CyberCare: Reasoning about Patient's Profile in Home Healthcare

Alessandra Mileo[1] and **Davide Merico** and **Roberto Bisiani**[2]

Abstract. This paper proposes a framework based on modern tools and technologies to enable home healthcare through the observation of i) patient's clinical details by means of a Wearable Acquisition Device, ii) movements detected by sensors networks and iii) habits/actions inferred by an ASP logic program.

1 Introduction: the social and clinical context

In recent years, Communication and Information Technologies have been introduced in specific fields of medical sciences in order to allow the *delivery of clinical care*. A centralized view of medicine at a distance led to the integration of Communication Technologies and Clinical Decision Support Systems (CDSS) performing medical reasoning tasks. The resulting framework is known as Telemedicine.

Contrary to all expectations, the introduction of these techniques in real contexts showed they were not easily applicable to any medical task, and they have thus been restricted to some aspects of healthcare, such as medical prescriptions [17].

The limitations of Telemedicine for more general medical tasks, e.g. the formulation of a diagnosis, are related to the absence of standard protocols for data exchange and memorization between the Health Institutions.

Recent studies about the acceptance of technologies for the elderly [9, 6] showed that the best technological solution has to be chosen depending on the specific problem at hand, thus confirming previous research on this topic [15]. Moreover, while people tends to look for social relationships in activities such as cleaning or playing cards, in situations related to safety or health and personal care they are more likely to change their home environment in order to cope with their hierarchy of needs.

These considerations strengthen the argument that the success of intelligent technologies in healthcare depends on the need of each patient, and even on a given set of conditions under which he seems to need help.

In our proposal, we do not focus on the introduction of robots to domicile healthcare: beyond their high costs of set up and maintenance, their presence is rather intrusive and their acceptability is strongly related more to emotional components of people's image of them than to the effective help they can provide. Our perspective is shifted on *tools* and *technologies* that can unobtrusively help users and interact with them to increase home safety and personal healthcare. In order to do that, the interaction and communication between the patient and the system should be as much intuitive and transparent as possible through suitable interfaces and voice as well as other multimedia content processing.

We use ZigBee-sensors networks instead of classic monitoring tools (e.g. cameras), because they are simpler, faster and cheaper to install and use in existing domotic environments.

Our idea of CyberCare is based on an Intelligent Component aimed at collecting (temporally) local information about the patient's profile (medical parameter, clinical setting) and context (habits, localization), reasoning about it to determine the intervention required and provide the specialist with the context of the emergency, thus saving medical experts' time in determining how to operate.

Similar solutions to home healthcare have been proposed so far, such as the RoboCare project [4] and the KGP agent model [16], but they were mainly based on efficient and adaptive planning to monitor patient's daily activities. CyberCare is rather based on subsequent inferences to detect emergencies related to any single activity as they arise. In our reasoning model, a transition is referred to the state of an action (interrupted, abnormal, changed) and each inference allows to change this state. Patient's profile is updated through off-line reactivity capabilities, on the basis of the state transitions of each daily action. Nonetheless, we focus on single activities to detect emergencies when necessary, rather than considering a global daily plan that has to be monitored as a whole. In this way, thanks also to real time localization, any emergency related to a specific action execution can be treated faster as a single entity, while still keeping track of it to eventually update patient's habits off-line.

For these reasons, we argue that the introduction of modern sensors networks technologies as well as an Intelligent Component in our framework would enable patients to be, to some extent, self-sufficient in their own houses by increasing their safety.

Section 2 of this paper illustrates the features of a Location System based on sensors networks under the ZigBee protocol. Section 3 describes the CyberCare Intelligent Component system and Section 4 presents conclusions and further hints for development.

2 The Location System

The Location system used in CyberCare is based on concurrent use of ZigBee networks and Data from Inertial Measurement Units.

ZigBee is a wireless technology developed as an open global standard to address the unique needs of low-cost, low-power, wireless sensors networks. The standard takes full advantage of the 802.15.4 physical radio specification developed at the Institute of Electrical and Electronics Engineers (IEEE). The specification is a packet-based radio protocol that meets the needs of low-cost, battery-operated devices. The protocol allows devices to intercommunicate and be powered by batteries that last years instead of hours.

