Wearable Computing for Medical Applications

Personal Health System for Parkinson's Disease Patients

Michael Lawo
neusta mobile solutions GmbH
Bremen, Germany

m.lawo@neusta.de

Otthein Herzog
TZI Center for computation and communication technology at Universität Bremen
Bremen, Germany
herzog@tzi.de

Abstract—**Parkinson's disease (PD) is a progressive neurological condition. It results from degeneration of dopamine producing neurons. This paper is on research partially funded by the European Commission (AAL programme and ICT FP7) where project consortia go towards the development of a personal health system with a closed loop of detection, response and treatment capabilities for patients with chronic diseases especially those with PD.**

Keywords-wearable computing, Parkinson's disease)

I. INTRODUCTION

The concept of wearable computing can be used to support people based on wireless networks to ubiquitously access information. Wearable computing can be a powerful technology to master the demographic change. The technology might allow people to longer stay in their homes and to enjoy life in an independent way.

Wearable computing means for the user simultaneous actions: the primary task, e.g. walking, sitting while talking or even sleeping, happens in the real world, is often mobile and has basically nothing to do with using a computer. The secondary task especially in healthcare applications is based on observing the user in the actual context. This secondary task should be as ambient as possible. As long as the patient is fine nothing should happen. If an extraordinary situation occurs the secondary task should provide the necessary information to judge the situation and propose solutions to handle the exception. This handling could happen by the person wearing the wearable or another person, e.g. a care giver, a relative, a friend, a person coming along, or the physician during consultation hours. Here immediately two questions arise: (1) How to gain the relevant context, and (2) how to design the interface?

Due to system restrictions in size, weight, and energy supply in addition to the context detection developer and user are more challenged as if designing a mobile computing solution. To handle the dual task setting we have to acknowledge that the cognitive load a user can manage is limited and the extension of this load to be coped with requires training. This is especially true when dealing with elderly citizens an issue requiring special attention.

In healthcare many data have to be taken into account like activity, pulse, weight, blood pressure. What and how much did a person eat or drink. If and how extensive a person did snore while sleeping or smoke during the day. These data describe the user context, could be measured and input to a recording system by the user.

II. STANDARDIZATION

Between the years 2004 and 2009 the European Commission funded with wearIT@work [1] a project not focusing on completely new technologies but new applications. Results achieved were an open hardware platform, open software framework (Figure 1) and for seven different application domains solutions as well as a business model for exploitation purposes [2, 3].

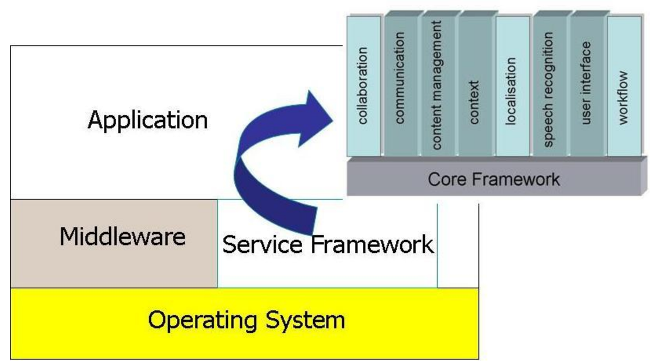

Figure 1: Software Framework

The concept of wearable computing is to achieve to a large extend the context automatically, reducing the user input as far as possible. Context information can basically be deducted by sensor information fused with application knowledge. Sensors can be in the environment or integrated into the clothing or attached to the body of a person. Wearable computing systems allow to model and detect activities [4]. Robust solutions are required reducing the complexity of the user interface.

There are different kinds of sensors available. They can be complex sensor systems or simple sensors like accelerometers, yaw sensors, light sensors as well as microphones, gyroscopes and RFID reader. We differentiate between discrete (event) sensors, e.g. reading a value or identification of a state (RFID-tag), and continuous or steady sensors based on the observation of a signal applying filter techniques; in the simplest case the

978-1-4577-1591-4/11/$26.00 ©2011 IEEE

reach of a threshold is required to detect a specific context. Here machine learning methods are applied [5].

The context might require providing continuous, cyclic or event driven information. Energy efficiency is thus a critical success factor and depend on the user requirements as changing the batteries is a user interaction which might be difficult due to age related handicaps. The wireless data communication has also to be energy efficient (e.g. ZIGBEE instead of Bluetooth). Data compression techniques are required to find an optimal balance between bandwidth and energy consumption.

