Ambient Lighting Assistance for an Ageing Population

Specific Targeted Research Project

Deliverable 4.3: General Model

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Preface

This document forms part of the Specific Targeted Research Project (STREP) "Ambient Lighting Assistance for an Ageing Population" (ALADIN) funded by the Information Society Technologies (IST) priority of the Sixth Framework Programme of the European Commission as project number IST-045148. The ALADIN project aims at the following Deliverables:

D1.1 Specification of the criteria for selecting the test persons, i.e. the sample of users to be involved (incl. a justification for the selection of the sample) and the description of tests to be performed.
D1.2 Description of every-day events and activities where daylight and artificial light play a major role including the corresponding psycho-physiological effects on individuals.
D1.3 Description of support and advice measures aimed at preserving the mental and physical fitness of older adults.
D1.4 Project presentation.
D1.5 Final plan for using and disseminating knowledge.
D2.1 Measuring instruments that capture the psycho-physiological data in every-day events and activities of older adults in place.
D2.2 Modular components that can be combined for achieving cost-effective lighting systems and allow continuous and hardly noticeable changes of certain lighting parameters.
D3.1 The intelligent and adaptive lighting control system is ready for testing.
D3.2 GUI with manual user controls for light parameters is ready for testing.
D3.3 A classical biofeedback solution is ready for testing.
D3.4 An advice and support application for enhancing the mental and physical fitness of older adults is ready for testing.
D3.5 Application for visualising one's psycho-physiological data including information about how these are correlated with one's emotional and physical state is ready for testing.
D4.1 Report on the test results and the evaluation of the system as a whole.
D4.2 Fully functional solution (soft- and hardware) including possible redesigns and extensions.
D4.3 Description of a general model about the correlations between environmental variables and the psycho-physiological states of older adults.
D5.1 List of publications, press releases, scientific papers and guidance notes for designers.
D6.1 Consortium agreement, progress reports, final report including the evaluation results.

The ALADIN project and its objectives are documented at the project website www.ambient-lighting.eu. More information on ALADIN and its results can also be obtained from:

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1 Introduction – Background and aims of the project

We approached the *"Description of a general model about the correlations between environmental variables and the psycho-physiological states of older adults"* from several different starting points.

First of all, there is salutogenesis as a major goal in this project. The concept of salutogenesis was developed by the American/Israeli sociologist Aaron Antonovsky (1979). According to this model, health cannot be understood as a state but has to be conceived as an ongoing process. Along with this idea goes the concept of a continuum between health and disease. A person's state of health dynamically moves within this continuum. The process of moving on this continuum embraces several variables which have a substantial influence on the development of health, i.e. biological premises, psychological state and social embedding. The ALADIN project is situated within the three respective variables. Besides, the ALADIN prototype includes a fourth variable to influence the development/maintenance of health of elderly people, i.e. technological support.

The second starting point refers to the type of model we define and illustrate. This model encompasses the interactions and interdependencies of the variables involved in salutogenesis and illustrates the effectiveness of open and closed-loop systems.

The concept of open and closed-loop systems is the third starting point in the development of our general model. These two types of systems will be explained in detail in chapter 2.3. In short, an open loop system refers to a controller that does not use feedback to determine if its input has achieved the desired goal. In contrast, in a closed-loop system feedback is used on how the system is actually performing. This allows the controller to dynamically compensate for disturbances to the system.

In this report we also combine the knowledge derived from the field tests with general and specific suggestions for improvement. Additionally we provide detailed information about the decision-making process for the various parts of our ALADIN system as well as the methods to evaluate its functioning.

<u>Background and aims of the project</u>

The project addresses the main strategic objective of "Ambient Assisted Living (AAL) for the Ageing Society", which is defined as:

> "to extend the time during which elderly people can live independently in their preferred environment with the support of Information and Communication Technology" (ICT).

This definition however does not specify the way of how to achieve and contribute to independent living of the elderly. In order to answer that question it is useful to keep Pollack`s (2005) classification in mind that has been developed for describing the different types of assistive systems designed to support older adults:

1. **Assurance systems** aim primarily at ensuring safety and well-being and at reducing caregiver burden, by tracking an elder's behaviour and providing up-to-date status reports; e.g. motion and position sensors.
2. **Compensation systems** provide guidance to elderly individuals as they carry out their daily activities, reminding them of what kind of training or exercises they need to do and how to do them; e.g. alarm-clocks for the intake of pharmaceuticals.
3. **Assessment systems** attempt to infer how well a person is doing health-wise, for example by assessing what his or her cognitive level of functioning is, based on continual observation of his or her performance or monitoring of routine activities. These technologies are embraced by the term "AAL technologies".

Whereas assurance systems are already available as commercial products, compensation systems that actually intervene and assist elderly individuals in accomplishing their daily activities mainly exist as research prototypes. However, the research challenges can be found primarily in the "*development of assessment systems that provide continual, naturalistic assessment of the cognitive and affective status of older adults*" (DoW, page 7). The ALADIN prototype was particularly developed for maintaining, supporting and increasing the well-being and quality of life of individuals aged 65 years and older with the help of an individualised adaptive lighting system that adapts itself continuously to specific situations.

The ALADIN prototype is the first technology with adaptive lighting that aims to enhance people's well-being, quality of life, mental and physical fitness as well as improving their sleep quality. These aims from ICT were realised by a combination of innovative technological solutions from lighting technology, smart sensor technology, computer- and information technologies. These have been tested and applied in extensive lab tests and field trials.

The ALADIN project is based on the premise that adequate lighting is essential for well-being and quality of life. This is substantiated by studies that have proven the importance of adequate lighting conditions in environmental surroundings of humans – especially the elderly (Kobayashi, 1999; Kohsaka, 2000; Murphy, 1996; Wakamura, 2000; Shochat, 2000). However the effects of lighting associated with well-being and life are mostly unknown to technical engineers or technicians. This may be a reason why innovative technologies that optimise the residential lighting conditions are still rare. At least for the time being new lighting technologies are predominantly used for improving the interior living conditions, in other words the physical environment, and not for enhancing the well-being of elderly people at home. Besides, current lighting solutions are not user-specific nor are they able to react to different situations or environments.

Definitions used in this document

"Environment" here is defined as the habitual space of a person, which is considered to be constant within limits. The term "variables" refers both to objective physical surrounding variables (related to the physical world, e.g. temperature, natural light, humidity etc.), and variables associated with the subjective "social world" that encompasses direct and indirect interaction between social individuals. Both types of variables are considered to describe dynamical phenomena that have a direct or indirect impact upon the psycho-physiological state of an individual and may thereby also influence important health parameters such as well-being and quality of life.

The psycho-physiological states of older adults are highly correlated to well-being and quality of life. Quality of Life (QoL) could be defined as the overall enjoyment of life. Albert (1997) has provided a taxonomy which has proven to be useful for classifying aspects of QoL that are of particular importance for elderly populations. We have incorporated them as follows:

''Quality of life'' (QoL) in general subsumes two domains in gerontological research, which both are related to our research field. In our context the term QoL refers to a great extent to health-related quality of life (HRQoL); the other, non-health or environment-based quality of life (Spilker and Revicki, 1999) is also to a minor extent relevant for our research. Jaeschke et al. (1999) define HRQoL domains as aspects of life that improve when a physician successfully treats a patient. At a minimal level, HRQoL domains include functional status (e.g., whether a patient is able to manage a household, use the telephone, or dress independently), mental health or emotional wellbeing (e.g.symptoms of depression), symptom states (e.g., pain, shortness of breath, fatigue), and social engagement (e.g. involvement with others, engagement in activities). Non-health or environment-based QoL refer to infrastructure, mobility and access to health care services.

The HRQoL domain was fully addressed in our research (see section 4.2.1), which is due to the focus of our research on the improvement of health-related variables. In contrast the non-health QoL was only addressed to a minor extent, e. g. in the advice system (see section 3.4).

