VILNIUS UNIVERSITY

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INTEGRATION OF METHODS OF AFFECT RECOGNITION AND ADAPTIVE CONTROL OF SERVICES IN THE ENCLOSED ENVIRONMENT MICROCLIMATE CONTROL SYSTEM

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VILNIAUS UNIVERSITETAS

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AFEKTO ATPAŽINIMO IR ADAPTYVAUS PASLAUGŲ VALDYMO METODŲ INTEGRAVIMAS UŽDAROS APLINKOS MIKROKLIMATO VALDYMO SISTEMOJE

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INTRODUCTION

Scope and Topicality of the Problem

When developing modern artificial intelligence (AI) based systems, it is important for them to be useful and able to adapt to the dynamic environment. Particular attention is paid to the development of smart services, improvement of their quality, monitoring behaviour of their users and integration of adaptive components. It is important for these systems to enable many services to be automatically controllable and adaptable to specific needs of the user. One of the areas of development of such systems is personalization of services. These systems are also important to reduce the cost of resources and provide services at the right time, with a view to increase the quality of services and reduce risk. In order to adequately represent the reality and control processes that provide services in AI systems, computer technologies have been introduced, linking various disciplines, namely, bio-medicine, psychology, computer engineering, etc.

In 1995, the technologies allowing us to identify, interpret, and simulate human emotional states were merged into one of the branches of artificial intelligence, called affective computing. According to the pioneer of affective computing, R.W. Picard, "... *if we want computers to be genuinely intelligent and to interact naturally with us, we must give computers the ability to recognize, understand, even to have and express emotions*" (Picard, 1995). It becomes clear that emotion recognition is becoming an important part of the development of AI systems. Important areas of application of affect recognition methods include smart home control systems, remote control service systems based on the internet of things technology, etc.

The design capabilities of adaptive systems, able to change the parameters of the ambient environment according to pre-set static parameter values are analysed in some research studies (Marreiros et al., 2007a; Marreiros et al., 2007b; Masatoshi et al., 2010). These systems are based on control techniques that reduce energy consumption and create a suitable environment for human activities.

There are numerous projects in the area of development of the intelligent environment to introduce solutions for architectural fusion of electronic devices (IoT-A, 2013), as well as for the middleware software development of heterogeneous physical devices with a view to create their convenient control services (HYDRA, 2010). The interconnection of embedded systems and provision of intelligent services are analysed in the project to ensure an efficient usability of services (Smarcos, 2012).

In the research area of affect recognition, several solutions to create adaptive service systems have been proposed (Bielskis et al., 2009; Drungilas et al., 2010, Dzemydienė et al., 2010). These systems allow us to select the social e-care services as control scenarios of devices assisting a person and assessing his/her personal emotions. A further development of intelligent services providing adaptive systems requires the integration of direct control of personal environment and affect-recognition methods. One of the most widely discussed cases in the problematic domain is the comfort control systems of the closed environment, which would change the parameters of the closed environment to that which will enable a person (or an artificial agent) to express satisfaction about his/her surrounding environment.

In automatic control systems of microclimate, environmental comfort of indoor premises is usually governed by ISO standards, adjusted to the control of ambient light, temperature and CO2 settings in the air (ASHRAE, 1999; ASHRAE 2005; CIBSE, 1994). The comfort of the environment determines the level of workstation ergonomic characteristics that affect human health, productivity, emotions, motivation, etc. (Masatoshi et al., 2010). The settings of comfort control are extremely relevant and widely considered when developing smart home systems. However, the comfort control systems are not sufficiently automated; they are often not user-friendly (Eiben et al., 2010). Therefore, there is a need to modify the existing methods and propose new ones of affect recognition and adaptive control, which would allow us to develop a closed environment climate control system by implementing dynamic provision of service in accordance with the estimates of the affect state of humans.

The internet of things, smart technologies, and the development of context-aware systems are based on the most advanced achievements in machine learning and application of adaptive decision-making methods. Particular attention is paid to such intelligent technology applications, where services are provided to minimize energy and other costs and to offer individually the most appropriate service or comfort settings for the user. When developing adaptive systems that would be able to change environment settings according to user needs, there is a problem of integration of artificial intelligence and human-computer interaction techniques. There are still not enough methods to solve this problem, which would allow an accurate assessment of physiological states of humans and link them directly to automation of the quality improvement service as well as directly adapt the services to the dynamic subject areas. The evaluation of the service quality requires the solution of problems with regard to selection of criteria, application of decision-making systems, integration of robotic, sensory, knowledge management and automated control systems of processes.

Affect recognition methods in adaptive control systems are based on the ability to assess human response to environmental changes by analyzing physiological parameters (Cowie et al., 2001; Rani, 2003; Mandryk, 2005). Some of researches of this kind examine the effectiveness of affect recognition methods in subject areas of different complexity (Lisete et al., 2003, Villon and Lisete, 2006). Already developed affect recognition methods and biological feedback(Rani, 2003, Mandryk, 2005, Kaklauskas et al., 2010; Kaklauskas et al., 2011) are used to evaluate the effect of environmental factors on humans. Particular attention is paid to the application of affect recognition methods in the design of smart home systems, implementing adaptive indoor microclimate control systems. However, the proposed systems are usually automatically controlled in accordance with pre-set parameters and they unable to react to changes in the affect state of humans and its dynamics. At present, the existing methods are not suitable for real-time adaptation of services that could control ambient environment using the affect evaluation. Therefore, the integration of affect recognition and adaptive control methods is the major issue in the development of adaptive service systems.

Object of Research

Control methods of affect recognition and adaptive control that allow developing an integrated adaptive control system of the closed environment microclimate.

Aim and Objectives of Research

The aim of dissertation is to modify existing methods and propose new ones of affect recognition and adaptive control in order to develop a control system of the closed environment microclimate, implementing dynamic provision of services, based on the estimated affect state of human.

The objectives:

1. To make a comparative analysis of affect recognition methods in order to identify their possible ways of application in the construction of adaptive control systems.
2. To analyse integration possibilities of adaptive control and affect recognition methods for the development of a microclimate control system of the closed environment.
3. To create a system model, integrating affect recognition and adaptive control methods, in order to implement an adaptive microclimate control system in the closed environment.
4. To evaluate experimentally the designed prototype of a microclimate control system of the closed environment according to different evaluative conditions of affect.

Methodology of Research

Affect recognition methods and their application is a relatively new field in informatics engineering. Therefore, in order to assess currently applied affect recognition methods and associated scientific achievements, information retrieval, organization, analysis, comparative analysis and synthesis techniques have been applied. The analysis of scientific literature using scientific databases establishes the context of research that identifies the level of solution of affect recognition methods and problems of their application. In order to integrate the affect recognition and automatic microclimate control in closed environment approaches by proposing an adaptive service control system, based on the needs of users, the affect recognition, digital control and machine learning methods are analysed in this work.

With a view to create an adaptive control mechanism of the closed environment of microclimate, a constructive research method is applied. This research method covers the theoretical analysis of affect recognition, machine learning, adaptive control techniques and examination of application aspects, offering new models, methods, and an experimental framework. In order to validate and verify the developed system prototype and experimentally evaluate the behaviour of the system, the prototype of a physiological signal measurement system has been developed and used. Based on the measured data, namely, galvanic response of human skin, electrocardiogram, skin temperature data, and expert evaluation, using different scenarios of the environmental condition, a simulation model of the adaptive control system of microclimate has been developed. Statistical evaluation methods have been applied to compare the experiment results.

Scientific Novelty

New research results of computer engineering have been achieved:

- The integrated adaptive control method has been proposed for a microclimate control system of the closed environment. It is an improved method of a microclimate control system of the closed environment, when a person participates in a system as a sensor of environmental comfort and the evaluation of its affect enables us to estimate the suitability of environmental parameters for that person. This is one of the newest applications of affect recognition methods for the development of adaptive services oriented to human needs.

- By applying the actor-critic reinforcement learning method able to extract the missing information about the system during its operation, an adaptive microclimate control system of the closed environment has been created. Other than currently offered climate control systems, the proposed method, depending on the context, enables the adaptation of services offered for the user in dynamic subject areas.
- The prototypical affect recognition system has been developed and the simulation model of the proposed parameter adaptation system of environmental microclimate has been experimentally evaluated.
- The integration of clustering of human physiological parameters, using SOM, and classification, using MLP, methods has been proposed. This solution allows us to remove labelling errors of the training samples and enhances thereby the classification accuracy by solving a wide range of classification tasks, where the supervised learning algorithms are applied.

Defended Propositions

- It is reasonable to apply computerised affect recognition methods in the development of adaptive services, oriented to user needs, and to select these methods in terms of their ability to make a more accurate assessment of human responses to environmental changes.
- It is purposeful to integrate affect recognition and adaptive control techniques in the development of a control system, which would be adaptive and responsive to the needs of users.
- The integration of methods for human affect evaluation and reinforcement learning techniques provides an effective development of adaptive services for a microclimate control system of the closed environment.
- The developed adaptive microclimate control system ensures optimal parameters of lighting, temperature, and air quality, based on human affect evaluation.

Practical Importance

The model for a microclimate control system of the closed environment which implements dynamic provision of service, based on the evaluation of estimates of human affect states, has been proposed. This model, including the reading of human physiological signals, parameter analysis, affect evaluation and adaptive control principles, can be applicable in other subject areas, where the improvement of the quality of services is based on human affect evaluation methods. Contextual knowledge of evaluation and assessment of the closed environment microclimate as well as control mechanisms are used to create a methodology for developing intellectual systems designed to create smart services, thus improving the quality and competitiveness of products. The application of this model allows us to improve the quality of contextual services by adapting them to the needs of an individual user, when the service assessment criterion is determined by the estimates of user affect.

The paper also proposes the method designed to remove labelling error of the training sample that allows increasing the accuracy of classification, while solving a wide range of challenges when the algorithms of supervised learning are used.

The proposed methods of affect recognition and adaptive control principles have been used for developing control techniques for environment services, assistance of disabled persons, robotized systems of adaptive control (Bielskis et al., 2008; Bielskis et al., 2009; Bielskis 2010; Dzemydienė et al., 2011), and a human-friendly and energy-saving conception of smart environment (Drungilas et al., 2010; Bielskis et al., 2012; Bielskis et al., 2013).

Approbation and Publications of the Research

The main results of the thesis were published in 13 scientific papers including 5 articles in ISI Web of Science database and refereed journals with a citation index, 1 in other ISI Web of Science database refereed journals, 2 in the Lithuanian reviewed scientific periodical journals, and 5 in the international scientific conference proceedings.

The research results were presented and discussed at two national and four international conferences in Lithuania and abroad.

Structure of the Doctoral Thesis

The dissertation consists of an introduction, four chapters, and conclusions. The total scope of dissertation is 116 pages that include 43 figures, and 5 tables.

The introduction describes the relevance of research, analysis of the significance of the contemporary research context, statement of the problem, formulated goal and objectives, and defines hypotheses and research methodology. The main scientific results, the practical value and novelty of the results and publishing indicators of approval are defined as well.

Chapter 1 deals with computerized affect recognition methods and the overview of possibilities of their application in the construction of adaptive systems. The review of the most commonly used analytical methods of affect recognition of scientists in the world is provided. This section indicates that computer-based affect recognition methods are sufficiently accurate to assess human response to environmental changes, and are useful for creating constructions of an adaptive control of the environmental microclimate according to human affect evaluation.

Chapter 2 considers abilities of machine learning methods and their applications to the development of adaptive control systems. It describes the most important methods to develop such systems. Implementation principles, based on the classical control systems and modern machine learning, are revealed as well.

Chapter 3 describes the main theoretical problem solving methods. The model of an adaptive control system of the closed environment microclimate is proposed, allowing the adjustment of environment settings, based on the evaluation of ambient microclimate affect. Realisation principles for integrating control methods of the closed environment and methods of affect recognition are introduced. Based on the analysis in the previous chapters, this chapter shows that the integration of human affect recognition methods with reinforcement learning techniques provides an effective development of adaptive services for a microclimate control system of the closed environment.

Chapter 4 describes experimental results of the proposed system. The case study of an empirical model is introduced, as well as the experimental studies are applied to experimentally validate the performance of the proposed model. The results of experimental simulation have shown that using an actor-critic reinforcement learning model and the function of affect evaluation, it is possible to achieve the optimal light, temperature, and air quality parameters in terms of human affect evaluation.

General conclusions of the thesis introduce the results, conclusions, and recommendations.

1. AFFECT RECOGNITION METHODS AND THEIR APPLICATIONS IN COMPUTER-BASED SYSTEMS

Affect is a strong enough and short emotional reaction, usually arising when subject relevant circumstances of life suddenly change. This term describes emotion, mood, and attitude. Emotion or emotional response is a direct representation of affect of the important event (stimulus) evaluation for the entity (Ekman, 1994).

