JOURNAL OF MEDICAL INFORMATICS & TECHNOLOGIES Vol. 13/2009, ISSN 1642-6037

e-health, telemedicine, system integration

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COOPERATION FRAMEWORK FOR PERSONAL AND HOME CARE MONITORING SYSTEMS

The scenarios of cooperation between personal healthcare systems are discussed in this paper. Current telemedical solutions for home care provide the patient with a seamless diagnosis based on selected vital parameters. The application of two or more specialized systems monitoring the same subject rises the question of possible interference and cooperation. The cooperation between home care and wearable systems is of particular interest, because of their complementary features. Considerations of various cooperation scenarios led to the specification of three cooperation levels with regard to the required software integration. The paper presents also the design of a cooperation protocol for two prototype surveillance systems, enabling the use of communication resources of the stationary system to carry the messages of the wearable system over the wired transmission channel.

1. INTRODUCTION

The telemedicine is known by its spectacular achievements as telesurgery or worldwide teleconsultations, but from the most patients' point of view it manifests its advantages through two kinds of everyday diagnostic instruments: home care devices, often embedded in the infrastructure of intelligent house and personal wearable devices. The first category is nowadays developed for the homes of bed-ridden patients or elderly people living on their own. Most favourite solutions use the dedicated equipment discreetly and repeatedly monitoring the disease-dependent diagnostic parameters and automatic distant interpretation of the data transmitted over a wired digital link (e.g. Internet). The second category is designed for patients in motion and usually uses the body area network (BAN) to communicate several physiological sensors with the wearable server which provides the data interpretation and the long-distance wireless link with the medical surveillance centre [1-2].

When the same subject is considered for a bimodal health monitoring, the question of possible interference and cooperation of systems is worth to be investigated. In aspects of diagnostic range and quality, both systems may mutually join their competences and compensate for their drawbacks yielding an optimized diagnosis for the moving patient. Considering the most expected usage scenarios for people requiring the monitoring but still active professionally, the most desirable surveillance system should provide a broad-range patient diagnostics within the closed surface of his or her home but also should follow his or her outdoor trips or activities with a possible compromise between the diagnostic range and the mobility when necessary.

Current solutions of home care diagnostic systems use the network of star-shaped topology composed of the central monitoring server (also with archive and expert system services) and multiple patient-side units considered as independent clients. This assumes a direct one-to-one connection between the central and remote components without interaction between simultaneous monitoring tasks. In case of two different systems (e.g. diabetic and cardiac) dedicated to the same patient, two independent diagnostic procedures covering a common subset of parameters (e.g. the heart rate) are running in parallel and possibly yield different outcomes. Rarely both such systems come from the same manufacturer and the results calculated by the same server may be interchanged within a common database. In most cases, however, both systems work independently and the results coexist in the patient's health record being the possible cause of ambiguity.

Information systems for telemedicine are usually described in the bibliography as closed, i.e. without assuming the possible interaction with other systems or integration in the framework of a complex patient-oriented service. Therefore, the cooperation of two patient-side units requires the modification of both: their embedded software, and also the supervising nodes software. In result of the studies of possible usage scenarios, considering the expenses necessary for the adaptation of the existing monitoring systems software, we postulate to distinguish three cooperation levels:

- sharing of the communication resources,
- overlapping measurement and interpretation competences,
- collaboration in estimation of diagnostic outcome.

Despite the interest of a deep cooperation, only the first level is described in this paper.

2. MATERIALS AND METHODS

This section provides a more detailed description of the proposed cooperation levels.

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2.1. SHARING OF THE COMMUNICATION RESOURCES

Accordingly to different intended usage, each considered realization of monitoring system usually has a specific communication interface:

– In wearable systems the commonly used interfaces are wireless, allowing for a virtually unlimited operation range at the cost of high energy required for the long-distance transmission (GPRS, satellite),
– In home care systems the wired, relatively cheap wideband connections are used, however this limits their operation range to the in-house patients.

When two or more different systems operate in the same area (e.g. a wearable system is used in house), there is no economical reason for continuing the usage of separate transmission channels. Sharing the communication resources consists in the support of transmission of the external system messages within the communication protocol (fig. 1).