If one wants to test the impact of a technological prototype such as the ALADIN system upon cognitive and emotional processes of an individual in his or her natural habitat, it has to be taken into account that the setup and maintenance of the device requires a certain amount of social interaction. Thus, as the device is socially embedded, the empirically observed effects on the individual cannot be solely attributed to the device, as they may also be dependent on the social interaction associated with setting up and maintaining the device. This may be compared to the so-called “Hawthorne Effect”, i.e. a subjects’s behaviour and performance may change if he or she is observed during a research study and temporarily change his or her behaviour or performance as a result.

In short, the test situation comprises a complex system with a human interacting with his or her environment (Figure 1).

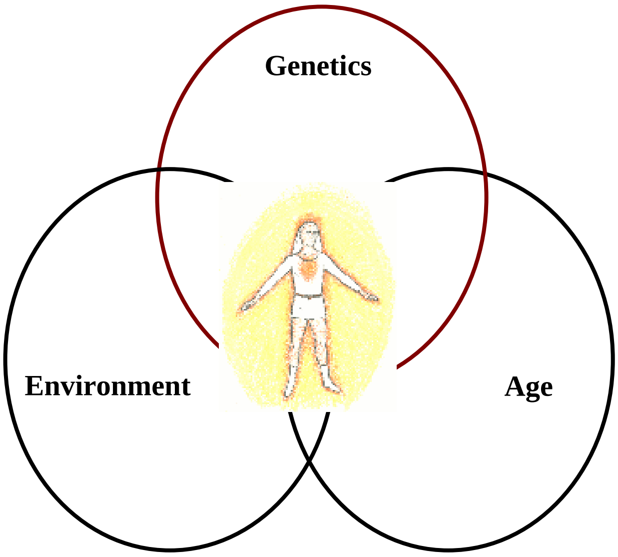

Figure 1: Interaction between environmental variables, age and genetics to the psycho-physiologic state of persons (source of picture: www.puramaryam.de).

Throughout the lifespan, the individual genotype can be considered to be an almost fixed variables, whereas phenotypic-related variables (e.g. influenced by environmental settings and age) may vary greatly across individuals. Thus, as research in epigenetics has shown, age and environmental conditions have to be considered to be interacting variables that have an impact upon a person according to the individual genetic composition of a person.

Optimal models are therefore models that are not only able to describe biological systems but also model their interaction with the environment. However, not only environment and genetics influence the optimal model but also age has to be taken into account as an impact factor on biological systems. **Age** is a factor which adds – technically speaking - some “attenuation” to parts of the system, e. g. some slowing of physiological functions. But this can often be compensated with higher efficiency in some other parts of the system e.g. faster decision-making thanks to experience compensates for slower reaction time to multiple stimuli.

This is the reason why we have opted for a general model adapted from biopsychosocial systems theory and used it as the basis of the ALADIN prototype. In chapter two this adapted biopsychosocial model will be explained. This model was chosen because it illustrates best the different stages on which light might have a direct or indirect influence. Moreover it has already been proven to be useful in medical contexts. In the next section, chapter 3, the prototype with its multiple functions and parts is presented. In a third step we will discuss the limitations of the current system and then focus on possible future developments of the ALADIN system.

2 Definition of a general model

The general goal is to enhance artificial lighting for biological systems respectively people, especially the elderly. How can technology combine individual differences of light perception with light effects on individual biological functions? This is only possible if the system is able to adjust the lighting to each individual.

As we learned from bionics[1] (Bley, 1994, pp. 68-99), there are two mechanisms for control. The first mechanism is an open-loop system which is appropriate for many well-defined demands like basic vision (simple explanation: turning on light with a switch). The second mechanism, which is much more appropriate to fulfil individual needs, is a closed-loop system with immediate feedback to the person (simple explanation: turning on light with dimming function). How can we proceed from the usual open-loop systems to a closed-loop system?

For this, we first have to go back to the aims and goals of the project. As explained before, the aim was not only to improve lighting conditions in the homes of the elderly but mainly to improve the well-being, quality of life, mental and physical fitness as well as sleep quality of each individual by taking into account individual differences as well as different situations. Therefore we need a health-related concept to understand the mode of functioning of AAL technologies.

2.1 Background for the general model

For the description of a general model we decided to use the well-known and widely accepted biopsychosocial (BPS) model proposed for the first time by the American psychiatrist George Engel (Engel, 1977). This serves as a starting point for describing socially embedded technological systems(see figure 2 below).

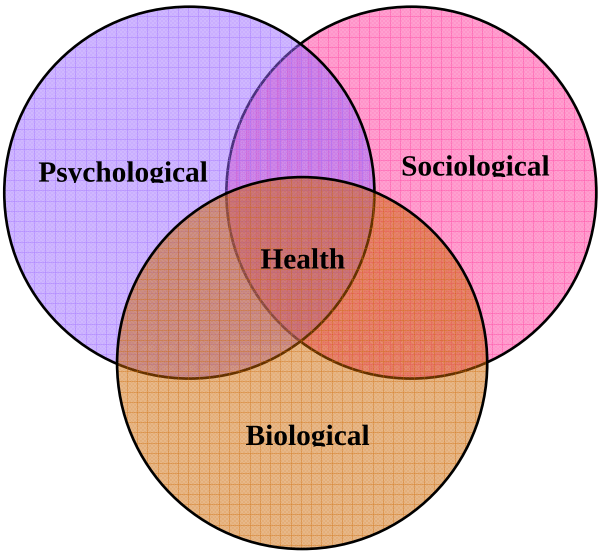

Figure 2 : Biopsychosocial (BPS) model of health

[1] Bionics is the application of biological methods and systems found in nature to the study and design of engineering systems and modern technology

The BPS model starts from the assumption that biological, psychological, and sociological dimensions have to be considered as intertwined dimensions that all contribute to individual health and well being. This model actually has led to a major shift within the health sciences and has changed the focus from disease to health oriented perspective, thereby recognizing that psychosocial factors (e.g. beliefs, relationships, stress) may impact recovery, the progression of and regeneration from illness and disease as well as the maintenance of health. In autogenetic (i.e. produced within the organism) approaches, in particular, health is not only seen as the absence of disease but as a complex condition with more than only one impact factor. Defining health and well being as multifaceted and complex-constructs has also broadened and extended the disease oriented therapeutic approach by blowing the trumpet for prevention programs, such as smoking prevention and exercise training. Seen from this perspective, AAL technologies, if they are able to support and increase health, may also be seen as preventive strategies.

2.2 The general model

AAL technologies can be conceived as socially-embedded technological subsystems that are able to dynamically interact with biological organisms and therefore have an impact on the biological, psychological and social levels. For our purposes, we extended the BPS model to include technology which resulted in a technological biopsychosocial model.