[1] Dipartimento di Informatica e Comunicazione, Università degli studi di Milano, email: mileo@dico.unimi.it

[2] Dipartimento di Informatica, Sistemistica e Comunicazione, Università Statale di Milano-Bicocca, email: roberto.bisiani@disco.unimib.it, davide.merico@disco.unimib.it

Among the ZigBee protocol features, we mention:

- Low duty cycle - Provides long battery life
- Low latency
- Support for multiple topologies: Static, dynamic, star and mesh
- Direct Sequence Spread Spectrum (DSSS)
- Up to 65,000 nodes on a network
- 128-bit AES encryption Provides secure connections between devices
- Collision avoidance
- Link quality indication
- Clear channel assessment
- Retries and acknowledgments
- Support for guaranteed time slots and packet freshness

ZigBee technology was not originally conceived to be used as location system. However, some commercial products have been developed to enable ZigBee nodes localization [13].

Inertial Measurement Units and components, which sense either acceleration or angular rate, are being embedded into common user interface devices more frequently as their cost continues to drop dramatically. These devices hold a number of advantages over other sensing technologies in that they measure relevant parameters for human interfaces and can easily be embedded into wireless, mobile platforms.

The Wearable Acquisition Device (WAD), developed by Microsystems [10], includes a three-dimensional accelerometer and a three-dimensional inclinometer that are used by the system to determine the position of the patient and his behavior to perceive when an emergency arises and how do patients react to the situation.

3 The Intelligent Component at a glance

The Intelligent Component of CyberCare is situated on a personal computer we call the Home Processor (Figure 1).

The reasoning process is based on (temporally) local details about the patient, collected real-time whenever an emergency is detected.

In Artificial Intelligence, the possibility of making assumptions rather than just doing deductions from a given knowledge base, has been considered very attractive and widely used for declarative representations of problems in a variety of areas. One way to use the assumption-based framework is that of applying Default Reasoning, especially in areas where you don't want to enumerate all of the exceptions of a situation, even if you could think of them all.

The intuition is that of using automated commonsense (nonmonotonic) reasoning to analyze patient's clinical[3] and environmental settings in order to detect the origins of an emergency and its resolution by reasoning on exceptions.

Our knowledge base does not contain the whole medical knowledge that may be related to the specific case. This would be too huge to manage when the inference process is running, while emergencies require rapid answers.

According to results provided by the inference engine the system can then update patient's clinical profile and habits definition by modifying and adapting numerical thresholds in logic predicates.

This means that instead of reasoning on similar medical cases only, the Intelligent Component is in charge of extracting and reasoning about the current situation of the patient at the time the emergency arose. The main tasks performed by the Intelligent Component are:

- monitoring patients through a sensors network and a WAD device;
- collecting both static and dynamic data about the patient (habits, biomedical data, location) and the environment the patient moves in (rooms, areas of interest);
- extracting such data as soon as the need of assistance is detected, an convert them into logic predicates;
- determining solutions to emergencies through an inference engine (ASP solver) evaluating the ASP program composed by the extracted predicates and logic rules[4];
- convert ASP solutions into actions through external modules;
- periodically (at the end of each day) adapting patient's profile automatically (off-line learning);

