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IT Strategies for Sustainable Healthcare Systems: Case Studies

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Abstract

In this paper the challenge of sustainable healthcare has been addressed by examples of intelligent cost-effective IT solutions multiplying human capabilities in three different directions. Intelligent monitoring improves the frequency and depth of patient surveillance without any hotelling expenses. The NEUROWEB project is promising an accelerated knowledge acquisition at the frontline of neurology and genomics, hopefully leading to personalized and optimal treatments. Brvain bioelectrical imaging provides a novel low-cost, high spatio-temporal resolution technology of brain studies which directly address the physical phenomena behind the neural activity. Case studies outlined emphasize specific features essentially contributing to sustainability.

Keywords:

brain mapping, patient-monitoring, telemedicine, information distribution, genomics

Introduction

It is generally agreed that the steadily growing expenses of healthcare cannot be stopped without intelligent solutions saving manpower in routine procedures of care or without well organized knowledge centers efficiently disseminating validated information between specialists, or without equipments with improved diagnostic capabilities. A further aspect of the design of sustainable systems is the involvement of new technologies like mobile phones, internet, etc. The case studies shown below provide examples with obvious benefits in this direction.

Materials and methods

In sustainable healthcare systems patients and medical doctors should benefit for a long run from the application of Information Technology. Improved diagnostic procedures, easy and continuously updated knowledge management,, solutions for home care are just some examples. In the followings, we briefly discuss three example projects applying state-of-art IT.

General frame of a cardiovascular tele-monitoring system

Telemedicine provides a cost-effective and comfortable means of medical care [1, 2]. There are several Tele-Monitoring Systems (TMS) that can receive ECG and other signals via various telecommunication connections. In the usual setup, a portable device records and stores the measured electrical signals which are transmitted via modem-based digital links [3], fax [4], or phone [5] to a workstation. After signal processing, the results can be displayed, or printed for human evaluation.

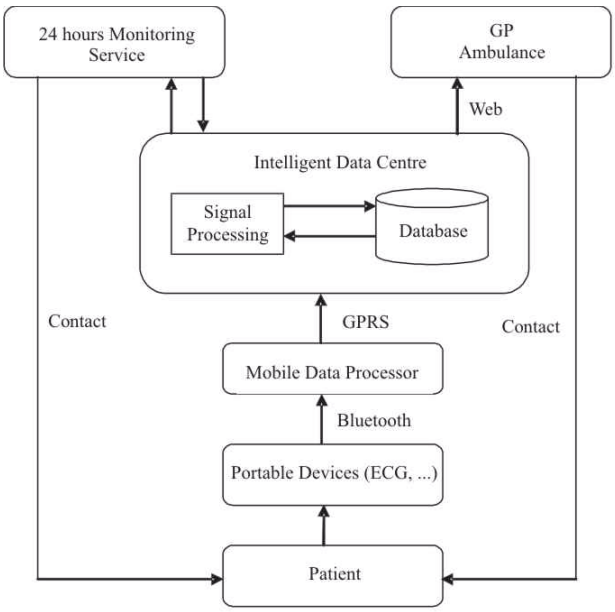

Figure 1 - The TMS architecture

The architecture of our TMS is shown in Fig 1. The monitoring procedure starts at the Monitoring Service by recording a sample of 12-lead ECG measurements. Our methods use these ECGs as baseline measurements. Later on, a portable 3-lead ECG (I, II, V2) device is used to monitor the patients in their home and to transmit the ECG results via Bluetooth to a mobile phone, which forwards them to a data centre. The ECG sampling rate of the device (300Hz, 600Hz) and duration (30 sec., 60 sec.) can be changed remotely from the Monitoring Centre at any time. The portable ECG recorder is shown in Fig 2. If needed (e.g. in the case of electrode reversal), an automatically generated warning SMS and/or e-mail is sent to the patient. Then an AI expert system evaluates the results, and if needed an alarm signal and the related actual and the previously collected trend data are sent to the 24-hour

Monitoring Service. An alarm signal is an indicator of a significant change in a clinical parameter (or parameter vector). The final medical diagnosis is to be drawn by the cardiologist at the Monitoring Centre. To avoid frequent false alarms, special attention was paid to the personalized analysis of significant and malignant changes in the monitored parameters.

Figure 2 - The mobile ECG device

Intelligent solutions

We added three intelligent features to enhance the TMS, electrode reversal detection, personalized evaluation and lead reconstruction (not detailed in the paper).