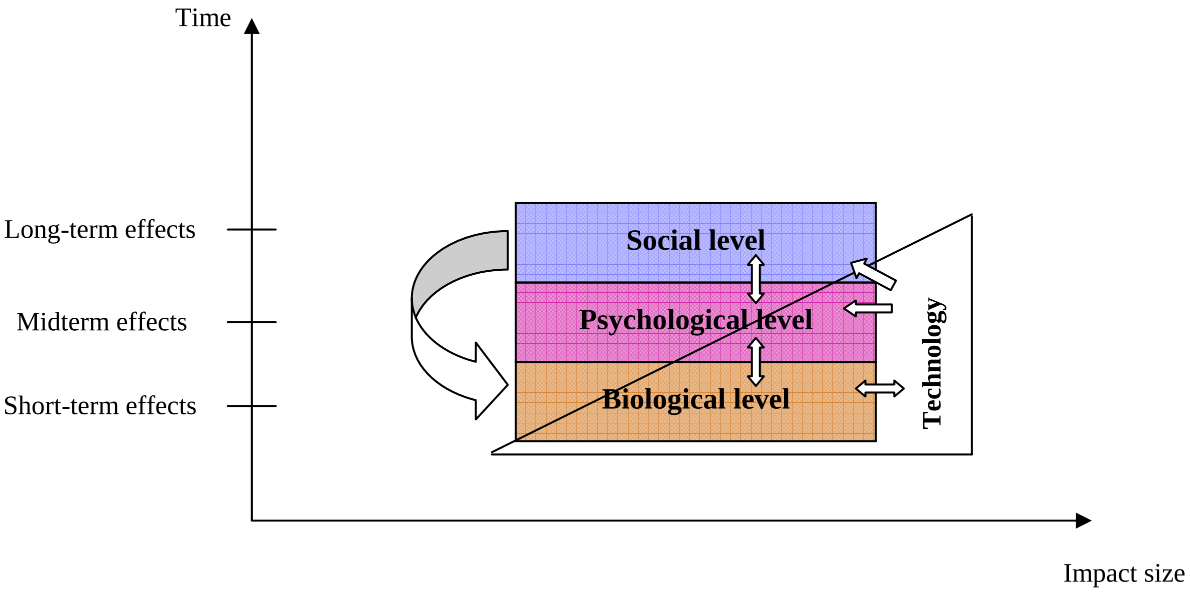

Figure 3 : Extended BPS Model with the inclusion of technology

As shown in figure 3 the technological device (in our case the ALADIN prototype) may have an impact upon the biological, psychological and social dimension of an individual. However, as the ALADIN prototype changes the lighting situation on the basis of physiological parameters, it can be assumed that the ALADIN device predominantly impacts the biological level of an individual, whereas psychological and social domains are influenced to a smaller degree. This is schematically depicted in figure 3, where the abscissa represents the impact and the ordinate represents the time frame in which this occurs. As can additionally be derived from figure 3, for heuristical reasons, we decided to categorize the effects on a time line in three types:

- short-term effects: from seconds to minutes
- midterm effects: from hours up to several weeks and even months
- long-term effects: from months up to years

As can be derived from figure 2 we assume that on the biological level the ALADIN system may have "**short-term effects**". It directly interacts with the biological dimension of an individual by transforming the received information about the physiological state with the help of algorithms into new lighting situations. This in turn influences the biological level of an individual. Technically speaking, a closed loop system has been created, in which reversed natural engineering takes place – technology adapts to the psycho-physiological state of human being.

At the same time the biological changes through technology may interact with the psychological level but these impacts can only be measured as **mid-term effects**. The psychological state of the person has great impact on his/her psycho-physiology and therefore can also have an impact on the interaction between the biological and technological level although presumably to a lesser degree than the biological parameters that are used in order to collect data ´from the individual and then fed into the ALADIN system. The psychological level is also influenced by the way technology is physically and socially embedded (e.g. visual impact of new technology, feeling of being part of new developments, etc.) and interacts with the social level.

On the social level, probably only **long-term** effects can be reliably measured. It takes quite a while until continuous biological changes affect psychological variables. It can be assumed that it takes even longer until a modified psychological state leads to a change in the behaviour associated with the social environment. This may in turn result in changes on the psychological and biological level. Besides, the social setting changes as a result of the set-up and maintenance of the ALADIN prototype due to the presence of study assistants who communicate and interact with the test persons.

As can be seen from the pathways and mechanisms that are explained above, utilizing an extended biopsychosocial model that also incorporates the environmental level that may be influenced or altered by technology, the time during which elderly people can live independently in their preferred environment is extended – one of the primary aims of AAL solutions.

Depending on how many social services we integrate in our model, the gradient of the technology level will get steeper or will flatten. We can also conceive of systems with low interaction on the biological level and high impact on the social level as well as of systems which not only exert unidirectional influence on the social and psychological levels but also interact with them by feeding the system with information from the respective levels. On the psychological and social level feedback need not be given immediately but can also be provided with a time-delay.

In the following sections we divide the paper according to the extended BPS model into the technological, biological, psychological and social levels. In each section we give information about our way of implementing the various components of each level. Finally, the mode of functioning of our ALADIN prototype will be presented and discussed.

2.3 Open loop system vs. closed loop system

2.3.1 Open loop systems

An **open-loop controller**, also called a **non-feedback controller**, is a type of controller which computes its input into a system using only the current state and its model of the system (Wikipedia, 2009).

For our purpose this would mean, that psycho-physiological data could only be inserted into the system once, at the beginning. Therefore we would already have to know what kind of lighting situation would influence the target population in a certain direction, e.g. activation or relaxation.

A characteristic of the open-loop controller is that it does not use feedback to determine if its input has achieved the desired goal – in our case activation or relaxation. This means that the system does not observe the output of the processes that it is controlling. Consequently, a true open-loop system can not engage in machine learning and also cannot correct any errors that it could make. It also may not compensate for disturbances in the system.

This has the drawback that the physiological needs of a biologic system (in the case of ALADIN the humans) cannot be optimally addressed, because a key biological principle is based upon the mechanisms of individual closed loop feedback and adaptive control.

2.3.2 Closed loop systems

To avoid the problems of the open-loop controller, control theory introduces feedback. Control theory is an interdisciplinary branch of engineering and mathematics, that deals with the behaviour of dynamical systems. The desired output of a system is called the “reference”. When one or more output variables of a system need to follow a certain reference over time, a controller manipulates the inputs to a system to obtain the desired effect on the output of the system. (Wikipedia, 2009). A closed-loop controller uses feedback to control states or outputs of a dynamical system. Its name comes from the information path in the system: process inputs (e.g. psycho-physiological data) have an effect on the process outputs (e.g. lighting intensity and spectrum), which is measured with sensors and processed by the controller. The result (the control signal – change in the psycho-physiological state) is used as input to the process, closing the loop.

Closed-loop controllers have the following advantages over open-loop controllers:

- disturbance rejection
- guaranteed performance even with model uncertainties, when the model structure does not match perfectly the real process and the model parameters are not exact
- unstable processes can be stabilized
- reduced sensitivity to parameter variations
- improved reference tracking performance

In a **closed-loop control system**, a sensor monitors the output (biological level) and feeds the data to a computer which adjusts the control input (technological level) continuously to keep control errors to a minimum and to maintain the desired biological and psychological level. Feedback on how the system is actually performing allows the controller (technological level) to dynamically compensate for disturbances to the system. An ideal feedback control system cancels out all errors, effectively mitigating the effects of any forces that may or may not arise during operation and producing a response in the system that perfectly matches the user's wishes.

Going back to the bodily functions, it should be mentioned that there is always interdependency or an interaction of these control loop systems, e.g. the control of pulse, blood pressure, core temperature and respiration frequency. This is necessary to make these loops efficient, but it is almost impossible to describe these nonlinear systems with appropriate algorithms for practical use.

As can be seen in figure 3, the general model is constructed as a closed loop system. Nevertheless, in some systems, closed-loop and open-loop control are used simultaneously. In such systems, the open-loop control is termed “feed forward” and serves to further improve reference tracking performance. In our case we have chosen to combine both systems. This gives the possibility to monitor the biological level and to adjust the technological level (e.g. lighting) to this level and again measure the biological level in order to reassure that this change made any difference. On the other hand subjects handling the system have the opportunity to switch off the system whenever they want.

3 Prototype as used in field tests

The ALADIN prototype consists of the following three components:

- An adaptive control circuit and biofeedback system which can adapt various light parameters such as intensity, light distribution or colour in response to the psycho-physiological data. The system therefore continuously registers physiological indicators of psychological processes on the surface of the body by wireless, smart sensors and transfers them to the adaptive feedback system. For this adaptive algorithms are used to compute the lighting conditions best suited to the individual or to a particular situation. *→ refers to the closed loop part (biological and technological level)*
- A manual control system that can be adjusted via graphical user interfaces (GUI). This system does not only permit to override the computationally derived lighting parameters by the algorithms, but also allows the resetting of all light parameters to their default values. Moreover, supervisors may also change the individual configuration of the adaptive algorithms by defining individually suitable values of the light parameters. These adjustments can in turn be used by the system for further refining and optimising the adaptive algorithms. *→ refers to the open loop part (technological and social level)*
- An advice and support application based on the most recent findings on the factors that influence people's sense of well-being, their mental alertness and physical fitness to assist older people in becoming aware of their own affective-cognitive states including their circadian rhythms. This is achieved by visualizing the psycho-physiological data received from the individual in a clear and accessible way. Additionally, exercises for mental fitness, and a history function concerning biofeedback and mental fitness are part of this application. *→ contains closed loop and open loop systems (technological, biological, and psychological level)*

Operation method of the prototype

Figure 4 illustrates the operating principle of the ALADIN system.