Cyclic retrievals, reducing the energy requirement for a single operation, the choice of procedures with low energy consumption and the implementation of the respective algorithms on the used processors help to reduce the energy consumption of the usually rechargeable batteries. As weight is a further key issue Li Polymer batteries are used providing high energy density with low weight. Up to date there exists no general approach for an optimal battery. However specific empirical methods and solutions exist for context detection systems [6]; there a procedure is presented for finding a compromise of energy consumption and detection rate instead of maximising the detection rate while neglecting the required energy.

III. Chronic Disease Management

Where all this were findings in the context of the wearIT@work project for the above mentioned 7 application domains with one supporting ward rounds and another helping visually impaired people we focussed in our next projects even more on the healthcare domain. In the EC ehealth & ICT funded project CHRONIOUS [7] wearable computing based healthcare solutions were developed for people with Chronic Obstructive Pulmonary Disease (COPD) and Chronic Kidney Disease (CKD) and Renal Insufficiency.

Chronic conditions are those which are long-term (lasting more than 6 months) and can have a significant effect on a person's life. Management to reduce the severity of the symptoms and to improve the quality of life is possible in many conditions. Management includes medication and/or lifestyle changes such as diet and exercise, and stress management [8].

At the same time, it should be noted that chronic diseases may get worse, lead to death, be cured, remain dormant or require continual monitoring.

Patients and physicians are generally optimistic about the benefits of proper disease management. Nearly four out of five patients (78 %) believe that there is better control of the disease than there was five years ago, and 74 % believe that with proper treatment, it is possible to live a full and active life. Similarly, 76 % of physicians say that the long-term health outlook for chronic disease has improved in the past decade, and most of this group (78 %) credit the improvement to better medications [8].

The CHRONIOUS project created a platform monitoring patient's health status (Figure 2). It is a ubiquitous system that can extract clinical knowledge in a highly personalized level using specific ontology platforms.

Continuous monitoring models promote home-based continuous care. Effectiveness and efficiency depend on the capability of both patients and relatives to manage their status (self-management) together with the collaboration of clinicians and medical experts.

The generic system architecture can be adapted to other chronic disease management programme. A disease prediction and diagnosis tool and the exploitation of the monitored parameters are provided for the production of new diagnostic models and protocols. Thus the formal care burdens can be reduced and formal care improved by reducing patients' visits for routine examinations.

Mainly two categories of users with different requirements are addressed:

(1) Patients, the real final users, wearing and interacting with the system, and

(2) Care givers using the system to monitor remotely the health conditions of the patients.

The projected used an extensive requirements analysis to gather the different expectations and needs also to be in compliance with ethical principles.

The local health institutions, professionals and hospitals, expected the reduction of acute events and related hospitalization costs up to 20-30% by emergency cases alert, rationalization of medical prescriptions for diagnostic routine examinations, decision and education support services for professionals involved, stronger integration with home care service providers both in terms of shared clinical pathways and technological interoperability, quick and efficient medical information's access trough a logical, structured and certified pathway similar to the human logic, sensible growth in cooperation and multi-actor approach to chronic diseases and an enhancement in ICT investments.

The foreseen impact on patients' life was to reduce routine visits to hospitals for diagnostic purposes, providing them with more tranquillity as the time of intervention when occurring time-critical situations are reduced. To integrate a reminding and alerting service linked to particular behaviours such as drug intake, eating and activities performed, requires an active participation of patients both in monitoring and in decision-making. The user friendliness of ICT equipment at home and for the patients and their families are still a challenge.

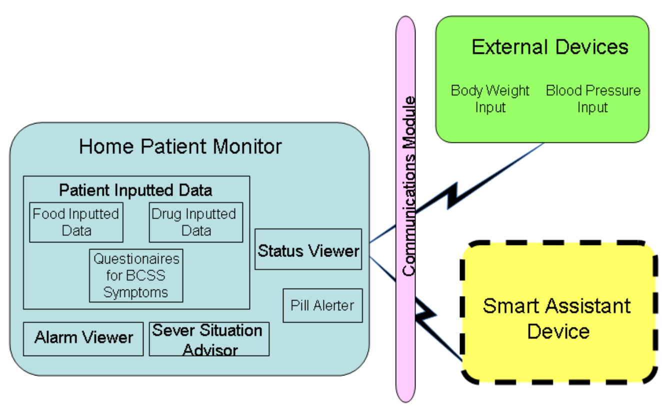

Figure 2: Managing and displaying the patient data

As a result of an advanced search engine prototype for bibliography retrieval was developed. This search engine is specifically targeted to clinicians and healthcare practitioners searching for documents related to COPD and CKD. To this aim, the tool exploits two pathology-specific ontologies that allow focused document indexing and retrieval. These ontologies have been developed on the top of a Middle Layer Ontology for Clinical Care (MLOCC), which provides a link with the Basic Formal Ontology, a foundational ontology used in the Open Biological and Biomedical Ontologies (OBO) Foundry. In addition link with the terms of the MeSH (Medical Subject Heading) thesaurus is provided to guarantee the coverage with the general certified medical terms and multilingual capabilities.