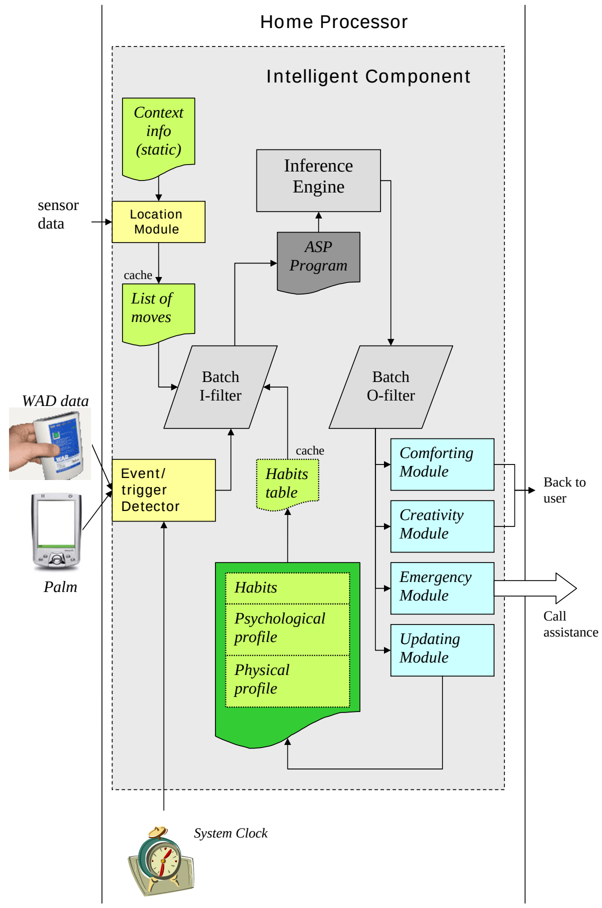

Figure 1. CyberCare: general Architecture

3.1 Event Detector

The Event Detector component is in charge of capturing external events and triggering the inference process in case of emergency. We consider three possible triggering events:

1. **significant changes of biomedical parameters** including blood pressure, ECG, temperature and others;

[3] Clinical details are formalized by the medical assistant during setup, while contextual information is extracted automatically by the Location Module and the Habits table.

[4] Logic rules enabling the system to reason about the emergencies and detect eventual anomalies in patient's behavior, are related to generic social settings and need to be defined by the knowledge engineer together with a medical expert.

2. **unexpected changes of patient's habits**, i.e., an action has not been performed within the time bound scheduled for it;
3. **explicit requests of help**.

It is worth mentioning that, in our view, clinical exceptions have higher priority than the behavioral ones.

This means that whenever a physical problem is detected together with a behavioral anomaly, only the former one is considered in the inference process. This allows the reasoning process to be selective, thus faster and much more effective in treating emergencies.

3.2 Location Module

The system has to collect information about patient's moves in the house in order to know what the context of an emergency is like. The Location Module is in charge of this task through Location Algorithms based on RSSI values (Received Signal Strength Indicator).

Location Engines use RSSI values combined with physical locations of reference nodes (with static location) to calculate positions of "blind nodes".

Reference nodes must be configured with an X and a Y value that correspond to the physical location. The main task for a reference node is to provide a "reference" packet that contains X and Y coordinates to the blind node, also referred to as *anchor node*.

A blind node communicates with its nearest reference nodes, collecting X, Y and RSSI for each of these nodes and calculates its position based on this parameter input using the location engine hardware.

The location estimation is performed at each node, hence algorithm is decentralized. This feature will reduce the amount of data transferred to radio, since only the calculated position is transferred.

All location information provided by ZigBee Location Engine are integrated with motion data computed by WAD inertial sensors to enhance position calculation precision.

3.3 Static and Dynamic Profile Extraction

General information about the patient is collected into a static profile to be later enriched run-time by dynamic data.

The static part of patient's profile includes:

- **clinical data**, represented as a set of logic predicates of the form $normal\_value(Parameter, Min\_value, Max\_value)$.
  and included in the ASP logic program when the system inference is triggered;
- **patient's habits**, expressed as
  $time(Action, Init, S1, Duration, S2)$.
  $place(Action, Room)$.
  indicating when and where an action is supposed to be performed; $S1$ and $S2$ represents the leeways in beginning and duration of the action, respectively;
- **patient's psychopathologies**, interaction-oriented details that have to be previously formalized by an expert and included in the knowledge base by the knowledge engineer[5].

Dynamic information is responsible for the system inference to be triggered. The dynamic component of patient's profile includes:

- **biomedical parameters** registered by the WAD and transmitted to the Intelligent Component by the Batch I-filter: $actual(Parameter, Min, Max, Time)$.
- **list of moves**, extracted by the Batch I-filter:
  $enter(Room, Time, N)$.
  $exit(Room, Time, N)$.
- **patient's requests**, transmitted through the palm device.

3.4 The Inference Process

To make the run-time reasoning task more efficient, we do not apply Machine Learning Techniques and case-based reasoning in the Inference Process, but rather Default Reasoning under the Answer Set Programming (ASP) paradigm.

ASP is based on the *stable model* semantics for Logic Programs proposed by Gelfond and Lifschitz [8] and it can be seen as bringing together concepts and results from Logic Programming, Default Reasoning and Deductive Databases.

In Default Reasoning you specify general knowledge for standard cases (the defaults) and modularly add exceptions. When you add an exception to default, you can't conclude what you could before. In that Default Reasoning is told to be *nonmonotonic*.

