Life Style Management using Wearable Computer

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Abstract. Wearable computers, embedded in clothing or seamlessly integrated in devices we carry with us, have a tremendous advantage to become the main gateway to personal health management. Current state-of-the-art devices allow to monitor basic physical or physiological parameters. Applications include e.g. improving performance in sports, early fall detection for elderly people, long-term heart monitoring in order to quantify recovery after surgery.
Those devices however tend to focus on elementary physical or physiological aspects of health management. In this article we point out that future wearable device will need to take into considerations social as well as mental aspects in addition to physical and physiological information in order to deliver truly personalized, proactive, wearable health or *life style* management systems. We highlight open research topics that need to be addressed to make this vision a reality.

1 Introduction

The current health care system faces many challenges in view of the aging population. Reducing health costs while maintaining universal and high quality of care are among the toughest challenges nowadays. At the same time, with an increasingly mobile life style, people desire more flexibility in their relation to the health care system, such as the possibility to get in touch with health care professionals anywhere and anytime.

Wearable computing has the potential to revolutionize health care by decentralizing it, giving more control to the patient, and shifting the focus from treatment to prevention. Wearable computers may become the main gateway to personal health management, therefore becoming *personal health assistants*. Current state-of-the-art devices already allow to monitor basic physical or physiological parameters. Applications include e.g. early fall detection for elderly people, or long-term heart monitoring in order to quantify recovery after surgery, as well as improving performance in sports.

The health care system nowadays is mostly designed to address "life threatening" situations that have an immediate effects on survival chances (e.g. heart conditions, diabetes). However, individual life style may have a strong influence on future health prospects, even if it has no immediate impact on survival. For example adequate nutrition habits, or practicing sports, may reduce the risk of cardiovascular diseases in the long run. The management of these lifestyle-related factors is difficult to integrate in the current health care system which is mostly based on sporadic visits of the patient to the health care professional. Implementing a health-friendly life style may also be a difficult task for the patient himself. Since the life style may not have immediate effect on the patient's health, there is no strong incentive to change one's behavior, and even if the patient perceives the need for a change, this may be a daunting task if unaided. Wearable computing has the potential to become an ubiquitous tool to help patients manage their life style in a more efficient way, and thus signal a shift toward user-centric *health-management* or *lifestyle-management*.

Health-management addresses a wider population than the current health care system, targeting the more general "health-savvy" citizen, rather than patients suffering from critical conditions. Furthermore, health is more than the mere absence of illnesses. Indeed the World Health Organization defines health as *[...] a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity* [1]. We envision that, in addition to supporting lifelong health-management, wearable devices will shift toward supporting the more all-encompassing concept of "well-being" along the three axes of physical, mental and social well-being.

This in turn will require new tools, technologies and algorithms to understand the user's state and provide him with adequate feedback on how to improve his condition. We argue that one of the key mechanism of wearable computing, *context recognition*, will need to be expanded significantly in order to understand higher level, more complex, contexts than what is currently state of the art. In particular, the detection of cognitive, social or emotional states may be required for the system to understand the current state and needs of the user.

In this article we highlight the open questions and future research topics that need to be addressed by the research community in order to make of this vision a reality. We describe our vision of life style management in section 2. We then review in section 3 current state of the art wearable devices, that mostly address the physical aspect of well-being. In section 4 we describe recent results evidencing that the detection of mental as well as social states is possible, and therefore that the combination of the three aspects of physical, mental and social well-being in a device may be a likely outcome. In section 5 we highlight the open questions that must be addressed. In particular, recognizing the user context, his daily routine, together with his social interactions, emotional or cognitive states, and correlating these with a sense of well-being or with potential long term clinical outcomes, are research topics that have not yet been tackled in the wearable computing community. Finally we conclude this paper in section 6.

2 Toward life style management

A picture of the physiological state of a patient can be painted by combining vital parameters like heart rate, temperature and motion activities with the person's context, e.g. sleep patterns, social interactions and other health indicators.

Recent developments in micro-and nanotechnology, low power computing, and wireless communication as well as in information processing have paved the way to non-invasive and mobile biomedical measurements and health monitoring [2] providing the technological platform for the advent of *personal health assistants* (PHA).

Figure 1 depicts a potential implementation of a PHA. Several sensors, distributed in clothes, transmit the measured physiological and context data over a body area network (BAN) to a computing unit (e.g. a PDA), which fuses the sensor data, estimates the health status and communicates with the surrounding networks.