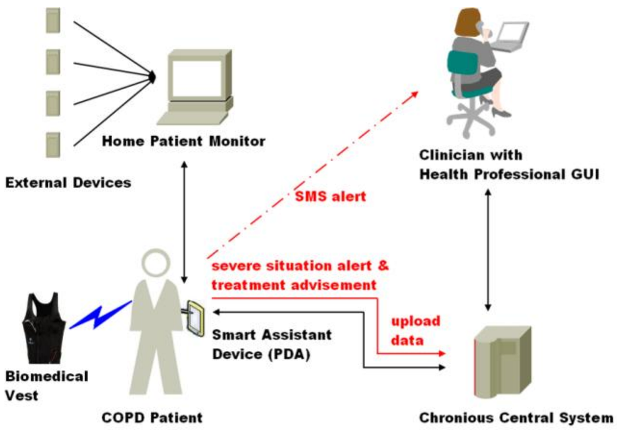

Figure 3: Handling an Alert

The CHRONIOUS search module aims at complementing out of shell search modules such as Google Scholar, PubMed and GoPubmed not only by improving the search capabilities within the specific pathologies, but also by providing the possibility to index and retrieve hospital-specific internal documentation. It was found that the ontology-thesaurus approach can overcome limitations of pure syntactical document search, in which two queries having different syntax but equivalent semantics yield different search results, and it can ease multilingual search issues. In addition, the adopted multi-layer ontology design offers a methodological support to separate concepts shared among different diseases from those diseases specific, that turns out in disease-specific ontology based on well founded and formalised concepts, and a knowledge architecture where further disease ontologies can be plugged-in. The development has demonstrated that the currently available open source software provide sufficient functionalities for realising ontology-based literature retrieval systems and ontology enrichment capabilities. However, it was shown in [9] that ontology enrichment cannot be either fully automatic or directly used by clinicians: both clinicians and ontology engineers are needed to semantically validate and to correctly insert and correlate the candidate concepts. In fact, clinicians have difficulties in browsing formal ontologies. For this reason, it is necessary to provide clinician suitable views of the ontologies and tools for a user friendly concept selection.

IV. Parkinson's Disease

Parkinson's disease is a progressive neurological condition, resulting from the degeneration of dopamine producing neurons in the *substantia nigra*, which is located within the basal ganglia, deep in the lower region of the brain, on either side of the brainstem.

Parkinson's disease (PD) is the second most common neurodegenerative disease after Alzheimer's disease. According to the World Health Organization, 5.2 million people suffer PD in the World, and more than 2 million Parkinson's patients live in Europe. Mortality is two to five times higher among affected persons than among age-matched controls.

Given that PD is mainly suffered by elderly persons, and that this population group is growing Parkinson's disease is becoming a public health problem of the first magnitude. The disease burden is considerable. This is due to the associated reduced capacity for self-care and quality of life that occurs in people with the disease. The healthcare costs involved with PD (medical and social) are considerable and affect multiple sectors. A conservative estimate, including loss of productivity and informal care is about 20 billion € per year. About 80% of that cost comes from indirect costs. Direct costs are estimated to be between 5.000 € and 10.000 € per patient and year depending on the country. The main components of this cost (30%) are hospital care and prescription drug (21%). It is furthermore known that patients with Parkinson's disease have 45% more hospitalizations and typically have 19% longer stays in hospitals.

Our movements are controlled by nerve cells in the basal ganglia region of the brain. To prompt a movement, the cells pass messages to one another - and to the rest of the body - using neurotransmitters (mainly, dopamine). In healthy people, these messages are carried efficiently. But, in people with Parkinson's, the messages are disrupted and are not transmitted smoothly to the muscles. This is when difficulties controlling movement arise. The messages fail to transmit properly because of a lack of dopamine - one of the neurotransmitters involved in the control of movement. In people with Parkinson's, between 70 and 80% of the cells which produce dopamine have degenerated and ceased functioning. If there is insufficient dopamine, nerve cells do not function properly and are unable to pass on the brain messages, resulting in Parkinson's symptoms. While dopamine is the main neurotransmitter affected, other neurotransmitter abnormalities also occur in Parkinson's. This is one explanation why simply replacing dopamine does not necessarily result in the benefits expected. The abnormalities in other neurotransmitters may also explain why so many no motor symptoms are present in Parkinson's. Why dopamine-producing cells become depleted is not clear. It is generally thought that multiple factors are responsible and areas of current research include ageing, genetic factors, environmental factors and viruses. It is also unclear why some people develop the disease but not others.