The representation of affect or an emotional state is based on two well-established models:

1. Basic emotional states are represented on the nominal measurement scale. This method is based on principle that there is a certain number of emotional states (eg. angry, happy, sad, scared, disgusted, surprised), in which a person may be (Oatley and Johnson-Laird 1987; Ekman, 1992). Any other condition is treated as a specific subset of the ground states.
2. A two- or three-dimensional model that allows us to represent any emotional states on the interval scale (Russell, 1980). The relevant dimensions express the level of valence, level of arousal, and the level of dominance.

A simplified model for representing emotional states, based on the view of emotions as a certain degree of arousal and valence is proposed by (Russell, 1980). In this way, any emotional state can be represented on a two-dimensional space with respect to arousal and valence (Fig. 1).

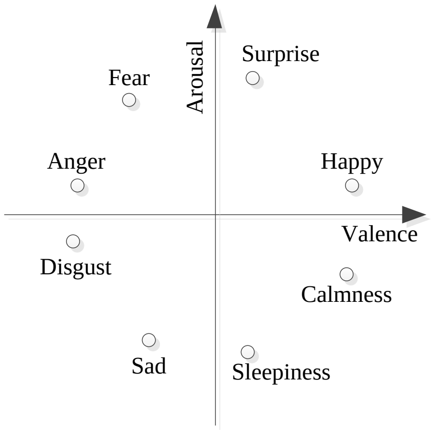


Fig. 1. Positions of the emotional state in the arousal valence space (Russell, 1980)

Affect recognition can be treated as transformation of physiological parameters into human emotional states that are defined as the nominal classes. Affect recognition is widely applied in the human-computer interaction to increase usability and adapt computer systems to specific user needs. There is a lot of approaches to recognise an affect, including sensory systems, data mining, knowledge representation techniques and other principles of artificial intelligence that help us to scan, analyse, and interpret human physiological parameters. One group of these methods is based on facial expressions or voice recognition principles (Cowie et al., 2001). There also are numerous scientific papers that analyze the physiological parameters such as the heart rate, galvanic skin response, temperature (Kim et al. 2004; Canento et al., 2011, Fletcher et al., 2010), electroencephalogram, and other data.

The data of three physiological signals, such as galvanic skin response (GSR), electrocardiogram (ECG), and temperature settings, can be used to evaluate human reaction to the environment i.e., to recognise the affect. (Wang, 2006; Fleurey et al., 2012; Dzemydienė et al., 2010; Drungilas et al., 2010; Bielskis et al., 2009).

Most of the methods, used to transform physiological parameters to classes of affect that define emotional states, belong to machine learning and pattern recognition domain. The most commonly used affect recognition methods are the k-nearest neighbor classificator, discriminant function analysis, artificial neural networks, support vector machines, various regression analysis methods, etc. (Chanel et al., 2009; Mandryk, 2005).

The complexity of the recognition algorithm depends mainly on the amount of features and their importance for the problem. In order to define the appropriate amount of features, selection of the features should be used. The feature selection is based on a certain criterion that determines the significance of one feature to another.

The summarized results of the analysis of affect recognition methods are presented in Fig. 2. The analysis of selected parameters processing methods shows the influence of a multilayer perceptron, support vector machines, Fisher's linear discriminant, k-nearest neighbors, decision trees, and SOM recognition classification algorithms accuracy influence on the feature corrections. We can see that the multilayer perceptron and Fisher’s linear discriminant are least sensitive to feature correction. Suggesting that these algorithms are most resistant to noise. The graph in Fig. 2 shows that SOM correction in almost all the cases (except for the support vector machine method) significantly increases the classification accuracy. We also discover that the support vector machine algorithm, in this case, is particularly sensitive to any correction of features.

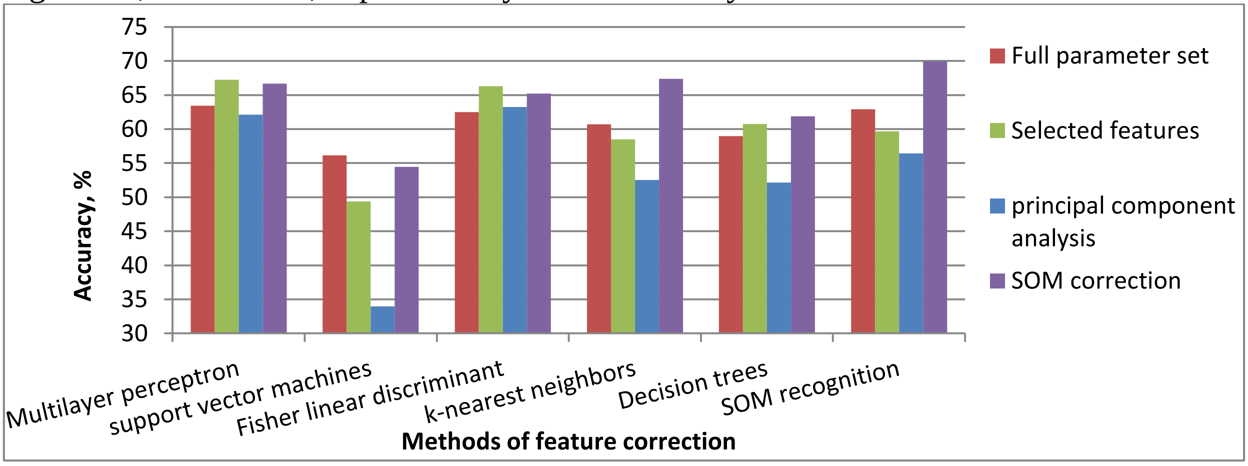


Fig. 2. The accuracy of affect recognition, using different feature correction methods

Thus, the majority of the affect recognition methods belongs to the machine learning and pattern recognition domain. Selection of a particular method depends on the reliability of raw data and the required accuracy of the result. Several methods are often combined to get the most accurate result. The analysis of affect recognition methods suggests that these methods can yield a sufficiently accurate assessment of human responses to changes of the environment. So, the computer-based affect recognitions methods can be used to create a service adaptation mechanisms to specific user needs.

2. METHODS FOR DEVELOPING ADAPTIVE SYSTEM

In designing an optimal control system, if all the a priori information about the controlled process (plant environment) is known and can be described deterministically, the optimal controller is usually designed using deterministic optimization techniques. If the a priori information required is unknown or incompletely known, an optimal control cannot be achieved by classical methods of control. Therefore, the design of this type of control systems is based on design a controller based only upon the amount of information available (in that case, due to lack of information can lead to large errors of control system) or by design a controller which is capable of estimating the unknown information during its operation and an optimal control action is determined on the basis of the estimated information (Fu, 1986). The last mentioned method is able to acquire the unknown parameters of the plant, using approximation techniques. The approximation of these parameters can be made using a machine learning component, which can gain sufficient knowledge of the controlled process and adjust the controller to increase the efficiency of the system. Classic self-learning and adaptive closed-loop automatic control system is shown in Fig. 3. The adaptive control system consists of a controller, plant (controlled object), and machine learning component. The plant is affected by external disturbance Z which is changing the state y' of the plant. The control signal u' in the system is expressed as the difference e' between the values of reference (target) r' and actual parameter y' of the plant. The controller defines the transfer function, mapping the state difference e' of plant to the control signal u'. The machine learning component should be used to define the transfer function of the controller more accurately, when it is lack of knowledge of the plant. The machine learning module adjusts the transfer function parameters of a controller to make more precise control signal u'.

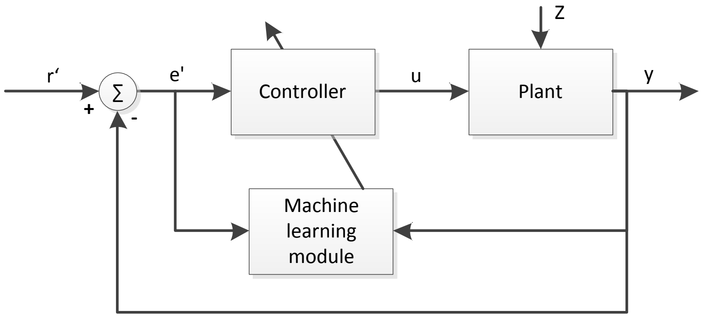


Fig. 3. Classic adaptive control system

The advantage of machine learning based control systems can be seen in the dynamic environment when the control conditions are constantly changing. In this case, the machine learning component allows to update the control parameters, constantly adapting them to changing environmental conditions.

There are several types of machine learning methods, which application depends on the problem domain. Sometimes it is not possible to solve a problem using a supervised learning when system attempts to derive general rules, on the basis of the sample data sets. There also are problems that do not have accurate data to solve the desired task or even to form clusters of data using unsupervised learning. In this case, the reinforcement learning method is suggested to use, which is closely related to the feedback-based control (Lewis and Vrabie, 2009). This type of machine learning approaches allows the program agent train in unknown environment in accordance with the experience that the agent receives when exploring the unknown environment using sensors to get the maximum accumulative reward. The reward can be expressed as an effectiveness of agent's actions, which agent receives when interacting with the environment.

The main task of reinforcement learning is to find the optimal strategy for the selected parameters, when the agent receives a positive or a negative reward while performing an action. Formally speaking, the agent **B** seeking the goal, at specific time intervals t feels the state of the environment, using sensors that generate the input signals, and it decides which action a_t to carry out according to the sensory information, and the environmental feedback (reward) r_t. The goal of learning agent is to choose an action in each step, which would give the maximum sum of rewards (Sutton and Barto, 2012). The classic model of the reinforcement learning is shown in Fig. 4.

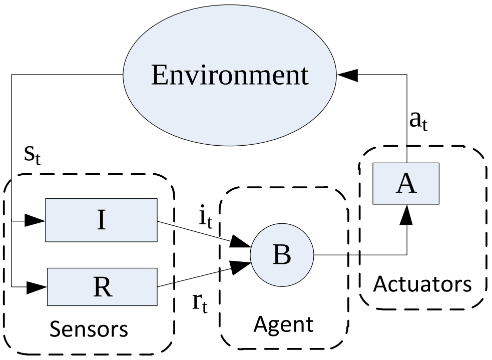


Fig. 4. Classical reinforcement learning model (Sutton and Barto, 2012)

The input function **I** is the environment sensory function at a given time, which enables agent to "see" the environment. **R** is a function of the reward. So the reinforcement learning model consists of three main components:

- **S** – set of environmental states, which can be countable or uncountable, finite or infinite.
- **A** – set of agent actions that can be countable or uncountable.
- **R** – set of reward signals that can be countable or uncountable.

The reinforcement learning is based on trial and error learning approach in which the agent explores the environment applying an action from a set of possible actions in order to find the best strategy (decision-making function which maps state to the action) which would give maximum sum of rewards.

Main components of reinforcement learning based tasks are the following:

- Agent – entity, which is learning when perceiving its environment through sensors and acting upon that environment through actuators.
- Environment – nondeterministic, changing in time, can be defined as Markov Decision Process (MDP).
- Policy π – decision making function of the agent. It specifies what action the agent should take in any of the situations it might encounter.
- Reward function R – defines the goal of the agent. It maps the state of the environment to a single number, a reward, indicating the intrinsic desirability of the state. The agent's objective is to maximize the total reward it receives in the long run.

- Value function – the total amount of reward the agent can expect to accumulate over the future when starting from the current state.

All of these components allow us to define a task for reinforcement learning. The interconnection of these components is based on the MDP.

The control system of the closed environment microclimate is quite complex, involving multicriteria control of environment parameters, and the analysis of physiological signals. Therefore, it is necessary to apply machine learning techniques, which are able to extract the missing knowledge about the system during its operation, in order to implement the adaptive climate control system of the closed environment.

3. AFFECT RECOGNITION IN THE CLOSED ENVIRONMENT MICROCLIMATE CONTROL SYSTEM

Systems, based on affect recognition have some similarities. From architectural point of view, four main components can be distinguished, which can be found in currently existing affect recognition based systems:

1. Sensory subsystem, which includes equipment (cameras, microphones, skin conductivity sensors electrocardiogram sensors, etc.). This subsystem enables capturing quantitative data from human physiological signals that represent the affect.
2. Data processing subsystem, which includes the process of raw data filtration, labelling, parameter extraction. This subsystem allows sensors to transform the raw data into relevant quantitative assessment of physiological signals by certain characteristics. In other words, the subsystem returns physiological features.
3. Knowledge acquisition subsystem that enables the assessment of affect, according to the physiological features.
4. Control subsystem including processes from simple emotional state representation of the user to the control of physical equipment.

