Enabling a Pervasive Approach for Intelligent Decision Support in Critical Health Care

Carlos Filipe Portela[1], Manuel Filipe Santos[2], Álvaro Silva[3], José Machado[4], and António Abelha[4]

[1,2] Centro Algoritmi, Departamento de Sistemas de Informação, Universidade do Minho, Portugal
[3] Serviço Cuidados Intensivos, CHP – Hospital Santo António, Porto, Portugal,
[4] Departamento de Informática, Universidade do Minho, Portugal
{cfp,mfs}@dsi.uminho.pt, moreirasilva@clix.pt, {jmac,abelha}@di.uminho.pt

Abstract. The creation of a pervasive and intelligent environment makes possible the remote work with good results in a great range of applications. However, the critical health care is one of the most difficult areas to implement it. In particular Intensive Care Units represent a new challenge for this field, bringing new requirements and demanding for new features that should be satisfied if we want to succeed. This paper presents a framework to evaluate future developments in order to efficiently adapt an Intelligent Decision Support System to a pervasive approach in the area of critical health (INTCare research project).

Keywords: Intensive Care, Pervasive Environments, Critical Health Care, Intelligent Environment, Real-Time, Online, Remote Connection.

1 Introduction

INTCare [1-4] is an ongoing research project involving the Intensive Care Unit of the Porto Hospital Centre whose objective is to implement an Intelligent Decision Support System (IDSS) to predict the dysfunction or failure of six organic systems and the patient outcome in order to help doctors deciding on the better treatments or procedures for the patient. The good results obtained so far [5-7] motivated the transformation of this system into a pervasive IDSS. A framework to evaluate the efficacy of the new characteristics has been developed as a way to attest their feasibility. A Critical Environment has special characteristics and needs, such as fast, efficient, secure and ubiquitous operations in real time. At the moment, we choose the ICU to make our tests. ICUs are considered a critical environment because they have some complex health care situations [8]. The activities occurring in it are sometimes adverse, dangerous and tiring. and the various organ systems of the patient may be affected at the same time [9] what represents a challenge for the systems [8] that operate in this environment. The ICU main objectives are diagnose, monitor and treat patients with serious illnesses and recover them for their health previous state and quality of life [10]. With the introduction of Intelligent Environments (IE) this type of

M.M. Cruz-Cunha et al. (Eds.): CENTERIS 2011, Part III, CCIS 221, pp. 233–243, 2011.

monitoring could be done remotely. These operations could be supported by the new technologies based on Pervasive Healthcare Computing that allow the execution of remote tasks (access and control).

Pervasive HealthCare can be defined as “healthcare to anyone, anytime, and anywhere by removing locational, time and other restraints while increasing both the coverage and the quality of healthcare” [11].

A pervasive medical environment is designed to allow smart interactions by mobile devices with the patient sensor and data servers. Is imperatively necessary help the doctors make the best decision and take a pro-active attitude in the patients’ best interest [1, 12]. For this is important that medical staff have all important and essential information, in real time, online, and in electronic format. The best solution is modify the environment paradigm, making it intelligent, where all information will be available at the right time and the right place, eliminating any kind of barrier either be it time or place. This is very important because the communications between health care professionals represents a large part of their activity [13]. This development aims the remote access to the health data and future predictions of patient conditions made available by the INTCare system, guarantying the maximum quality, security and privacy.

The main objective of this paper is to present the requirements that should be addressed in order to bring pervasiveness to an IDSS and an evaluation framework in order to guarantee the results. This paper is divided into eight chapters. The first one introduces the necessities of the new environment and the motivation of the work, the second gives an idea about what is the INTCare system. The third one presents the environment evolution, comparing the past (*As was*) and the present (*As is*). The forth chapter presents the main features necessary to enable a pervasive environment. In order to evaluate the implementations, the chapter five proposes a framework to evaluate the environment. At the end, some discussion about the significations of each result will be done, including conclusions and future work.

2 Background

Like Roy and Das [14] told: “The essence of pervasive computing lies in the creation of smart environments saturated with computing and communication capabilities, yet gracefully integrated with human users (inhabitants)”. Nowadays, we can verify that pervasive and ubiquitous computing and ambient intelligence are concepts evolving in a growing number of applications in health care and the influence of it increase every days [15]. Some similarities can be found in other study [16] related to the developing of pervasive computing: there will be an evolution from isolated “smart spaces” to more integrated Hospital environments, which can be accessed remotely. The necessities are global and the medical staffs "require" information about their patient available through the world and, if possible, with some patient condition previsions to help in the decision-making process. An intelligent and pervasive environment requires that a large number of tasks could be done automatically and the information should be accessed electronically. however the Health Care providers are registering, manually, the patient characteristics into the computer system, hindering automation of some tasks like the retrieval, registration and display of information [7].

