The proposed architecture takes advantage of recent technological advances in computing, networking and mobile wireless telemedicine to provide an integrated platform for patient compliance to therapy with messaging regarding drug plan, examination plan, and actions with respect to treatment in a personalized manner. Further, the system helps patients to be informed and educated on the their medical problem, participate actively, in close collaboration with their health care provider, to their on-going care, and to respond to risk factors through lifestyle changes or other appropriate means. Physicians would be continuously

informed about their patient compliance with therapeutic procedures, as well as monitoring their basic risk factors, remotely and off-hours. As far as healthcare providers are concerned, the proposed system leads to cost reduction due to compliance to therapeutic procedures and helps them to create more "personal relation" with the patients. Thus, the proposed platform enhances the effectiveness of health care and improves health standards and in the same time helps the patient to continue some normal and work activities in order to be an "active" citizen. All the above have been indicated by a small-scale controlled clinical trial study implemented in different European countries including Greece. Further and more detailed analysis is needed to better assess the potential clinical and economic benefits of such a system.

References

[1] S. A. Schroeder, J. A. Showstack, and H. E. Roberts, "Frequency and clinical descriptions of high-cost patients in 17 acute-care hospitals", *N. Engl. J. Med.*, vol. 300, pp. 1306–1309, 1979.

[2] G. F. Anderson and E. P. Steinberg, "Hospital readmissions in the medicare population", *N. Engl. J. Med.*, vol. 311, pp. 349–352, 1998.

[3] H. Dormann, A. Neubert, M. Criegee-Rieck *et. al*., "Readmissions and adverse drug reactions in internal medicine: the economic impact", *J. Int. Med.*, vol. 255, no.6, pp. 653–663, 2004.

[4] S. E. Frankl, J. L. Breeling, and L. Goldman, "Preventability of emergent hospital readmission", *Amer. J. Med.*, vol. 90, pp. 667–674, 1991.

[5] A. Clarke, "Are readmissions avoidable?" *BMJ*, vol. 301, pp. 1136–1138, 1990.

[6] H. Graham and B. Lively, "Can readmissions to a geriatric medical unit be prevented?" *Lancet*, vol. 1, pp. 404–406, 1983.

[7] N. Barber, J. Parsons, S. Clifford, R. Darracott, and R. Horne, "Patients' problems with new medication for chronic conditions", *Qual. Saf. Health Care*, vol 13, no. 3, pp. 172–175, 2004.

[8] M. Monane, R. L. Bohn, J. H. Gurwitz, R. J. Glynn, and J. Avorn, "Noncompliance with congestive heart failure in the elderly", *Arch. Int. Med.*, vol. 154, pp. 433–437, 1994.

[9] S. A. Eraker, J. P. Kirscht, and M. H. Becker, "Understanding and improving patient compliance", *Ann. Int. Med*., vol. 100, pp. 258–268, 1984.

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