Health and assistance processes modelling and management at home and in residential structures by fusing sensor data

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Abstract

The life expectancy improvement and the increasing incidence of chronic diseases in the population in rich countries make evident the problem of managing the process of care at home and in residential structures. This article proposed a system based on sensors data to identify the most appropriate solution to be activated when a health problem arises. In particular the proposed system allows identifying anomalies, their assessment and their management.

Keywords: Process modelling, Sensors System, Fusing data

1. Introduction and Background

Due to the lifestyle and environmental changes, as well as healthcare improvements and increased life expectancy, the management of chronic diseases is more and more becoming one of the most important focus of new health policies being currently the leading cause of adult death and disability worldwide (Alwan et al, 2010). Currently health care services tend to be fragmented, curative, hospital-based and disease-oriented rather than person-centred. On the contrary, chronic diseases and multi-morbidity require a more integrated and people-centred approaches to service delivery (WHO, 2015) and, by the use of ICT solutions, a better coordinate care across providers and service settings.(Anderson G, 2010) ICT solutions can be applied:(Grone O, 2001)

- at *micro* level, to support the empowerment of citizens (better-informed patients and carers have the potential to improve the quality of clinical care by facilitating the provision of feedback to individual health professionals on the outcomes of care they deliver);
- at *meso* level, to integrate multi-professional teams and institutions;
- at *macro* level, to allow better planning of services based on epidemiological investigations and outcomes.

New organizational models of healthcare are needed; in this perspective patients becomes partners in the process, contributing to almost every decision or action level and integration between hospital and home care are needed (Sabato 2009).

Various methodologies where provided in the literature for managing health care processes and clinical trials (Fazi 2000), (Grifoni 1997).

In order to support the possibility for chronic patients to safely live in not hospitalized environments (either at home or in residential structures) it becomes crucial to manage critical events. Several elements have to be considered in order to identify and activate the most appropriate solutions. A clear identification of the specific health need associated with a level of severity, the mapping of the healthcare processes with associated resources that could provide an answer to the health need, criteria of preferences to refine selection once the minimum set of health criteria are satisfied (e.g. distance between the subject and the health service, previous experiences between the specific subject and the specific health operators, preferences expressed by the patient).

To overcome the aforementioned critical issues, a system has been developed for the automatic identification of the most appropriate solution to be activated when a health problem arises. The system acts at the previously mentioned *meso* and *micro* levels to orchestrate the available resources / actors in order to meet the patient needs.

The present work describes the system and reports its testing in a simulated environment.

2. Methods

2.1. Case study

A simulated case study was used to design and test the system (no real interventions were executed).

The specific health context is described:

- *Patient*: subjects living at home and suffering from chronic cardiovascular issues.
- *Analyzed parameters to define the health status*: body temperature, arterial bloody pressure (min and max), hearth rate.
- *Health issue*: 3 different health issues are identified, with an associated level of life-risk, based on the available parameters: fewer (low risk), infarction (medium risk), stroke (high risk).
- *Social/Health resources to be activated*: specialized physician, general practitioner, nurse, social operator.
- *Health organizations*: City Hospitals (Florence, Italy).
- *Healthcare processes*: 3 generic healthcare processes are defined to be activated based on the specific health issue.

The specific problem to solve with the implemented system was:

Which are the best protocol to activate and the most appropriate resource to involve when a specific health issue arise?

The case study organized to test whether the system is able to correctly address the above reported problem consists of:

- A simulated list of patients with their geographical coordinates (real addresses in Florence, Italy);
- A simulated list of health organizations with their geographical coordinates (real addresses in Florence);
- A simulated list of social/health professionals with their specialization and geographical coordinates (real addresses in Florence);
- A simulated list of previous interventions where the combination of patients-operator was reported and a level of satisfaction expressed by the patient was stored;
- A simulated list of health events characterized by a combination of the aforementioned 4 parameters.

The system was fed with the simulated lists and piloted with the simulated events. The system responses was then manually analysed for validation to check whether:

- the health issues were correctly identified from the comprehensive analysis of raw clinical data;
- the specific healthcare protocol was correctly activated once the health events were classified;
- the most appropriate resource was identified based on minimum level of expertise required by the health event, current availability of professionals, level of urgency in requiring an intervention, previous experiences between the specific patient and the social/health resource, patient satisfaction, geographical location.

2.2 Activating healthcare resources based on multiple sensor data and processes modelling

The process for activating healthcare resources is modelled by using the Business Process Model and Notation (BPMN), and it consists of different steps:

1. Identification of the anomalies
2. Assessment of the anomalies
3. Management of the anomalies.

2.2.1 Identification of the anomalies

The healthcare resources are asynchronously activated by abnormal values detected by sensors. The asynchronous activation determines a check for detecting potential anomalies.