INTCare is IDSS that is prepared to work in critical environments and are being modified to also be pervasive. This IDSS is implemented in terms of a Multi Agent System in order to process some tasks automatically and to ensure their success. The flexibility of such approach makes the incorporation of new agents to integrate the IDSS in the Pervasive Intelligent Environment an easy task. INTCare is capable of predicting organ failure probability and the outcome of the patient for the next hour, as well as the best suited treatment to apply[17] .

To achieve this, it includes models induced by means of Data Mining techniques [12], [4, 18-20]. This system has so particular Features [17] that allow operate in pervasive environment: Online Learning, Real-Time, adaptability, Data Mining and Decision Models, Optimization and Intelligent Agents. Now some pervasive and ubiquitous characteristics are being added.

3 Pervasive Environment

The objective is to create a “smart environment” able to operate autonomously, prepared to acquire and apply knowledge about its users and their surroundings, and adapt to the users’ behaviour or preferences with the ultimate goal to improve their experience in those environment [21], facilitating the mode how they work and improve the patient condition. To do this, we had to understand *as was* the environment and define the necessary modifications to make it pervasive (*As is*). Accomplishing these changes we are extending the existing environment in order to turn it prepared to an automated information system for ICU taking into account the harmonisation with the whole information system and activities within the unit and the hospital [22].

3.1 As Was

The project started in 2008 and during this time some important steps were given: transforming a paper based and manual process information system to an automatic and electronic one. The data was collected in offline and in an irregularly mode making the analysis of patient data and the search of past information a very hard and time-consuming work. The existing information systems were only used information consultation and not to register patient data. For example the bedside monitors only showed patient vital signs (VS) values, these weren't stored in any place. In fig 1 is visible how Medical Staff have been working in the ICU. Normally they analyse the patient condition, looking for the VS values from the bed side monitors and, every one hour, they wrote the results in the Paper Based Nursing Record (PBNR). After that, the PBNR values were made available to be analysed and stored manually into tables. The Lab Results constitute another important data source being collected, in average, one or two times a day. The data was only available to be consulted in pdf format only 2 hour after the measuring. To store the results into a database the medical staff should read the documents and insert, manually, the values into the tables. Only after this process the patient information will be available in the database (DB) and in electronic format. This process was very inefficient and was the origin of many errors.

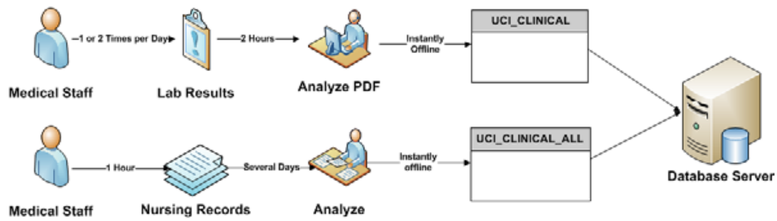

Fig. 1. ICU Past Environment

3.2 As Is

After some interactions with ICU staff and some analyses of the environment, we defined the necessities and requirements for the ICU. We had to change several processes and reformulate the information system (IS) architecture. Along the last three years we introduced a lot of modifications into the IS architecture [17, 23]. In particular some intelligent agents were designed to do some tasks automatically and replacing some manual operations. “Intelligent agents with their properties of autonomy, reactivity, and proactivity are well suited for dynamic, ill-structured, and complex environments” [24], such as an ICU. The system actually working in the ICU environment can perform all tasks in online, real-time and electronic mode. The agents are used to perform automatic tasks like collecting and storing patient data. The intelligent agents collect data from four data sources: Electronic Health Record (EHR), Lab Results, Vital Signs and drugs system. All data is received and send, automatically and at the same time, to the Electronic Nursing Record (ENR).

ENR is a system which was developed with the objective to receive all medical data and put it available to Doctors and Nurses (responsible to consult and validate the data in an hourly-based mode). It is a mechanism to integrate and subsequently access patient data. The digital nature of an ENR allows data contained within it to be searched and retrieved [25]. When some data errors appear, they should be corrected putting the exact values on ENR. On the other hand, we have some data that are still collected manually; this data is registered by the doctors or nurses and is concerned to three information’s types: procedures, adverse events and some nursing records like fluid balances.

These types of operations normally are not programmed and are done by the nurses near the patient. The use of ENR improves the data quality and reduces the number of unidentified patients in the monitoring system [5]. When the data is valid, it should be stored into the database. With this process we can ensure that the data that are available in the environment are real and are correctly associated to the patients.