In order to develop an adaptive control system of microclimate which would be able to create the most appropriate closed environment comfort conditions for person it is necessary to combine affect recognition and adaptive control techniques. According to this principle, the system should be able to change the settings in a closed environment when the feedback of environmental climate control system is expressed as sensory information of human affect recognition. The overall view of such a system is shown in Fig. 5. The reference value of the adaptive automatic control system corresponds to the reference of affect value, which defines what must be achieved in a human affect estimate. Human participates in a system as an environmental comfort sensor, which enables the estimation of relevance of human affect to environmental comfort parameters.

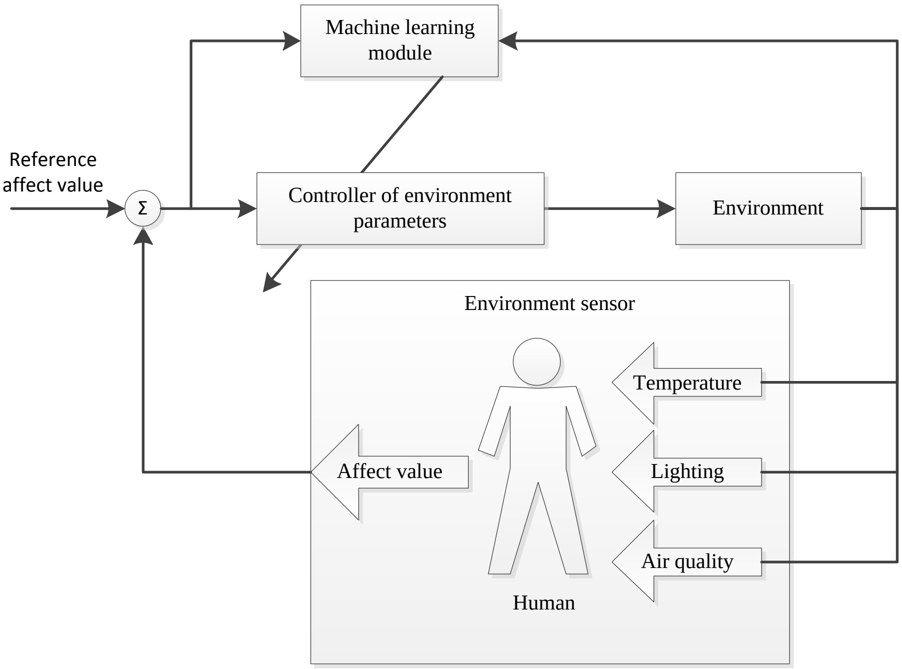


Fig. 5. Closed environment control system, based on affect recognition

According to the American Society of Heating, Refrigerating and Air Conditioning Engineers – (ASHRAE) standards, the ambient environment quality, or the comfort of environment is defined by three parameters: thermal comfort, visual comfort and indoor air quality (ASHRAE, 2005).

Thermal comfort is largely a state of mind, separate from equations for heat and mass transfer and energy balances. However, the perception of comfort is expected to be influenced by the variables that affect the heat and mass transfer in energy balance model. The most common approach to characterizing thermal comfort for the purposes of prediction and building design has been to correlate the results of psychological experiments to thermal analysis variables. That is, human subjects with various clothing levels and performing different activities are placed in environment with different air temperatures and surface temperatures, different humidity, and different airflow velocities and patterns. The subjects are then asked to express their level of comfort. The level of comfort is often characterized using the ASHRAE thermal sensation scale, given in (Table 1). The average thermal sensation response of a large number of subjects, using the ASHRAE thermal sensation scale is called the predicted mean vote (PMV)

Table 1. The evaluation scale of thermal comfort (ASHRAE, 2005)

Value	**Sense**
+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
1	Slightly cool
2	Cool
3	Cold

In order to objectively assess the PMV Fanger (Fanger, 1982) suggested the calculation methodology. His analysis indicated that the sensation of thermal comfort was most significantly determined by narrow ranges of skin temperature and sweat evaporation rate, depending on activity level. Therefore he derived:

$$PMV = 3{,}155(0{,}303e^{-0.114M} + 0.028)L' \tag{1}$$

where: M – metabolic rate, L' – thermal load on the body, defined as the difference between the rate of metabolic heat generation and the calculated heat loss from the body

The predicted mean vote is the average response of a large number of people. Given the subjective nature of comfort, there will actually be a distribution of satisfaction among a large group of people. Fig. 6 shows an empirical relationship between the percentage of people dissatisfied (PPD) with a thermal environment as a function of the PMV.

$$\mathrm{PPD} = 100 - 95\mathrm{e}^{-\left(0.03353\mathrm{PMV}^4 + 0.2179\mathrm{PMV}^2\right)} \tag{2}$$

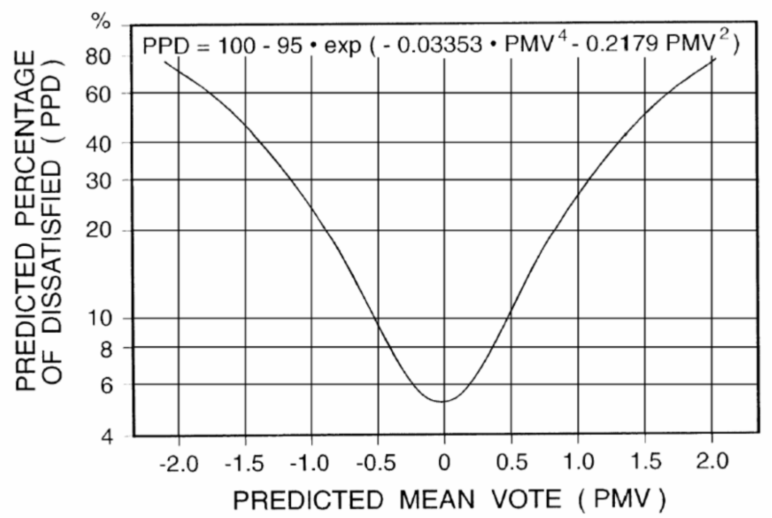


Fig. 6. Relation of PMV and PPD characteristics (Fanger, 1982)

Visual comfort is specified by the level of indoor illumination (CIBSE, 1994), consisting of intensity, colour and other parameters of lighting. In the scientific literature, there are proposed common indoor lighting recommendations corresponding to the visual comfort. However, unlike in the case of thermal comfort, there is no well-established methodology of quantitative evaluation of visual comfort index, using human physiological parameters. Indoor air quality is mainly affected by CO2 concentration in the building (ASHRAE, 1999).

The objective assessment of thermal, visual and air comfort can be expressed using measurements of human physiological parameters. Similarly as in the case of thermal comfort evaluation, it can be measured the human skin temperature, other characteristics that reflect the human affect to the different ambient temperature, lighting and air quality conditions. Affect recognition expressed as one-dimensional value can be treated as a feedback of closed environment comfort control system.

According to the ASHRAE comfort evaluation scale, adaptive control system feedback function should return values from the interval of $[-3, 3] \in R$. It means that using a two-dimensional affect recognition model, which maps any emotional state to the valence and arousal scales can be expressed in adaptive control system as a feedback value from the interval [-3, 3]∈R. According to adaptive control reinforcement learning paradigm, we call this value the Ambient Comfort Affect Reward (ACAR), expressed as a function of:

$$ACAR = f\{ar(t_o, ecg, gsr), va(t_o, ecg, gsr)\}, \ ACAR \in [-3, 3], \tag{3}$$

where: *ar* and *va* are an arousal and valence functions respectively, dependent on human physiological parameters: t_o – temperature, ecg – electrocardiogram *(ECG),* and *gsr* – galvanic skin response (GSR).

It was shown (Bielskis ir kt., 2009; Bielskis ir kt., 2010; Dzemydienė ir kt., 2010; Drungilas ir kt., 2010), that the (3) type function can be approximated, using neural networks, fuzzy logic or other regression methods.

Because there is not enough data on which we could mathematically describe the function, maping the physiological parameters to the ACAR index, it is required expert assessment. Expert using approximate reasoning can derive sufficiently precise function. In this case, the most appropriate (3) function approximation method is fuzzy logic, as one of the most widely used universal approximators. According to the researchers, who defined affect evaluation methodology (Russell, 1980; Mandryk, 2005, Perry, 2007, Ekman, 1992), physiological parameters are transformed to the two-dimensional model for the assessment of the affect, which then may be used for defining other characteristics. The two inference systems can be defined, using fuzzy logic, that are connected sequentially and outputs the values of arousal and valence, and from them the ACAR index (Fig. 7).

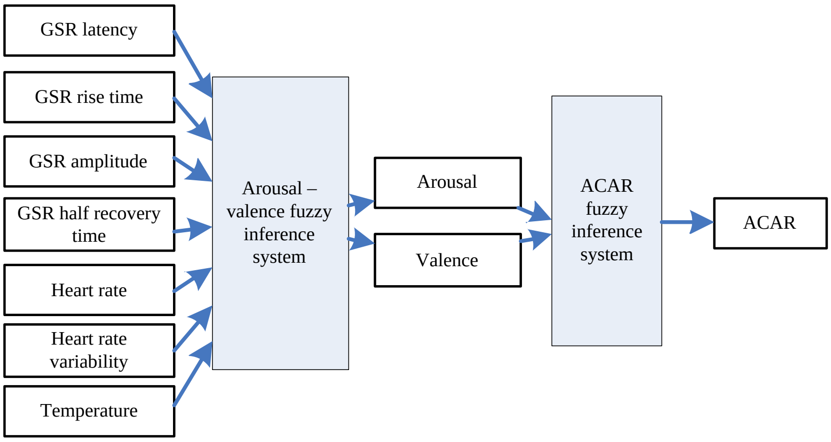


Fig. 7. ACAR index fuzzy inference system

From the digital control point of view, it can be created a model for control a closed environment microclimate forming units (temperature, illumination and air quality) using human affect evaluation. According to this principle, it can be developed a closed control system using the reinforcement learning and the affect recognition methods (Fig. 8).

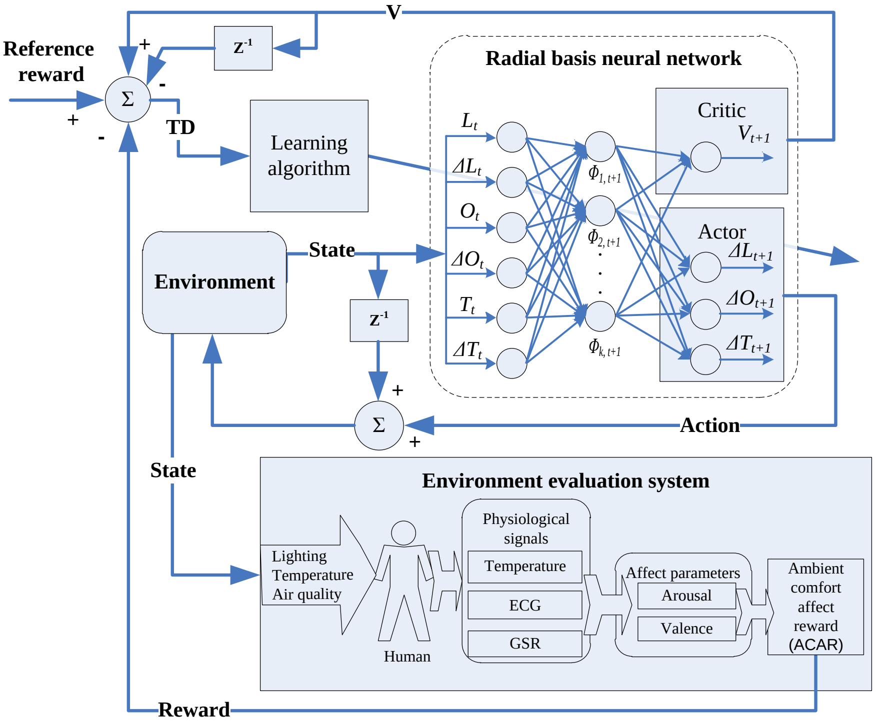


Fig. 8. Structure of reinforcement learning-based closed environment microclimate control system

The architecture of the closed environment microclimate control system as shown in Fig. 9 can be used to find such environmental state characteristics that create an optimal comfort for people affected by this environment. This system consists of three main parts: the instrumented interconnected environment sense and control system, the intelligent system, and the interface.