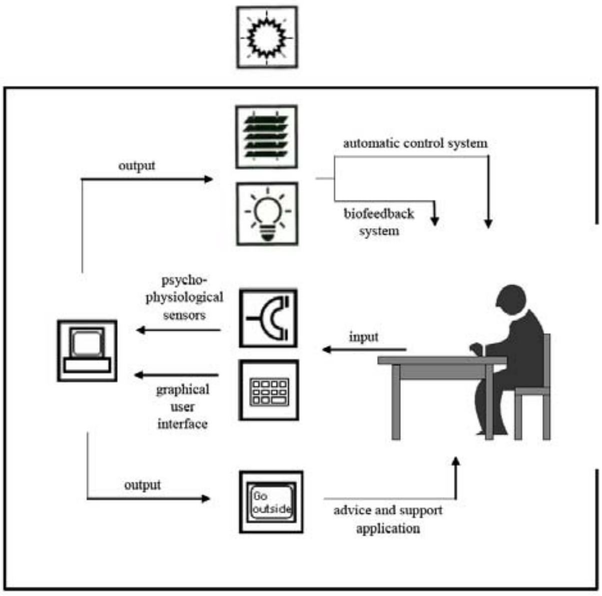

Figure 4: Components of the ALADIN Prototype as open and closed loop systems

One goal was the ease of operation for elderly people. Therefore we decided to implement the system on an interactive television set (TV). Users can control the ALADIN system by a standard remote control. The chosen parameters and settings are displayed on a separate menu of the TV. From the main menu they can select individual applications of the ALADIN system, like for example adaptive lighting or exercises or watching TV. During adaptive lighting and biofeedback exercises psycho-physiological data of the user are monitored, i.e. SCR and/or pulse, and are either used to calculate and apply new lighting situations (adaptive lighting), or visualized on TV screen (biofeedback) for giving the user feedback. In both cases a feedback loop is created. In addition to adaptive lighting, users can also switch to a manual lighting mode at any time. Furthermore, activation exercises as described above are supplied to help users get mentally activated. After finishing the exercises their results are then visualized in an accessible manner, where users can see how they improved over time. Based on these results also well-being advice are provided by the system to support the users.

3.1 Technological level of the prototype

3.1.1 Lighting devices and bus box

At the beginning of the project, we discussed using light emitting diodes (LEDs) for the prototype. The advantages of LEDs are their small size, elegant design as well as their broad range of colour temperatures without frequency spikes. The disadvantage is that the commercially available LEDs require extensive adaptation to fit specific requirements.

Therefore we decided to use other luminaires according to the following criteria:

- High efficiency
- Colour temperature of 2700 and 8000K
- Acceptable price
- Available by the requested delivery date
- Available light concepts
- Feasible colour mixture

Concerning the bus box, the consortium decided despite the higher price that LUXMATE-software should be utilised, because of the availability of source code. The size of the bus box was conditioned by the large number of components that would have to fit into it.

3.1.2 Selected lighting effects

Laboratory tests were conducted in order to:

- examine the psycho-physiological reactions (e.g. heightened concentration or alertness, relaxation) triggered by light variables and how these reactions can be influenced by changing light parameters (lab tests at BLL, see Del. 1.2).

The main aim of the laboratory tests at BLL was to measure the psycho-physiological reactions, e.g. increased alertness or relaxation, of older people to light and lighting parameters such as contrast or intensity within one single closed room.

BLL therefore tried to establish correlations between light parameters as independent variables and physiological signals, cognitive performance (continuous performance test) and subjective perception (rated by questionnaires).

Tests at Bartenbach Light Laboratory pursued two objectives:

- Investigate the effects of different lighting situations on older adults in terms of psycho-physiological impact, subjective perceptions and performance
- Produce recommendations for the prototype lighting system to be installed for the field tests (WP 4)

Following questions were to be answered:

- Are 250 cd/m^2 sufficient for activating older test persons?
- Is a colour temperature of 4000K sufficient for activating older test persons?
- Is there a difference between a colour temperature of 3000K and 4000K as far as its relaxing effect on test persons is concerned?
- Is there a difference between 50cd/m^2 and 100cd/m^2 as far as their relaxing effect on test persons is concerned?

Results concerning lighting parameters

Four different situations with dim lighting did not produce any differences in the blood pressure of the test persons. Lighting situation with 4000K and 100cd/m^2 was perceived as significantly less relaxing than the other lighting situations. A HRV analysis showed no significant differences between the 4 dim light situations.

Results concerning unvarying bright lighting revealed that the two light situations with 4000k and 500cd/m^2 were perceived as significantly more activating, in the questionnaires, that those with 250cd/m^2. Results in the continuous performance test (CPT) were significantly better for lighting situations below 6500K and 500cd/m^2 compared with standard lighting. The numbers of correct pairs in the memory game were slightly higher in the dynamic light situations produced by genetic algorithms than in continuous light situations but the difference could not be proved with statistic significance.

Bright light produced the most significant effects in the performance tests. Relaxing effects of all the dim light situations could be shown in the heart rate variability (HRV) analyses. Based on these results we can conclude that bright light of at least 500 cd/m^2 and 6500K is needed to achieve activation in older test persons. In practical terms this means that the adaptive lighting system has to be dimmable in the range from 0 to 750 cd/m^2. As far as the lighting devices are concerned, these have to offer a colour temperature between 3000 and 8000 K.

3.1.3 Data glove – sensor

In the beginning it was planned to utilise a common available sensor belt which could be worn around the chest. In the course of usability testing, we learned that standard heart rate belts were not usable with people over 65 . Instead of the belt the consortium decided in August 2007 to modify a glove sold by Beurer GmbH. Consequently, we had to develop a special physiological data glove with pulse measurement and electrodermal activity, which was the best accepted solution. Other technologies available on the market such as T-Shirts with integrated sensors were not usable with this target group because they only work with very skinny people.

Becker Meditech (BMT) used the glove to attach sensors for pulse and skin conductance at the thumb and at the first finger. The battery and blue tooth box were attached on the top of the glove, i.e. the back of the hand (figure1 and 2). Eight devices were developed, and they were used in the pre-tests and field tests in this version. The usability for elderly persons was good, after one demonstration of usage, only minor problems with the handling of the glove occurred (mostly contact problems with electrodes).

Figure 1: Data glove with battery and bluetooth transmitter box

Figure 2: Data glove worn on the left hand without transmitter

3.1.4 Adaptive algorithms

We decided to test two different mathematical solutions to control the adaptive lighting. Therefore FHV and UPB developed each an adaptive algorithm capable of controlling the intensity and the colour temperature of the emitted lighting. FHV developed a genetic algorithm and UPB a simulated annealing algorithm.

Genetic algorithm

Genetic algorithms are inspired by evolution in nature. The base is a population of individuals. Each of these individuals has a certain fitness-value assigned during its lifetime, and depending on this fitness-value they are more or less likely to participate in the breeding process for the next generation. Hereby parts of the parents are mixed to form a new child, including random mutations. The idea is that finally the strongest individual (i.e. most fittest for the purpose at hand) will survive. In the ALADIN application individuals resemble a specific light-set and light-distribution in the room. Their fitness-value is then determined by measuring psychophysiological responses to the light-set resembled by the individual in accordance to desired results (target values). Over the course of the adaptive lighting session, the most appropriate light-setting, specific to the person's current state and for the desired result (activation or relaxation) will be found.

Simulated annealing algorithm

Our system's goal is to try and vary the lighting parameters in order to achieve a certain psycho-physiological state, characterized by the extracted features. The studies show that the more relaxed a person feels, the lower their skin conductance response (SCR), skin conductance level (SCL) and heart rate (HR) features are. Thus, the system's goal is to try and find the minimum of the SCR, SCL and HR features in the lighting parameters domain in order to achieve the subject's relaxation or activation, respectively. Achieving a person's desired psycho-physiological state is a problem of finding the certain lighting parameters that determine the optimum of biological features. Such a problem can be solved using stochastic algorithms. A good description of its principle is given in Metropolis (1953), while Kirkpatrick (1983) and Cerny (1985) show how it can be used for combinatorial problems.