On the stage of system design, the support requires to consider:

– selection criteria for the optimal transmission channel,
– rules and constraints of automatic initiation and termination of the mediation service,
– definition of the external message embedding (at the source) and dispatching (at the recipient).

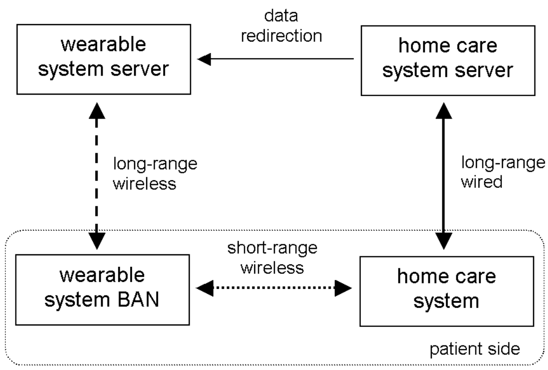

Fig. 1. Block diagram of two monitoring systems cooperation at the level of communication resources sharing

Besides the software adaptation mentioned above, the cooperation of two systems requires the data interfaces complying with a common standard. Since a wired connection limits the patient's mobility (even in house), the only reasonable solution is to add a wireless low-range digital interface (e.g. Bluetooth, ZigBee or WiFi) for the home care system.

2.2. OVERLAPPING MEASUREMENT AND INTERPRETATION COMPETENCES

This level of cooperation is applicable for the systems that provide partly overlapping lists of competences (e.g. calculation of the heart rate in both diabetic and cardiac monitoring systems). As far as the measurement of the physiological phenomena is based on different methods or the calculations of the diagnostic parameters are based on different algorithms, there is a rivalry between the concurrent systems. Assuming the existence of an independent validation of the diagnostic outcome quality, this rivalry is an opportunity for the optimization of system outcome (fig 2).

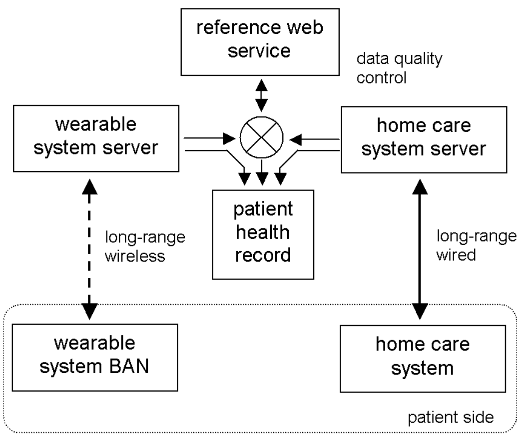

Fig. 2. Block diagram of two monitoring systems cooperation when measurement and interpretation competences are partly overlapping

When multiple values are available as results from different monitoring systems, this process favourites the result of best quality to override the others. The optimization of patient's diagnostic description requires to specify:

- optimization criteria based on a disease-dependent validation of diagnostic results quality, or an arbitrary selection of results priority,
- rules of data interchange between the systems on the level of patient-side devices.

For overlapping competences of currently applied monitoring systems working with a common database (e.g. patient health record), the arbitrary selection of best result is currently the only practical method. For only a few most used parameters the international regulations require independent quality tests with use of reference data sets and the manufacturers rarely specify the results in user-accessible documents. The optimization of multiple-systems monitoring quality needs conditional accuracy lists for each diagnostic parameter for the automatic selection of best result. Better option is the external reference algorithm (e.g. a web service [3]) occasionally called for providing the close-to-true diagnostic results that are used as a background for the selection between output values of concurrent patient systems.

2.3. COLLABORATION IN ESTIMATION OF DIAGNOSTIC OUTCOME

The collaboration of monitoring systems in the estimation of diagnostic outcome assumes the contribution from a wide range of diagnostic parameters issued by all concurrently working monitoring systems. Its background is the improvement of diagnostic quality with the extension of the basis of considered physiological facts. The main system design has to optionally support the external parameters and has to consider a mechanism for active prompt for the data from the cooperating systems when necessary.