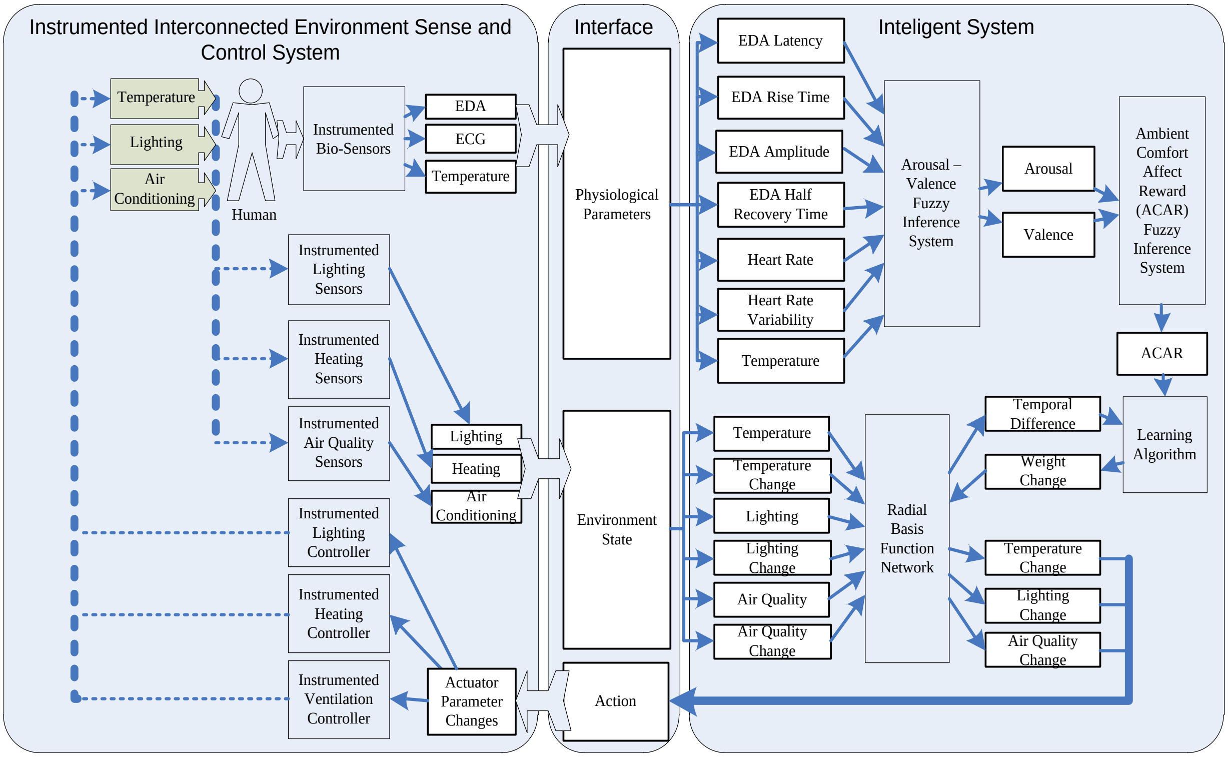


Fig. 9. Architecture of closed environment microclimate control system

The instrumented interconnected environment sense and control system is equipped with embedded smart devices that can sense the environment state – heating, lighting, air conditions and respectively control the actuators which change the ambient environment microclimate. As the human is the main criterion to evaluate the comfort of ambient environment there are instrumented bio-sensors used to scan physiological signals of the human like galvanic skin response (GSR), electrocardiogram (ECG) and skin temperature.

The interface is responsible for fluent data exchange protocols between different platforms that implement the instrumented interconnected environment sense and control system, and the intelligent system.

The intelligent system is used as decision support system to predict action that changes the parameters of the environment actuators, according to the parameters of environmental state and human physiological signals.

The radial basis neural network is the main component of the closed environment microclimate control system, responsible for two roles – the policy structure, known as the actor, used to select actions, and the estimated value function, known as the critic that criticizes the actions made by the actor. The critic is used as value function approximator for continuous learning tasks, because discrete state representation of environment can be problematic. The continuous MDP can lose its Markov property if the state discretization is too coarse. As a consequence, there are states which are not distinguishable by the agent, but which have quite different effects on the agent’s future. Using the reinforcement learning for control tasks is a challenging problem, because we typically have continuous state and action spaces. For learning with continuous state and action space, a function approximation must be used. Linear function approximations are very popular in this problem area, because they can generalize better than discrete states and are also easy to learn at least when using local features (Sedighizadeh and Rezazadeh, 2008). A feature state consists of N features, each having an activation factor in the interval [0, 1]. Linear approximations calculate their function value by

$$f(x) = \sum_{i=1}^{N} \phi_i(x) \cdot w_i \quad , \tag{4}$$

where: $\varphi(x)$ is the activation function and w_i is the weight of the feature i. Instead of keeping track of each unique state separately, we seek to find a function that approximates the state space with a small number of adjustable parameters.

Radial basis functions (RBFs) are the natural generalization of coarse coding to continuous-valued features. Rather than each feature being either 0 or 1, it can be anything in the interval [0, 1], reflecting various degrees to which the feature is present. A typical RBF feature, i have a Gaussian (bell-shaped) response $\phi_s(i)$ dependent only on the distance between the state s and prototypical or center state of the feature, c_i and relative to the feature's width σ_i

$$\phi_s(i) = \exp\left(-\frac{\left\| s - c_i \right\|^2}{2\sigma_i^2} \right) . \tag{5}$$

The RBF network is a linear function approximation using RBFs for its features. The learning algorithm is used to adopt RBF network weights in order to fit the actor and the critic functions. The feature of the actor-critic learning is that the actor learns the policy function and the critic learns the value function using the temporal difference (TD) method simultaneously. The TD error $\delta_{TD}(t)$ is calculated by the temporal difference of the value function between successive states in the state transition as

$$\delta_{TD}(t) = r(t) + \gamma V(t+1) - V(t), \tag{6}$$

where $r(t)$ is the external reinforcement reward signal, $0 < \gamma < 1$ denotes the discount factor that is used to determine the proportion of the delay to the future rewards. The TD error indicates, in fact, the goodness of the actual action. Therefore, the weight vector θ of the policy function and the value function are updated as

$$\vec{\theta}_{t+1} = \vec{\theta}_t + \alpha \delta_t \vec{e}_t, \tag{7}$$

where α is the learning rate and the eligibility trace, e can be calculated by:

$$\begin{cases} \vec{e}_0 = 0, \\ \vec{e}_{t+1} = \gamma\lambda \vec{e}_{t-1} + \nabla_{\vec{\theta}_t} V(t). \end{cases} \tag{8}$$

So, the analysis of affect recognition methods and adaptive control principles has shown that affect evaluation is helpful in creating a feedback of automatic climate control system of the closed environment. The closed environment microclimate control system can be implemented using affect evaluation as the ambient comfort feedback.

4. EXPERIMENTAL RESULTS OF THE CLOSED ENVIRONMENT MICROCLIMATE CONTROL SYSTEM

When collecting the training sample used for affect recognition, sometimes, because of overlays, it is difficult to discriminate the emotional states. So, the errors could come from labelling the data points (teacher noise). Classifying data into somewhat similar clusters can lead to noise reduction, and therefore, higher accuracy.

Self-organizing maps (SOM), that discovers the natural association found in the data, the unsupervised self-learning algorithm was used for clustering the physiological parameters. SOM combines an input layer with a competitive layer where the units compete with one another for the opportunity to respond to the input data. The winner unit represents the category for the input pattern. Similarities among the data are mapped into closeness of relationship on the competitive layer. The SOM here defines a mapping from the input data space R^4 into a two-dimensional array of units. Each unit in the array is associated with a parametric reference vector weight of dimension four.

Fig. 10 shows the SOM grid (dimension of 10×10), where each unit contains R^4 weight vector that groups GSR parameters by similarities. The numbers represent training data classes, and colours – the different clusters after training.

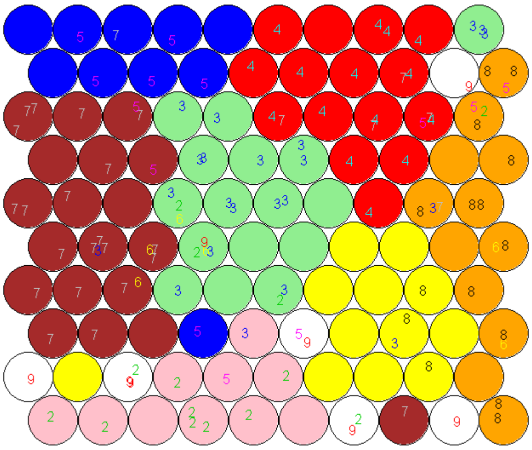


Fig. 10. Clusterization of physiological parameters using SOM

Further, the classified data by SOM is used for MLP training (the SOM outputs became inputs of the MLP) to find out if teacher noise elimination is important in this experiment. So, two training samples were made: the first one was made from SOM's predicted data, and the second sample made from data not processed by SOM. It was made 10 runs of 5-fold cross-validation, in a total of 10 × 5 = 50 experiments for each tested configuration to evaluate MLP classification. Statistical confidence is given by the t-student test at the 90% confidence level. MLP training progress for 1 of 50 experiment configurations, is shown in Fig. 11. It shows the accuracy dynamics for the first and the second training samples as bold and thin lines respectively. As we can see, convergence is faster for the first trainings sample. So, it was useful to pre-process MLP's training sample with SOM as well as MLP easier finds the pattern. Finally, after 5-fold cross-validation, the classifying accuracies were calculated: 35.78±1.91% and 32.11±8.07% for the training samples processed and not processed with SOM respectively. Using the training sample pre-processed with SOM, the classifying accuracy increases by 3.67% and the training process is more stable.

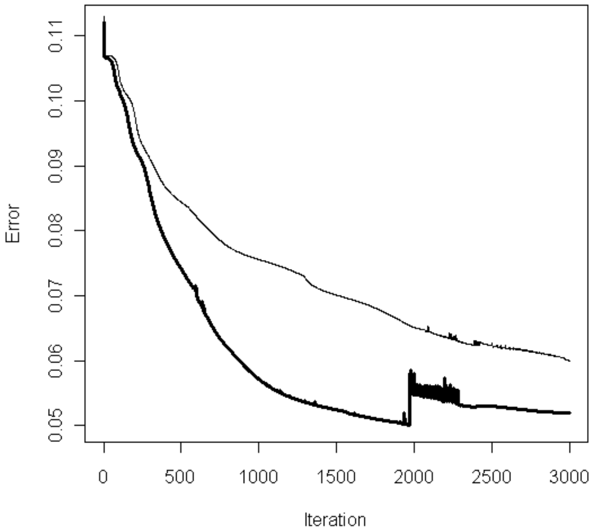


Fig. 11. Multilayer perceptron learning progress for two different cases

The reward function of the services improvement algorithm can be expressed as a function of affect estimate. In this case, the services will meet the climate control i.e., lighting, heating and air-quality settings. According to Russell emotional state representation model, the maximum comfort is achieved when the arousal value is close to 0, while the valence value is close to 1. The maximum comfort of the room is created when air temperature is 22 ° C, light intensity is 95% and air quality is 90%. So, it can be created a function that would map the values of closed environment microclimate parameters to the estimate of two-dimensional affect as the level of valence and arousal. Since it is impossible to define strict boundaries of affect values the inference function will be created using method of fuzzy logic, implemented using Matlab Fuzzy Logic Toolbox package. General affect fuzzy inference system architecture is presented in Fig. 12, where the inputs of the system correspond to parameters of temperature, lighting and air quality, and outputs – the estimates of arousal and valence.