3.2 Biological level of the prototype

Laboratory tests were conducted in order to:

- define the target values for the control system by examining which psycho-physiological states accompany “successful” everyday events and activities (lab tests at BME, see Del. 1.2).

The results from BLL lab tests described in chapter 3.1.2 were then used for the lab tests at BME. The BLL measurements were then to be correlated with the results obtained when test persons perform the activities or find themselves in previously defined situations (Láng, 2007).

As a result of various discussions among partners about the functions of the ALADIN prototype it was decided to focus on the states of activation and relaxation. Most activities and situations can be associated with either state, e.g. for some people cooking a meal is a stressful activity whereas for others preparing a five-course dinner may help them relax.

3.2.1 Selected biosignals

The following biosignals were measured in the laboratory tests:

- Electromyogram (EMG); high muscle tension often occurs under stress.
- Electrodermal activity (EDA) → skin conductance level (SCL) and skin conductance response (SCR); measures of SC can be interpreted as mainly reflecting changes in sweating activity and this signal was found to be a good and sensitive indicator of a stressing event.
- Electrocardiogram (ECG) → inter-beat intervals (RR); can be used to measure heart rate (HR) and RR to determine the heart rate variability (HRV).
- Heart rate variability (HRV); A high HRV in the mid frequency band indicates a state of relaxation, whereas a low HRV in this band indicates a potential state of mental stress or high workload.
- Respiration; fast and deep breathing can indicate excitement such as anger or fear but sometimes also joy. Slow and deep breathing indicates a relaxed resting state.
- Reaction time tasks; extended reaction times will show an increase in general fatigue whereas shortened reaction times indicate alertness.

Results concerning biosignals

Test results in relaxing conditions showed that heart rate is significantly lower the more relaxing a situation is perceived. Concerning mid frequency of HRV the analysis of heart rates show no significant reduction in line with higher levels of relaxation. The same result was found for skin conductance level. In contrast, the skin conductance response was significantly lower the more relaxing the situation was. Additionally, lower subjective activation rating scores are mainly associated with lower skin conductance response.

Test results in activating conditions showed that heart rate was significantly higher the more activating the situation. For mid frequency of HRV the frequency analysis of heart rates showed no significant increase in line with higher level of activation. SCL showed no reduction in line with higher level of activation. In contrast, SCR increased significantly the more activating the situation was. Additionally, higher subjective activation rating scores are mainly associated with higher SCR.

Skin conductance response (SCR) has turned out to be the most appropriate psycho-physiological target value for the envisaged automatic lighting adaptation, i.e. the intelligent control loop. This parameter proved to be the most sensitive for different activities. For SCR, a very clear and practically important relationship with activation and relaxation levels was found. Besides, this relationship does not only have statistical significance but shows very high absolute differences in pair-wise comparisons. As a further useful benefit, SCR shows no habituation effect.

Heart rate is the second candidate as an appropriate psycho-physiological target value. Heart rate significantly corresponds with the high activating and relaxing situations. The absolute differences however were very small. All the other psycho-physiological parameters have not proved to be sensitive and/or specific enough due to very high individual differences. They might be used as psycho-physiological target values on an individual level.

The decision of the consortium was to implement HR and SCR as psycho-physiological measurements. Target values were defined as a relative value, increasing or decreasing baseline.

3.3 The advice system – interface between biological and technological level

The advice system is another control circuit which handles the user interaction, biofeedback, mental jogging and data presentation. The goal was to create the user interaction as simple as watching television. Within the advice system people have the possibility to conduct either exercises which measure their current mental fitness or exercises which measure their ability to relax, i.e. biofeedback. The user has the opportunity to monitor his/her current state and will get advice if performance is low. In contrast to the biofeedback application, which represents a closed loop system again, the advice system works as an open loop control. Nevertheless the results from the exercises may be used to give the algorithm information about current state of fitness and therefore light can be adjusted. Correspondingly, although both systems - the advice system with mental fitness and relaxation measurement and the adaptive light control - can operate independently from each other, they actually have to be seen as one working unit. The advice system also checks the individual’s daily performance and provides calibration values to the adaptive control.

The ALADIN System learns the best values for the best lighting situation as a closed loop system. Nevertheless ALADIN can operate also as an open loop system, because people still want to have control over the technology they are using. Therefore the closed loop system will only start, when the user has activated the whole system. It is also conceivable to have at the beginning a phase of combined closed and open loop circuits. The sensors are mandatory for the learning phase. After about two or three months, once the system has learned the variations during the day of its user, i.e. his or her circadian rhythms, it can be changed into an open loop system with an arranged program for each day of the week. The wearing of physiological sensors is not needed for adaptive lighting. It is only during the daily mental jogging and biofeedback routines for relaxation that this is required. When major changes occur, such as e.g. the start of a different season, another closed loop phase is needed.

3.4 Psychological level of the prototype

The main aim of the ALADIN project is to improve the life quality, well-being, mental and physical fitness of elderly people. Besides, we decided to include sleep quality as a test variable. For this purpose, we had to find adequate psychological and physiological tests to evaluate the current measures of the respective target value. Furthermore, adequate exercises for mental activation and relaxation had to be identified. These exercises were included in the prototype.

3.4.1 Psychological and physical measurements

A wide range of psychological and physiological tests are available. We had to find tests which are sensitive and specific enough for a longitudinal study on a healthy population in the age of 65 and over. Usually, clinical questionnaire instruments are devised for assessing and identifying the distress of “vulnerable” populations. These tests tend to discriminate between healthy persons and persons with certain symptoms. E.g. Beck’s depression inventory is good at identifying a person with depressive disorder out of a normal population, but has limitations when it comes to monitoring a healthy normal population with depressive mood.

Concerning **well-being** we decided on the WHO (FIVE) Well-being Index (Bech, 2004). The WHO-5 is a frequently used and statistically proven test which is rather fast to conduct because of its 5 items.

In respect of **life quality** we chose to use the scales for acquisition of life quality (Skalen zur Erfassung der Lebensqualität – SEL) (Averbeck, 1996). These comprise the following factors:

- Questions on mood
- Health-related complaints
- Self-reported health
- Social environment
- Life attitude
- Body quality
- Self-assessed life-quality

This measurement tool was chosen because of its diversified factors. We assumed that light had an influence not only on psychological variables, but also on health-related complaints, which is why we decided to use this questionnaire.

With regard to **mental fitness**, we chose two different measurements out of the Nuremberg Age Inventory (NAI) (Oswald, 1997):

- Picture Test
- Number Connection Test

The picture test was chosen because of its sensitivity to memory skills. Subjects are shown seven pictures in a row, each for three seconds. Subsequently they are asked to repeat what they have seen. The number of correct answers refers to the score achieved.

Number connection test was chosen because of its sensitivity to general mental fitness and independence from language. Nevertheless it is being influenced by motor skills. In this test subjects have to connect unsorted numbers from 1 to 30 in a box. The average time achieved of two cycles indicates the test score.

Concerning **sleep quality**, we chose the standardized Pittsburgh Sleep Quality Index (PSQI) (Buysse, 1989). It contains following components which are added up to a general score of sleep quality:

- Subjective sleep quality
- Sleep latency
- Sleep duration
- Sleep efficiency
- Sleeping disorders
- Consumption of sleeping pills
- Daytime drowsiness

Although changes in sleep quality tend to occur over time we wanted to know whether this short period of six weeks with lighting would have an impact on this variable.

In terms of **physical fitness** we searched for an adequate solution to test this parameter but did not find tests which were sensitive to changes concerning people with only minor physical impairments. Therefore FHV and GRP together decided to develop a fitness test which is based on the principle of acceleration and deceleration time of heart rate. This test is a modified version of the known geriatric assessment “Stand up and go”.