Electrode reversal detection. The 3 signal electrodes and the fourth ground electrode can be placed in distinct 24 configurations, out of which only one is correct. This error is often made by inexperienced users. The correlation between reversed and normal (correctly placed) signal morphology is examined in all the 24 cases. We use linear discriminant analysis to decide whether the electrodes were reversed or not. If there is an incoming home measurement in the Intelligent Data Center, the algorithm systematically generates the 18-element vector based on the incoming recent measurement and the baseline measurement stored in the database. In case of interchange the patient will be notified with a warning SMS or/and email to check the placement of the electrodes.

To test the method, we used a training sample of 598 ECG records (60 sec., 1KHz, 3-lead) in each group. The testing sample included 65 ECGs in each reversal group (60 sec., 600Hz, 3- lead) and a single baseline measurement (60 sec., 600Hz, 12-lead) for each subject. The linear discriminant analysis revealed that out of the 65 properly placed ECGs 64 were correctly classified, which means 98.4% sensitivity. In 14 reversed groups the sensitivity was at least 90%, in 4 group the sensitivity was between 80% and 90% and in 3 groups the sensitivity was lower than 80% (51% worst case). Out of the 1495 interchanged ECGs 1316 were classified correctly, which means 88% specificity.

Personalized evaluation. A new learning type interpretation algorithm was developed to make the evaluation system personalized. The method calculates the personalized decision thresholds for several P, Q, R, S, T wave-parameters of the patient. If any of the ECG parameters of the incoming measurements exceeds the decision threshold, then a significant change in that ECG parameter is assumed to be present. At first threshold calculation is based on published standard deviations representative on the whole population. Based on home/monitored signals the thresholds are gradually adapted to the patient monitored.. After 100 home measurements the threshold is calculated exclusively from the patients' own measurements. This algorithm automatically considers both long term ECG variability and small, habitual electrode misplacement errors

The Tele-Monitoring System is currently being implemented as an application for monitoring persons under extreme working conditions. The implementation supports further monitored signals like temperature, blood oxygen level and acceleration.

Advanced knowledge dissemination: The NEUROWEB project

NEUROWEB is a startup European research project in the Sixth Framework Program of the European Community, aiming to integrate and share knowledge and information in neurology and neurosciences. The project is led by the National Neurological Institute "Carlo Besta" of Milano, Italy. The consortium has four IT companies, five academic institutions, one governmental body and four neurological/stroke clinics in Italy, Hungary, Netherlands and Greece. The project runs from mid-2006 to 2008 and the expected outcome is an internet-based software framework that allows:

- the integration into a single virtual database the clinical and genetic databases of the 4 participating clinical centres, which are different in structure, language, territorial area and pathologies of interest;
- to query also the databanks present on the web containing human polymorphism profiles in normal and pathological populations.

For the professional user, the system provides the following main functions:

- Clinical diagnosis validation based on Clinical Protocol Paths. This means that the system will search for cases with a similar anamnesis and medical data using a pre-defined set of clinical protocols. Similarity analysis will be based on standard data mining tools and on a reference ontology that connects the various databases. of the clinical partners (ontology driven reasoning). See Clinical Engine and Semantic Engine in Fig. XX..

- Genomic Polymorphic Analysis. It will be possible to inspect a patient's genomic status against the state-of-art in Genomic Research to contrast genomic and clinical data. (Genomic Engine in Fig. XX) The genomic engine will mine public genomic databases in order to extract (and continuously update) a collection of polymorphisms related to the pathologies of interest; then it will cross-check these polymorphisms against the available genomic information concerning specific patients.

Special system components will automatically search available public databases and other resources and offer new scientific results that bear importance for a given case.

We plan to support "learn by search and example": an IT architecture which will remember users experience and offer the capability to verify existing Patient Records (Clinical and/or Genomic data) by new experimental Clinical Protocol Paths.

The architecture of the planned system with the Semantic, Clinical and Genomic Engines is shown in Fig. 3.