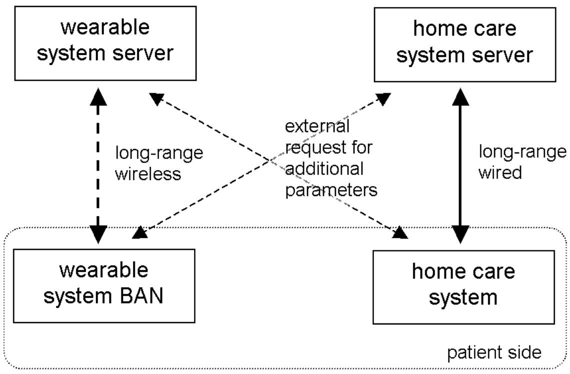

Fig. 3. Block diagram of two monitoring systems collaboration in estimation of diagnostic outcome

This mode of cooperation mimics a grid measurement approach to the optimal diagnostic result and offers the unprecedented flexibility. Although a manufacturer-independent application of such collaboration in real monitoring systems seems to be particularly difficult because it requires the implementation of:

- medical rules specifying the parameters accuracy as dependent on the applied measurement methods and the expected data reliability improvement when considering the outcomes of several method,
- technical specification of search and query for the additional parameters from external monitoring systems with the authentication and quality estimation procedures.

The efforts for such implementation needs a standard data requesting protocol to be implemented by various manufacturers in the supervising servers and the authorization for data requesting allowing the patient-side devices to provide the measurement results to the external centres.

3. PROTOTYPE COOPERATION OF MONITORING SYSTEMS

3.1. SYSTEM DESCRIPTION

The prototype cooperation was designed between two laboratory patient monitoring systems:

1. The wearable, body area network (BAN)-based cardiac monitor including MW705D GPS receiver (Mainnav), Aspekt500 12-leads ECG recorder (Aspel) and PXA-270 portable evaluation kit (Collibri) powered from the 4800 mAh 7.2V Li-Ion rechargeable battery pack [4-5],
2. The home care video-based presence detection and motion estimation system designed as a component of the intelligent house infrastructure.

For the remote-to-server communication the wearable system uses the packet radio (GPRS) wireless connection payable per data volume (standard datastream of 18kbps). The home care system uses the wired broadband internet connection supporting the real-time motion picture transmission (standard data stream of 1800kbps). Since the GPRS connection does not provide the bandwidth required for the video transmission, the sharing of the communication resources was implemented in the asymmetrical way. The prototype cooperation consists of the following modifications of the standard communication protocols in considered systems:

- The wearable monitoring system may be switched for using the alternative (wired) communication channel when the patient is in house,
- The home care system may accept the external (non-video) data, embed it into the packets, separate it at the recipient and redirect to the cardiac system server.

The home care system was additionally equipped with the Bluetooth class II digital interface of the range of 10m, being the input for the external (cardiac) data. The home care system is conditionally included as a node of the body area network of the wearable system, which may use it as a long-range communication server instead of the GPRS interface (fig. 4).

3.2. DEFINITIONS OF COOPERATION RULES

The cooperation between two systems is initiated and terminated automatically depending on the measured conditions and accordingly to the specified rules. The conditions set has to be complete, i.e. to cover all possible situations and the rules have to cover all possible behaviour of both systems. Even for the relatively simple prototype consisting of two cooperating systems and two patient states (in- and out house), we have to consider:

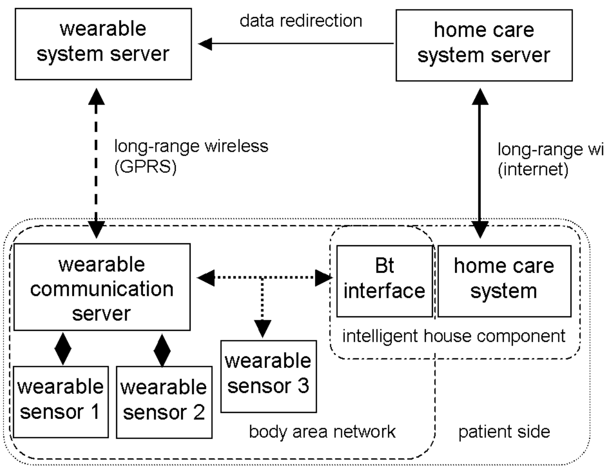

Fig. 4. Block diagram of the prototype cooperation of wearable and home care monitoring systems

- the detection of patient status by the presence on the video system,
- the detection of patient status by the quality of the Bluetooth communication between systems,
- the authentication and authorization for the external data support,
- the detection of quality of the GPRS connection,
- the quality of GPS positioning (usually affected in house).