The Index “I” of fitness was defined as follows:

1. Subjects had to sit down in a chair and relax for five minutes; this was done as baseline measurement
2. Subjects should stand up and sit down for 20 (10 if fitness is low) times as fast as they were possible to do; acceleration of heart beat was measured in this period, and the time the 20 stand ups were done
3. Subjects were again asked to sit down and relax for 5 minutes; speed of deceleration was measured in this period of the test

Fitness index was calculated by this procedure:

$$\mathrm{I}_{Fitness} = \frac{n_{StandUps}}{|\Delta Puls| * t_{StandUps}}$$

3.4.2 Exercises for mental activation and relaxation

Regarding **mental activation** we decided to have in total four exercises out of which the subjects were able to choose. In order to train not only one particular mental capability we incorporated exercises which train different mental capabilities:

- **Calculating capacity** was trained with trinomial arithmetic problems

- **Memory** was trained with mnemonic tasks (list of 24 words which should be memorized and then words were shown and subjects should remember whether they had learned them or not)
- Ability for fast **visual detection** was trained with series of letters; subjects were asked to detect whether all letters of a particular word were contained in a series of characters.
- **Sensitivity for estimation** was trained with a field of white and black discs; subjects had to estimate whether more white or black discs were displayed. This test did not depend on knowledge and therefore could not be influenced.

Additionally to literature research these tests were chosen on recommendation of an expert (Dr. Sophia Poulaki) in the field of mental training for elderly and training in dementia.

Regarding **relaxation** we relied on biofeedback. This is a method to get control over your autonomous functions of the body by visualising physiological parameters. It is based on the human capability to modify bodily functions through learning processes. A biologic signal, in our case heart rate or skin conductance level, are measured and communicated to the person. The person is then enabled to willingly control these parameters and to influence usually autonomous body functions. Within the scope of ALADIN biofeedback can be regarded as an efficient method for mental and bodily relaxation.

For the relaxation application we chose to use either SCR or pulse for biofeedback named respectively either “muscle relaxation” or “breathing exercise”, which was understandable for the test persons. For visualisation we use a corresponding increasing or decreasing number and the face of an avatar. When people are relaxing, the avatar seems to go to sleep, whereas during increasing activation or mal-relaxation the face turns into a scared facial expression.

3.5 Social level of the prototype

As can be derived from the description of work, we did not intend to include the social level in our prototype. This prototype was only meant to work on three levels, i.e. technological level, biological level and psychological levels. However, during the conduction of the field-test we came to realize that the social level played a major role. Test-persons were always happy when their supervisors came by to assist them or to do the questionnaires. This social interaction might have had a substantial impact on our data.

4 Limitations of the prototype

4.1 Technological level

Design of luminaires

The design of the lamps was assessed by test-persons as futuristic or even monstrous and some test-persons said the light was too bright. Bright bluish light (8000K) was assessed as uncomfortable, whereas the more red light (2700K) was sensed as nice and pleasant. Five test-persons mentioned in focus groups that they would rather accept light spots than this big structural change with the actual lamps. In at least four households luminaires had to be exchanged once or even more often during the testing period due to flickering of the lamps or because of malfunction.

Computer and data glove

The computers (Mac mini) deployed in the tests were easy to hide because of their small size, and they were well accepted also in terms of almost no noise, and low energy consumption. Concerning software functionality problems occurred with computer hung up and no input via remote control.

The data glove did not fit every test person and especially some women with slim fingers had problems with data transfer to the Mac computer. The main problem is the contact from the electrodes to the skin.

Apart from too small fingers, the data transfer sometimes did not work and people had to restart the respective function.

An information about battery charge was requested. Due to Bluetooth limitations subjects were not able to interrupt a session of biofeedback or automatic light control, which meant that they should not leave the room during the session.

The pre-tests with a commercial pulse belt designed for sportive activities were not succesful. Elderly test persons were not able to put on the belt properly. This led us to establish an ongoing developmental process in course of which we produced the sensor glove as a good solution.. The hand is the right place to measure SCR and also pulse from arteries at the fingers. Furthermore it was easy to put the glove on and off. Limitations in functioning were seen due to different hand size.

Adaptive algorithms

Considering the current state of the art in informatics, the two chosen algorithms demonstrate already very innovative and new approaches towards closed loop systems and the control of light. The genetic algorithm seemed to work better in situation with activation and the simulated annealing algorithm was found to be better in relaxing light situations.

4.2 Biological level

No problems were seen in this level with the chosen psycho-physiological variables.

4.3 Advice system – interface between technological and biological level

Advice and support system

History function of the advice and support system worked well and subjects did not have problems handling it. To be able to analyse data, the computer needed information from exercises conducted in the morning, at lunch time and in the evening from three consecutive days. Advice was given quite seldom which was due to the fact that exercises, especially the mental fitness exercises, were too easy and therefore subjects reached most of the time good or excellent results. Mental exercises were accepted very well and conducted quite often. Relaxation exercises were also done almost every day but subjects reported that often the feeling did not match the result at the end of the exercise, i.e. they felt relaxed but system told them they were not and vice versa.

In the field tests we learned that the advice received from the advice system was considered insufficient. The subjects were mostly disappointed when they received the recommendations from the system, as they were not detailed enough in their opinion. Computer based medical expert systems all share this problem. Each item of advice for a complex question should be crosschecked by a medical professional, like the private practitioner of the respective person. For individualized advice, the administrational effort for the field tests of this study would have been too high.

4.4 Psychological level

<u>Psychological target values</u>

Social and health-factors, such as frequency of visiting friends/family members, time spent at home alone, integration in a social network, doing voluntary service, the degree of disability (both mentally and physically) – all these factors influence a person´s psychological condition, mood and sleep quality. Controlling for all these elements is not possible in field tests. Nevertheless a survey of mood, sleep quality and current psychological condition every day gives a good impression of the psychological state of a test person and the possible interaction with test results.

A general problem in studies on health related topics are multivariate constructs and definitions. Terms like well-being, quality of life, mental and physical fitness are multivariate constructs. However, good approximations of a health related state are possible with many validated psychological questionnaires. Nevertheless, only rough approximations are possible, with a non obtrusive and non disturbing measurement of physiological and psychological parameters. The impact of artificial lighting on well-being is a long term measurement with questionnaires. The impact of artificial lighting on alertness and relaxation can be measured in the short-term and with objective parameters. Since these parameters are individually different in any time period measured, some calibration is necessary and relative measurements are more valid. With this limitation in mind we developed the calculation of target values in the two different control algorithms.

4.5 Social level

This level was not integrated in our prototype system, but in the evaluation of our field trials it became obvious that it played a role: test-persons relished the attention they received and in some cases the lighting installation became a topic of social conversation. Therefore it is very important to socially embed technology, as social interaction and a good customer relationship between a service provider and the elderly customer is very important for the acceptance of the technological devices. The elderly customer will probably require individual support in the handling of assisting devices. So whilst assisting devices have the primary benefit of enhancing people’s life quality through optimal functioning technology, there is still a need to change for customizing the system to each customer. Therefore, a service provider should be available in short term for immediate and efficient support and maintenance.

4.6 Results from field tests

Financial Limitations

Ideally, the field trials would last a whole year to level out seasonal differences but given the high costs of the prototype we could not afford to produce and implement more than four prototypes. The favoured solution, luminaires with high intensity LEDs could not be realised because of both supply problems and financial constraints. Mass customization should be a goal to achieve cheaper products with individualized functions and design

Limitations of the study design

Due to the within-subject design, the time for testing the different parts of the system was too short to be able to detect significant changes in long term parameters such as sleep quality and physical fitness. Hence, new studies should use a between-subject design comparing four groups, i.e. advice system only, lighting system only, advice system and adaptive lighting as one system, and a control group. This would additionally allow for comparing the impact of the different parts of the system. Second, the sample for a first prototype test (12 test-persons) is sufficient for exploratory hypothesis generation, which was intended by the study. To detect significant changes in a re-test design, more test persons would be needed. Besides, in any future test the social dimension should be taken into account right from the start. The personal contact with the assistants creates a positive atmosphere, and the subjective test results could be biased because of this (Hawthorne Effect). Every field-experiment (in pharmaceutical studies called Phase 4) with non standardised conditions has several other factors which have to be considered in the analysis of the data especially with regard to cognitive and emotional processes of test persons.