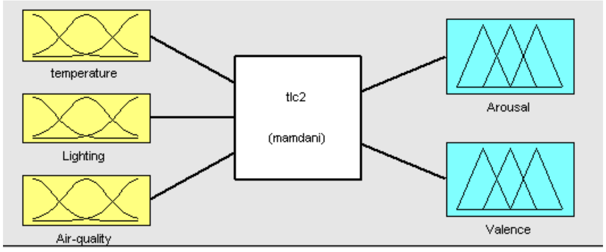


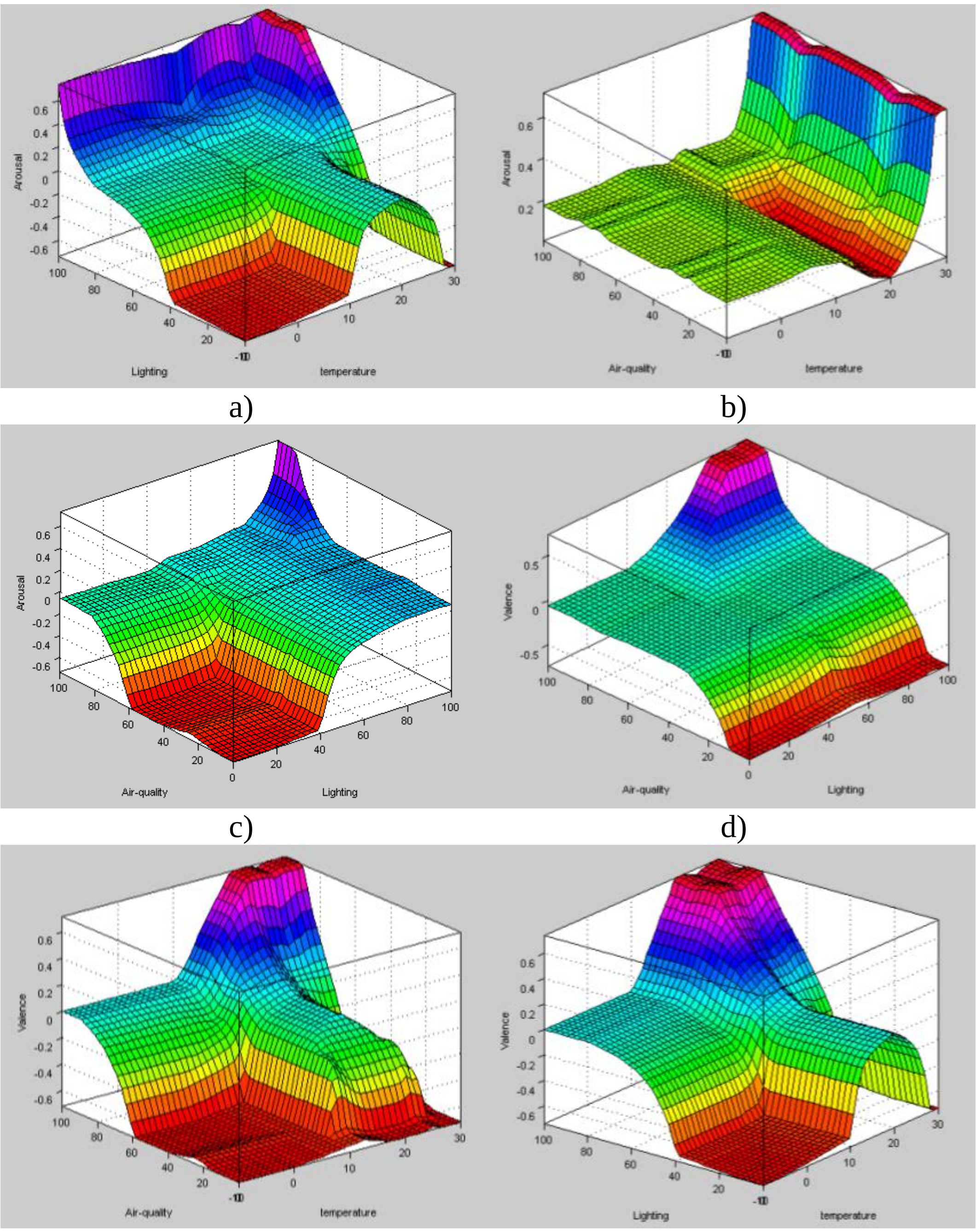
Fig. 12. Arousal-valence fuzzy inference system

Arousal and valence fuzzy inference system is based on the rule base. Because each input variable is divided into three linguistic variables to cover the entire set of input linguistic variables it is necessary to create 27 rules (Fig. 13). Rules are constructed by expert in such way that any temperature, lighting, and air quality value is displayed in the corresponding valence and arousal region, describing the level of affect.

1. If (Temperature is Low) and (Lighting is Low) and (Air-quality is VeryLow) then (Arousal is Low)(Valence is Low)
2. If (Temperature is Low) and (Lighting is Low) and (Air-quality is Low) then (Arousal is Low)(Valence is Low)
3. If (Temperature is Low) and (Lighting is Low) and (Air-quality is Mid) then (Arousal is Low)(Valence is Low)
4. If (Temperature is Low) and (Lighting is Mid) and (Air-quality is VeryLow) then (Arousal is Mid)(Valence is Low)
5. If (Temperature is Low) and (Lighting is Mid) and (Air-quality is Low) then (Arousal is Mid)(Valence is Low)
6. If (Temperature is Low) and (Lighting is Mid) and (Air-quality is Mid) then (Arousal is Mid)(Valence is Mid)
7. If (Temperature is Low) and (Lighting is High) and (Air-quality is VeryLow) then (Arousal is High)(Valence is Low)
8. If (Temperature is Low) and (Lighting is High) and (Air-quality is Low) then (Arousal is High)(Valence is Low)
9. If (Temperature is Low) and (Lighting is High) and (Air-quality is Mid) then (Arousal is High)(Valence is Mid)
10. If (Temperature is Mid) and (Lighting is Low) and (Air-quality is VeryLow) then (Arousal is Low)(Valence is Low)
11. If (Temperature is Mid) and (Lighting is Low) and (Air-quality is Low) then (Arousal is Low)(Valence is Mid)
12. If (Temperature is Mid) and (Lighting is Low) and (Air-quality is Mid) then (Arousal is Mid)(Valence is Mid)
13. If (Temperature is Mid) and (Lighting is Mid) and (Air-quality is VeryLow) then (Arousal is Mid)(Valence is Low)
14. If (Temperature is Mid) and (Lighting is Mid) and (Air-quality is Low) then (Arousal is Mid)(Valence is Mid)
15. If (Temperature is Mid) and (Lighting is Mid) and (Air-quality is Mid) then (Arousal is Mid)(Valence is High)
16. If (Temperature is Mid) and (Lighting is High) and (Air-quality is VeryLow) then (Arousal is Mid)(Valence is Low)
17. If (Temperature is Mid) and (Lighting is High) and (Air-quality is Low) then (Arousal is Mid)(Valence is Mid)
18. If (Temperature is Mid) and (Lighting is High) and (Air-quality is Mid) then (Arousal is High)(Valence is High)
19. If (Temperature is High) and (Lighting is Low) and (Air-quality is VeryLow) then (Arousal is Low)(Valence is Low)
20. If (Temperature is High) and (Lighting is Low) and (Air-quality is Low) then (Arousal is Low)(Valence is Low)
21. If (Temperature is High) and (Lighting is Low) and (Air-quality is Mid) then (Arousal is Low)(Valence is Low)
22. If (Temperature is High) and (Lighting is Mid) and (Air-quality is VeryLow) then (Arousal is High)(Valence is Low)
23. If (Temperature is High) and (Lighting is Mid) and (Air-quality is Low) then (Arousal is High)(Valence is Low)
24. If (Temperature is High) and (Lighting is Mid) and (Air-quality is Mid) then (Arousal is High)(Valence is High)
25. If (Temperature is High) and (Lighting is High) and (Air-quality is VeryLow) then (Arousal is High)(Valence is Low)
26. If (Temperature is High) and (Lighting is High) and (Air-quality is Low) then (Arousal is High)(Valence is Low)
27. If (Temperature is High) and (Lighting is High) and (Air-quality is Mid) then (Arousal is High)(Valence is High)

Fig. 13. Rule base of the arousal and valence fuzzy inference system

The following is a partial representation of the arousal and valence functions created in three-dimensional space.



a) b)

c) d)

e) f)

Fig. 14. Arousal and valence functions: a) lighting and temperature mapping to arousal, b) air quality and temperature mapping to arousal, c) air quality and lighting mapping to arousal, d) air quality and lighting mapping to valence, e) air quality and temperature mapping to valence, f) lighting and temperature mapping to valence

According to the graphs it can be seen that the estimates of arousal and valence are close to 0 and 1 respectively only when environmental parameters are close to the corresponding values: air temperature 22°C, light intensity 85%, and 95% of air quality. This is confirmed by the rules activation test (Fig. 15, Fig. 16). The assessment of environment with a low level of comfort (temperature = 10°C, light intensity =50%, and air quality=50%) shows that arousal = -0.231, valence = -0.667. According to Russell emotional state model which corresponds approximately the emotional state "sad". The assessment of environment with a high level of comfort (temperature=21°C, light intensity=85%, and air quality=100%) shows that arousal = 0.075, valence = 0.74. According to Russell emotional state model which corresponds approximately the emotional state “happy”.

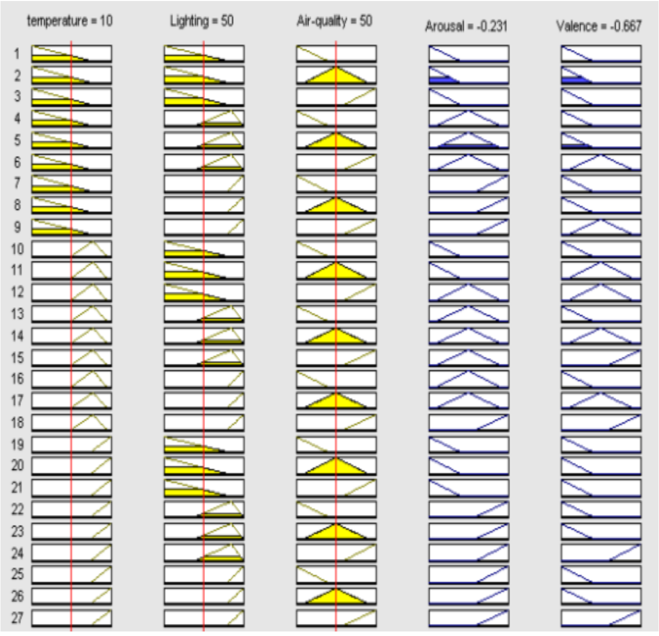


Fig. 15. Activation of rules of the affect fuzzy inference system when evaluating low environment comfort

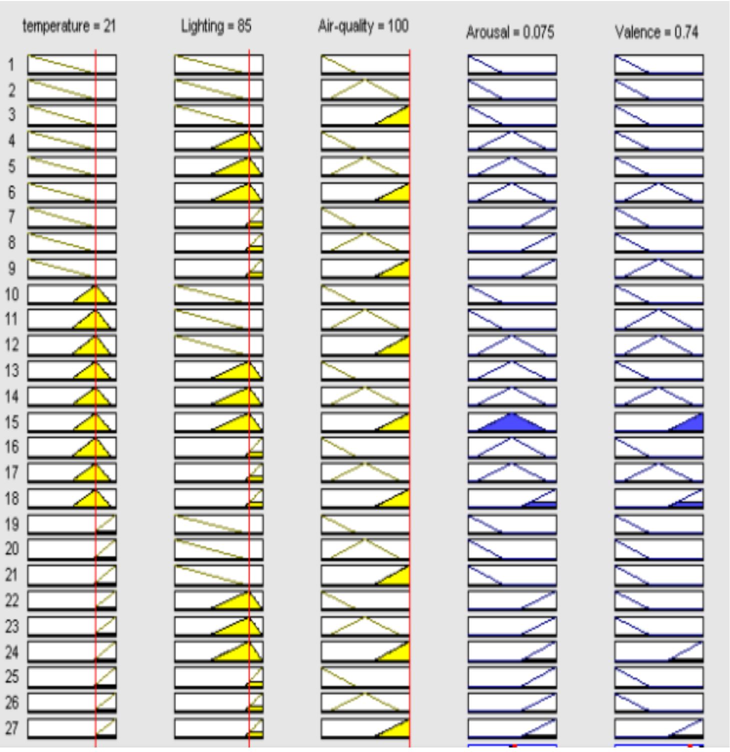


Fig. 16. Activation of rules of the affect fuzzy inference system when evaluating high environment comfort

The adaptation of comfort in accordance with the affect assessment is made using the TD(λ) reinforcement learning algorithm. Therefore it is necessary to create a function that transforms the valence and arousal to appropriate quantitative intrinsic value – the

ACAR index. In this case, there is also used ACAR index fuzzy inference system which general architecture is presented in Fig. 17.

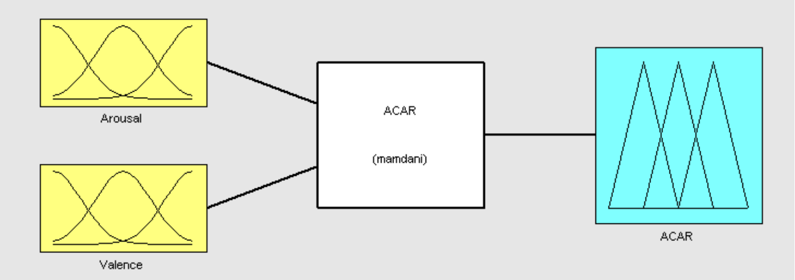


Fig. 17. Fuzzy ACAR index inference system

The created function is shown in Fig. 18.