For identifying the anomaly we made use of the theory of Dempster - Shafer, as this method does not require a priori knowledge of the event and allows to assign a degree of uncertainty regarding a given situation.

Although the theory of Dempster-Shafer is computationally complex, because it is closely linked to the number of elements of the frame of discernment Θ, in this case the frame of discernment is formed by only 2 elements:

$$\Theta = \{ [\mathit{Normal}] , [\mathit{Abnormal}] \}$$

Consequently we can go to define the power set, formed by all the possible combinations of the elements of the frame of discernment, such as:

$$2\Theta = \{ [\ ], [\mathit{Normal}], [\mathit{Abnormal}], [\mathit{Normal}, \mathit{Abnormal}] \}$$

The model is based on the mass function for each sensor described by:

$$mSi(\mathit{Normal}) = (1+e(vi - ti))-1$$

$$mSi(\mathit{Abnormal}) = 1 - mSi(\mathit{Normal})$$

where vi indicates the measured value to be analyzed and ti gives the threshold value relative to the sensor i.

The value mSi(*Normal*) is obtained by logistic regression with sigmoid function so that the results are comprised between 0 and 1.

Logistic regression is a special case of generalized linear model. It is a regression model applied in cases where the dependent variable is dichotomous, that is attributable to the values 0 and 1 (as are all the variables that take only two values: true or false, male or female, healthy or sick, etc.).

The regression formalizes and solves the problem of a functional relationship between variables measured on the basis of sample data extracted from a hypothetical infinite population.

More formally, the regression is a method of estimating the conditional expectation of a dependent variable, or endogenous y, given the values of other variables or exogenous, x1, …., xk : E [y | x1, …., xk].

They have at their disposal a number n of sensors each one concerning a specific characteristic, such as temperature, minimum pressure, maximum pressure, heartbeats, etc..

After assigning the masses to each feature, or to each sensor Si:

$$mS1 (\mathit{Normal}), \dots , mSn (\mathit{Normal})$$

$$ms1 (\mathit{Abnormal}), \dots, msn (\mathit{Abnormal})$$

Through the combination rule of Dempster:

$$m_{12}(A) = \frac{\sum_{B \cap C} m_1(B) m_2(C)}{1 - \sum_{B \cap C} m_1(B) m_2(C)}$$

It is carried out the fusion of the mSi (*Normal*) so that to obtain a single mass and general to determine the situation "Normal", or m(Normal).

It runs the same procedure for the msi (*Abnormal*) in order to obtain the single mass and to determine the general situation "Abnormal", i.e. m(*Abnormal*) .

The results obtained are then compared. They determine an emergency situation if:

$$m(\mathit{Abnormal}) >> m(\mathit{Normal})$$

then the measurement recorded data outliers, and intervention is required.

If:

$$m(\mathit{Normal}) > m(\mathit{Abnormal})$$

then measurements showed values in the media and no action is required.

2.2.2 Assessment of the anomalies

After identifying the occurrence of a fault it is necessary to decide the most appropriate procedure. However, the choice of the appropriate method depends on the assessment of the risk level of the situation. Based on the risk assessment it can be turned on an appropriate method. Given x as value of risk assessment for the present situation, then if:

- x> maximum threshold of risk, then the procedure A will be performed
- if minimum threshold of risk <x <maximum threshold of risk, will run ProceduraB
- x<minimum threshold of risk, in this case the procedure C will be performed

The **Procedure A** is activated in situations of high alarm, or when the level of risk is greater than the maximum threshold level of risk. This procedure is also applied when an abnormal situation is identified and the ontology diseases module has not been able to provide information about the type of pathology in progress.
In this case it is very risky to the rescue intervention to domicile and it is preferable the immediate hospitalization of the patient through the management of an emergency. Patient information will then be analyzed and a request for emergency assistance will be sent to the public hospital in the same cluster of the patient or hospital neighbouring if the necessary resources are not available.

The **Procedure B** is applied in situations of average - high risk or when the level of risk is between a threshold value of minimal risk and a threshold value of maximum risk.
In that case the intervention of rescue can be performed in the patient home by the competent professionals.
The objective of this procedure is to identify the most suitable professionals, among all the available, to carry out the rescue by using the detected information from the devices.
We have implemented the algorithm using the structure of Greedy algorithms, that, at each iteration, choose the best solution at that time, or it is identified excellent local. This choice was dictated by the fact that there may be cases where the health professional "preferred" may be unavailable at the time of the call.
The algorithm for the procedure B involves the following steps:

Step 1. The step allows the identification of potential health care professionals. For identification the following information are considered: patient, kind of potential problem and a level of risk. The step identifies a list of health care professionals that meet the following characteristics:

- The types of professionals is among the medical specialists or general practitioner eventually supported by nurses or social professionals;
- The professionals of the list must belong to the same cluster as the patient.