In our study several environmental factors could have had an influence on the results, such as season of the year, changing weather conditions, natural daylight in and size of the living room. All these factors can have an influence on a person’s wellbeing, life quality, mental and physical fitness. In our focus group discussions it emerged that the season and the changing weather conditions probably had the biggest influence. Considering the long duration of natural daylight during spring and especially during summertime, field tests conducted in only one season of the year, i.e. wintertime because of short duration of natural daylight, might be preferable. Influencing factors like size of the living room, number of windows and orientation of the flat, i.e. either north, east, south or west, can hardly be controlled but nevertheless could have some influence on the results concerning psychological testing.

5 Future developments of the prototype

Taking into account the current state of the art in technological development we created the best solution of a closed loop system. Nevertheless, there are some improvements that can and will have to be done in the future.

In this chapter we describe the possible improvements at each level of the general model. Most improvements refer to the technological and social level.

5.1 Technological Level

For the technological level we have to bear in mind the three main topics which are indispensable when creating technology for humans. These are:

- **Easy access**
  describes that the respective technology should be available for everyone
- **Effortless processing**
  refers to design aspects. This means that technology should be developed in a way that everyone can operate and use it immediately without having to read an extensive manual beforehand.
- **Efficient action**
  stands for the idea that the user should be able to quickly reach his or her intended goal with the assistance of the technology

Within the ALADIN prototype all of the three topics were covered and especially for easy access and effortless processing we were able to realise them in our prototype. Mainly the “Efficient Action” part will have to be improved and advanced in the future when new algorithms and luminaries will have been developed.

5.1.1 Lighting devices and bus box

The luminaires and the Digital Addressable Lighting Interface (DALI) bus system, which create a certain type of light either for relaxation or for activation, represent a major part of the technological level.

The luminaires that were used in the field test phase, are the most efficient solution according to a moderate prize concept and scientific use at the moment. Alternatively, LED could be an option for a time to market situation in probably two years due to their high efficiency and good expression of several colour temperatures, i.e. LED lights in a wave length range that is in accordance with the biological requirements (age adjusted). Additionally, for a future system lamps will be redesigned and new light sources should be taken into account, such as LEDs. Beside the number of lamps per square meter, also the total number of lamps should be individualised as many test-persons stated that light was often too bright.

In the ALADIN Prototype we used a LUXMATE DALI bus box. This relatively high prized product was applied, because the company Zumtobel, located in Austria, provided a source code for programming this bus box. Other manufacturers of DALI systems that are currently available on the market, do not provide source codes, so reverse engineering would be necessary. In a future system other bus systems like KNX or DNX with open source codes should also be tested to find out which solution is best for regulating lighting intensity and spectrum.

The prototype system with eight separate circuits for the luminaries is perfect for a scientific system to do research with different spatial distributions of the lighting.

For a future ALADIN product, there may be the possibility to reduce the circuits from eight to a minimum of two circuits. The reason is that the spatial distribution in small rooms has in most cases not much importance for the measurement of physiological parameters. To reduce the costs of the final ALADIN product, we think two circuits for non research use in smaller rooms are appropriate.

5.1.2 Sensors for capturing psycho-physiological data

The results of lab tests at BME suggested the usage of pulse and EDA as psycho-physiological data. EDA can be measured best on the palm or on the fingers. Additionally in the decision process we chose to develop a glove instead of using a sensor belt. Therefore we decided to also measure pulse at the fingers. The sensor glove was a completely new development and no such systems are yet on the market which can measure the chosen parameter in such a good quality.

Nevertheless, for future measuring devices we suggest to use even more non-obtrusive sensors, and if there is a need to wear the sensors they should be easy to put on or wearable such as small sensors like an earring or a wrist band. In future applications no disturbance of the user should occur as this would significantly reduce the acceptance.

The ALADIN system as an intelligent closed-loop system should continuously register the psycho physiological data during the whole day (including sleep-wake-cycle). The captured signals should ideally reflect wellbeing parameters. A permanent capturing of the psycho physiological indicators is still limited by the sensors and the hardware, especially online long term measurement of parameters is restricted to the available small and mobile energy supply. Future developments, like “low power bluetooth” could provide more flexibility. In this case additional sensors, e.g. acceleration sensors, environmental sensors and light sensors could be implemented in a future end user product.

This all means, that new ways of measuring psycho-physiological states have to be found and brought to marketability. Wearable electronics and textile electronics could include wireless and online transfer of data to a computer where data can be processed. In developing new ways of measurements, other parameters such as core temperature, breathing or heart rate variability could be captured and also give useful information about relaxation and activation. At present these parameters can not be captured and transferred wireless.

5.1.3 Hardware and algorithms

The computer deployed in the tests turned out to be a good solution. Future developments could be integrated in the TV set, e.g. Philips AmbiLight, and the cost of the computer reduced. Negotiations with TV manufacturers are in progress.

The procedure of dynamically finding a specific lighting situation that supports the user best in achieving a certain goal, is basically a trial-and-error procedure. With ten individually controlled light circuits, each of which can be set to intensity and colour values between 0 and 255, the number of different possible lighting situations is enormous. As it would be impractical to test every single one of them for their effects, choosing the most appropriate values in a fast and effective way is the goal of the algorithms. Furthermore, one and the same light scene could cause different effects in different situations.

Our approach was to use search strategies that can find optimal lighting situations by selectively generating new lighting situations out of a base of known values and testing them against a goal value. We decided to use two different approximations and to test them both independently for effectiveness: a simulated annealing algorithm and a genetic algorithm (see chapter 3.1.4). But both algorithms did not use all possibilities in lighting. The genetic algorithm mainly used quite high light intensities whereas the annealing algorithm always dimmed the light down for both activation and relaxation situations. Nevertheless, these were the best up to date solutions which could be found.

A big problem in wireless physiological measurements are artefacts which occur during measurement due to movements of a test-person. Therefore special algorithms (cognitive evaluation) or measuring devices have to be developed which allow the recognition and masking of artefacts in data.

The algorithms are a good start for the complex task associated with finding optimal lighting conditions / settings for individualised relaxation and activation. The algorithms still have to be improved with the results of the field tests. Further research has to be conducted to find an optimised general control algorithm out of more possible solutions. The ALADIN prototype provides a perfect base for further research on the development of new and optimised algorithms.

A possible way might be that several institutions (universities) working in the fields of informatics could work with the ALADIN system to find an optimal solution. One solution could be an intelligent control circuit consisting out of various algorithms. In an ideal system it should be possible to integrate and to analyse all data concerning circadian rhythms. We found out that the genetic algorithm worked better for activation and the simulated annealing was more efficient in achieving the relaxation task. In future maybe a combination of these two algorithms or a synthesis with fuzzy algorithms may work better. As this will require a lot of future work which cannot be accomplished in the framework of this project, a promising solution is to build an open source system where different scientists or research groups can work independently to explore their own solutions and algorithms.

As we could see from the field tests calibrating the lighting system with the individual parameters of the user on a day-to-day basis is necessary. This could be realized by using the parameters of the daily examination of relaxation and activation. The test results in combination with light settings applied by the ALADIN system should be combined with a separate genetic algorithm. This algorithm can help to achieve a calibration vector field which is primed by the ALADIN adaptive algorithms with individual daily defined start values.

5.2 Biological level

In the current version of ALADIN we used EDA and pulse as psycho-physiological indicators of activation and relaxation. These are also the best known variables in psycho-physiology for the states of activation and relaxation. However, there still is a broad variety of other possible parameters which are more or less suitable to use, when evaluating the status of well-being, life quality, mental and physical fitness and sleep quality. In the future, when other variables, such as motion sensors, blood pressure, electroencephalography, breathing, and level of certain hormones in the blood, are understood more in-depth and new ways of measuring them will be developed (non-obtrusive and wireless solutions), it is also conceivable to use such variables. However, potentially disturbing artefacts of these parameters will still be present in field tests.

5.3 The advice system – interface between biological and technological level

To overcome the acceptance problems, individualised recommendations with detailed information should be provided in cooperation with medical “case managers” possibly located in a call center. A possible partner which showed interest would be Sophia mit P.S. Suedbayern GmbH, Germany (see Section 5.5. for more details).