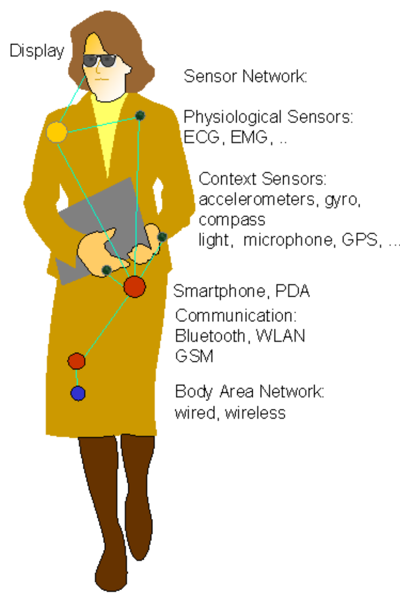

Fig. 1. Architecture of a Personal Health Assistant. Sensors, distributed in clothes, estimate the health status of the user. Feedback may be provided to the user or recorded signals sent to surrounding networks for further processing.

Yet health is not the mere absence of illnesses. According to the World Health organization, *health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity* [1]. This definition is very broad and close to a definition of "happiness" [3] and therefore difficult to quantify and model, yet it is undeniable that physical, mental and social factors are all important in achieving a balanced life style.

Visually, one may think of a life balance "sphere" along three axes representing the physical, mental and social states (figure 2). If the life balance "vector", that is the current user state, falls within this sphere, he may be considered in a "healthy" state. If the life balance "vector" falls out of this sphere however, actions must be taken to compensate for these deviations.

We envision that future wearable personal health assistants will tend to support everyday well-being, or quality of life, along the three axes of physical, mental and social states.

These wearable devices will thus need to detect the user state, or context along those three axes. Based on the user state, together with the knowledge of past events, the wearable device may provide feedback or hints to the user in order to improve his life style. In order to personalize the system, the position and the size of the individual life balance sphere have to be adjusted by a calibration procedure, e.g. after recreative vacations of the user.

Such wearable devices target the "health-savvy" citizen rather than patients suffering from critical conditions. As such, they operate alongside the traditional health care system, and complement it by providing continuous, lifelong, monitoring, together with real-time feedback about one's health status.

Nowadays, personal health assistants tend to focus mostly on the aspect of physical health. In the future mental and social aspects will be integrated as well. As a consequence, research in this field will have to draw not only from medical science, but also from cognitive science, behavioral and social science, neurobiology, psychology, making it an extremely inter-disciplinary field of research.

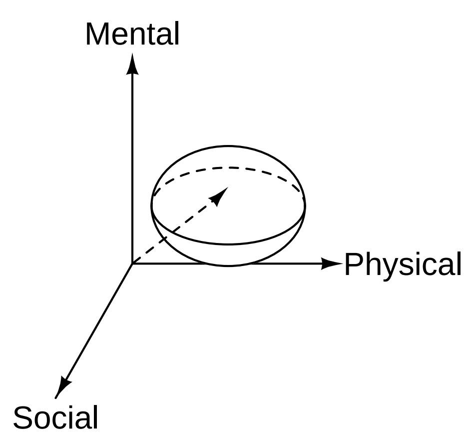

Fig. 2. According to the World Health Organization, health is a sense of physical, mental and social well-being. Visually, an individual life balance "sphere" may represent the ideal conditions for well-being. The arrow indicates the current user's state measured by the wearable device.

3 Evaluation of the physical state

At the moment, the detection of the physical state of the user (e.g. user activity, user location, physiological parameters) is more advanced in comparison to the detection of social or mental states. Normally, few and distinct features define physical states; additionally, sensor data and the physical state are closely related facilitating the classification process. As a consequence, most personal health assistants nowadays rely on information about the physical context of the user to infer his health status.

The user physical state can be picked up by transducers that convert physical activity or physiological signals into electric signals that are then processed by personal health assistants. Table 1 summarizes the non-invasive sensors which can be implemented in a daily outfit, and the information which they may reveal about the user. In recent years, several wearable health systems have been developed using a subset of the sensors listed in table 1, depending on the target application.