Step 2a. If the list is not empty, for each operator on the list it is calculated the value of preference; otherwise:

Step 2b. It goes back to Step 1 by changing the selection criteria of health workers to be included in the list as follows:

- The types of health care professionals is among the general practitioners or doctors specialized in managing the type of anomalies;
- The health professionals must belong to the cluster closest to the cluster analyzed in the first iteration.

Step 3. it was chosen for the intervention the health professional that has the highest value of preference.

The **Procedure C** is applied in low risk situations or in routine activities such as changing a drip.
The low level of risk can be managed by the nursing staff, social support professionals or relatives of the patient with the support and under the control of the staff.
The algorithm for the procedure C involves the following steps:

Step 1. The step allows the identification of potential health care professionals. For identification the following information are considered: patient, kind of potential problem and a level of risk. The step identifies a list of health care professionals that meet the following characteristics:

- The types of professionals is among the nurses or social professionals;
- The professionals of the list must belong to the same cluster as the patient.

Step 2a. If the list is not empty, for each operator on the list it is calculated the value of preference; otherwise:

Step 2b. It goes back to Step 1 by changing the selection criteria of health workers to be included in the list as follows:

- The types of health care professionals is among the nurses or social professionals specialized in managing the type of anomalies;
- The health professionals must belong to the cluster closest to the cluster analyzed in the first iteration.

Step 3. it was chosen for the intervention the health professional that has the highest value of preference.

2.2.3 Management of the anomalies

The management of the anomalies is based on information on patients, kind of anomaly, available healthcare personnel, history of interventions to favour already consolidated matches between patients and the health operators and to consider the patient satisfaction on previous interventions.

To facilitate the choice of the health care professionals to be sent for the aid has been introduced the value of preference.
The preference value is based on four parameters, described below, that are normalized and combined.
The four parameters are:
- Parameter of Frequence: percentage of interventions of health professional X on the patient Y.
The number of interventions made by the health professional X on patient Y is computed using the table of the "History of the interventions". This value is

compared with the total number of operations carried out by X.
The percentage of the interventions made by X to Y will be then obtained, that is (combination rule of Dempster):

$$\%\ (\text{interventions of X}) = \frac{\text{Number of intervantion of X on Y}}{\text{Number of total intervantion of X}}$$

The Frequence parameter feature is quite important as the project is mainly targeted to elderly people and for these users is preferable to have operators already known. This creates a more serene and trustful collaboration between professional and patient. It was therefore decided to give a 40% weight to this feature and accordingly the value of the coefficient is 0.4.

Parameter of Score: Preferences of the patient Y for the health professional X
The table of "History of the interventions" is used to analyze all the feedback left by the patient Y related to the health professional X.
Each patient can give a value ranging from 1 to 5 to the health professional.
The total score is obtained by an arithmetic average of the scores given by the patient Y to the health professional X, the value obtained will be rounded to the nearest integer.
This parameter is useful, however it is not the most efficient and significant in the choice of the health professional, then we assigned a weight of 10 and accordingly the value of the coefficient is 0.1.

Parameter of Distance: distance between patient Y and health professional X
The distance between the healthcare personnel and patients has influence on costs and the quality of services and must be evaluated in assigning and planning resources (Rafanelli M, 1995). The distance is calculated by the geodesic distance, between the healthcare professional and the patient.
A health professional is "available" when he is in his workplace, while it is "not available" as soon he leaves the workplace to go to make a rescue or when off duty.
Scores are obtained based on the distance between the two seats going to prefer, and then assigning a higher score, the association between operator and patient with minimum distance.
This feature appears to be the most important because the proximity is a key point in the speed of the operation, it will thus be considered with a weight of 30%. Accordingly it will be multiplied by a coefficient of 0.3.

Parameter of Relevance: type of the HCP, the following categories are considered:
Medical specialists;
General practitioner;
Nurses;
Social professional.

The preference, depending on the severity of the situation, will be paid to the choice of a medical specialist or a general practitioner than that of a social professional.

This feature presents importance of 20%, and then will be multiplied by a coefficient of 0.2.

The preference value is provided by the combination of the values of the characteristics, weighted according to their importance, and the availability of a health professional.
The availability value of a health professional, as already mentioned, can be "available", and then has a value equal to 1, or "not available" and has a value equal to 0.
Obviously, in the case of non-availability of a health professional, his preference value will be cancelled and then he will be "excluded" from the list of possible candidates to perform the surgery.
The preference value is then defined as:

$$\text{Preference\_value}_Y = D \cdot \left(\sum_{i=1}^{n}\left(Coeff_i \cdot \text{Score}_i\right)\right)$$

where we denote by:

D, the availability of the health professional Y, that can be 0 or 1;

Coeff_i, we indicate the coefficient of the characteristic i

Score_i, we indicate the score obtained by the health professional Y with respect to the feature i.