For a ready to market product the software has to be continuously developed for service personnel. Easy to use maintenance menus and remote control programs should be integrated.

5.4 Psychological level

5.4.1 Psychological and physical measurements

Concerning the psychological level we recommend to keep the instruments concerning well-being, life quality and sleep quality.

For the measurement of mental fitness other tests should be chosen. Although the authors of the Nuremberg Age Inventory state that it is an instrument to assess not only people with disabilities, but also mentally healthy persons, we made the experience that we reached ceiling effects for the picture test and improvement for the number connection test was mainly due to learning effects. Therefore other geriatric assessment tools should be included to assess mental fitness.

With regard to physical fitness, the new developed fitness test was already a good method to measure our test-persons ability to recover from physical stress. Nevertheless this is not a proven instrument and therefore further studies on this new test for non-disabled persons should be performed in order to be able to make reliable statements about a person's recovering time. A future work would be to develop a validated fitness test for small changes in fitness.

5.4.2 Exercises for mental activation and relaxation

Concerning the exercises for mental activation, all were well accepted and people liked to carry them out. Nevertheless a bigger variety of exercises to chose from is recommended because test-persons in field tests were rather quickly bored by this restricted number of exercises. Good input especially for the mental training could be the professional software named COG-Pack, which contains proven tests. Additionally it is conceivable to include automatic change of level of difficulty when a person reaches a certain score.

Regarding relaxation exercises, i.e. biofeedback, we made good experiences with it. Nevertheless also in this section people got bored rather quickly by the restricted number of exercises. For the visualisation we used an avatar which changes the face dependent on the degree of relaxation. This was not too well accepted by our test-persons and in future systems other styles of visualisation should be tried, e.g. a balloon rising when relaxed and falling when getting activated.

5.5 Social level

Although it was not intended to include the social level into our ALADIN system, social interaction was inevitable because we could not expect test persons to handle the system on their own. In the interviews and from the personal diaries it became clear that the presence of the supervisors who helped them with technical problems as well as the interaction with the coaches/assistants who conducted the tests exerted an influence on test persons.. They actually expressed their wish for more social elements in the system, e.g. competitive mental activation exercises which can be played with somebody else. We do believe that the future assistive technological systems for older people should also comprise social services or at least facilitate contact with other people, esp. those living near them.

Our partner GRP is in close relationship with the non-profit organisation Sophia mit PS GmbH which provides assistive technology together with assistive services. Sophia includes a personal service when needed and a voluntary carer who contacts the elderly person in a mutually agreed time interval. Additionally, GRP has recently set up the new scientific institution "Peter-Schilffarth-Institute for Social technology (PSI)" which aims at evaluating new housing technologies for the older generation and to ensure the inclusion of social aspects to technology. With the SOPHIA system the existing ALADIN prototype could be upgraded to a socially embedded technological system with the help of the PSI.

6 Conclusions

Based on in depth analyses of needs and expectations of the target group, a prototype was developed, tested in lab tests and subsequently deployed in real-life settings . To figure out which lighting spectra and lighting intensity was the best suitable for individual persons we had to design a system which allowed us to vary intensity in a wide range up to 500 cd/sqm and spectrum in a range up to 5000 K. The psycho-physiological target values create a 3D field with the aim to find out the optimum frequency/intensity in combination with HR & SCR parameters. ALADIN is a promising solution with closed loop control for biological active lighting based on an extended biopsychosocial (BPS) model. The system has demonstrated its functionality in extended field trials.

The ALADIN prototype is the first technological system which is both situation and user specific and uses a closed loop system for adapting light to the needs of the user. This has not been done before with any other technology and therefore the prototype is a path-breaking starting point for further developments on this field.

Further work is required in several respects, e.g. defining new parameters which can be extracted from heart rate and skin conductance response, e.g. acceleration and deceleration capacity which probably reflects more directly sympathetic and or parasympathetic nervous activity. These two physiological systems reflect a scientifically proven connection to relaxation and activation, but the best way for its physiological measurement remains unclear for the time being. Furthermore sensors could be integrated in the environment intelligently, e.g. a TV relaxation chair or activity chair (office furniture).

Due to the daily individual variations of these values an additional effort has to be made to define adaptive algorithms. In the last decade a lot of research has been done on neuronal networks, genetic algorithms and fuzzy control systems. Each of these algorithms has advantages and disadvantages when it comes to combining target values with control units. But as already stated above, a promising possibility would be to provide the existing algorithms as an open source solution to encourage other researchers to improve them and maybe find new solutions for adapting light to the psycho-physiological states of persons.

Until this prototype reaches marketability some revisions have to be done. A major point for sure is the time range in which certain effects on the psychological and social level of the extended BPS model can be measured. What we have seen in our field tests is only the tip of the iceberg. To uncover the rest tests will have to be done with a longer testing period. On the psychological and especially on the social level, changes do not occur directly within seconds as on the biological level. These changes arise only after a certain latency period. This period also depends on the individual and will have to last for more than 3 months. Additionally the latency depends on the assessment character of the system, i.e. the system needs time to learn how to transfer the individual psycho-physiological state into a response. Besides, the users need time to adapt to the system. But in our project it was not possible to extend the testing period due to time and financial constraints.

In the future when technologies are more advanced than nowadays and in a collaborate effort with other researchers it should be possible to build a system which works well and is accepted by users. Furthermore with new technologies even latency periods for certain psychological and social effects might be reduced and the adaptation of human and technology might become more efficient.

As AAL technologies can be conceived as socially-embedded technologies, the ALADIN prototype – also a AAL technology – will have to strengthen the social level in future developments. This will have to be born in mind when redesigning the prototype and drawing up plans for exploitation of results. As it stands, ALADIN is a promising platform that requires further development to become a customisable product in the nearer future.

References

Albert, S. M. ‘‘Assessing Health-Related Quality of Life Chronic Care Populations. In *Measurement in Elderly Chronic Care Populations.* Edited by J.A. Teresi, M. P. Lawton, D. Holmes, and M. Ory. New York: Springer Publishing Company, 1997. Pages 210–227

Antonovsky, A. (1979). Health, Stress and Coping. San Francisco, Jossey-Bass-Publications.

Averbeck, M., Leiberich, P., Grote-Kusch, M-T, Olbrich, E., Schröder, A., Brieger, M., Schumacher, K. (1996). *Skalen zur Erfassung der Lebensqualität.* Erlangen: Swets Test Services.

Bech, P. (2004). Measuring the Dimension of Psychological General Well-Being by the WHO-5. *QoL Newsletter*, *32*, 2.

Bley, H. (1994). Kompendium Medizin und Technik: Grundlagen und Anwendungen der Elektrophysiologie, Elektromedizin, Elektrotherapie, bildgebenden Verfahren, Labordiagnostik, Informatik, Sicherheitsaspekte in Praxis und Klinik. Gräfelfing: FORUM-MEDIZIN Verlagsgesellschaft mbH.

Buysse, D., Reynolds III, CF, Monk, TH, Berman, SR, Kupfer, DJ. (1989). The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research. *Psychiatry Research, 28*, 21.

Engel, G. (1977). The need for a new medical model: a challenge for biomedicine. *Science, 196*(4286), 129-136.

Jaeschke, R., Guyatt, G.H., Cook, D.J. and Miller, J. (1999). Definition and assessment of quality of life, *Pract. Med.,* 4, pp. 155–162.

http://en.wikipedia.org/wiki/Open_loop_control (retrieved on Jan. 20, 2009)

http://en.wikipedia.org/wiki/Control_theory (retrieved on Jan. 20, 2009)

http://www.puramaryam.de (retrieved on Jan. 22, 2009)

Oswald, W., Fleischmann, UM. (1997). *Das Nürnberger Altersinventar (kurz: NAI)* (4 ed.). Göttingen: Verlag Hogrefe.

Spilker B, Revicki D. (1996) Taxonomy of quality of life. In: B S, editor. Quality of life and pharmacoeconomics. 2nd ed: Lippincott-Raven; p. 25-31.