In Help-AAL [10] a wearable computing solution for patients with PD is under investigation. There we intend to provide Parkinson Patients with a system that can supply specific amounts of drug according to their physical activity requirements at any moment. Because it is a continuous drug delivery system, drug peaks and "valleys" in the blood stream are avoided and so improving classical PD symptoms.

The HELP system ("Home-based Empowered Living for Parkinson's disease patients" Figure 4) is made up of a wearable subcutaneous pump, an intraoral cartridge inserted in patients' mouth, a wearable movement sensor, blood pressure device and a control system that is constantly sending data, checking the patient and calculating the right quantity of drug to be supplied.

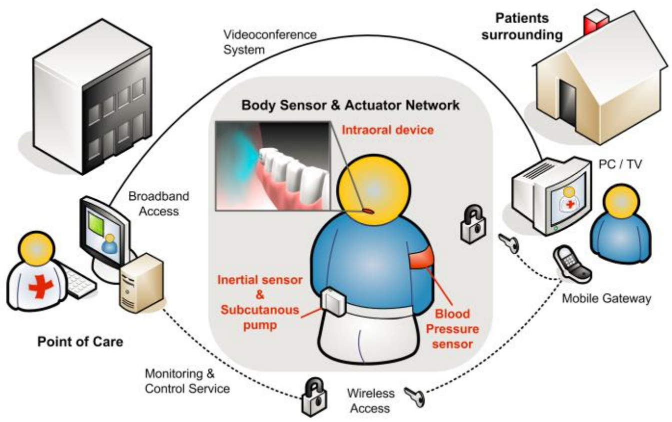

Figure 4: HELP Architecture

The HELP Project consortium has designed a Health Monitoring System specifically targeted for the needs of Parkinson Disease (PD) patients.

Without treatment, PD progresses over 5–10 years to a rigid, a kinetic state in which patients are incapable of caring for themselves. Death frequently results from complications of immobility, including aspiration pneumonia or pulmonary embolism. The availability of effective pharmacological treatment has altered radically the prognosis of PD; in most cases, good functional mobility can be maintained for many years, and the life expectancy increased substantially. Primarily, therapies are aimed at minimizing symptoms and maximizing function and quality of life.

However, intensive supportive care is needed, demanding the allocation of enormous resources besides the strictly medical ones. This suggests an alternative way to face PD, not only in managing patients at an individual level, but also in optimizing cost effectiveness of health care plans.

The HELP System proposes solutions to improve quality of life of PD patients based on [11]:

- A Body Sensor and Actuator Network made up of portable/wearable and home devices to monitor health parameters (e.g. blood pressure) and body activity (e.g. to detect gait, absence of movement), and to release controlled quantity of drugs in an automatic fashion.
- A remote Point-of-Care unit to supervise the patients under clinical specialists control.

With this project the consortium intends to provide a proof that a monitoring drug delivery system can improve the quality of life of Parkinson patients. It will be tested whether this system is seen like an improvement in the three different countries of pilots (Israel, Italy, and Spain). The HELP consortium is very targeted on the eHealth market and interested in whether commercialize or improve the prototypes, services and devices.

Therefore the new project REMPARK in PD management will be based on results from the previous projects and basically deal beside technical innovations with improvements concerning the user acceptance.

In our research we will go together with our project partners towards the development of a personal health system with a closed loop of detection, response and treatment capabilities for management of PD patients at two levels:

At the first level we work on the development of a wearable monitoring system able to identify in real time the motor status of the PD patients, and evaluating ON/OFF/Dyskinesia status. We aim at sensitivity greater than 80% and specificity greater than 80% in operation during ambulatory conditions. We will also develop a gait guidance system able to help the patient in real time during their daily activities.

At a second level, the intelligent analysis of data provided by the first level, supported with a disease management system allowing neurologists to access accurate and reliable information to decide about the treatment that best suits the patient, improving the management of their disease, in particular to adjust so called therapeutic window.

There are a couple of challenges to meet in this research: (1) the identification of motor status in real time, (2) the development of a gait guidance system, (3) a user interface to collect direct feedback from the patient, and (4) a server to allow interaction with the doctor in charge and track the evolution of the patient's condition.