3. Results

To implement all the algorithms we used the Java programming language of the web platform. Process modelling was performed using the BPMN standard, the models were incorporated into Java code using software Camunda which offers a graphic panel to enable the realization of the process model. The association between the Java classes and the corresponding elements of the BPMN model is via XML.
The proposed approach allows activating healthcare resources based on multiple sensor data and processes modelling in different operative contexts.
In this paper we present a simulation based on the Florence area, with a simulated list of health structures, social/health professionals, patients and sensors capturing data for cardiologic patients.
In Florence there are five public hospitals, therefore our value k, which is the number of clusters, will be just equal to 5.
As centroids of the five clusters were chosen coordinates (represented in the form of latitude and longitude) obtained by the addresses of the hospitals themselves.
The figure shows the arrangement of the centroid on the map of the city and assigned patients.
First, we assumed the presence of 4 different sensors, whose measurement include:

- S1 that detects the basal temperature, wherein abnormal values are the temperatures higher than 37;
- S2 that detects the minimum pressure, where abnormal values are greater than 85
- S3 that detects the maximum pressure, where abnormal values are greater than 140
- S4 that detects heartbeats, where abnormal values are greater than 86.

If the sensors have detected the following values:

S_1	S_2	S_3	S_4
39	85	180	85

Analyzing the values of the patient, the algorithm detects the presence of an abnormal situation.
It was also created a knowledge base (based on ontologies) for simulating the identification of the type of event identified. The combination of the values of the four sensors provided us information on the following possible conditions: fever, heart attack, stroke.
An emergency can be activated after checking by phone the presence of other symptoms like abrupt loss of vision, speech, or the ability to understand speech. As an alternative may be asked to the patient to apply a sensor to verify the presence of a stroke.

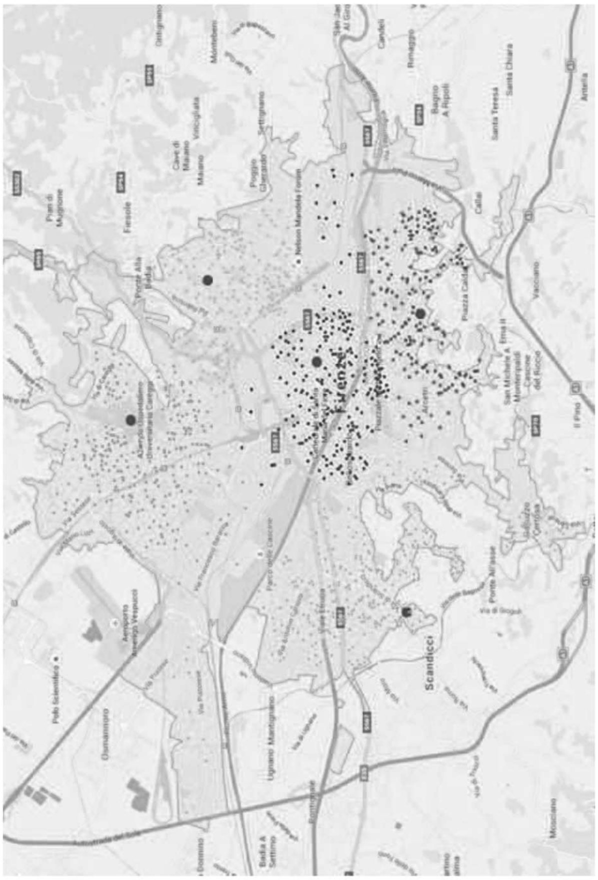

Figure 1:

The overall module has been tested simulating different data from sensors for activating different procedures and social/healthcare resources.

4. Discussion and Conclusion

The increased life expectancy has led the majority of the population over the age of 65, defined elderly, to play an important role in today's society. The increasingly frenetic rhythms of everyday life have done that the elderly are alone more and more.
Minimize response time, thanks to the system, allows avoiding situations extremely dangerous for patients, allowing in extreme case, to save their life.
Currently the "weights" to be attributed to each feature, used to calculate the level of attractiveness (in terms of preference value) of a health professional, are considered statically and pre-defined. In a future evolution it could be considered to provide patients with the opportunity to register their preferences degree for each feature.
The location of the healthcare professionals is currently regarded as fixed and defined on the basis of the registered office.
As a future work the algorithm can be upgraded to allow for identifying the GPS position of the healthcare professionals. Based on this information it can be calculated the position of the operator that is closer to the patient; this will make more efficient the algorithm for the choice of the operator minimizing intervention times.

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