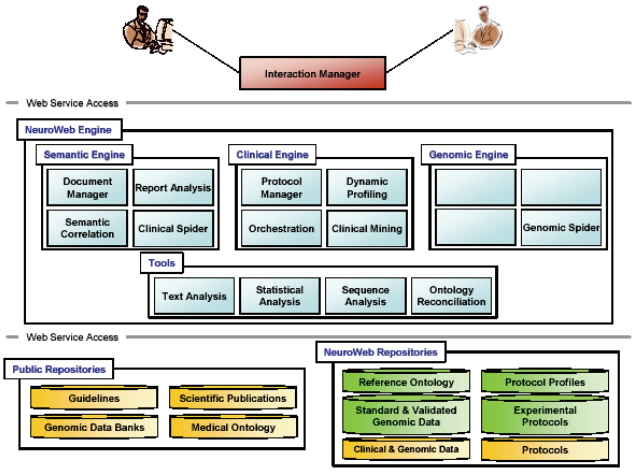

Figure 3 - The NEUROWEB architecture

The protocol manager will enable users to define, modify, store, retrieve according to criteria defined by clinicians and execute clinical protocols. Moreover, it will support the definition of new experimental protocols that can be defined and statistically validated by the NEUROWEB system. Protocol execution will rely on a protocol enacter that orchestrates and invokes remote web services, and a clinical miner that supplies the functionalities to extract data from the clinic databases involved in the project.

The Semantic Navigator, joined to a Text Miner, will support intelligent searches on distributed databases of clinical cases, with direct reference to the information stored in the Patient Records, through a unified interface shielding the user from the details of organization specific implementation. The Clinical Miner will learn the issued meta-queries and also rank them.

The whole system will also include:

- A tele-consulting system based on discussion forums. Each thread in discussion forms should be linked to a case, a query (several cases) or to a protocol. Users should be able to retrieve past discussion on the basis of queries, cases, and protocols.
- A front-end for the MEDLINE database, enabling to associate clinical papers to queries. Users should be able to navigate from cases and workflows to relevant literature, and vice versa. Associations should be established in a manual manner by clinicians.

The first results of the project are expected by mid-2007.

Elaborating new modalities: The BEM project

The BEM project's (Brain Electro-Mapping) aim is to create a system that with the modeling involved takes the challenge of creating a high-resolution mapping method that is able to show the possible changes in brain function after a stoke incident at the level of bioelectric equivalent sources. The investigation of brain plasticity requires the highest possible resolution available. The main goal is to create a cost-effective alternative to current solutions (fMRI, PET) that is comparable to those in spatial resolution, while significantly better in temporal resolution, allowing a rather accurate characterization of within brain communications. This project if financed by the Government of Hungary, runs from mid-2004 to mid-2007.

A high percentage of the stroke affected patients (over 70%) tend to recover from their state through a healing, functional regeneration process (this property of the brain is called plasticity). To understand this process and extend our current knowledge we develop a brain source mapping and imaging modality which could intensely help doctors at supporting and accelerating the process by therapy, and could validate drug effects promising this speed-up. The system presented herein solves the inverse EEG problem taking EEG measurements to calculate bio-electric activity at cortical level. The problem is solved using the mathematical description of bio-physical processes. Figure 4 presents the tasks of such a system, the process of EEG-based brain mapping.

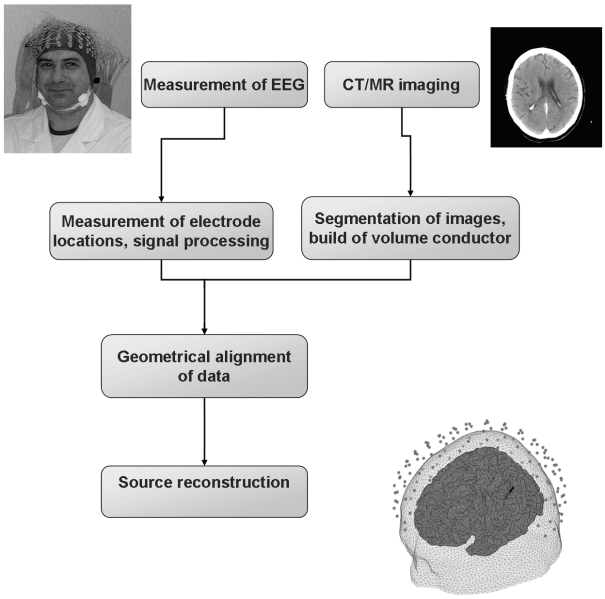

Figure 4 - The BEM architecture

Surface Laplacian maps One of the other methods the project is to utilize is the surface Laplacian maps. This method calculates cortical radial currents based on the EEG (scalp recorded potential-distribution). This method has high importance and tradition in medical analysis of brain activity, therefore this was the first stage of our modeling. Figure 5 presents images created by the linear Laplacian operator.