V. Lessons Learnt

When addressing the introduction of wearable computing solutions, it is important to keep in mind that the technology introduces an added layer of digitization into everyday routines, skills, and knowledge. Unlike a laptop or a PDA, a wearable computing solution follows us around, and merges into our lives and everyday interactions. Thus, it demands a paradigm shift in the perspectives on reality and human interactions, creating new concepts like mediated and augmented reality. John Naisbitt [12] introduced the concept of "High Tech High Touch" – signifying the co-evolution of technology and human culture. According to him, we are currently in a state of imbalance where technology has accelerated rapidly but social change has not kept the pace. The design of a wearable system effects and is effected by human and social factors, shaping together the outcomes of the system. However, the potential benefits of wearable computing are big. Wearable computing systems offer the possibility of accessing "live information" while performing (primary) tasks in the real world. These systems also create specific challenges with regard to ergonomics, health, safety, and privacy.

When introducing new information and communication technologies, particularly when personal technologies, it is important to take into consideration the persons who will be using this technology [12]. A number of other questions must also be addressed, for instance, what are the implications of using this technology? What concerns do users have? How do wearable computing systems influence the user's behavior, and social or organizational norms? How do these systems shape personal or professional identities? All our research builds upon the UCD approach (ISO 13407 (1999), Human-centred design processes for interactive systems). It guides not only in the analysis of tests performed by the design teams, but also by presenting findings from interviews conducted with members of the projects itself.

When conducting tests they never follow the same format as there never is an 'isolated lab' context. Instead, we have to follow a living lab (LL) approach allowing the users to experiment with the prototypes in a setting that is as natural and similar to their typical every day settings as possible. Despite these variances all tests provide opportunities for the users to interact with the wearable technologies in the course of their daily activities. These interactions are the focus of observations. Additionally users must be interviewed providing feedback.

It is important to recognize the different goals and orientations of those involved in the end-user observations and tests. Developers can gain further insight as to potential problems and challenges in the prototypes being tested, receive feedback from users regarding: ease of use, weight, heat, location of the wearable on the body, and suggestions. These elements produce a basis for further development and modifications conducted on the prototypes.

The tests facilitate first-hand observation of user interaction allowing to investigate which aspects users feel are affecting their use of the system and also to observe the interactions of developers and users.

Therefore: (1) Users and this means all stakeholders if developers, medical people, patients or relatives must be involved during the whole lifetime of any project. (2) Users must participate in the implementation of the technical solutions.

ACKNOWLEDGMENT

The authors wish to acknowledge their gratitude and appreciation to all the people of the 42 partners from wearIT@work, the 19 partners from CHRONIOUS and the 8 partners from Help-AAL for their fruitful work and contribution during the development of various ideas and concepts presented in this paper as well as the European Commission for partial funding.

REFERENCES

[1] www.wearitatwork.com accessed 09.29.2011

[2] M. Lawo, O. Herzog, M. Boronowsky and P. Knackfuss, "The Open Wearable Computing Group", IEEE Pervasive Computing, Vol.10 (2), April-June 2011, pp. 78-81.

[3] M. Lawo, E. Pasher, R. Pezzlo (Eds.) "Intelligent Clothing", IOS Press, Amsterdam, 2009.

[4] G. Abowd, A. Dey, R. Orr and J. Brotherton "Context-awareness in wearable and ubiquitous computing" Virtual Reality 3, 1998, pp. 200–211.

[5] C. M. Bishop "Pattern recognition and Machine Learning", Springer, 2006.

[6] M. Stäger, P.Lukowicz, G. Tröster "Power and Accuracy Trade-offs in Sound-Based Context Recognition Systems", Pervasive and Mobile Computing 3(3), June 2007, pp. 300-327.

[7] www.chronious.eu accessed 09.29.2011

[8] www.healthinsite.gov.au/topics/Health_and_Wellbeing accessed 9.29.11

[9] S. Kiefer, J. Rauch, R. Albertoni, M. Attene, F. gianini, S. Marini, L. Schneider, C. Mesquita, X. Xing, M. Lawo "The CHRONIOUS Ontology-Driven Search Tool: enabling access to focused and up-to-date healthcare literature", Proceedings of eChallenge 2011, Oct. 2011, pp. 1-8

[10] www.help-AAL.com accessed 09.29.2011

[11] Poster of the consortium presented at the AAL Forum Lecce, Italy, 09.26-28.2011, unpublished

[12] J. Naisbitt: "High Tech High Touch", Broadway Books, 1999.

[13] E.Pasher, Z.Popper, H.Raz, M.Lawo, "wearIT@work: a wearable computing solution for knowledge-based development", Int. J. Knowledge-Based Development, Vol. 1, No. 4, 2010, pp.346-360.