Cooperation rules for sharing of the communication resources between two systems are displayed in table 1.

Table 1. Prototype cooperation rules for sharing of the communication resources between the wearable and home care systems

rules	conditions	actions
1. patient identified as "in house"	1. Patient is present on video system, 2. Bluetooth link established successfully, 3. Successful authentication and authorization for external data support by home care system.	1. Switch off the GPS module and set the data flag to not present, 2. Use the alternative long-range communication server, 3. Switch off the GPRS interface.
2. patient identified as "out house"	1. Bluetooth link weak or broken, 2. Patient is not present on video system.	1. Terminate the mediated communication session and mark the last data sent, 2. Try to establish GPRS link, buffer the data until successful, 3. Switch on the GPRS interface.

The presentation of the applied cooperation rules does not include the server software modification, in the prototype we assume that both servers unconditionally allow for sharing of the communication resources and the redirection of the cardiac data by the server of video surveillance system is defined. In the extended prototype a full negotiation protocol will be implemented in order to simulate the temporary suspension of resource sharing, the non-availability of the final data recipient and the break of transmission in the alternative channel.

4. PROTOTYPE TESTS AND RESULTS

The tests of prototype cooperation between the wearable and home care systems were focused on two aspects:

- The technical correctness of data carrier switching between the default (wireless) and the alternative (wired) channel, with particular attention to the data buffering,
- The savings on the payment for the telecommunication service provider and the usage of the wearable system battery determining its autonomic operation time.

The results of carrier switching delay are displayed in table 2.

Table 2. Delay time between the packets using the standard and alternative data carriers

switching direction	**success rate [%]**	**average delay time [s]**	**standard deviation delay time [s]**
wireless to wired	93	6.35	1.05
wired to wireless	71	17.3	8.10

Despite the simplified cooperation mode, the success rate representing the percentage of successful switching between the carriers is far from 100%. The most common reasons for inefficient switching were the errors in conditions detection and the average quality of both (GPRS and Bluetooth) wireless digital links.

The results of the economical aspects tests are displayed in table 3.

Table 3. Economical benefits of conditional use of the standard and alternative data carriers

communication mode ratio	**autonomy time [hours]**	**autonomy time gain [%]**	**communication payment [PLN]**	**communication payment savings [%]**
in house 100% of time	24.7	51,5	0	100
in house 80% of time	23	41.1	19	80
in house 60% of time	21.3	30,7	38	60
in house 40% of time	19.6	20.2	57	40
out house 100% of time (no cooperation)	16.3	0	95	0

5. DISCUSSSION

The implementation of a prototype cooperation between the wearable and home care systems revealed several practical conclusions (for the communication mode ratio of 80% of in house time as the most probable scenario):

- Significant (76PLN daily or 80%) cost economy due to the suspending of the GPRS connection when unnecessary,
- Moderate (41.1%) energy economy due to the use of the short-range wireless connection within the BAN (Bluetooth) instead of the long-range connection based on the GPRS.

From the technical point of view, the most important result is a relatively long response time (6.35 or 17.3 seconds) resulted from the fact that the wearable system has to buffer the messages until it has the reception of every data packet confirmed by the server.

Overlapping competences requires the use of open systems and standardized processing lists, the competences reliability may also be assessed for each particular case, as it is done within the continuous quality control,

Collaboration in estimation of diagnostic outcome needs even more open systems including the rules of use of the external diagnostic data and the rules of querying for such information. It rises many questions concerning mutual reliability, time synchronization and mutual authentication.

ACKNOWLEDGMENTS

The scientific work supported by Polish State Committee of Scientific Research in the years 2009-2011 under the grant no N518 426736 (18.18.120.875).

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