The fig. 2 outlines the actual reality of ICU. Like the figure shows the environment has changed, and now only some tasks are manual. Be noticed that the data validation kept manual because only the humans can see if the data associated to some patient are correct or not (due to the semantics associated to clinical interpretation).

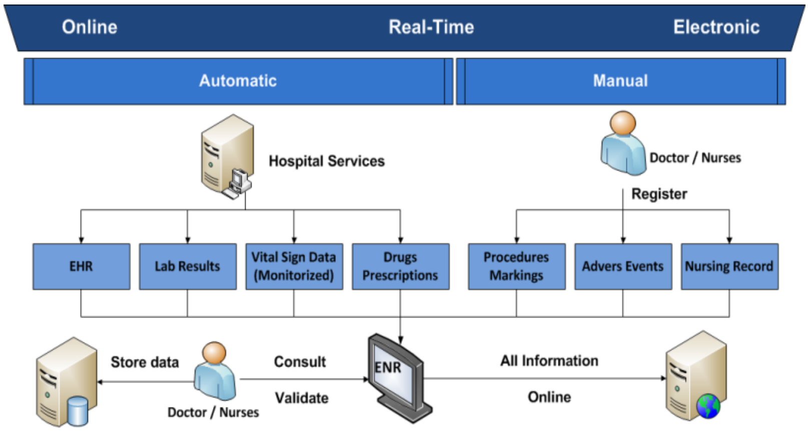

Fig. 2. UCI Current Environment

4 Environment Features

In order to set up the environment to an IDSS like INTCare, some features of the system [17] need to be assured. The main features for this environment are:

a) ***Real Time***: All patient data have to be collected in real-time for that some patient sensors have to be added to ICU. Is necessary creates some control tasks in the Environment to ensure that the manual data are inserted in database, as immediately as possible, after the events occurs.

b) ***Electronic Mode***: In this environment all data have to be available in electronic mode for this the nursing staffs has to verify if all data have electronic access and if not, they have to register the manual data in ENR.

c) ***Online***: The information of each patient need to be available online, i.e. all data have to be accessed through the ENR independently on the environment type.

d) ***Autonomous***: It has to have as many as possible automatic tasks. Almost all of the tasks in the environment can be performed automatically by Intelligent Agents, however is very important that data validations continue to be manual operations.

e) ***Safety***: *A*ll patient data presented on database and servers have to be safe and protected. The data security has to be ensured and nobody without access can consult the data. This is the one of the most critical aspect in these environments.

f) ***Reliable***: This aspect has two types. The first, the nurse staff is responsible to validate the data, in ENR, moments after collection. The second, the systems that will operate in these environments only can see the data that it looked for. With this, the user is sure that the data he can see online is guaranteed true.

g) ***Accurate***: All operations have to be approved before someone does something. The tasks have to be good defined and precise, i.e. the operation have to be valid and never can put the patient in risk. With this is possible avoid any phishing.

h) ***Privacy***: There are two types of privacy: the patient and the health care professional. PID always has to be hidden to people out of hospital. On the other hand all tasks done on this environment need to be identified and associated to one person. With this we can know who did the operations and blame for something that happened.

i) ***Adaptive*****:** The environment has to be the capability of adapt to the change of some variables, always ensure the proper functioning of the same. Sometimes is necessary optimizing some tasks and the system have to be prepared for that. If this is possible this type of operations should be performed automatically.

j) ***Secure Access*****:** The hospital access point has to be protected and encrypted. A virtual private network with access protocols is essential because this type of operations have to be secure. Only people who have access to the ICU can see the information and operate, local or remotely, in this environment. Is extremely dangerous if foreign people accede to the hospital and see what they can't see

k) ***Context awareness*****:** is concerned with the situation a device or user is in, and with adapting applications to the current situation [14]. All users need to be focused on the environment and to know the importance of the success of the operations because there can't be any type of negligence.

l) ***Risk List and Contingence Plan*****:** This is a critical area where anything can fail. Is necessary to predict some problems, define the risk impact, the happen probability and prepare some contingence task.

If the aspects safety (e), privacy (h), and secure access (j) aren't always guaranteed is better not do nothing, because any type of operations can put in risk the patients, the hospital and all people that operate there. The other important aspect is the Effective data consistency since it provides the foundation to ensure that medical practitioners receive up-to-date a correct data on time, whenever they need [26]. This type of environments have to be concerned with the safety of users, reduction of cost of maintaining the environment, optimization of resources task automation or the promotion of an intelligent independent living environment for health care services and wellness management [10]. An important characteristic for the pervasive environment lies in the autonomous and pro-active interaction of smart devices used for determining users' important contexts, realization of tasks, consults of vital sign and patient information, which ensure the success of distance operations. Our environment aims to support web applications for different platforms in order to allow users to access the application using one portable device (laptop, mobile, PDA).