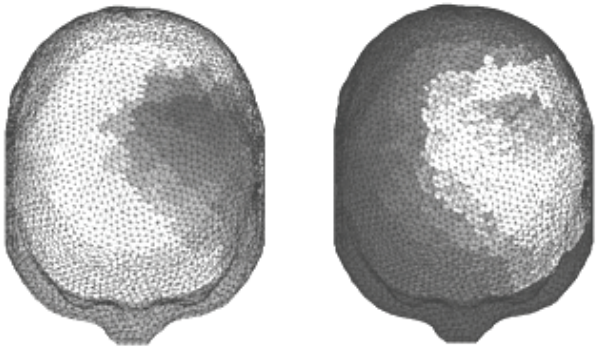

Figure 5 - Potential (left) and Surface Laplacian (right) maps in a finger tapping experiment

Analysis of error As currently there exist no study that investigates plasticity in these matters, it is only presumed that it requires the millimeter-precise recovery of neural brain activity. Similar studies involving the estimation of brain activation casuality underline this thesis [7, 8, 9, 10, 11]. The effectiveness of such a system is dependent of the resolution it is able to reach, therefore it is important to investigate the factors that affect it. In this analysis the following factors are considered:

- parameters describing the geometry of the volume conductor (the model representing the head and the brain)
- conductivity parameters of the volume conductor
- noise arising at EEG measurements
- possible errors entering the system at electrode positioning.

According to results of analysis a source localization error of under 2mm for near cortical sources would need an EEG measurement SNR of 20dB or higher and uncertainties of at most 1mm rms in electrode placement. Tests revealed, that localization error reacts sensitively to changes in conductor geometry parameters, but allows for an under 1mm localization error with errors of 5% in conductivity parameters.

Results

The paper briefly described three projects currently being implemented at the University of Pannonia, Veszprem, Hungary. Results achieved so far were discussed above, new results are expected particularly from the startup projects. We believe that the application of such IT based intelligent solutions is the only way of making our healthcare systems in the long run sustainable.

Acknowledgments

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References

[1] Hersh W, Helfand M, Wallace J. A systematic review of the efficacy of telemedicine for making diagnostic and management decisions. J Telemed Telecare 2002;8;197-209

[2] Hailey D; Roine R; Ohinmaa A. Systematic review of evidence for the benefits of telemedicine. J Telemed Telecare 2002;8 suppl.:1-7

[3] Ong K; Chia P; Ng, WL, Choo M. A telemedicine system for high quality transmission of paper electrocardiograpic reports. J Telemed Telecare 1995;1:27-33.

[4] Bertrand CA; Benda RL; Mercando AD, Matilda MT, Bailey KE. Effectivenes of the fax electrocardiogram. Am J Cardiol 1994;74:294-295

[5] Scalvini S, Zanelli E, Volterrani M, Martinelli G, Baratti D, Buscaya O, Baiardi P, Glisenti F, Giordano A. A pilot study of nurse-led, home-based telecardiology for patients with chronic heart failure. J Telemed Telecare. 2004;10(2):113-7.

[6] Lux RL. Electrocardiographic potential correlations: rationale and basis for lead selection and ECG estimation. J Electrocardiol. 2002;35: Suppl:1-5.

[7] Weinstein DM, and Johnson CR. Effects of geometric uncertainty on the inverse EEG problem. Computational, Experimental, and Numerical Methods for Solving Ill-Posed Inverse Imaging Problems: Medical and Nonmedical Applications, 1997

[8] Astolfi L, Cincotti F, Mattia D, Ding L, He B, Salinari S, Babiloni, F. Estimating Causality among Cortical Areas of the Human Brain: A Study on the Application of Directed Transfer Function and Structural Equation Modeling to High Resolution EEG. International Journal of Bioelectromagnetism, 2004.
[9] R.N. Klepfer RN, Johnson CR and MacLeod RS. The Effects of Inhomogeneities and Anisotropies on Electrocardiographic Fields: A Three-Dimensional Finite Element Study. IEEE Trans Biomed Eng, 1997.
[10] Ferree TC, and Tucker DM. Development of High-resolution EEG Devices. International Journal of Bioelectromagnetism, 1999

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