Sensors	Observation
Sensing of vital parameters	
ECG	Heart rate, heart rate variability (HRV)
EMG	Muscle activities and fatigue
Galvanic Skin Response	Skin perspiration
Temperature	Skin temperature, health state (fever)
Respiration	Breathing rate, physical activity
Blood oxygen	Status of the cardiovascular system, heart rate
Blood pressure	Status of the cardiovascular system, hypertension
Sensing of the user's context	
Accelerometer	Motion patterns of the body and limbs
Microphone	Speaker recognition, localization by ambient sounds, activity detection, speech features
Visible light sensor	Localization of light sources
Rotation (gyroscope)	Body movements
Compass	Orientation of the body and the head
Air Pressure	Vertical motion in elevator or staircase
IR light sensor	Sunshine, localization of lamps
UV light sensor	Localization of fluorescent light tubes
Environment temperature	Outdoor, indoor
Humidity	Location, weather conditions
WLAN / GSM / CDMA	Location, user environment
Bluetooth, ZigBee	Services and devices nearby

Table 1. Overview of sensors used for the detection of vital and context parameters.

The flexible belt of Polar[1] accommodates a one-channel ECG and accelerometer. The analysis of the heart rate enables the management of fitness, weight, rehabilitation as well as professional training. The Bodymedia HealthWear Armband[2] is worn on the back of the upper right arm; focusing on weight management, it measures movement, heat flux, skin temperature, near-body temperature, and galvanic skin response, allowing accurate calculations of energy expenditure. VivoMetrics[3] developed a “LifeShirt System” affording the continuous ambulatory monitoring system of pulmonary, cardiac and other physiologic data, dedicated mainly for research. ECG, accelerometers and sensors for respiratory measurement are embedded in undershirt garment; an external PDA stores the data and extracts the vital parameters. The Stanford Lifeguard system[4] has been designed for extreme environments. It comprises physiological sensors (ECG/respiration electrode patch, pulse oximeter, blood pressure monitor), a wearable cigarette packet sized box, and a base station.

Several projects have been initiated to monitor the physical health status based on wearable systems. The EU-Project MyHeart [4] focuses on the design of a PHA capable of early and mobile detection of atrial fibrillation, allowing immediate treatments e.g. by medication. Post-stroke neurological recovery can be stimulated by exercise and perhaps by medications [5]. Wearable sensors within the PHA are necessary to capture the motor activity and to assess the effects and efficacy of treatment interventions. In [6], an accelerometer system, fastened by an elastic waist belt to the subjects back in the lumbosacral region, enables the assessment of the motor recovery system and of the effectiveness of physical therapy of post-stroke hemiplegic patients.

Status and open problems Over the last years, systems detecting the basic physical state have achieved a mature level allowing first commercial application. Several research groups are active to improve the robustness of theses systems and to extend their functionality. What are the main road blocks preventing a further proliferation at the moment ?

Smart clothes pose two critical challenges. On the one hand, the acceptance of the potential users wearing smart clothes everyday demands for a high level of wearing comfort and intuitive handling. On the other hand, cooperations between clothing manufacturers, electronic suppliers and the retail have to be established to close the manufacturing, trading and maintenance chain.

Most of the sensors mentioned in table 1 require a close, permanent and mostly large-area contact to our skin to ensure sufficient signal quality. On the other hand, many people prefer casual clothes with an as small as possible contact pressure. Textile design and signal processing are requested to reduce the motion artifacts in the sensor signals. Yet, the signal performance achieved in a

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[1] `http://www.polar.fi/`
[2] `http://www.bodymedia.com`
[3] `http://www.vivometrics.com/`
[4] `http://lifeguard.stanford.edu/`

standard medical setup can not be guaranteed in a mobile environment. Methods have to be provided to correlate the clinical and mobile data.

The interaction between the user and the wearable system remains an open research topic. Conflicting demands - unobtrusiveness of the device v.s. intuitive handling, reduced attention v.s. short-term acuteness - have to be balanced and adapted to the actual situation

Furthermore, the PHA as a mobile and communicating device has to be embedded in the local and national IT landscape, involving network providers, as well as private and public health services.

4 Evaluation of the social and mental state

It is relatively common nowadays to extract contextual informations about the activities of a user. Yet social and mental states are also an important part of well-being [7, 8]. In particular, social networks were shown to positively influence life expectancy [9], as well as happiness, or positive emotions [10].

We take the possibly surprising stance that social and mental state may be evaluated using only wearable devices. We believe that even accelerometers, microphone, galvanic skin response (GSR), temperature and ECG sensors are sufficient in combination with local communication devices (e.g. WLAN) to detect the basic mental states like stress, fear, depression, as well as basic social states like interactions or communication styles.