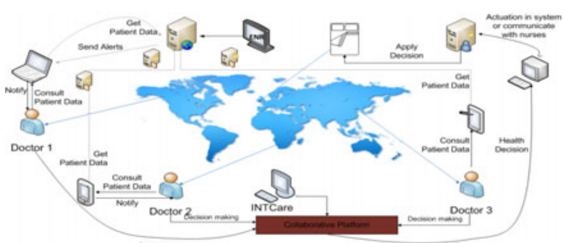

Fig. 3. Hospital Pervasive Access

Now, at any time, the user (ICU professional) can consult patient's information by some device regardless of where he is. Like was presented before [7] exist many possible communications in the Hospital throughout the world. However is necessary to make some modification in the architecture with the objective to enable a secure connection. The fig. 3 illustrates the alterations introduced, the doctors only can connect to the hospital through online applications in this case the interface will be the ENR. ENR gives the possibility to put, online, all data about the patient. This data will be validating by the doctors / nurses that are present in the ICU and near the patient. The connection is protected and only users with access privileges can connect to the hospital and see the data. This group will be limited and if someone needs access to the system, have to request access to the team in charge of the ICU, with this option we can control who is accessing to the system remotely. Out of the ICU the doctors only can consult the data; the validation is not possible because they are so far the patient. The patient is in ICU on Porto, doctors make a secure connection to the hospital, regardless of where they are, the time at which they are accessing and the device they are using, they can consult and analyse patient data. If they see something wrong like bad lab results, bad prescriptions, bad previsions or anything else, they can use a collaborative platform and talk with other specialists about what is the best decision / treatment to apply to the patient. In this task, INTCare can be a good help because it gives the best decisions based in some previsions and earlier treatments to particular patient problems. After the decision, this can be communicated to someone on ICU to accomplish it, may be given an instruction to the system to make an autonomous operation, can be made some treatments changes, or can be prescribed new drugs through drug system. All decision and their results will be stored in database with the objective to improve the decision; this requires an adaptation of the predictive and decision system.

5 A Framework to Evaluate Environment Quality

An important issue is the evaluation of the proposed approach in order to determine its efficiency. The evaluation should incorporate two strands: technical and human. The data from the remote connections will be used to support the technical evaluation. A framework will be defined in order to facilitate the users giving their opinion about their interaction with the environment. The results obtained will be submitted to a panel of experts from several areas (e.g. Information System, Communication, and Health). The system will start working for tests very soon; we are making the latest implementations and modifications in the ICU. This framework considers a set of measures and a scale of possible answers. The scale ranges from one (R1 – the lowest level) to five (R5 – the highest level). Each measure is then associated to particular range, e.g., data access has three possible options R [1-3], and the Reliability System has five possible answers, R [1-5].

5.1 Surveys

To the human evaluation we consider some online questionnaires that will be concerned with the connection (A), the data (B), and the environment and user satisfaction (C). The table 1 shows the measures and the evaluation scale of each.

Table 1. Environment Evaluation Measure

Measure		Evaluation Scale				
		R1	**R2**	**R3**	**R4**	**R5**
Connection Secure	A_1	No	Yes			
Connection Velocity	A_2	Too Slow	Slow	Normal	Fast	Very Fast
Data Access	A_3	Many Delay	Some Delay	Just In Time		
Reliability System	A_4	None	Little	Some	A Lot	All
Privacy	A_5	No	Yes			
Data Accuracy	B_1	50% or less	51% to 75%	76% to 99%	All	
Electronic Data	B_2	50% or less	51% to 75%	76% to 99%	All	
Online Data	B_3	50% or less	51% to 75%	76% to 99%	All	
Access	C_1	Difficult	Normal	Easy		
Adaptive Environment	C_2	No	Yes			
Interface	C_3	Very Bad	Bad	Good	Very Good	Excellent
Global Satisfaction	C_4	Very Bad	Bad	Good	Very Good	Excellent

5.2 Results Analysis

Understand the environment, realize if it is really intelligent and verify if is working as expected, is the base of success of a pervasive environment. The questionnaires will be filled by people that interacted with the environment inside and outside of ICU. The table I configures the base of the evaluation framework. In this table a scale of measures was defined ranging from R1 (min) to R5 (max). However, for some measures the max score are R2 (A1, A5, C2), R3 (A3, C1) or R4 (B1, B2, B3). For each question, the user will choose an answer according to the possibilities (table 1). Based on the answer one score will be assigned. The final score will be based in the weighted evaluation of each set: connection, Data and Environment and User Satisfaction.