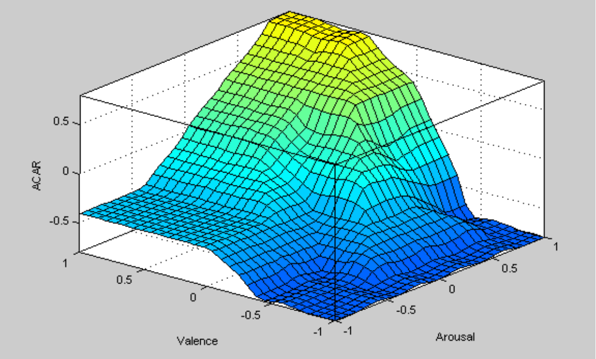


Fig. 18. Function mapping arousal and valence to ACAR index

According to the functions view it can be seen that the ACAR index is close to 0 when arousal is close to 0, and valence is close to 1. As well as this is confirmed by rules activation test (Fig. 19, Fig. 20). On the negative values of valence and arousal (arousal=-0.205, valence = -0.488) the ACAR index = -0.558. When arousal is close to 0 and a valence close to 1 (arousal = 0,000125, valence = 0,913) the ACAR index = 0.000184.

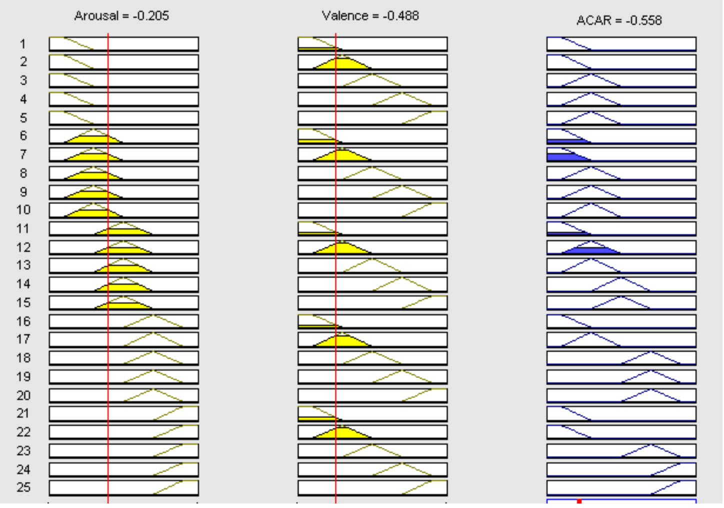


Fig. 19. Activation of rules of the ACAR index fuzzy inference system, when evaluating negative valence and negative arousal

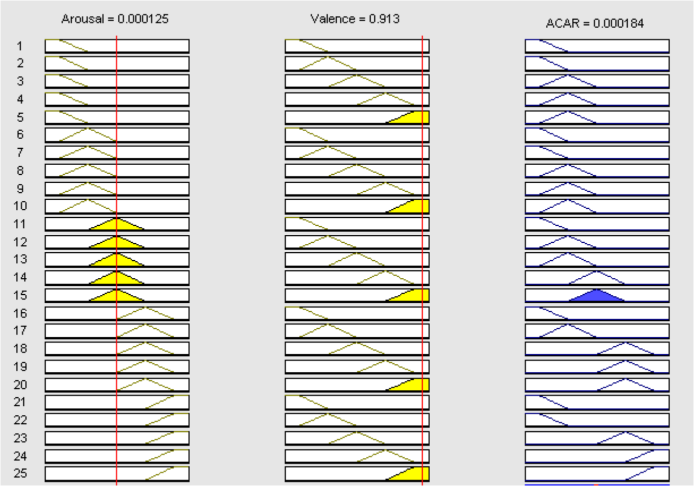
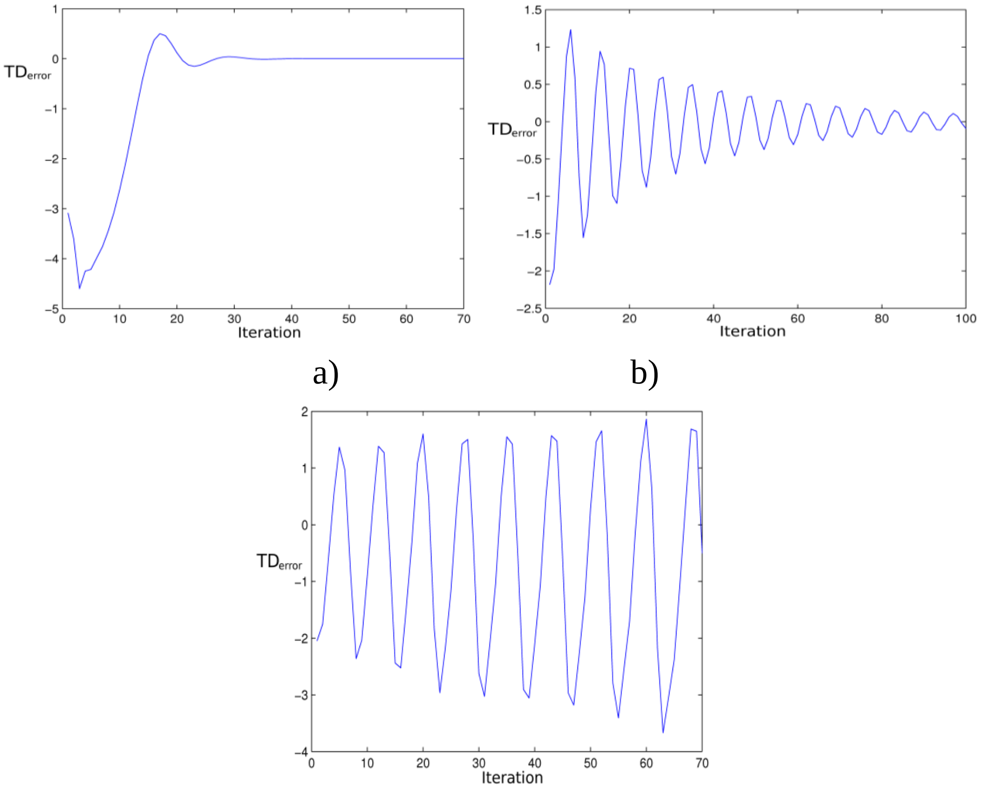


Fig. 20. Activation of rules of the ACAR index fuzzy inference system, when evaluating positive high valence and zero arousal

A further estimations are made using previously defined the ACAR index inference system. Microclimate control in accordance with the affect evaluation the simulation will be carried out according to the following steps:

1. Fix initial state of the environment microclimate (temperature, illumination, air quality);
2. The valence and arousal quantitative values are calculated for a given environmental condition using affect fuzzy inference system;
3. The ACAR index is calculated using ACAR index fuzzy inference system;
4. The TD(λ) algorithm is applied to calculate the action (temperature, lighting and air quality changes), and the corrections of parameters;
5. The action and approximated value function weights are adjusted;
6. Return to step 2 until the desired accuracy or a fixed number of iterations are reached.

The main characteristic of operation of the closed environment microclimate control system is the dynamics of TD error $\delta_{TD}(t)$. The optimum state is obtained if this parameter converged to 0 in finite time, i.e. there is no need any change of the state. The proposed ambient comfort control algorithm is applied in order to track the optimal environmental state, using MatLab software tools. The corresponding parameters (γ – discount factor, λ – decay factor, α – learning rate) for the closed environment microclimate control system are set for different experimental setups. The detailed simulation results are shown in Fig. 21. The simulation results indicate that the proposed closed environment microclimate control system can be stable ($\delta_{\mathrm{TD}}(\mathrm{t})$ – converges to 0) using appropriate parameters (Fig. 21 (a, b)). As well as the $\delta_{\mathrm{TD}}(\mathrm{t})$ –can diverge (Fig. 21 (c)).

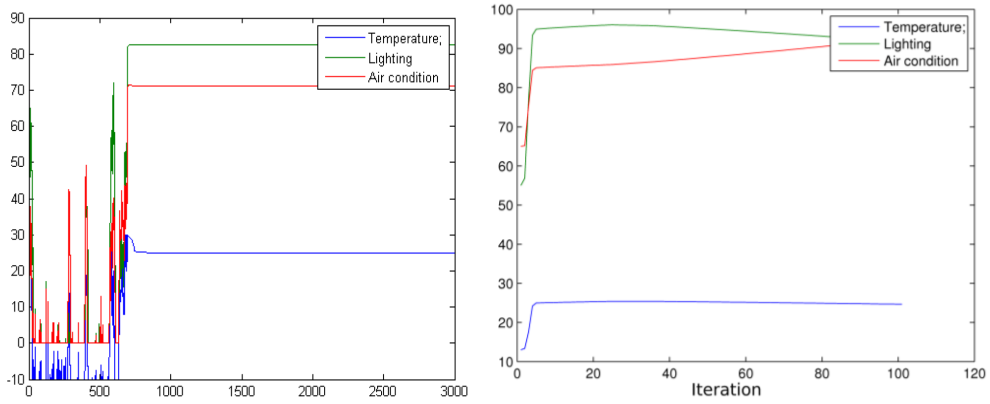


a) b)

c)

Fig. 21. Dynamics of temporal differences using appropriate controller parameters: a) γ=0.8, λ=0.5, α=0.2; b) γ=0.8, λ=0.5, α=0.01; c) γ=0.9, λ=0.9, α=0.02

The Fig. 22 shows, that starting from the various initial states of the environment the optimum state is obtained after some iterations. The first steps of the iterations shows that the agent is learning i.e. searching for the best actions that lead to the goal state.



a) b)

Fig. 22. Dynamics of the closed environment microclimate characteristics using the appropriate parameters of the controller: a) γ=0.95, λ=0.9, α=0.5; b) γ=0.8, λ=0.5, α=0.2

GENERAL CONCLUSIONS

1. The computer-based affect recognition methods are sufficiently accurate to assess human responses to changes in the environment. Therefore, these methods can be used as certain constructions to develop a control system of adaptive services (e.g. adaptation of environment comfort), based on the needs of users.

2. In order to improve the accuracy of affect recognition, the methods of integration of human physiological parameter clustering, using SOM, and classification, using MLP, have been proposed. This solution enables to remove training sample labelling errors, thus enhancing the classification accuracy in solving a wide range of challenges using supervised learning algorithms.
3. The analysis of affect recognition methods and adaptive control principles has shown that affect evaluation is helpful in creating a feedback of automatic climate control system of the closed environment. This principle has led to the creation of a new microclimate control method for the closed environment. The uniqueness of this approach is that the person is involved in the system as an environmental comfort sensor, which enables us to estimate the relevance of comfort parameters to the human. This is one of the newest application methods of affect recognition, creating services adaptive to the user needs.
4. The control system of the closed environment microclimate is quite complex, involving multicriteria control of environment parameters, and the analysis of physiological signals. Applying the actor-critic reinforcement learning method, which is able to extract the missing knowledge about the system during its operation, it is possible to realise the adaptive climate control system of the closed environment. Other than currently offered climate control systems, the proposed method, depending on the context, enables us to adapt the provided services according to the dynamic subject areas.
5. The experimental results of the control system of the closed environment microclimate have shown that it is possible to achieve optimal parameters of lighting, temperature, and air quality in terms of human affect evaluation. It shows that the integration of the human affect evaluation methods and reinforcement learning techniques provides an effective development of adaptive services for the control system of the closed environment microclimate.

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SHORT DESCRIPTION ABOUT THE AUTHOR

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AFEKTO ATPAŽINIMO IR ADAPTYVAUS VALDYMO METODŲ INTEGRAVIMAS UŽDAROS APLINKOS KOMFORTO VALDYMO SISTEMOJE

Darbo aktualumas ir problemos formulavimas

Kuriant šiuolaikines dirbtinio intelekto (DI) sistemas svarbu, kad jos būtų naudingos ir gebėtų prisitaikyti dinaminėje aplinkoje. Ypač didelis dėmesys skiriamas išmaniųjų paslaugų kūrimui, jų kokybės didinimui, stebint vartotojų įpročius ir įvedant adaptyvumo komponentus. Svarbu, kad šios sistemos įgalintų daugelį paslaugų valdyti automatiškai ir adaptuotis prie konkrečių vartotojo poreikių. Viena iš tokių sistemų kūrimo sričių – paslaugų personalizavimas. Šiose sistemose taip pat aktualu mažinti resursų sąnaudas, paslaugas atlikti tiesioginės kreipties rėžimu, reikiamu laiku, siekiant didesnės teikiamų paslaugų kokybės ir rizikos sumažinimo. DI sistemose, siekiant kuo adekvačiau įvertinti realybę ir gebėti valdyti paslaugas teikiančius procesus, siūlomos įvairias disciplinas (biomediciną, psichologiją, kompiuterių inžineriją ir kt.) siejančios kompiuterinės technologijos.

Technologijos, skirtos atpažinti, interpretuoti, imituoti žmogaus emocines būsenas, 1995 metais buvo apjungtos į vieną iš dirbtinio intelekto šakų – afektinę kompiuteriją. Cituojant afektinės kompiuterijos pradininkę R. W. Picard, kuri teigia, „... kad kompiuteriai būtų tikrai protingi ir natūraliai su mumis bendrautų, mes turime suteikti kompiuteriams gebėjimą atpažinti, suprasti ir netgi išreikšti emocijas“ (Picard, 1995), suvokiama, jog emocijų atpažinimas tampa svarbia dirbtinio intelekto sistemų kūrimo dalimi. Taikomosios sritys, kuriose aktualūs afekto atpažinimo metodai, apima išmaniojo būsto valdymo sistemas, daiktų interneto technologijomis grindžiamas nuotolinio valdymo paslaugų sistemas.