A series of recent research approaches motivates our confidence. In the social context, wearable devices were devised to analyze relations between individuals based on measured interactions [11], or by automatic conversational analysis [12], and it was shown that aspects such as people's status in a social networks can be detected from vocal signaling [13]. Understanding social networks may help to design more efficient systems for data distribution [14], but could also be used to detect the amount of social interactions of persons and take measures when e.g. elderly remain alone for extended periods of time by messaging relatives.

Mental states include emotions, or contexts such as concentration, stress or depression. Emotion classes may be detected from brain signals [15], or physiological signals such as cardiovascular patterns [16, 17]. See [18] for a review of how emotions may be detected. Recently, these findings in psychology and physiology were demonstrated in interactive applications (e.g. emphatic painting [19]) and are the topic of several research projects. In [20] e.g., four wearable sensors (EMG, SpO2, skin conductance, respiration sensor) have been applied to detect and to classify eight different emotions like anger, grief, joy or hate with a classification accuracy between 60 and 70 percent. Within the project AUBADE[5] a wearable platform for analyzing the emotional states in real time is devised, using signals obtained from the face. The HUMAINE project investigates human-machine interactions based on emotions[6]. In [21], a model of user's emotions has been presented which combines a sensory apparatus, an ontology

[5] http://www.aubade-group.com

[6] http://emotion-research.net/

of emotion concepts and an active interface adapting to the user's perceived emotional state. Using only GSR, temperature, and heart rate data, five emotional states - neutrality, anger, fear, sadness and frustration - could be detected with a recognition rate better than 70 percent. Correlation between depression and gait velocity allows the evaluation of depression using accelerometers only [22]. Signs of depression may also be detected from vocal signals [23]. Cognitive "contexts" may also be detected. In particular the level of concentration was shown to influence EEG recordings [24], and wearable systems were able to detect stress in ambulatory settings [25]. Cognitive assistants were devised to help people with memory problems or huge workloads [26]. The INTREPID project[7] aims at developing a multi-sensor context-aware wearable system for the treatment of phobias.

Clearly, these few examples only illustrate particular aspects of the mental or social states. On the other hand, the full potential of a continuous on-line monitoring based on multi-model sensor data acquisition at the human body has not been exploited yet.

5 Open questions

Several challenges must be tackled before personal health assistants may exploit social and mental modalities in addition to physical information. Detecting social and mental states is still a recent and challenging topic, especially since these states do not generally translate to simple physical outcomes that could be picked up by single sensors. Objective measures of quality of life from physical, mental and social parameters must still be investigated, together with the minimal set of sensors required to acquire the necessary data. Furthermore, defining the kind of feedback that a wearable device could provide to improve well-being remains an open research topic. We foresee devices that take proactive measures, for instance to improve the social contacts of elderly people. Also, we argue that simply providing daily summary and trends of the "well-being parameters" may be enough for the user to become conscious about his own life style, and support him implementing changes, therefore paving the way toward a "life style management" device. In the following we will highlight several open questions in more detail.

Feature selection and data recording Depending on the aimed application a set of physical and physiologic parameters will be selected for continuous monitoring in a first step. Aiming at obtaining proper models and classification results in subsequent steps, it will be important to guide this selection process by life style related needs and technical feasibility. Inter-disciplinary cooperations have to be established to answer two important open research questions: (*i*) What are the signals required to detect context, social interaction and activity? (*ii*) What is the minimum set of signals to achieve a desired performance?

[7] `http://www.cordis.lu/ist/directorate_c/ehealth/projectbooklet/projects.html`

Data base design From the viewpoint of data collection, a continuous recording of vital and context parameters (as presented in table 1) offers high-resolution data incorporating time-stamps. In the medical domain various types of long-term data bases can be identified - ranging from registries (only few core data elements) up to research data bases (in-depth data about a defined population subset) [27]. Integrating these valuable data sources with ongoing mobile data in a data warehouse system would allow to correlate objective measures with health or subjective well-being. However, current medical data bases focus on unhealthy people. Aiming at detecting social and mental status too, additional data bases (e.g. for "stressed" people) are needed. In [21] it was suggested to create a data base of emotional concepts, in order to be able to categorize emotions and to infer emotional trends over time.

Modeling In health science, well studied human models are available, for example to estimate the risk of postoperative incidents or to evaluate health-related quality of life [28], [29]. Augmenting these models by contextual data, social interactions or activities of daily living, could dramatically increase the predictive power [30]. To ensure a broad acceptance in health care related applications, a transparent modeling is highly indicated.