The weight of the measure (a percentage value) was defined taking into account the importance of each environment attribute for the ICU. The calculation of each metric is equal to (for all the set):

$$\sum_{k=0}^{n} \frac{K_\chi \, x \, R_\chi}{M_\chi}$$ Where,

n: is the number of metrics in the group;

K: is the weight associated to this measure;

R: stands for the value of R score for the question chosen by user (e.g. R2 → 2);

M: is the maximum of the score (K x Max R Value to this measure).

x: corresponds to the question id.

Individually, the metrics are defined by:

Connection $$\chi = \frac{0{,}25A_1 + 0{,}1A_2 + 0{,}3A_3 + 0{,}15A_4 + 0{,}2A_5}{3.05} \quad (1)$$

Data $$\alpha = \frac{0{,}4B_1 + 0{,}3B_2 + 0{,}3B_3}{4} \quad (2)$$

Environment /User Satisfaction $$\beta = \frac{0{,}2X_1 + 0{,}3X_2 + 0{,}2X_3 + 0{,}3X_4}{7} \quad (3)$$

Global Evaluation Environment $$\Omega = \frac{0{,}3\chi + 0{,}4\alpha + 0{,}3\beta}{3} \quad (4)$$

According to the results obtained we can make some modifications or improve some aspects. Table 2 establishes the significance for each metric (1-4) in terms of a classification value ranging from Very Bad to Very Good. These percentages were agreed by the ICU and Information System professionals.

Table 2. Results Evaluation

Metric	Very Bad	Bad	Acceptable	Good	Very Good
1	< = 70%	< = 75%	< = 85%	< = 90%	> 90%
2	< = 75%	< = 85%	< = 90%	< = 99%	= 100%
3	< = 75%	< = 80%	< = 85%	< = 90%	> 90%
4	< = 80%	< = 85%	< = 90%	< = 95%	> 95%

6 Discussion

The features defined and evaluated in this work made possible to transform the system in order to be more secure, robust, easily accessible and intelligent. Is expected the system will improve the patient outcome in the future due to some new facilities like the data availability in online, real-time and in electronic format. With the ICU pervasive access recast, is possible to accede to knowledge portions that can support the decision making process, anytime, anywhere. Beyond the performance of INTCare, the evaluation of the success of the proposed environment depends on the results obtained after a sample of 100 surveys answers that will be done to all people that directly interacted with this new ICU environment and can answer (patient, doctors, nurses, other professionals). Based on the results obtained for each category and according to table 2 we will decide on what to do in the future. The results also can give us indications about if the new environment is or not prepared to implement a remote IDSS like is INTCare.

7 Conclusion

The right technologies in a smart environment can get some important objective: “help health care professionals to manage their tasks while increasing the quality of patient care” [8]. Like we can prove, is possible create a Pervasive and Intelligent Critical Health Care Environment for data acquisition and data consult with the max security and reliability for the ICU, their professionals, patients and applications. Almost all tasks can be intelligent and performed autonomous and in real-time.

The proposed environment allows for a total availability of data in electronic format wherever we need at the time that we want. However there are some operations that need to be performed manually like is the mode how data is validated. We can change the mode of data is validated. The data can be pre-validated automatically but the final verification has to be done by ICU professionals. We can improve the form how data is validated, but this process always needs to be human. Nothing can fail because patients’ lives are at risk. The impact of this on the society will be big, because the doctors can see the patient condition and treat him remotely. New systems have to be created and others need to be modified, because this environment will allow pervasive computing and new features can be added to the actual systems. The principal difference between this model and the previous is in the form of the data is collected, available and how it can be accessed. With the implementation of new environment and the guarantee of the success of operations at a distance, some new treatments can be performed and some lives can be saved.

8 Future Work

Now we are analysing the new environment and arrange some meetings with the objective to develop a Risk List and a contingency plan. The objective is to define actions that can avoid problems if something fails on the system. In the future we hope to have the entire ICU adapted to a pervasive and intelligent approach. The prevision and decision models will be improved and prepared to the pervasive environment.

Acknowledgment. The authors would like to thank FCT (Foundation of Science and Technology, Portugal) for the financial support through the contract PTDC/EIA/72819/2006. The work of Filipe Portela was supported by the grant SFRH/BD/70156/2010 from FCT.

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