Nagrinėjamos adaptyvių sistemų kūrimo galimybės, kurios pagal tam tikras užduotas statines parametrų reikšmes geba keisti supančios aplinkos parametrus (Marreiros ir kt., 2007a; Marreiros ir kt., 2007b; Masatoshi ir kt., 2010). Šių sistemų valdymas grindžiamas metodais, siekiant mažinti energijos sąnaudas ir kuriant žmogaus veiklai tinkamą aplinką.

Intelektualios aplinkos kūrimo srityje vykdoma nemažai projektų, siekiant pasiūlyti architektūrinius elektroninių prietaisų apjungimo į bendrą visumą sprendimus (IoT-A, 2013). Tarpinės programinės įrangos kūrimas įvairialypių fizinių įrenginių apjungimui, siekiant sukurti patogias įrenginių valdymo paslaugas (HYDRA, 2010). Įterptinių sistemų apjungimas ir intelektualizuotų paslaugų teikimas projekte taikomas užtikrinant efektyvesnį paslaugų vartotojiškumą (Smarcos, 2012).

Vykdant mokslinius tyrimus afekto atpažinimo srityje buvo pasiūlyta keletas sprendimų sukurti adaptyvias paslaugas teikiančias sistemas (Bielskis ir kt., 2009; Drungilas ir kt., 2010; Dzemydienė ir kt., 2010). Šios sistemos leidžia parinkti socialinės e. rūpybos paslaugas kaip asmenį asistuojančių įrenginių valdymo scenarijus, vertinant žmogaus emocines būsenas. Tolimesnis, intelektualias paslaugas teikiančių adaptyvių sistemų vystymas reikalauja tiesioginio žmogaus supančios aplinkos valdymo ir afekto atpažinimo metodų integravimo. Vienas plačiausiai nagrinėjamų šios probleminės srities atvejų – tai uždaros aplinkos komforto valdymo sistemos, gebančios keisti tam tikrus aplinkos parametrus, į kuriuos reaguodamas žmogus (ar dirbtinis agentas) gali išreikššti pasitenkinimą jį supančia aplinka.

Automatinio patalpų mikroklimato valdymo sistemose aplinkos komfortas dažniausiai reglamentuojamas ISO standartais, pritaikytais aplinkos apšvietimo, oro temperatūros bei CO2 kiekio ore parametrų valdymui (ASHRAE, 1999; ASHRAE, 2005; CIBSE, 1994). Nuo aplinkos komforto lygio priklauso darbo vietos ergonominiai rodikliai, kurie veikia žmogaus sveikatą, darbo produktyvumą, emocijas, motyvaciją ir kt. (Masatoshi ir kt., 2010). Komforto parametrų reguliavimo uždaviniai ypač aktualūs ir plačiai nagrinėjami kuriant išmaniojo būsto sistemas. Tačiau komforto reguliavimo sistemos nėra pakankamai automatizuotos, jos dažnai nėra patogios vartotojui (Eiben ir kt., 2010), todėl atsiranda poreikis modifikuoti esamus ir pasiūlyti naujus afekto atpažinimo bei adaptyvaus valdymo metodus, leidžiančius išvystyti uždaros aplinkos mikroklimato valdymo sistemą, realizuojant dinaminį paslaugų teikimą pagal žmogaus afektinių būsenų įverčius.

Daiktų interneto, išmaniųjų technologijų, kontekstą suvokiančių sistemų vystymasis yra grindžiamas naujausiais pasiekimais mašininio mokymo bei adaptyvių sprendimo priėmimo metodų taikymų srityje. Ypač didelis dėmesys skiriamas tokių intelektualių technologijų taikymams, kuriuose paslaugos teikiamos, siekiant minimizuoti kaštus, energijos sąnaudas, individualiai pasiūlyti vartotojui labiausiai tinkamas paslaugas ar komforto sąlygas. Kuriant paslaugų adaptavimo prie besikeičiančios aplinkos ir vartotojų poreikių sistemas, atsiranda dirbtinio intelekto bei žmogaus ir kompiuterio sąveikos metodų integracijos problema. Šiai problemai spęsti vis dar trūksta metodų, kurie tiksliau leistų įvertinti žmogaus fiziologines būsenas ir tiesiogiai jas susieti su paslaugų kokybės gerinimo proceso automatizavimu, leisiančiu betarpiškai adaptuoti teikiamas paslaugas dinaminio pobūdžio dalykinėse srityse. Paslaugų kokybės įvertinimas reikalauja išspęsti kriterijų parinkimo, sprendimo priėmimo sistemų taikymo uždavinius, integruojant robotizuotas, sensorines, žinių valdymo bei automatizuotų procesų valdymo sistemas.

Adaptyviose valdymo sistemose afekto atpažinimo metodai grindžiami gebėjimais vertinti žmogaus reakciją į aplinkos pokyčius, analizuojant fiziologinius parametrus (Cowie ir kt., 2001; Rani, 2003, Mandryk, 2005). Dalis tokio pobūdžio mokslinių tyrimų nagrinėja afekto atpažinimo metodų efektyvumą įvairaus sudėtingumo dalykinėse srityse (Lisetti ir kt. 2003; Villon ir Lisetti, 2006). Naudojant jau sukurtus afekto atpažinimo metodus, nagrinėjamas aplinkos veiksnių įtakos žmogui vertinimas, pasitelkiant biologinį grįžtamąjį ryšį (Rani, 2003, Mandryk, 2005, Kaklauskas ir kt., 2010; Kaklauskas ir kt., 2011). Ypač didelis dėmesys afekto atpažinimo metodų taikymui skiriamas kuriant išmanaus būsto sistemas, diegiant adaptyvaus uždarų patalpų mikroklimato valdymo sistemas. Tačiau siūlomų sistemų automatinis reguliavimas dažniausiai vykdomas pagal iš anksto užduotus parametrus, neatsižvelgiant į toje aplinkoje esančio žmogaus afektinės būsenos pokyčius ir jų dinamiką. Šiuo metu egzistuojančių metodų nepakanka, norint realiu laiku adaptuoti paslaugas, kurios valdo žmogų supančią aplinką, naudojant jo afekto vertinimą, todėl adaptyvias paslaugas teikiančių sistemų kūrimo pagrindiniu uždaviniu tampa afekto atpažinimo ir adaptyvaus valdymo metodų integracija.

Tyrimo objektas

Afekto atpažinimo ir adaptyvaus paslaugų valdymo metodai, kurie leidžia išvystyti integruotą adaptyvių paslaugų valdymą uždaros aplinkos mikroklimato reguliavimo sistemoje.

Tyrimo tikslas

Modifikuoti esamus ir pasiūlyti naujus afekto atpažinimo bei adaptyvaus paslaugų valdymo metodus, leidžiančius išvystyti uždaros aplinkos mikroklimato valdymo sistemą, realizuojant dinaminį paslaugų teikimą pagal žmogaus afektinių būsenų įverčius

Darbo uždaviniai

1. Atlikti kompiuterinių afekto atpažinimo metodų palyginamąją analizę, kuri nustatytų jų taikymo galimybes, konstruojant adaptyvių paslaugų valdymo sistemas;
2. Išanalizuoti adaptyvaus valdymo ir afekto atpažinimo metodų integracijos galimybes tikslingam uždaros aplinkos mikroklimato valdymo sistemos išvystymui;
3. Sukurti afekto atpažinimo ir adaptyvaus valdymo metodus integruojančios sistemos modelį, realizuojantį adaptyvią uždaros aplinkos mikroklimato valdymo sistemą;
4. Eksperimentiškai įvertinti sukurtos uždaros aplinkos mikroklimato valdymo sistemos prototipą skirtingomis afekto įvertinimo sąlygomis.

Ginamieji disertacijos teiginiai

1. Adaptyvioms, prie vartotojų poreikių prisitaikančioms sistemoms kurti tikslinga taikyti kompiuterinius afekto atpažinimo metodus, vertinant jų galimybes, kuo tiksliau įvertinti žmogaus reakcijas į aplinkos pokyčius.
2. Tikslinga integruoti afekto atpažinimo ir adaptyvaus valdymo metodus, siekiant išvystyti adaptyvią, prie vartotojų poreikių prisitaikančių paslaugų valdymo sistemą.
3. Žmogaus afekto vertinimo metodų integracija su skatinamojo mokymosi metodais užtikrina efektyvų adaptyvių paslaugų uždaros aplinkos mikroklimato valdymo sistemoje išvystymą.
4. Sukurta aplinkos mikroklimato adaptyvaus valdymo sistema leidžia pasiekti optimalius apšvietimo, temperatūros ir oro kokybės parametrus pagal toje aplinkoje esančio žmogaus afekto vertinimą.

Tyrimo metodika

Informatikos inžinerijos moksle afekto atpažinimo metodų kūrimas ir jų taikymas yra pakankamai nauja sritis, tad norint įvertinti šiuo metu taikomų afekto atpažinimo metodų ir su jais susietų mokslinių pasiekimų svarbą, darbe buvo taikyti informacijos paieškos, sisteminimo, analizės, lyginamosios analizės ir apibendrinimo metodai. Analizuojant naujausią mokslinę literatūrą iš mokslinių duomenų bazių, konkretizuojamas tyrimo kontekstas, įvertinant darbe keliamos problemos išspręstumo lygį ir išskiriant esmines afekto atpažinimo metodų ir jų taikymo problemas. Siekiant integruoti afekto atpažinimo ir automatinio uždaros aplinkos mikroklimato reguliavimo metodus, pasiūlant adaptyvaus valdymo sistemos išvystymą pagal vartotojų poreikius, darbe nagrinėjami afekto atpažinimo, skaitmeninio valdymo bei mašininio mokymo metodai.

Siekiant sukurti aplinkos mikroklimato adaptyvaus valdymo mechanizmą, taikomas tyrimo konstravimu metodas, apimantis teorinių afekto atpažinimo, mašininio mokymo, adaptyvaus valdymo metodų nagrinėjimą bei pritaikymą, pasiūlant naujus modelius, metodus bei eksperimentinės sistemos sukūrimą. Siekiant atlikti sukurtos sistemos prototipo validaciją ir verifikaciją bei eksperimentiškai įvertinti sistemos elgseną, buvo sukurtas ir panaudotas prototipinis fiziologinių signalų matavimo techninės įrangos maketas. Remiantis išmatuotais žmogaus odos galvaninės reakcijos, elektrokardiogramos, odos temperatūros duomenimis bei ekspertiniu vertinimu, naudojant skirtingus aplinkos būsenos scenarijus buvo sudarytas aplinkos mikroklimato adaptyvios valdymo sistemos imitacinis modelis. Eksperimento rezultatams palyginti taikytas statistinis tyrimų rezultatų vertinimas.

Gauti rezultatai

Pasiūlytas fiziologinių žmogaus parametrų klasterizavimo ir klasifikavimo metodų apjungimas leido padidinti afektinės būsenos atpažinimo tikslumą. Vertinant klasifikavimo tikslumą, išskirti dirbtinio intelekto metodai, kurie labiausiai tinka afekto atpažinimui. Patvirtinta, jog adaptyvioms, prie vartotojų poreikių prisitaikančioms sistemoms kurti tikslinga taikyti kompiuterinius afekto atpažinimo metodus, nustatant jų galimybes, kuo tiksliau įvertinti žmogaus reakcijas į aplinkos mikroklimato pokyčius.

Pasiūlytas kiekybinio afekto įvertinimo principas, leidžiantis sukurti uždaros automatinės aplinkos komforto valdymo sistemos grįžtamąjį ryšį ir jį pritaikyti, pasiūlant aplinkos mikroklimato parametrų valdymo sistemos modelį, grindžiamą žmogaus afekto įvertinimu. Parodyta, jog tikslinga integruoti afekto atpažinimo ir adaptyvaus valdymo metodus, siekiant išvystyti adaptyvią, prie vartotojų poreikių prisitaikančių paslaugų valdymo sistemą.

Siekiant kiekybiškai įvertinti afektą, naudojant fiziologinių parametrų reikšmes, buvo sukurtas ir išbandytas sistemos prototipo modelis, gebantis nuskaityti fiziologinius signalus, kaupti diskretizuotų signalų skaitmeninius duomenis, iš jų išskirti fiziologinius parametrus bei juos interpretuoti. Parodyta, jog žmogaus afekto vertinimo metodų, susietų su fiziologinių parametrų įverčiais ir grįžtamojo ryšio panaudojimu integracija su skatinamojo mokymosi metodais užtikrina adaptyvių paslaugų uždaros aplinkos mikroklimato valdymo sistemoje išvystymą.