Adaptivity and calibration Aiming at providing truly personalized, proactive wearable health management systems, adaptivity and personal calibration are very important. Although there are objective measures to detect abnormal physiological conditions (e.g. heart condition), when it comes to social or mental contexts it is likely that people will experience different levels of well-being even in similar environmental conditions depending e.g. on age, social class, past history. As a consequence, a personal calibration is necessary, together with adaptive algorithms for context recognition. Traditionally, context-recognition algorithms relying on off-line training are used to detect physical status. In the present case however, on-line learning may be a prerequisite to achieve personal calibration. This new breed of adaptive context recognition algorithms may make use of bio-inspired techniques, which were shown to provide adaptivity and learning in other fields [31].

Liability and privacy Fostering well-being through wearable computers is complementary to the traditional health care system and does not apply to the same population class. In particular, wearable computers are not currently envisioned in life-critical situations, but more as a support tool, as a personal adviser, for the health-savvy citizen. In case of critical conditions, the traditional health care system takes over. Privacy may be guaranteed by developing standalone wearable devices that do not transfer data to on-line services. When database creation is envisioned, procedures that guarantee anonymous data collection must be the rule.

6 Conclusion

In this article we described a vision for the future of personal health assistants, which encompass the three axes of well-being as defined by the World Health Organization: social, mental and physical well-being. We reviewed the current state of the art personal health assistants, that mostly deal with the physical aspect of well-being. We highlighted recent results showing that some social or mental states can be detected automatically by wearable devices. We are thus confident that these three aspects of well-being will be integrated in future personal health assistants. These will go beyond current state of the art, and not only address patients suffering from critical conditions but also the health-savvy citizen that desires to analyze and improve his life style in order to better his health prospects.

As social and mental aspects, as well as physical aspects, are considered in personal health assistants, research will have to draw not only from medical science, but also from cognitive science, behavioral and social science, neurobiology, psychology, making it an extremely inter-disciplinary field of research. The generalization of personal health assistants will allow to collect data from a much larger population than what is currently standard in clinical trials, together with accurate and detailed contextual information and time stamping. As a consequence, we believe that fruitful exchanges are likely between the field of wearable health assistants and medical science as well as "soft" sciences.

While several major obstacles remain along the way, we believe that in the near future, with the joint work of the research community, we will see this vision of *life style management* devices become a reality.

References

1. WHO: Preamble to the Constitution of the World Health Organization as Adopted by the International Health Conference, New York, 1922 June, 1946; signed on 22 July 1946 by the Representatives of 61 States and Entered into Force on 7 April 1948 (1948)
2. Lymberis, A.: Smart wearables for remote health monitoring, from prevention to rehabilitation: Current r&d, future challenges. In: Proc of the 4th Annual IEEE Conf on Information Technology Applications in Biomedicine. (2002) 272–275
3. Saracci, R.: The world health organization needs to reconsider its definition of health. British Medical Journal **314**(7091) (1997) 1409–1410
4. MyHeart: Fighting cardio-vascular diseases by preventive lifestyle & early diagnosis (2006) Available from: `http://www.hitech-projects.com/euprojects/myheart/`.
5. Stein, J.: Wearable sensor technology for functional assessment after stroke. IEEE Eng. Medicine and Biology Mag. (2003) 26–27
6. Akay, M., Tamura, T., Higashi, Y., Fujimoto, T.: Unconstrained monitoring of body motion during walking. IEEE Eng. Medicine and Biology Mag. (2003) 104–109
7. Diener, E., Suh, E., Oishi, S.: Recent findings on subjective well-being. Indian Journal of Clinical Psychology **24**(1) (1997) 25–41