In the first prototype of CyberCare we evaluate the ASP program by using the Smodels solver, an implementation of the stable model semantics for logic programs implemented by Patrik Simons [12].

Smodels treats variable-free programs and it has to be used together with Lparse, a front-end in charge of performing the grounding procedure to produce a variable-free logic program for Smodels.

One may argue that Answer Set Programs grounding could be very costly; in this setting, the interaction-oriented approach allows us to restrict grounding to a finite and quite reduced domain including few biomedical data, daily activities and rooms of the house. As for the time unit, at the end of any inference we mark successfully completed actions and in the subsequent inference we limit time units from the current (discrete) instant of time back to the bound of the last unchecked activity.

The Smodels solver supports constraints, choice rules and weight rules [11, 14] and can be thus considered powerful enough to give interesting solutions to complex reasoning tasks.

To represent Default Reasoning in Smodels we have to express that an atom or predicate is an *assumable*[6] by telling that it is to be considered *true* unless some other rules indicates its negated[7] holds:

$assumable$:−*not exception*.

An activity A is considered $normal$ by default at time T, unless any anomaly is detected:

$normal(A, T)$:−*not anomaly*(A, T).

The following *exception rule* indicates that an anomaly on action A holds by default at time T when A has not been performed within the given time bounds[8]:

$$\begin{array}{lll} anomaly(A,T) & :- & time(A, Init, S1, L, S2), \\ & & not\ done(A,R,T), place(A,R), \\ & & Init + S1 + L + S2 < T. \\ done(A,R,T) & :- & was(R,T1,T2), place(A,R), \\ & & time(A, Init, S1, L, S2), \\ & & T1 < T2 < T, \\ & & Init - S1 < T1 < Init + S1, \\ & & L - S2 < T2 - T1 < L + S2. \\ was(R,T1,T2) & :- & enter(R,T1,N1), T1 < T2, \\ & & exit(R,T2,N2), N1 = N2 - 1. \end{array}$$

---

[5] Not included in the actual prototype.

[6] An *assumable* is a ground instance of a possible hypotheses that can be considered true when consistent.

[7] We consider Negation as Failure [7].

[8] This is only the simplest case. Further possible explanations for a behavioral anomaly can be treated by introducing corresponding exception rules.

The above rules refer to actions that are supposed to be completed at the time the inference is running. We also want the system to monitor actions that are being executed. These actions are checked to keep track of eventual delays in the initial time scheduled for them. Interruptions due to physical problems are also considered[9]. In exceptional cases, patients can be asked for indications related to their change of habits, but we don't consider this case in the first prototype of the system, cause we want it to be as less intrusive as possible.

3.5 The Output Modules

Inference results are interpreted by the batch output filter (Batch O-filter) that captures logic predicates included in the solutions (stable models) provided by Smodels and call the appropriate module, external to the inference engine.

The initial prototype of the system will include:

- the Updating Module analyzing what happened in the last twenty-four hours and updating[10] patient's profile accordingly;
- the Emergency Module redirecting the treatment of physical emergencies to the appropriated service.

Thanks to the modularity of the system, this list can be extended. As an example, we could provide a Creativity Module interacting with the patient when he asks for company, or a Support Module to provide psychological support through interactive screens.

4 Conclusions and Future Work

We propose a framework for home healthcare based on sensors network technologies, patient's profile observation and environment analysis through logic programming.

Patient's profile management and clinical assistance are oriented to the context of a specific emergency rather than to the general case-based analysis. This shift of perspective limits the amount of knowledge to be considered at a time, and that's the reason why we proposed not to use canonical Machine Learning Techniques, that need to treat a large amount of data in order to learn how to get to a solution/treatment.

The patient- and interaction-oriented approach based on Default Reasoning results in being unobtrusive, modular, declarative [1], efficient and self-adapting.

Non intrusiveness is granted by the fact that information about the user is extracted automatically by the location system and the WAD device: no complex statistical information or general medical knowledge are needed to determine the nature of the emergency.

Modularity is given by the Default Reasoning and a declarative specification of the problem, while efficiency and self-adaptation are granted by the fact that we use ASP inference engines and off-line profile update instead of case-based analysis and Machine Learning.

The interaction is fully intuitive, as we deal with multimedia contents and the patient is provided with a palm device that works like a remote control TV switch to interact with the system.