Remiantis afekto vertinimo principais buvo sudaryta ekspertinė afekto įverčio funkcija, kuri leidžia realizuoti adaptyvios sistemos grįžtamojo ryšio grandinę.

Eksperimentiniai imitacinio modeliavimo rezultatai parodė, jog naudojant aktoriaus-kritiko skatinamojo mokymosi modelį bei afekto pokyčių įvertinimo funkciją, galima pasiekti optimalius apšvietimo, temperatūros ir oro kokybės parametrus pagal toje aplinkoje esančio žmogaus afekto vertinimą.

Mokslinis darbo naujumas

Rengiant disertaciją buvo gauti šie informatikos inžinerijos mokslui nauji rezultatai:

- Pasiūlytas integruotas adaptyvių paslaugų valdymo metodas uždaros aplinkos mikroklimato reguliavimo sistemoje. Tai patobulintas uždaros aplinkos mikroklimato valdymo metodas, kai žmogus dalyvauja sistemoje kaip aplinkos komforto jutiklis, kurio afekto įvertis leidžia nustatyti aplinkos mikroklimato tinkamumą tam žmogui. Tai vienas naujausių afekto atpažinimo metodų pritaikymas, kuriant adaptyvias, prie žmogaus poreikių prisitaikančias paslaugas;
- Taikant aktoriaus-kritiko skatinamojo mašininio mokymo metodą, kuris geba išgauti trūkstamas žinias apie sistemą jos veikimo metu, sukurta adaptyvi uždaros aplinkos mikroklimato reguliavimo sistema. Skirtingai negu šiuo metu siūlomos mikroklimato reguliavimo sistemos, pasiūlytas metodas, priklausomai nuo

konteksto, leidžia adaptuoti vartotojui teikiamas paslaugas dinaminio pobūdžio dalykinėse srityse;

- Sukurtas afekto vertinimo sistemos prototipas ir eksperimentiškai įvertintas pasiūlytos aplinkos mikroklimato parametrų adaptavimo sistemos imitacinis modelis;
- Pasiūlytas fiziologinių žmogaus parametrų klasterizavimo, naudojant SOM, ir klasifikavimo, naudojant MLP, metodų apjungimas. Šis sprendimas leidžia panaikinti mokymo imties sužymėjimo klaidas ir taip padidinti klasifikavimo tikslumą, sprendžiant įvairaus pobūdžio klasifikavimo uždavinius, kai apsimokančiose sistemose yra taikomi prižiūrimo mokymosi algoritmai.

Praktinė darbo reikšmė

Pasiūlytas uždaros aplinkos mikroklimato valdymo sistemos modelis, realizuojantis dinaminį paslaugų teikimą pagal žmogaus afektinių būsenų įverčius. Šis modelis, apimantis žmogaus fiziologinių signalų nuskaitymą, parametrų analizę, afekto įvertinimą bei adaptyvaus valdymo principus, gali būti praktiškai pritaikomas ir kitose dalykinėse srityse, kuriose paslaugų kokybės valdymas būtų grindžiamas žmogaus afekto įvertinimo metodais. Uždaros aplinkos mikroklimato atpažinimo ir vertinimo kontekstinės žinios bei jų valdymo mechanizmai, panaudoti sukuriant jų taikymo metodiką, galėtų pasitarnauti intelektualių, išmaniųjų paslaugų teikimo sistemų kūrimui, taip didinant siūlomų paslaugų ar produktų konkurencingumą. Taikant šį modelį, sudaromos galimybės gerinti kontekstinių paslaugų kokybę, pritaikant jas prie individualių vartotojo poreikių, kai paslaugų vertinimo kriterijus nustatomas pagal objektyvų vartotojo afekto įvertį.

Darbe taip pat pasiūlytas mokymo imties sužymėjimo klaidų naikinimo metodas, leidžiantis padidinti klasifikavimo tikslumą, sprendžiant įvairaus pobūdžio uždavinius, kai apsimokančiose sistemose yra taikomi prižiūrimo mokymosi algoritmai.

Darbe pasiūlyti afekto atpažinimo metodai bei adaptyvaus valdymo principai buvo panaudoti, kuriant neįgalius asmenis asistuojančios aplinkos paslaugų valdymo metodus, robotizuotas adaptyvaus valdymo sistemas (Bielskis ir kt., 2008; Bielskis ir kt., 2009; Bielskis ir kt., 2010; Dzemydienė ir kt., 2011) bei žmogui draugiškos ir energiją tausojančios išmaniosios aplinkos koncepciją (Drungilas ir kt., 2010; Bielskis ir kt., 2012; Bielskis ir kt., 2013).

Darbo struktūra

Disertaciją sudaro įvadas, 4 skyriai ir bendrosios išvados. Disertacijos apimtis – 116 puslapių, 43 paveikslai ir 5 lentelės.

Įvade aprašomas mokslinio tyrimo aktualumas, analizuojama jo reikšmė, pateikiamas šiuolaikinių mokslinių tyrimų kontekstas, pateikiama problemos formuluotė, nagrinėjamos problemos aktualumas, formuluojamas tikslas ir uždaviniai, apibrėžiamos tyrimo hipotezės, aprašoma tyrimo metodika. Pateikiami pagrindiniai mokslinio darbo rezultatai bei disertacijos gautų rezultatų praktinė vertė ir naujumas, disertacijos rezultatų publikavimo rodikliai ir aprobavimas.

1 skyriuje nagrinėjami kompiuteriniai afekto atpažinimo metodai ir apžvelgiamos jų taikymo galimybės, konstruojant adaptyvias sistemas. Pateikiama pasaulio mokslininkų dažniausiai naudojamų afekto atpažinimo metodų analitinė apžvalga. Šiame skyriuje parodyta, jog kompiuteriniai afekto atpažinimo metodai pakankamai tiksliai

įvertina žmogaus reakciją į aplinkos pokyčius ir leidžia sukurti uždaros aplinkos mikroklimato adaptyvaus valdymo pagal žmogaus afekto vertinimą konstrukcijas.

2 skyriuje nagrinėjamos mašininio mokymosi metodų taikymo ir panaudojimo galimybės, kuriant adaptyvias valdymo sistemas. Aprašomi svarbiausi šių sistemų kūrimui taikomi metodai, kuriant adaptyvaus valdymo sistemos modelį, taikomą aplinkos mikroklimato valdymui. Atskleidžiami klasikinių valdymo sistemų ir šiuolaikinių mašininiu mokymu grindžiamų valdymo sistemų realizavimo principai.

3 skyriuje formuluojami ir aptariami pagrindiniai teoriniai problemos sprendimo metodai. Pateikiamas uždaros aplinkos mikroklimato adaptyvios valdymo sistemos modelis, kuris leidžia reguliuoti aplinkos mikroklimato parametrus pagal afekto vertinimą. Pateikiami uždaros aplinkos valdymo metodų integracijos su afekto atpažinimo metodais realizacijos principai. Remiantis ankstesniuose skyriuose atlikta analize, šiame skyriuje parodoma, jog žmogaus afekto vertinimo metodų, susietų su fiziologinių parametrų įverčiais ir grįžtamojo ryšio panaudojimu, integracija su skatinamojo mokymosi metodais užtikrina efektyvų adaptyvių paslaugų uždaros aplinkos mikroklimato valdymo sistemoje išvystymą.

4 skyrius skirtas sistemos eksperimentinių rezultatų aprašymui, kuriame pateikiami empiriniai pasiūlyto modelio atskiro atvejo analizės tyrimai, taip pat eksperimentiniai tyrimai, siekiant eksperimentiškai patvirtinti pasiūlyto modelio veikimą. Eksperimentiniai imitacinio modeliavimo rezultatai parodė, jog naudojant aktoriaus-kritiko skatinamojo mokymosi modelį bei afekto pokyčių įvertinimo funkciją, galima pasiekti optimalius apšvietimo, temperatūros ir oro kokybės parametrus pagal toje aplinkoje esančio žmogaus afekto vertinimą.

Bendrosiose išvadose pateikiami darbo rezultatai, išvados ir rekomendacijos.

Darbo rezultatų aprobavimas

Moksliniai rezultatai publikuoti 13 mokslinių darbų, iš kurių: 5 straipsniai ISI Web of Science duomenų bazėje referuojamuose ir turinčiuose citavimo indeksą leidiniuose, 1 straipsnis kituose ISI Web of Science duomenų bazėje referuojamuose leidiniuose, 2 straipsniai Lietuvos recenzuojamuose moksliniuose periodiniuose leidiniuose, 5 straipsniai tarptautinių mokslinių konferencijų pranešimų medžiagoje.

Dalyvaujant konferencijose tyrimų rezultatai buvo pristatyti ir aptarti 2 nacionalinėse ir 4 tarptautinėse konferencijose Lietuvoje ir užsienyje:

1. 7-oji mokslinė konferencija Technologijos mokslo darbai Vakarų Lietuvoje, 2010 m. gegužės 14 d., Klaipėda;
2. The 14th International Conference Electronics‘2010, May 18-20, 2010, Kaunas;
3. The 10th International Conference on Artificial Intelligence and Soft Computing (ICAISC) 2010 June 13-17, 2010, Zakopane, Poland.
4. The 10th International Conference Reliability and Statistics in Transportation and Communication (RelStat’10), October 20-23, 2010, Riga, Latvia.
5. 15 –oji Respublikinėje konferencijoje Kompiuterininkų dienos (Klaipėda, 2011); rugsėjo 22-24, 2011.
6. The 16th International Conference Electronics‘2010, June 18-20, 2012, Palanga;

Bendrosios išvados

1. Remiantis atlikta pasaulio mokslinių darbų analize afekto atpažinimo srityje bei afekto atpažinimo metodų lyginamąja analize, galima teigti, jog kompiuteriniai afekto atpažinimo metodai pakankamai tiksliai leidžia įvertinti žmogaus reakciją į

aplinkos pokyčius, todėl kaip tam tikros konstrukcijos gali būti naudojamos kuriant adaptyvių paslaugų (pavyzdžiui, aplinkos komforto adaptavimo) valdymo pagal vartotojų poreikius sistemas.

2. Siekiant padidinti afekto atpažinimo tikslumą, pasiūlytas fiziologinių žmogaus parametrų klasterizavimo, naudojant SOM, ir klasifikavimo, naudojant MLP, metodų apjungimas. Šis sprendimas leidžia panaikinti mokymo imties sužymėjimo klaidas ir taip padidinti klasifikavimo tikslumą, sprendžiant įvairaus pobūdžio uždavinius, kai apsimokančiose sistemose yra taikomi prižiūrimo mokymosi algoritmai.
3. Analizuojant afekto atpažinimo metodus ir adaptyvaus valdymo principus pastebėta, jog kiekybinis afekto įvertinimas leidžia sukurti uždaros aplinkos automatinės mikroklimato valdymo sistemos grįžtamąjį ryšį. Šis principas leido sukurti naują uždaros aplinkos mikroklimato valdymo metodą, išsiskiriantį tuo, jog žmogus dalyvauja sistemoje kaip aplinkos komforto jutiklis, kurio afekto įvertis leidžia nustatyti aplinkos komforto parametrų tinkamumą tam žmogui. Tai vienas naujausių afekto atpažinimo metodų pritaikymas, kuriant adaptyvias, prie žmogaus poreikių prisitaikančias paslaugas.
4. Uždaros aplinkos mikroklimato valdymo sistemos aprašymas yra pakankamai sudėtingas, apimantis daugiakriterinį aplinkos parametrų valdymą bei žmogaus fiziologinių būsenų nagrinėjimą. Aktoriaus-kritiko skatinamojo mašininio mokymo metodo, kuris geba išgauti trūkstamas žinias apie sistemą jos veikimo metu, taikymas leido realizuoti adaptyvią uždaros aplinkos mikroklimato reguliavimo sistemą. Skirtingai negu šiuo metu siūlomų mikroklimato reguliavimo sistemų, pasiūlytas metodas, priklausomai nuo konteksto, leidžia adaptuoti vartotojui teikiamas paslaugas dinaminio pobūdžio dalykinėse srityse.
5. Eksperimentinis uždaros aplinkos mikroklimato valdymo sistemos tyrimas parodė, jog galima pasiekti optimalius apšvietimo, temperatūros ir oro kokybės parametrus pagal toje aplinkoje esančio žmogaus afekto vertinimą. Tai parodo, jog žmogaus afekto vertinimo metodų integracija su skatinamojo mokymosi metodais užtikrina efektyvų adaptyvių paslaugų uždaros aplinkos mikroklimato valdymo sistemoje išvystymą.

Trumpos žinios apie autorių

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