8. Diener, E., Lucas, R.E.: Subjective emotional well-being. In: Handbook of Emotions (2nd Ed.). Guilford, New York (2000) 325–337
9. Giles, L.C., Glonek, G.F.V., Luszcz, M.A., Andrews, G.R.: Effect of social networks on 10 year survival in very old australians: the australian longitudinal study of aging. J. Epidemiol Community Health **59** (2005) 574–579
10. Danner, D.D., Snowdon, D.A., Friesen, W.V.: Positive emotions in early life and longevity: Findings from the nun study. Journal of Personality and Social Psychology **80** (2001) 804–813
11. Choudhury, T., Pentland, A.: Sensing and modeling human networks using the sociometer. In: Proceedings of ISWC 2003. (2003)
12. Basu, S.: Conversational Scene Analysis. D. phil. thesis, MIT, Cambridge (2002)
13. Pentland, A.: Social dynamics: Signals and behavior. In: Proc. of the Intl. Conf. On Developmental Learning. (2004)
14. Kempe, D., Kleinberg, J., Tardos, E.: Maximizing the spread of influence through a social network. In: In Proceedings of the Ninth International Conference on Knowledge Discovery and Data Mining. (2003)
15. Davidson, R.J., Ekman, P., Sarion, C.D., Senulis, J.A., Friesen, W.V.: Approach-withdrawal and cerebral asymmetry: Emotional expression and brain physiology i. Journal of Personality and Social Psychology **58**(2) (1990) 330–341
16. Schwartz, G.E., Weinberger, D.A., Singer, J.A.: Cardiovascular differentiation of happiness, sadness, anger, and fear following imagery and exercise. Psychosomatic Medicine **43**(4) (1981) 343–364
17. Ekman, P., Levenson, R.W., Friesen, W.V.: Autonomic nervous system activity distinguishes among emotions. Science **221** (1983) 1208–1210
18. Scherer, K.R.: What are emotions? and how can they be measured? Social Science Information **44** (2005) 695–729
19. Shugrina, M., Betke, M., Collomosse, J.P.: Empathic painting: Interactive stylization using observed emotional state. In: Proc. of the 4th Intl. Symposium on Non-photorealistic Animation and Rendering (NPAR), ACM Press (2006) 87–96
20. Picard, R.W., Vyzas, E., Healey, J.: Toward machine emotional intelligence: Analysis of affective physiological state. IEEE Trans. Pattern Anal. Mach. Intelligence **32** (2001) 1175–1191
21. Lisetti, C., Nasoz, F., LeRouge, C., Ozyer, O., Alvarez, K.: Developing multimodal intelligent affective interfaces for tele-home health care. Human-Computer Studies **59** (2003) 245–255
22. Lemke, M., Wendor, T., Mieth, B., Buhl, K., Linnemann, M.: Spatiotemporal gait patterns during over ground locomotion in major depression compared with healthy controls. Journal of Psychiatric Research **34** (2000) 277–283
23. Moore, E., Clements, M., Peifer, J., Weisser, L.: Comparing objective feature statistics of speech for classifying clinical depression. 26th Annual International Conference of the IEEE EMBS (2004) 17–20
24. Lutz, A., Lachaux, J.P., Martinerie, J., Varela, F.J.: Guiding the study of brain dynamics by using first-person data: Synchrony patterns correlate with ongoing conscious states during a simple visual task. Proceedings of the National Academy of Sciences **99**(3) (2002) 1586–1591
25. Healey, J.A.: Wearable and Automotive System for Affect Recognition from Physiology. D. phil. thesis, MIT, Cambridge, MA (2000)
26. Lamming, M., Flynn, M.: Forget-me-not: intimate computing in support of human memory. In: Proceedings of FRIEND21 Symposium on Next Generation Human Interfaces. (1994)

27. Lauer, M., Blackstone, E.: Databases in cardiology. In Topol, E., ed.: Textbook of cardiovascular medicine. 2nd ed. Lippincott Williams & Wilkins, Philadelphia (2002) 981–1003
28. Roques, F., Nashef, S., Michel, P., Gauducheau, E., de Vincentiis, C., Baudet, E., Cortina, J., David, M., Faichney, A., Gabrielle, F., Gams, E., Harjula, A., Jones, M., Pintor, P., Salamon, R., Thulin, L.: Risk factors and outcome in European cardiac surgery: analysis of the EuroSCORE multinational database of 19030 patients. European Journal of Cardio-thoracic Surgery **15**(6) (1999) 816–823
29. Kudielka, B., Hanebuth, D., von Kanel, R., Gander, M., Grande, G., Fischer, J.: Health-Related Quality of Life Measured by the SF12 in Working Populations: Associations With Psychosocial Work Characteristics. Journal of Occupational Health Psychology **10**(4) (2005) 429–440
30. Sung, M., Marci, C., Pentland, A.: Wearable feedback systems for rehabilitation. Journal of NeuroEngineering and Rehabilitation **2**(1) (2005) 17
31. Kasabov, N.: Evolving Connectionist Systems. Springer-Verlag, Heidelberg (2006)