Preliminary tests on a few profile instances showed that CyberCare could be profitably employed in home healthcare services supporting the delivery of care. Our initial studies have been mainly addressed to the elderly, but the patient's profile specification and analysis we propose allows us to easily extend this framework to deal with other categories of subjects having social disadaptations (e.g. hyperactive children), and it could thus represent a desirable tool to support the National Social Service.

[9] For lack of space we omit the related code.

[10] Updates are made in terms of changing S1, L, S2 values according to some heuristics.

Nonetheless, we are aware of the fact that more detailed and huge experimental results are needed to evaluate effectiveness of this approach in different social contexts, and provide significant empirical data. This aspects will be detailed in a future extended paper, where an advanced prototype will also be presented. Such a complete prototype is supposed to be employed in a restricted area of the city of Milan (Italy).

A further issue is related to the solutions obtained by the system. One of the interesting aspects of using ASP semantics in this context is that all possible solutions to an emergency (interventions, diagnosis, modules' activation, etc.) are considered equally valid. There are efficient techniques to enforce priorities and ordering relations among solutions of an ASP program [2, 3], and it would be interesting to investigate how to apply these techniques in the Healthcare scenario.

In a future paper we want to investigate further extensions of the framework, such as i) ordering rules and predicates to select the preferred solution among the possible ones and ii) automatically updating rules rather than just thresholds, to efficiently reason about new unexpected situations [5].

References

[1] C. Baral, *Knowledge Representation, Reasoning and Declarative Problem Solving*, Cambridge University Press, 2003.

[2] G. Brewka, 'Logic programming with ordered disjunction', *Proc. of AAAI02. Extended version presented at NMR02*, (2002).

[3] G. Brewka, I. Niemelä, and T. Syrjänen, 'Implementing ordered disjunction using answer set solvers for normal programs', *Proc. of JELIA02*, 444–455, (2002).

[4] A. Cesta and F. Pecora, 'The robocare project: Multi-agent systems for the care of the elderly', *ERCIM News No. 53*, (2003).

[5] J. Del Grande, T. Schaub, and H. Tompits, 'A preference-based framework for updating logic programs: Preliminary report', *Workshop on Preferences and Their Application in Logic Programming Systems*, (2006).

[6] E. Dishman, 'Inventing wellness systems for aging in place', *Computer, IEEE*, 34–41, (2004).

[7] P.M. Dung and P. Mancarella, 'Production systems with negation as failure', *IEEE Transactions on Knowledge and Data Engineering*, **14**(2), 336–352, (2002).

[8] M. Gelfond and V. Lifschitz, 'The stable model semantics for logic programming', *ICLP/SLP*, 1070–1080, (1988).

[9] M.V. Giuliani, M. Scopelliti, and F. Fornara, 'Elderly people at home: Technological help in everyday activities', *Int's Workshop on Robots and Human Interactive Communication*, (2005).

[10] MsWebCare, 'Web based solutions for healthcare', *http://www.mswebcare.it*, (2001).

[11] I. Niemelä and P. Simons, 'Extending the smodels system with cardinality and weight constraints', *Jack Minker, editor, Logic-Based Artifcial Intelligence, Kluwer Academic Publishers*, 491–521, (2000).

[12] Helsinky University of Technology, 'Smodels solver', *http://www.tcs.hut.fi/Software/smodels/*, (2002).

[13] N. Patwari, A. O. Hero III, M. Perkins, N. S. Correal, and R. J. ODea, 'Relative location estimation in wireless sensor networks', *IEEE Trans. Signal Process. 51, 8 (August 2003)*, 21372148, (2003).

[14] P. Simons, I. Niemelä, and T. Soininen, 'Extending and implementing the stable model semantics', *aij*, **138**(1-2), 181–234, (2002).

[15] Y.A.W. Slangen-de Kort, C.J.H. Midden, and A.F. van Wagenberg, 'Predictors of the adaptive problem-solving of older persons in their homes', *Env. Psych*, **18**, 187–197, (1998).

[16] K. Stathis and F. Toni, 'Ambient intelligence using kgp agents', *2nd European Symposium for Ambient Intelligence*, 351, (2004).

[17] J. Teich, J. Schmiz, G. Kuperman, and D. Bates, 'Effects of computerized physician order entry on prescribing practices', *Archives of Internal Medicine*, **160**, 2741–47, (2000).